Connected Vehicles for Safety, Mobility, and User Fees:

Evaluation of the Minnesota Road Fee Test

February 2013

www.dot.state.mn.us

Your Destination...Our Priority

Accessibility Statement

To request this document in an alternative format, please contact the Affirmative Action Office at 651-366-4723 or 1-800-657-3774 (Greater Minnesota); 711 or 1-800-627-3529 (Minnesota Relay). You may also send an e-mail to ADArequest.dot@state.mn.us.

(Please request at least one week in advance)

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
4. Title and Subtitle Connected Vehicles for Safety, Mobility, and User Fees: Evaluation of the Minnesota Road Fee Test		5. Report Date February 2013
		6.
7. Author(s) Jennifer A. Rephlo		8. Performing Organization Report No.
9. Performing Organization Name and Address SAIC (Science Applications International Corporation) 8301 Greensboro Drive McLean, VA 22102		10. Project/Task/Work Unit No.
		11. Contract (C) or Grant (G) No. 92809
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Traffic, Safety & Technology 1500 W County Road B2 Roseville, MN 55113		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes http://www.dot.state.mn.us/mileagebaseduserfee/pdf/EvaluationFinalReport.pdf		

16. Abstract (Limit: 250 words)

In 2007 Minnesota legislature approved a 5,000,000 project in order to demonstrate technologies which will allow for the future replacement of the gas tax with a fuel-neutral mileage charge. The Minnesota Department of Transportation (MnDOT) organized a study to examine the implementation and operation of a mileage based user fee program (MBUF), which might allow for the supplementation or replacement of traditional gas taxes. The primary objectives of the study were to: assess the feasibility of using consumer devices for implementing Connected Vehicle and MBUF applications. These applications included localized in-vehicle signing for improving safety, especially for rural areas, and the demonstration of the proposed Connected Vehicle approach for providing location-specific traveler information and collecting vehicle probe data. The study consisted of 500 voluntary participants, equipped with an in-vehicle system comprised of entirely commercially available components, primarily a smartphone using an application capable of tracking participant vehicle trips. Successfully meeting its primary objectives, the system was capable of assigning variable mileage fees determined by user location or time of day, as well as presenting in-vehicle safety notifications which had measureable effect on the participants driving habits. MnDOT contracted Science Applications International Corporation (SAIC) to perform research for the project and an evaluation of its findings. This document is the final report from SAIC, providing a summary of the study, its findings and an evaluation of the project as a whole.

17. Document Analysis/Descriptors		18. Availability Statement
mileage based user fee MBUF gas tax Connected Vehicle	smartphone miles fee intellidrive MN Road User Fee	No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	306	

Acknowledgements

SAIC would like to thank Cory Johnson, the Minnesota Department of Transportation project manager, as well as the following individuals, for their support and guidance throughout the effort:

- Vicki Albu, Minnesota Department of Public Safety
- Dharam Bobra, Hennepin County
- Kenneth Buckeye, Minnesota Department of Transportation
- Tom Dumont, Minnesota Department of Transportation
- Sue Groth, Minnesota Department of Transportation
- Matt Gjersvik, Minnesota Department of Transportation
- Ken Hansen, Minnesota Department of Transportation
- Virgil Hawkins, Wright County
- Christine Krueger, Minnesota Department of Transportation
- James McCarthy, FHWA Division Office
- Patricia McCormack, Minnesota Department of Public Safety
- Jeremy Neeck, Minnesota Department of Revenue
- Ray Starr, Minnesota Department of Transportation
- Nick Thompson, Minnesota Department of Transportation

The team would also like to acknowledge the Battelle deployment team and the PMO staff from Mixon-Hill for their support in providing information for data analysis and evaluation, as well as Arvid Menon from the University of Minnesota for his support of the Cooperative Intersection Collision Avoidance Systems test.

