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National Evaluation of Mileage-Based Charges for Drivers

Initial Results

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This paper presents initial results and conclusions from the National Evaluation of a Mileage-Based Road User Charge, a 2-year field study conducted by the University of Iowa Public Policy Center. The study, which evaluates technical feasibility and user acceptance of mileage-based charging as a potential replacement for the current motor fuel tax, was authorized by the 2005 Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users, which reauthorized federal transportation funding. This study is the first to examine road user charges on a national and multijurisdictional scale. Approximately 2,650 volunteers from 12 areas throughout the country participated in the study, which concluded in July 2010. The system mileage charges were totaled and apportioned to the federal, state, and local levels with the use of onboard computers installed in participants' vehicles. The onboard computers contained Global Positioning System (GPS) receivers with an associated geographic database to identify the taxing jurisdictions in which the vehicles traveled. The average participant drove approximately 9,000 mi during the study (the study totaled more than 21 million miles). Approximately 92.5% of all driven miles were successfully measured by both the GPS and the onboard diagnostics system (OBD-II). Of the miles driven without GPS, 6.9% could be reliably assigned to jurisdictions by using straightforward interpolation techniques. Approximately 0.6% of total miles driven could not be reliably assigned to a state or local jurisdiction. Participant attitudes regarding the system and the overall concept of mileage-based charging were assessed. At the end of the study, 71% had a highly or somewhat positive view, and 17% held a highly or somewhat negative view. Participants consistently (but to varying degrees) preferred audit ability, which consisted of receiving detailed monthly invoices, over maximum privacy protection.

The National Evaluation of a Mileage-Based Road User Charge study was established and funded under sections 1919 and 1934 of the 2005 Safe Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) transportation reauthorization. The objective of the study was to assess the technical feasibility and user acceptance of mileage-based charging as a possible alternative to the current motor fuel tax.

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Interest in mileage-based charging as a potential replacement for the motor fuel tax stems from concern about the future revenue-generating capacity of the motor fuel tax. The average fuel efficiency of passenger vehicles has risen steadily for the past several decades and the Obama administration has announced a program to further improve average new vehicle fuel efficiency by 5% per year between 2012 and 2016, culminating in an average efficiency of 35 mpg. Any increase in fleet fuel efficiency translates directly into a corresponding decrease in fuel tax revenue. Since motor fuel taxes contribute nearly 90% of the total revenue for the federal Highway Trust Fund, this reduction in tax revenue will critically affect surface transportation financing. Two recent federal commissions have expressed concern about the future viability of the motor fuel tax and have recommended an eventual transition to a mileage-based charging system (*1, 2*).

STUDY STRUCTURE

The study involved deployment of a prototype mileage-based charging system in the vehicles of approximately 2,650 volunteer participants in 12 different locations throughout the United States during a 2-year period. The charging system utilized an onboard unit (OBU) that was temporarily installed in each participant's vehicle for a period of 10 months. The OBU computed hypothetical mileage-based user charges for federal, state, and, where applicable, local jurisdictions and periodically uploaded accrued charges over a cellular communications link to a billing center. The billing center, in turn, created monthly mileage charge invoices that were sent to participants to simulate operation of a mileage-based charging system. The OBU used a Global Positioning System (GPS) receiver to determine the jurisdiction in which travel occurred for purposes of assessing state and local charges but did not retain or transmit any GPS coordinates or other specific information regarding specific vehicle location or routes traveled.

Throughout the term of their participation in the study, participants were given a series of questionnaires to assess their acceptance of the mileage-based charging concept versus the fuel tax, level of concern about privacy issues, and preferences regarding trade-offs between protection of privacy and auditability of billing statements. The first questionnaire was administered during the training session before the participant's exposure to the system and the remaining six questionnaires were administered approximately every 6 weeks.

Figure 1 shows the design of the mileage-based charging system. An onboard computer (OBC), installed in the participant's vehicle, calculated and reported accrued charges.