TABLE OF CONTENTS

List of Figures

LIST OF TABLES

List of Acronyms

CICAS-SSA	Cooperative Intersection Collision Avoidance Systems Stop Sign Assist
ConOps	Concept of Operations
COTS	Commercial Off the Shelf
CR	County Road
DII	Driver Infrastructure Interface
DOR	Department of Revenue
DPS	Department of Public Safety
DSRC	Dedicated Short-Range Communications
DVI	Driver Vehicle Interface
DVS	Driver Vehicle Services
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
GPS	Global Positioning System
HTTPS	Hypertext Transfer Protocol Secure
ITS JPO	Intelligent Transportation Systems Joint Program Office
MBUF	Mileage-Based User Fees
MnDOT	Minnesota Department of Transportation
MRFT	Minnesota Road Fee Test
NHTSA	National Highway Traffic Safety Administration
OBD	On-Board Diagnostic Port
OR	Odometer Reading
OS	Operating System
PMO	Program Management Office
RFP	Request for Proposal
TH	Trunk Highway
USDOT	United States Department of Transportation
VIDM	Vehicle Identification Module
VMT	Vehicle Miles Traveled

Executive Summary

1 Introduction

Revenue derived from fuel taxes is a crucial source of funding for state departments of transportation. However, these revenues have decreased in recent years in many states and the U.S. Congress and many state legislatures are reluctant to increase the fuel tax.[1,2,3] Inflation, reductions in vehicle miles traveled (VMT), and increases in vehicle fuel efficiency are the key reasons for this decline in fuel tax revenues.[4] Accounting for inflation, Highway Trust Fund revenues have declined 20 percent since 2006.[5] This trend is expected to continue due to new vehicle efficiency standards recently announced by the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) that require newly manufactured vehicles to be 44 percent more fuel efficient by 2016 and 120 percent more efficient by 2025.[6] States have expressed growing interest in exploring options for replacing or supplementing the fuel tax, including the possibility of implementing road user fees, specifically mileage-based user fees in many cases.

In 2007, the Minnesota Legislature appropriated $5 million from the trunk highway fund for a technology research project exploring mileage-based user fees (MBUF). The law called for a pilot project to demonstrate technologies that would allow for the future replacement of the gas tax with a fuel-neutral mileage charge.

The Minnesota Department of Transportation (MnDOT) was tasked with leading the effort and this document reports the findings from the pilot project that ensued. The project is one of the first studies across the country to test MBUF concepts in practice. What makes the study unique is that it used technology as the means for assessing mileage-based user fees, and it combined this technology with other safety and mobility technologies in support of the United

---

[1] Wachs, M., "A Dozen Reasons for Raising Fuel Taxes," *Public Works Management Policy* vol. 9 no. 4 (2003), 235-242.

[2] National Surface Transportation Policy and Revenue Study Commission, *Transportation for Tomorrow,* (Washington, D.C.: s.n., 2008).

[3] Transportation Research Board, *Special Report 285: The Fuel Tax and Alternatives for Transportation Funding,* (Washington, D.C.: s.n., 2006).

[4] *Ring Fencing and Rate Setting: Policy Challenges of Road User Charging*, Presented by Travis Dunn, D'Artagnan Consulting, LLP., at 2012 MBUF Symposium, May 2012. Available at: http://www.ibtta.org/files/PDFs/Dunn_Travis.pdf.

[5] FHWA Highway Statistics, BLS.

[6] Congressional Budget Office, *How Would Proposed Fuel Economy Standards Affect the Highway Trust Fund?* May 2012. Available at: http://www.cbo.gov/sites/default/files/cbofiles/attachments/05-02-CAFE_brief.pdf

States Department of Transportation's (USDOT) connected vehicle and Cooperative Intersection Collision Avoidance Systems (CICAS) initiatives.

The objective of the Minnesota Road Fee Test (MRFT) was to inform future public policy decisions regarding mileage-based user fees and connected vehicle applications. In keeping with this objective, MnDOT sought to design an on-board equipment-based system that integrated a mileage-based user fee application with safety and mobility applications, and to test the system with real drivers. To this end, the test aimed to demonstrate the capability of one commercially available aftermarket device to accomplish three primary goals:

1) Assess mileage-based user fees;
2) Convey safety alerts to drivers through in-vehicle signing; and
3) Provide a means for vehicles to provide data for the purposes of generating travel times on major corridors.

2 The Project Team

The MRFT Project Team was led by MnDOT and composed of three prime contractors:

- Mixon Hill, who served as the program management oversight (PMO) contractor;
- Battelle, who led the field deployment team; and
- SAIC, who led the research and evaluation components of the test.

Additionally, the University of Minnesota's Institute of Technology ensured the DSRC transmission for the CICAS test. The project team is represented in Figure 1. SAIC is the author of the present report, which describes the evaluation of the MRFT deployment.

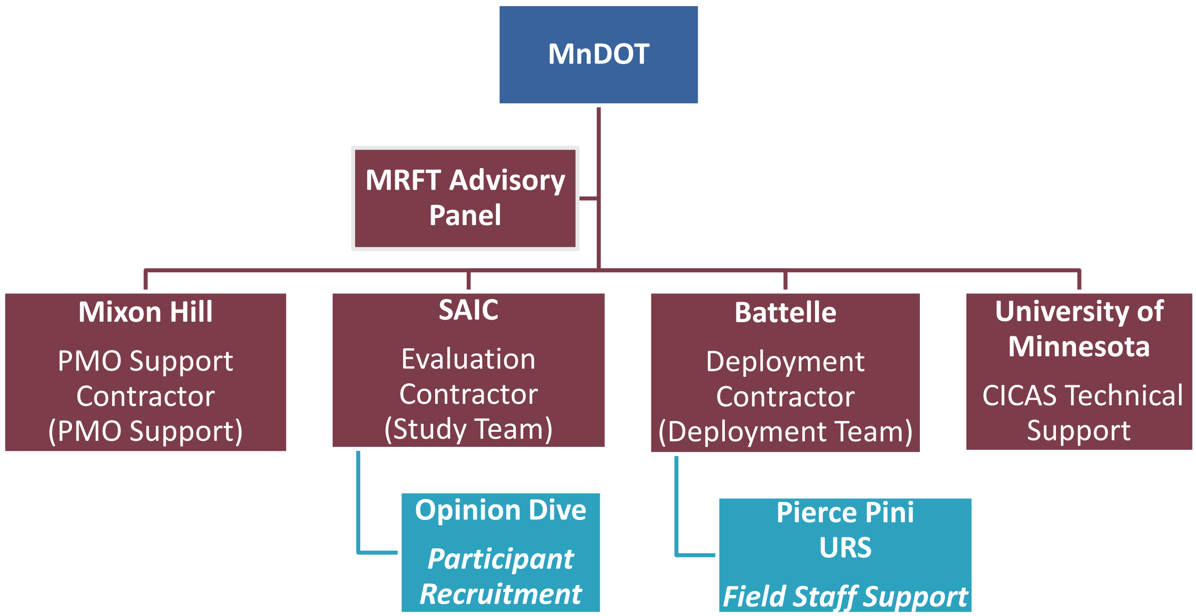


Figure 1. Minnesota Road Fee Test Project Team.

3 Evaluation Goals and Objectives

The overall objective of the project was to gather information to inform future public policy decisions regarding mileage-based user fees and connected vehicle applications. This included information such as:

- How the public would react to a mileage-based fee - *Would they be accepting of the size of the fee, were it comparable to the gas tax? How often would they want to pay? What method of payment would they prefer?*
- How the public would feel about privacy after having experienced a simulated system – *Would they be concerned about others having access to their data?*
- What kind of administrative/operational support would be required of an MBUF program - *How often might people call the help line? What would be the nature of their questions?*
- What sort of information the public requires to be accepting of an alternative funding mechanism – *Is the public aware of the projected revenue shortfalls? Does the public understand the problem?*

- How the public would feel about "value-added" services to MBUF such as in-vehicle safety signage – *Would there be safety benefits? Would they perceive safety benefits? Would they appreciate these as value-add propositions?*

More specifically, the goals of the evaluation were to:

- <u>Assess the technical performance of the technology used in the test</u> – This area of the evaluation looked at system reliability, system accuracy and precision, and opportunities for evasion and tampering, with a focus on not just the technologies and platforms used in the test, but also consideration of technologies that might be considered for future "real-world" deployments. This aspect of the test is discussed in *Volume II, Overview of Data and Technical Performance of the System*.
- <u>Assess participant perceptions of MBUF concepts and safety technologies</u> – A central focus of the test was to gather perceptions from the public regarding MBUF concepts, including their perceptions of a technology approach to MBUF, their perceptions of the in-vehicle safety alerts tested, and their perceptions of a system that combines the two. Although studies have been conducted of public perceptions of MBUF, this test provided an opportunity to gather feedback from drivers on issues such as privacy concerns after they had experience using an actual system. This aspect of the test is discussed in *Volume III, Driver Acceptance Assessment*.
- <u>Investigate the impacts associated with mileage-based user fees on driver behavior and revenue</u> – A real-world implementation of mileage-based user fees would have some impact on drivers' travel patterns, such as when they drive, how much they drive, and where they drive, since paying a fee based on miles driven rather than based on gallons of gas used can make drivers more aware of their driving behavior. This goal area focused on assessing whether drivers changed their driving behavior during the test as a result of paying by the mile. This goal area is discussed in *Volume IV, Assessment of Impacts on Mobility*.
- <u>Investigate the safety impacts of the safety technologies tested</u> – One goal of the test was to determine the impact of the in-vehicle safety alerts. This includes both driver perceptions of the alerts as well as an analysis of whether driver behavior changed as a result of the alerts. This aspect of the test is covered in two separate sections. The CICAS study, which was a limited study of seven drivers at one intersection, is discussed in whole in *Volume VI, In-Vehicle CICAS Evaluation*, and the study of driver responses to the safety alerts is presented in *Volume V, Assessment of Impacts of Speed-Related Signage on Safety*.
- <u>Investigate the feasibility of generating travel times using data from the same device used to assess mileage fees</u> – One goal of the pilot test was to determine whether a device designed to assess mileage-based user fees also has the potential to be used as a