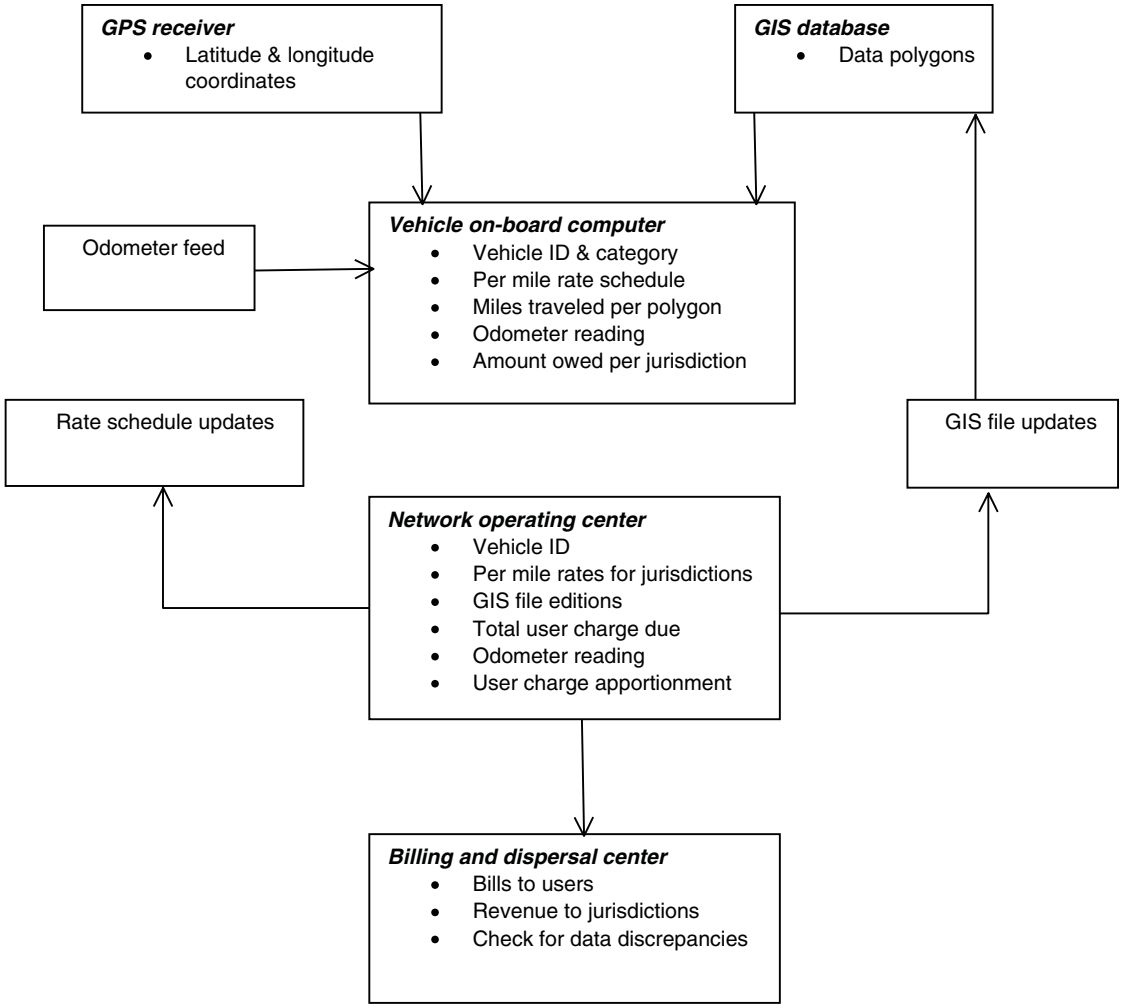


FIGURE 1 Overview of mileage-based approach to user charges (GIS = geographic information system).

The OBC used a connection to the vehicle's onboard diagnostics system II (OBD-II) to obtain vehicle odometer and speedometer data to determine the number of miles driven. The odometer feed is normally the most accurate indicator of distance traveled and serves as the primary source of vehicle miles traveled (VMT) data for per mile charge calculation. However, odometer data are not available on the OBD-II in all current vehicles, but the speedometer data are consistently available. The speedometer (which can be integrated over time to provide an estimate of distance) was used when the odometer was not accessible, and when the odometer was accessible, the speedometer provided an alternative or redundant measure of distance traveled. A GPS receiver determines the vehicle's position, and the OBC reconciles this position with a geographic information system (GIS) file that defines the boundaries of state, county, and municipal political jurisdictions, enabling the OBC to determine the state and community within which travel has occurred. In the event of temporary GPS signal loss (e.g., to signal occlusion or interference), vehicle location can be interpolated between known data points. It should be noted that the GPS also provides another redundant method to measure distance, although it is less accurate than either the odometer or speedometer method.

A file with the per mile charge rates for participating jurisdictions was also stored in the OBC. Individual charge rates were maintained for each jurisdiction. In addition, charge rates could be varied for different types and classes of vehicles or other factors. This facilitates a wide variety of possible charging schemes to meet various policy objectives.

The mileage-based charging policy employed by the study was based on achieving revenue neutrality by comparing the motor fuel tax on both an aggregate and individual vehicle basis. To achieve this, the charge rate employed was differentiated according to vehicle type to provide a mileage charge comparable to the amount of tax currently paid on the fuel consumed by that vehicle for the same travel. Vehicle makes, models, and model years were divided into 20 different classes based on ranges of Environmental Protection Agency estimated combined highway and city fuel efficiencies, and separate mileage charge rates were used for each class to approximate the amount of fuel tax paid per mile driven by a vehicle achieving the mean fuel efficiency of that class. Under this policy, federal per mile rates ranged from 2.19 cents per mile for a Class 1 vehicle (8.0 to 8.8 mpg) to 0.33 cents per mile for a Class 20 vehicle (53.4 to 59 mpg). A Class 10 vehicle, with EPA fuel efficiency in the range 19.5 to 21.6 mpg—the average for study participants—was assessed a federal rate of approximately 0.9 cents per mile. It should be noted that the selected charging policy is only one of a number of possible policies that could ultimately be applied to mileage-based charging (*3*).