device to collect second-by-second data that could be used in projecting travel times. Therefore, the purpose of this goal area was for the study team to investigate the feasibility of determining travel times based on data gathered from smartphones used in the test. This goal area is discussed in *Volume VII, Assessment of Utility of Travel Time Data.*

- Document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale – This aspect of the study is important as it provides insight into the success factors and pitfalls that may be encountered in a "full-scale" deployment of MBUF (e.g., multi-jurisdiction, statewide, or multi-state), connected vehicle applications, or any combinations thereof. This goal area of the evaluation included: documenting costs associated with development and deployment; documenting the challenges and limitations encountered by the participating organizations and stakeholders and any steps that were taken in an attempt to address these challenges; and documenting success factors identified by project stakeholders that should be considered for inclusion in subsequent tests or full-scale deployments. This goal area is discussed in *Volume VIII, Operation and Administration of an MBUF Program*.

4 Conduct of the Test

The project team selected the greater Twin Cities Metro Area as the location for the test. As the geographic boundary of a predefined "Metro Zone" was one of the factors used to determine the price for any given trip, it was desirable to select a county that would provide sufficient opportunity to obtain data on commute trips that begin outside the Metro Area and require crossing into the Metro Area. Among the counties surrounding the Metro Area, Wright County has the largest number of residents (49 percent) commuting into the Metro Area, and was therefore selected as the key study area for the test.

Focusing the Pilot Study on Wright County provided a mix of urban and rural opinions as 47 percent of the county is defined as "urban" and 53 percent of the county is defined as "rural."[7] It is important to note that Wright County's rural residents do live in close proximity to the Metro Area, so their viewpoints may differ from those in more remote areas of the state.

[7] Source: City Data, Wright County, Minnesota, http://www.city-data.com/county/Wright_County-MN.html (Accessed October 21, 2010).

4.1 Location of the Signage Zones, Travel Time Corridors, and CICAS Test

The project team identified a total of 98 signage zones for inclusion in the test. This included 46 school zones, 28 speed zones (areas of reduced speed), 17 curves, and a 10-mile construction zone, which included 7 individual signage zones.

Three corridors were identified by the project team for study as “travel time” corridors: a 1.6-mile segment of TH55 in the City of Buffalo, which is in Wright County; a 16-mile segment of TH55 in Hennepin County; and an 8-mile section of I-94 from TH 101/Main Street in Rogers to County Rd 109/Weaver Lake Road in Maple Grove. The CICAS test was conducted at the intersection of US Highway 169 and County Road 11 in Mille Lacs County, MN.

4.2 The Fee Structure for the Test

As shown in Table 2, the fee structure used in the test included a rate of $0.03 per mile for travel that is both during peak hours and in the predefined “Metro Zone” (as show in Figure 6) and $0.01 per mile for all other travel.

The intent was that participants would not be charged for travel that occurred outside of the state of Minnesota. However, to incentivize participants to use their device as much as possible, they were charged at the higher rate (i.e., $0.03 per mile) for any miles driven without the device (later in this report these are termed “non-technology” miles). As a result, if participants drove outside of the state but did not take their device, they were, in fact, charged for those miles, and at the higher rate. Similarly, if they drove during off-peak hours without the device, they were charged at the higher rate. Part of the reason for structuring the fee in this way was to explore how an “opt-in discount model” might work (i.e., in one possible real-world solution involving a technology approach to MBUF, drivers might not be required to have the technology, but could “opt-in” to using technology, and would pay a discounted rate for doing so).

Table 1. Fee Structure for the Test.

Current Driving Location		Peak Times Monday-Friday 7AM-9AM 4PM-6PM	Off Peak Times
Outside of Minnesota		$0.00	$0.00
Inside Minnesota	**Outside the Twin Cities Metro Zone**	$0.01	$0.01
	Inside the Twin Cities Metro Zone	$0.03	$0.01

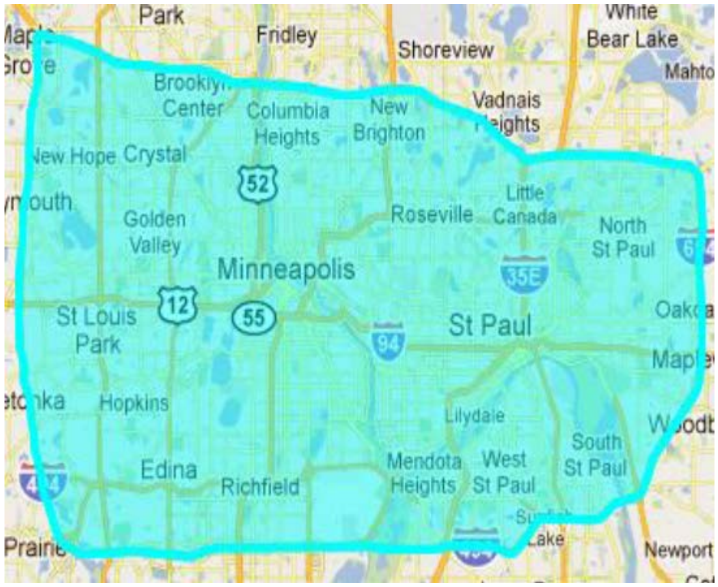


Figure 2. Boundary of "Metro Zone" (Loop formed by I-494/I-694).

Source: Google Maps

5 Key Data Sources

In assessing each of these evaluation goals, the study team utilized a number of data sources including:

- Service requests, which provided insight into the nature of the challenges drivers can face with this type of system.
- Data from the system, which allowed the team to explore driver response to the safety alerts, as well as to explore changes in driver behavior resulting from the MBUF system. Data available to the team included the following:[8]
    - Number of trips recorded per day;
    - Number of trips occurring through pre-defined safety zones;
    - Number of miles driven during the baseline period in each fee category;
    - Number of miles driven during the test period in each fee category;
    - Length of each trip in miles; and

[8] Note that these data were available for all trips, but assigning a trip to a participant was not possible unless the participant elected to provide the study team this level of visibility.

   - Second-by-second data for each trip including vehicle speed, heading, latitude, longitude, timestamp, and GPS accuracy.
- Participant perceptions as gathered through a multi-tiered approach including surveys, focus groups, and interviews.
- Stakeholder interviews, which helped the team document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale.

In total, the test included:

- Collection of over 660 million trip data points and nearly 4 million miles representing data on nearly 500,000 trips across a total of 478 participants who completed all test activities.
- Generation of 2,750 invoices, resulting in collection of over $32,000 in simulated fees.
- Collection of input from participants including 1,411 survey responses, 423 one-on-one telephone interviews, and 6 focus groups representing the viewpoints of 63 participants.

6 Key Findings

MnDOT deployed and tested an MBUF system with 500 Minnesota citizens. Some of the key features of Minnesota's approach were to use one commercial off the shelf (COTS) device with GPS capabilities to enable the collection of mileage-based user fees (MBUF) integrated with safety alerts and the generation of travel time data. The system designed for the test did accomplish all three of these functions as described in this report. However, this field study was not merely a test of a particular technological solution. It was also intended to test approaches to a variety of practical issues associated with an MBUF deployment, such as driver acceptance of technology features and concerns over privacy, the process of paying and remediating MBUF invoices, and other administrative and operational issues including fee setting, invoicing, and repudiation; communication and outreach to the public; and customer service.

Several key findings can be identified from the field test:

- MnDOT developed a better understanding of the "opt-in" discount system approach to MBUF.
- Participants were accepting of modest monthly MBUF invoices.
- Privacy was not of paramount concern to participants.