Periodically, the vehicle communicated, via a cellular data link, with a network operations center (NOC) to transmit its assessed mileage charge total. This communication utilizes standard commercial cellular data services. The NOC in turn transmitted data to a billing and dispersal center, which prepared and disseminated invoices to participants. The NOC could also transmit updates to the GIS and per mile pricing files to the vehicle.

Calculation of road user charges was done entirely in the OBC and data were uploaded from the vehicle in units of dollars. No GPS coordinate data or other information that could reveal the location of the vehicle at finer than jurisdictional granularity were uploaded from the vehicle or retained within the OBC. The data were transferred periodically, following a predetermined upload frequency without any involvement by the vehicle operator. The OBC was designed to be able to hold data for an extended period of time (several months) and upload on an opportunistic basis to accommodate vehicles that traveled outside of cellular data coverage zones for extended periods.

STRUCTURE OF FIELD TESTS

The field test was conducted in two phases, each lasting approximately 10 months. For each phase, participants were selected from six different geographic areas located throughout the United States. The sites were chosen to provide a representative cross section of national demographics. For the first phase, the six evaluation sites were Baltimore, Maryland; the Research Triangle area of North Carolina; eastern Iowa; Austin, Texas; Boise, Idaho; and San Diego, California. Two hundred participants were selected for each site, for a total of 1,207 participants. For the second phase, the evaluation sites were Portland, Maine; Miami, Florida; Chicago, Illinois; Wichita, Kansas; Billings, Montana; and Albuquerque, New Mexico. For this phase, approximately 240 participants were selected from each site, for a total of 1,446 participants.

To assure a participant pool of representative subjects, demographic profiles of each study area were constructed. The stratifying demographic variables used were gender (female and male), age (four age groups: 18 to 25; 25 to 45; 45 to 65; and 65 years old and above), and education level (no high school diploma, high school diploma or equivalent, some college, bachelor's degree or higher). Using the proportion of the total study site population that fell within each of the demographic cells, a stratified sampling technique was used to generate representative participant pools (one for each of the six sites).

A broad-based media campaign was used to recruit prospective participants in each of the study regions. Those responding to the solicitation for participation were subjected to an initial screening to ensure that they were at least 18 years old, were eligible for employment in the United States, held valid driver's licenses, had personal vehicles, and planned to reside in the community for 10 months, which was the duration of field testing. Finally, for technical reasons, the make, model, and year of their personal automobiles were verified for the technical specifications required for the OBC that was to be installed in the participants' vehicles. Generally, vehicles manufactured after the year 2000 have the necessary equipment, although there were some restrictions as to the vehicle's manufacturer.

After the conclusion of the media campaigns in the individual sites, eligible candidates were grouped based on their age, gender, and education level. Individuals were randomly drawn from each group until the desired number of participants was reached. The American Community Survey estimates were used to set the desired number of participants within each demographic group, therefore assuring that the final pool reflects each evaluation site's demographic characteristics. The selected candidate's willingness to participate was confirmed by phone. When a candidate declined, another candidate was randomly selected from the appropriate demographic group.

Participants were compensated for their involvement in the study. An incentive-based compensation model was used to keep participants aware of their involvement in the study and reduce the potential for dropout during the initial months of field testing. The total compensation amount was $895.

RESULTS OF FIRST AND SECOND YEAR

Participant Sample

The participant recruitment campaign resulted in 103,054 people completing the screening questionnaire. Twenty-four percent of those who completed the questionnaire were disqualified because of a vehicle that was older than the 2000 model year, an incompatible vehicle model, and all other criteria. The final pool of eligible candidates totaled 78,140 (28,587 in Year 1 and 49,562 in Year 2).

Samples of 200 people in Year 1 and 240 in Year 2 were randomly drawn from the pool of eligible candidates for each of the six sites based on gender, age, and education level. The samples drawn matched the demographic profiles of the study areas. In the first and second year, 3% and 5%, respectively, dropped out of the study during the 10 months of active participation resulting in a final study total of 2,522. The leading cause for a participant leaving the study was equipment incompatibility. Selling, crashing, or losing ownership of a vehicle were the reasons for the remaining dropouts. There was no demographic bias in this group that affected the overall representativeness of the study sample.

Table 1 contains a general comparison of the participants to the estimates for the entire United States (*4*). Review of the table reveals a close match between the study sample and the United States as a whole.

TABLE 1 Characteristics of Study Sample (*4*)

Characteristic	Study	United States
Gender (%)		
Male	48.5	49.2
Female	51.5	50.8
Age: mean age (population older than 18 years)	46.5	47.1
Education level (%)		
High school graduate or higher	92.0	84.0
Bachelor's degree or higher	25.0	27.0
Race (%)		
White	87.4	74.1
Black or African-American	5.7	12.4
American Indian and Alaska Native	2.2	0.8
Asian	1.5	4.3
Native Hawaiian and other Pacific Islander	0.4	0.1
Two or more races	1.7	2.1
Travel time: mean travel time to work in min (workers)	24.0	25.1
Income: median family income (2007 inflation-adjusted dollars)	$25,000–$75,000	$50,007

NOTE: N = 2,522.

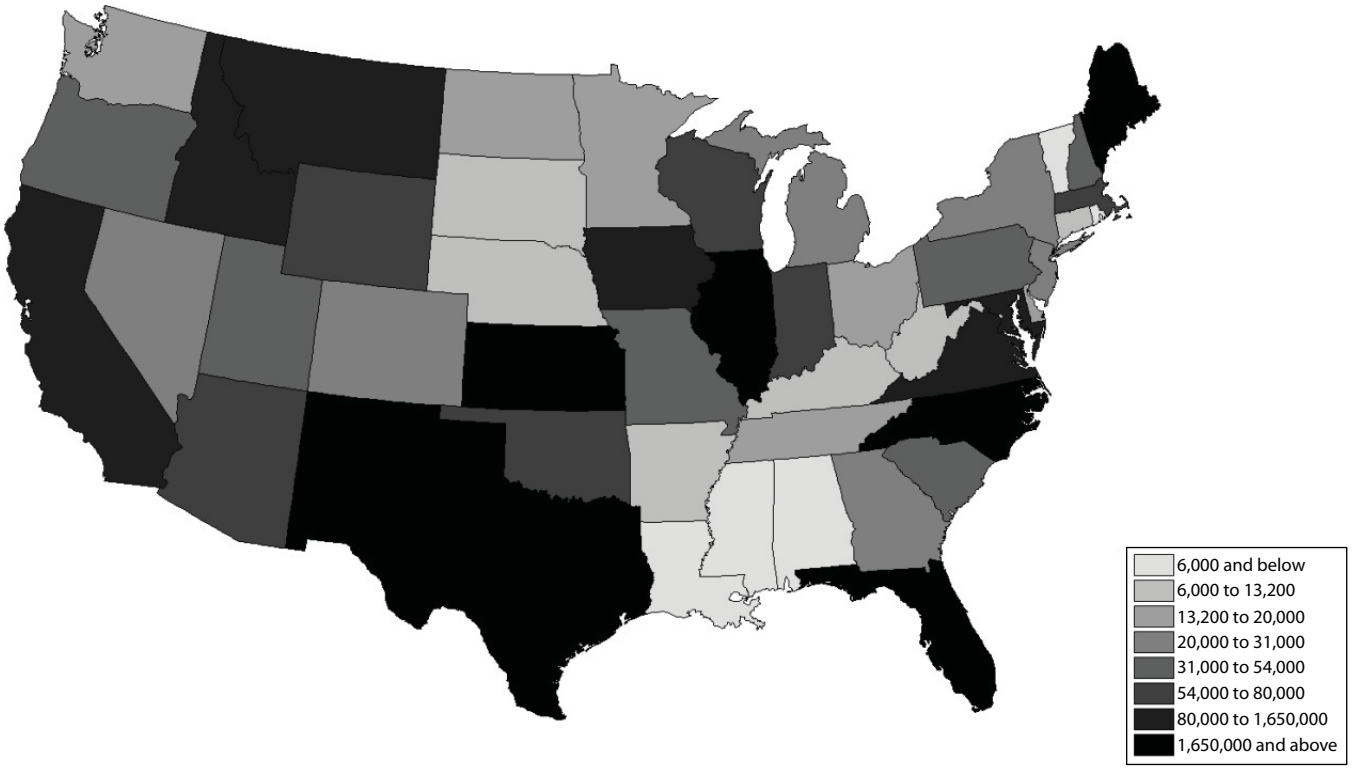


FIGURE 2 Cumulative VMT in states visited by study participants from December 2008 to June 2010.

Driving Data

The participants accumulated just over 23,000,000 VMT from December 2008 through June 2010 with a mean of 990 mi per vehicle per month. Over that period of time, the participants visited all of the 48 contiguous states. Figure 2 illustrates cumulative VMT in the states visited by the study participants. The interstate travel that the participants completed allows for the testing of the mileage-fee system nationwide.