- MnDOT developed a better understanding of customer requirements for an MBUF program.
- The basic messaging used in the MRFT was effective at conveying the need for a funding alternative to drivers.
- The test provided insight into the types of planning, management, and customer interactions that would be required of an MBUF program.
- Regardless of their perceptions, drivers showed some compliance to in-vehicle safety signage.
- Drivers value simplicity in the design of any alternative transportation funding program.

Each of these findings is described in more detail in the following sections.

6.1 MnDOT developed a better understanding of the "opt-in" discount system approach to MBUF

MnDOT met its goal of deploying the conceptualized system in a realistic and thorough manner. The MFRT offers the unique perspective of having 500 drivers who became experts with this particular implementation over a half-year period. These drivers have been the closest of anyone in Minnesota, and perhaps the nation, to having such a robust real-life experience with an MBUF concept and a specific COTS technology implementation.

Almost 500,000 individual trips were recorded in the 4-month test period (following a 2-month baseline period) and 83 percent of these trips were voluntarily linked to participant drivers for the purposes of the study team's data analysis and evaluation. The half-million trips represented almost 4,000,000 miles of travel recorded on the technology device and at odometer readings. These combined miles resulted in a total of nearly $38,000 in field test "revenue."

A unique component of the MRFT was that MnDOT created an MBUF program to which drivers could "opt-in." The purpose of this approach was to enable drivers to determine when and where they wanted to share personal data. The MBUF system was essentially a fixed fee system at $0.03 per mile. However, a discounted rate ($0.01 per mile) was available for drivers who were willing to share anonymized trip information with MnDOT. This tested approach served as a model for how an MBUF system might gain entry to the customer market place.

The results of the field test show that 77 percent of all the miles driven during the test were recorded on the device making it appear that drivers used the device approximately three-quarters of the time. However, participants' ability to obtain this discounted rate was not optimal. Because of software and hardware challenges, the device occasionally captured more or less miles than the participant actually drove. Reasons for this are varied and are explained in detail in Volume II.

6.2 Participants were accepting of modest monthly MBUF invoices

While this field test generated almost $40,000 in simulated revenue, the amount paid by each individual participant was modest, averaging $20 per month, which equates to less than a dollar a day for most drivers. This was designed to be a reasonable approximation to the current Minnesota fuel tax (as described in Volume IV), and is a relatively modest invoice amount compared to many utility bills. In considering initial reactions to the MBUF rates, only 17 percent of participants reported that the rates were higher than they expected and the rest reported they were the same (53 percent) or lower (30 percent) than expected. The majority of the participants also agreed that it was reasonable to vary a fee by time of day (i.e., peak/off-peak hours) and location (i.e., inside or outside the "Metro Area").

Non-payment and enforcement of payment was a minimal concern in the field test. Of course, there is some level of "self-selection" present in this type of research meaning that participants who volunteer and receive stipends have some motivation for complying. However, this is still an important finding since the assessment and invoicing process were not so tedious or difficult that bills were not paid. It was in fact a successful process, although participants did offer suggestions for improving the content and presentation of the material.

They were also asked, based on their 6 months of experience in the test, if they would prefer to pay mileage-based fees as a replacement for the fuel tax. While participants were quite divided on this question, with 37 percent indicating that they would prefer to pay a mileage-based fee as a replacement, 48 percent indicating they would prefer just to continue to pay the fuel tax, and 15 percent responding that they did not have an opinion or that they were not sure of their preference. Participants indicated numerous reasons for preferring a mileage-based fee, including that a mileage fee ensured that everyone paid their "fair share." Of the participants who indicated that they would prefer to continue to pay the fuel tax, common reasons were that a mileage fee highlighted the amount of money being paid each month in taxes while the fuel tax "hid" the cost in the price of a gallon of gas, and paying a monthly invoice was "just one more bill." The undecided participants indicated that they had not determined if a mileage fee would save them money or that it would depend on how a state would implement a mileage-based user fee system.

The fact that nearly 40 percent of respondents preferred a mileage-based user fee over the fuel tax at the end of the test is quite positive given that the majority of these participants were unaware of the idea of a mileage-based user fee prior to the start of this test and that this concept was completely new to them.