Equipment Performance

Onboard system performance has proved quite robust during the first phase of in-field operations. A small number of vehicle models were found to have various electrical system incompatibilities with the OBU and were excluded from the study. Several other vehicle models were excluded because of vehicle warranty issues. Among all remaining vehicle types, no significant problems have been encountered with the ability of the onboard equipment to capture odometer (and, where available, speedometer) data from the vehicle's OBD-II. At the beginning of the study, an OBC hardware problem was identified that affected the sensitivity of the GPS antenna for approximately 90 installed units. These OBCs were replaced before January 1, 2009.

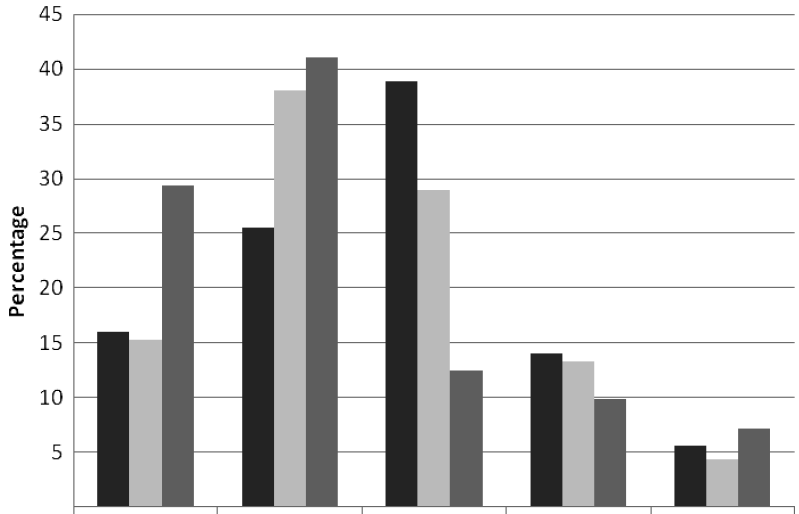
Following the repairs noted above, GPS performance has proved to be quite reliable. The OBC is designed to begin interpolation of vehicle location following any GPS outage that persists for an interval of at least 1 mi. If a GPS update is obtained before the vehicle has traveled 100 mi from beginning of the outage interval, mileage traveled during the outage is allocated to jurisdictions by using a simple straight-line interpolation between the GPS coordinates that bound the outage interval. If a GPS outage persists for more than 100 mi, no interpolation is performed and the mileage is reported as uninterpolated. For the period from January 1, 2009, through June 30, 2010, during which participants drove approximately 23 million miles, 7.3% were driven without a GPS fix; 6.7% of driven miles were interpolated and only about 0.6% were uninterpolated. Most interpolated miles appear to be associated with delays in establishing a GPS fix at the outset of a trip.

There have been no significant problems with the wireless data upload and no permanent or long-term loss of data due to communication or infrastructure failure. Three rate table updates have been downloaded to installed units without incident.

PARTICIPANT PERSPECTIVES ON KEY ISSUES

Initial and Final Opinions on a Mileage Charge

The question "How do you feel about the idea of replacing the gas tax with a mileage-based road user fee?" was asked on several questionnaires. The multiple appearance of the question allowed for the investigation of the opinion change as the participants' interaction with the system increased. The summary of their responses is presented in Figure 3. The opinions of the participants became more positive as they drove with the system. There was an increase from 41% favorable at the beginning of the study to 70%. This is indicative of a person adjusting their attitude based on increased knowledge gained through experience. The greatest shift came from those who first claimed a neutral position. Not everyone left the study with a positive view; a little more than 17% of the participants expressed negative views, down from 19% at the beginning of the study. Participants who have very negative views of the concept increased from 5.6% to 7.2%.



	Very positive	Somewhat positive	Neutral	Somewhat negative	Very negative
Baseline	16.0	25.5	38.8	14.1	5.6
Interim	15.3	38.0	29.0	13.4	4.3
Exiting	29.4	41.1	12.5	9.9	7.2

FIGURE 3 Participants' responses to "How do you feel about the idea of replacing the gas tax with a mileage-based road user fee?"

Privacy Versus Auditability

It is likely that acceptability of the new approach will depend to a large extent on perceptions regarding privacy. Two extremes were tested in the first-year field test: a maximum privacy configuration and a user auditable configuration. In the maximum privacy configuration, it is significant that the only figure that can be tied to a particular vehicle was a single dollar amount for total user charges and interest, if applicable, that were due (*5*). When data were transferred from the vehicle, it was only the sum of user charges for each jurisdiction that was calculated by the OBC; all that was required was the amount to be apportioned to each of the jurisdictions. In every case, the total amount for all jurisdictions equaled the single value uploaded in the initial contact made by the vehicle. This approach maximizes user privacy and ensures a fair distribution of revenue.

There remains an issue of auditability, however. The OBC can be configured to provide the user with a detailed record of charges. While this record would enable the vehicle's owner to understand the exact basis for the user charges in billing statements, it is possible that the detailed record could be seen as invasive. Because the trade-off between privacy protection and auditability is one of the key issues addressed in the national evaluation, the system was switched from maximum privacy protection to complete auditability for some of the participants during the course of the field testing.

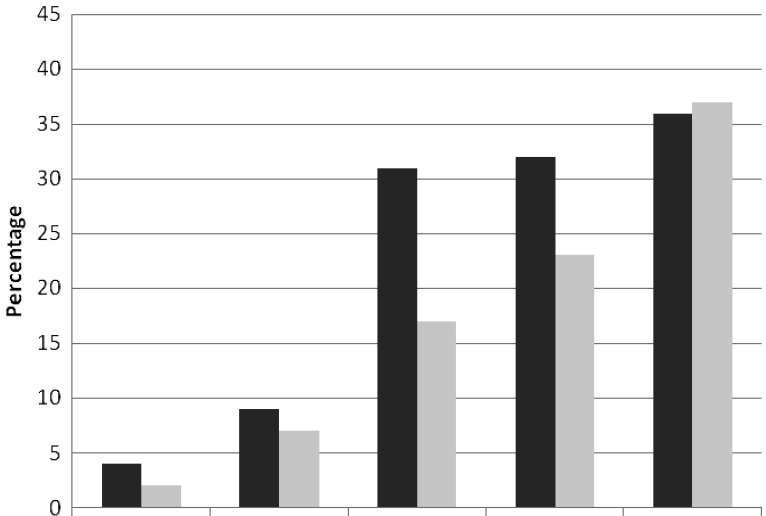
In the first year, the participants rated the two extremes. The participants were asked after each switch between the maximum privacy and complete auditability configuration (three switches were made) "What level of detail is preferred?" This question was an important aspect of the study for the comparison of the participants' views on privacy and the general acceptance of the road user charge. The results are summarized in Figures 4 and 5. The change in responses reveals that the participants, after being exposed to both configurations, shifted their desire for privacy protection to auditability. By the last switch, the participants were leaning toward a system that trades privacy for ability to audit the system. Figure 6 is an example of an invoice produced in the maximum privacy configuration, whereas Figure 7 shows one in the complete auditability configuration.

In the second year, the participants were provided with a third invoice configuration, called a modified auditable configuration. The third option fell between the two extremes in that it provided a monthly summary of travel and charges. Again, the participants were asked after each switch between the maximum privacy and auditability configuration (three switches were made) "What level of detail is preferred?" The results are summarized in Figures 8, 9, and 10. After being exposed to all three configurations, the participants began changing their desire from the privacy protection and the auditability configurations to the intermediate configuration. By the last switch, the second-year participants again were leaning toward a system that trades privacy for auditability, but not complete auditability. The participants preferred a general summary of travel over one that provides a daily log of travel. Figure 11 is an example of an invoice produced in the third configuration.

DISCUSSION AND CONCLUDING REMARKS

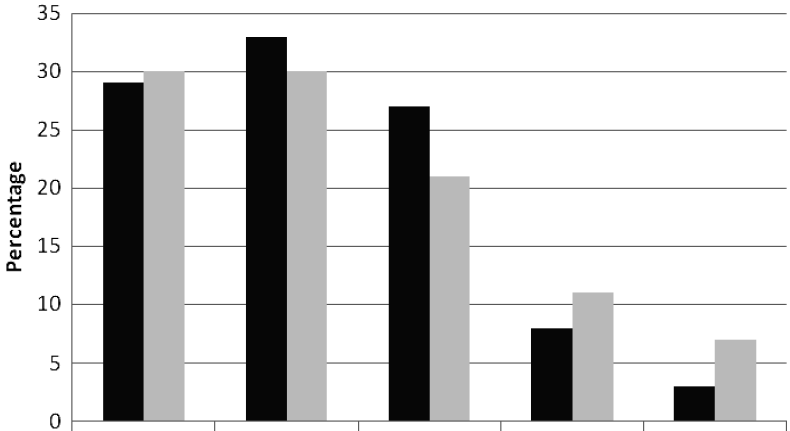
The field test has successfully demonstrated the following:

- Recruitment of a large and diverse candidate participant pool and selection of a set of participants reasonably representative in national demographics in a number of areas, including gender, age, education level, ethnicity, mean travel time, and income;
- Retention and continued active engagement of participants throughout the term of the study;



	Highly desirable	Somewhat desirable	Neutral	Somewhat undesirable	Highly undesirable
First Questionnaire	4	9	31	32	36
Final Questionnaire	2	7	17	23	37

FIGURE 4 Preference for maximum privacy configuration of first-year participants.