6.3 Privacy was not of paramount concern to participants

The privacy of individual drivers' data was of utmost concern during the conduct of this field test, and it was assumed that it would be a major concern of participants as well. Therefore, the MnDOT project team took multiple steps to ensure driver privacy through establishing an opt-in model and anonymizing the data collected by the deployment team. Because an MBUF system inherently relies on user information to assess fees, some amount of personal information is required (e.g., who the consumer is, how many miles have been driven). The amount and sensitivity of the information may vary based on the approach to collection. Systems that rely on higher levels of technology (e.g., GPS) require that more detailed and perhaps more "personal" information be collected. The MRFT application was designed to demonstrate that participants' data can be kept private; drivers had to expressly allow the study team access to their data for use in this research project.

All this had been explained to participants, but participants did not express much interest in knowing the details of the process. In fact, the MRFT study team found that drivers did not express fear about a lack of privacy per se, believing that they give up their privacy regularly (e.g., to mobile phone service providers). Instead, participants worried that their data would be vulnerable to access by wrongdoers (e.g., "hackers") who would seek to misuse the information. They wanted reassurance that their data could be safely held by the State, such as in the form of a security certificate program.

6.4 MnDOT developed a better understanding of customer requirements for an MBUF program

Volume VIII lays out the broad range of activities completed by the project team as part of the MRFT. Some of these were specific to the field test (e.g., issuing stipends related to participation) while others were activities which would need to occur in any real-world deployment similar to the field test. At present time, MnDOT does not regularly provide services on an individual basis to its customers. Whatever organizations participate in deploying a real world MBUF system will be required to become more responsive to individual concerns. Some of the activities expected to be present in a real world deployment are:

- Scheduling appointments.
- Capturing vehicle mileage.
- Process user agreements.
- Installing equipment.
- Training drivers.
- Preparing equipment kits.
- Uninstalling equipment.

- Processing on-site payment.
- Receiving and documenting a service request.
- Providing guidance for a known technical issue.
- Providing guidance for a new technical issue.
- Escalating issue to a specialist.
- Generating and mailing paper invoices.
- Processing payments received.
- Managing late payments.
- Developing and testing the application.
- Developing operational procedures.
- Establishing fees.
- Managing data.
- Managing hardware and software.
- Developing messages to drivers.
- Developing training materials.
- Developing and maintaining a participant portal.
- Coordinating across organizations.

Participants reported a generally high level of satisfaction with the service they received during the MRFT. Nearly all participants agreed that scheduling the odometer reading appointment was easy, the staff clearly explained all materials, and the staff successfully and fully answered all questions. Further, many participants wrote in additional comments recognizing the odometer reading staff for their understanding of the program as well as their ability to relay that information to the participants and answer any questions they had. The design and operation of these odometer readings operated well and the basis could be adopted and expanded to a larger scale deployment.

However, it is important to note that much of the cost associated with these activities occurs upfront during development and testing. Making an investment early on to understand the end users thoroughly, to craft and test procedures, and to train staff will enable long-term stability in deploying a system. Further, the MRFT supported only 500 drivers, so supporting activities were carried out by a small research team. In the real world, many activities would be outsourced to state organizations or specialized private firms (such as call centers or mail facilities) to process service requests or process paper invoices, resulting in efficiencies.

6.5 The basic messaging used in the MRFT was effective at conveying the need for a funding alternative to drivers

Participants in the study received very little education or training about the transportation funding issues driving the MRFT. Yet, by the conclusion of the study they easily understood the basic needs and saw the needs as reasonable and trustworthy. That implies that the messages used in the MRFT were very effective.

A solution is needed to bridge the transportation funding shortfall, and whether or not MBUF is determined to be the solution, developing communication strategies for effectively communicating with the public on the topic of transportation funding is critical. Communicating the problem is the first step. Future public outreach efforts are needed to make the larger community of road users knowledgeable about, and invested in, the transportation funding issues that face the state. MnDOT representatives report that the current situation is not that drivers do not care about this issue, but that it has not been raised to such a visible level as issues like education or health care. The revenue issue must become more tangible to drivers. Even encouraging a basic understanding of how much drivers currently pay in motor fuel tax today might benefit the discussion. One idea raised during the study was to publish the cost of the fuel tax at the pump. Further work might involve promoting the spending of dollars to build and maintain roads in terms of “your motor fuel taxes built this road.”

Key to communicating to drivers is to understand the segments of the population to be contacted. Most drivers in the field study were sensitive to ways in which the fuel tax is not equitable, but they also were concerned with how a mileage fee might penalize some drivers. Paying mileage-based user fees will have a very personal and practical effect on drivers. While on the whole it might be a fair solution, there will always be individual winners and losers during the transition to a new system (as demonstrated in Volume 4).