	Highly desirable	Somewhat desirable	Neutral	Somewhat undesirable	Highly undesirable
First Questionnaire	29	33	27	8	3
Final Questionnaire	30	30	21	11	7

FIGURE 5 Preference for maximum auditability configuration of first-year participants.

Monthly Road-User Charge Statement

A

Davenport, IA

Vehicle Make:	TOYOTA	**Previous Balance:**	$12.43	**Invoice Date:**	4/16/2009
Vehicle Model:	COROLLA	**Payments Received:**	$12.43	**Invoice No:**	6410
Vehicle Year:	2002	**Current Charges:**	$16.86	**Invoice Start Date:**	3/01/09
		Total Amount:	$16.86		

FIGURE 6 Invoice generated in maximum privacy configuration.

Vehicle Make:	HONDA	**Previous Balance:**	$28.10	**Invoice Date:**	4/16/2009
Vehicle Model:	CR-V 2WD	**Payments Received:**	$28.10	**Invoice No:**	6670
Vehicle Year:	2005	**Current Charges:**	$32.91	**Invoice Start Date:**	3/01/09
		Total Amount:	$32.91		

Road-User Charge Summary

	Vehicle Class Per Mile Rate	Total Miles Traveled	Total Amount
Arizona	$0.0092	646.8	$5.94
California	$0.0172	17.2	$0.30
Idaho	$0.0122	557	$6.79
Utah	$0.0119	425	$5.06
State Sub-Total (see below)			$18.09
Federal Sub-Total	$0.0090	1646	$14.82
Total Road-User Charges		1646	$32.91

Road-User Charge Detail

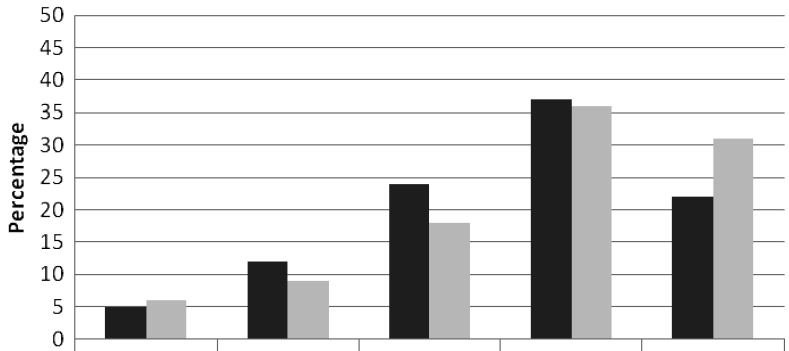
Date	State	Miles Traveled	Total Amount
03/02/2009	Arizona	4.3	$0.04
03/03/2009	Arizona	34.7	$0.32
03/03/2009	California	17.2	$0.30
03/04/2009	Arizona	215.7	$1.98
03/05/2009	Arizona	9.1	$0.08
03/06/2009	Arizona	15.2	$0.14
03/09/2009	Arizona	367.8	$3.38

FIGURE 7 Invoice generated in maximum auditability configuration.

- Robust and reliable hardware and communication infrastructure for collection and reporting of data; and
- Overall viability of the study design and implementation.

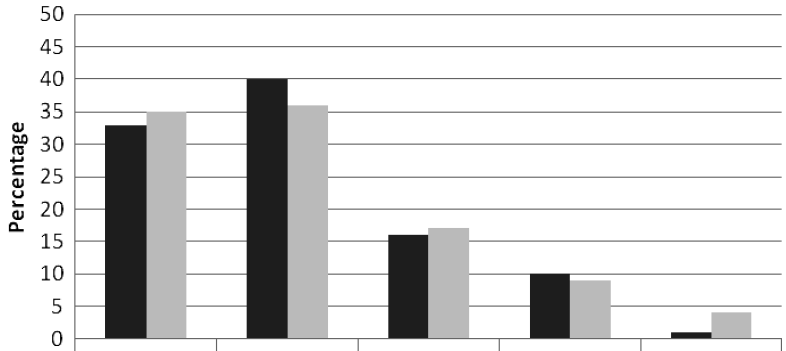
The field test was conducted in two phases, each lasting approximately 10 months and located in 12 states. For the first phase, the six evaluation sites were Baltimore, Maryland; the Research Triangle area of North Carolina; eastern Iowa; Austin, Texas; Boise, Idaho; and San Diego, California. For the second phase, the evaluation sites were Portland, Maine; Miami, Florida; Chicago, Illinois; Wichita, Kansas; Billings, Montana; and Albuquerque, New Mexico. During the two phases, 2,552 participants drove more than 23 million miles with the OBC becoming quite familiar with a road user charging system.

Unlike a traditional survey or focus group, where the responders are fairly uninformed regarding the details of a system, the participants in this test had time to learn and be exposed to the performance of a road user charging system. Therefore, the study was able to accurately measure changes in attitudes of informed subjects. Before enrolling in the study, each participant provided opinions regarding



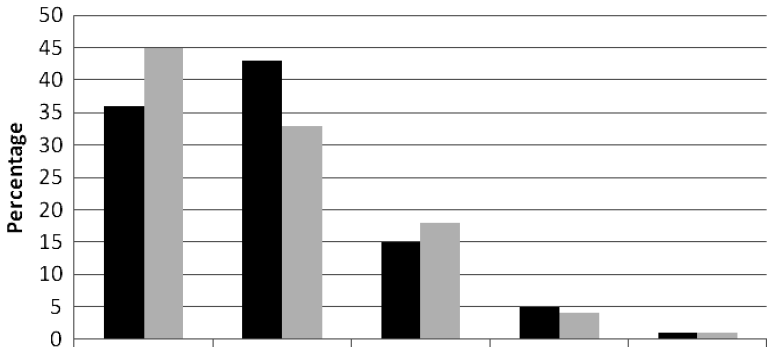
	Highly desirable	Somewhat desirable	Neutral	Somewhat undesirable	Highly undesirable
First Questionnaire	5	12	24	37	22
Final Questionnaire	6	9	18	36	31

FIGURE 8 Preference for maximum privacy configuration of second-year participants.



	Highly desirable	Somewhat desirable	Neutral	Somewhat undesirable	Highly undesirable
First Questionnaire	33	40	16	10	1
Final Questionnaire	35	36	17	9	4

FIGURE 9 Preference for maximum auditability configuration of second-year participants.



	Highly desirable	Somewhat desirable	Neutral	Somewhat undesirable	Highly undesirable
First Questionnaire	36	43	15	5	1
Final Questionnaire	45	33	18	4	1

FIGURE 10 Preference for intermediate configuration of second-year participants.

Monthly Road-User Charge Statement

C

Vehicle Make:	NISSAN	Total Miles:	1816	Invoice Start Date:	5/01/10
Vehicle Model:	MAXIMA	Previous Balance:	$52.75	Invoice End Date:	6/1/2010
Vehicle Year:	2005	Current Charges:	$53.74	Invoice No:	44620

Road-User Charge Summary

	Vehicle Rate Per Mile	Total Miles Traveled	Total Amount
Chicago	$0.0024	6	$0.01
Cook County IL	$0.0029	582	$1.64
Illinois	$0.0197	1817	$35.78
USA	$0.0090	1817	$16.33
		Total Charge	$53.74

FIGURE 11 Invoice generated in modified auditability configuration.

the concept of mileage user fee. At that time, the majority of the participants (more than 60%) expressed a neutral or negative view. After their experience in the study, the view of the system was rated as favorable by 70% of the participants.

Before the field test, early investigation showed privacy was a concern regarding the installation and monitoring of miles traveled. The perception of government invading an individual's right to privacy increased with the use of a GPS-based system. This concern was investigated over the two-phase test by assessing the participants' attitudes regarding the trade-off between privacy and the ability to audit the system. Toward that end, the participants were exposed to various system configurations through monthly invoices. In Phase 1, the participants were given invoices that provided maximum privacy protection (only the total amount owed was presented) and invoices that provided a daily audit of the miles traveled in each taxing jurisdiction. Sixty percent of the participants put aside their privacy concerns and rated the ability to audit the system positively (only 9% rated the maximum privacy as being positive). The participants in the Phase 2, similar to those in Phase 1, rated a system set to an auditable configuration as positive. However, when they were given a modified version of the auditable invoice, one that summarized their travel on a monthly basis, they preferred that configuration the most.

Overall, the prototype road user charging system developed and implemented for the study proved to be robust and reliable. While accruing road user charges for more than 23 million miles of travel in all 48 contiguous states, including several local taxing jurisdictions, the system was unable to reliably attribute only 0.6% of total miles to the correct charging jurisdiction(s). However, 6.7% of miles traveled had to be assigned to a jurisdiction via interpolation due to short-term GPS outages. Although this is not a significant issue for a charging system with relatively coarse jurisdictional boundaries (state, county, and city boundaries), it might pose some problems for a system attempting to assign road level or individual lane pricing. Wireless data upload was problem-free and no data were lost due to problems with communication infrastructure. Several rate table upgrades were successfully uploaded to participant vehicles during the study without incident.

Installation of the OBC and associated antennas into participant vehicles proved to be challenging. Installations, performed by trained, professional installers, required approximately 90 min to complete. A small number of vehicle make, model, and year combinations proved incompatible with the OBC due to either electrical system issues or OBD-II bus problems. This could be a significant issue in any future attempt to retrofit mileage-based charging hardware into existing vehicles.

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The Revenue and Finance Committee peer-reviewed this paper.