6.6 The test provided insight into the types of planning, management, and customer interactions that would be required of an MBUF program

The MRFT demonstrated that multiple organizations with different roles and responsibilities were required to complete a test with 500 participants. While a real-world deployment would be able to draw from the design and lessons learned during the MRFT, a real-world deployment would require coordination with many more individuals and organizations (e.g., customer service, data management, etc.) that interact virtually and in different geographic locations. Also, in order to implement an MBUF program on a regional or national level successfully, the involvement of multi-state groups must be considered, as challenges exist with the ability to collect fees from out-of-state drivers. Research is needed to understand how these groups could be formed and how they would function seamlessly from the perspective of drivers and in a way that maximizes the efficient use of resources.

One of the foremost unknowns relative to establishing a new transportation revenue source is the administrative and operational resources for doing so. These are important to understand for a couple of reasons. First, the amount of fee for which each citizen is responsible will include a portion of these administrative and operational costs. Second, the proportion of the fee that these costs represent will have a major impact on citizens' perceptions of the fee. Minimizing administrative and operational expenditures will be critical to obtaining buy-in from stakeholders and project partners. The MRFT provides insight into the types of planning, management, and customer interactions that would be involved in many of the road user fee approaches that a state might adopt. It is important to note that much of the cost associated with activities in an MBUF program occur upfront during development and testing. Making an investment early on to thoroughly understand the end users, craft and test procedures, and train staff, will enable long-term stability in deploying a system.

6.7 Regardless of their perceptions, drivers showed some compliance to in-vehicle safety signage

MnDOT leveraged the capabilities of the COTS GPS-featured technology to integrate connected vehicle features, and demonstrated that safety alerts can be provided without roadside infrastructure investments. The speed-related safety alerts were found to be effective at reducing speeds. Both visual and audible alerts appear to have improved speed limit compliance and reduced driver speeds, while drivers showed a greater reduction in speed when presented with audible alerts. The largest benefit was seen with the 7 percent of drivers who previously increased their speed upon entering the zone, but who slowed down upon entry when alerts were present. Overall there was an average reduction in speed of 9.0 mph among these drivers.

It may be wise to phase these elements in later, so as to not complicate the public acceptance issue of MBUF. Generally speaking, drivers saw the potential value in these services to drivers, but did not necessarily think they should be part of a revenue-oriented program. In fact, they reacted strongly to the presence of other features besides revenue features being present in the test. They recognized the need to find new, more stable revenue mechanisms. However, the topics of time of day and metro zone pricing, safety signage alerts, and the potential for improved travel times were not engaging topics for them. Participants preferred for the revenue issue to be handled in a way that is simple and not confused by layering other capabilities on top of it. It may make sense for a state to consider adding (or offering) these kinds of features in the future once the public has accepted a base program of MBUF.

Providing participants flexibility to customize safety alerts (e.g., location, volume, tone, etc.) would likely enhance participant acceptance. While the majority of the participants felt that the visual and audible alerts were useful tools for drivers, about half of respondents indicated that they would prefer to disable both the visual and audible safety alerts, implying that the signage features are useful for "other drivers." Telephone interviews with participants found that participants often drove through the same signage zone numerous times each week, or even each day, throughout the test. This repetition of safety warnings likely caused an increase in those responding that would like to disable the signage. The limited set of seven drivers who participated in the CICAS safety test spoke favorably about the intersection gap acceptance alerts, but it should be noted that this limited set of drivers was separate from the 500 MBUF participants and therefore they did not experience this safety signage as an added "feature" to the MBUF application.

The MRFT demonstrated that safety alerts can be delivered to drivers via a smartphone application. By cataloging sign locations using GPS coordinates, the field test produced a sample roadside sign database which was referenced by the MRFT application to determine if a participant was driving through a signage zone or not. As states improve processes for maintaining roadway infrastructure, many are using GIS to inventory certain roadway features such as sign locations. With the availability of this data and as GPS technology on smartphones continues as the norm, similar applications could be developed and made available for download to the general public without requiring any infrastructure investment.

6.8 Drivers value simplicity in the design of any alternative transportation funding program

Many of the participants in the MRFT who preferred the fuel tax over an MBUF program noted that one of the significant reasons they preferred the fuel tax was its simplicity. The current fuel tax requires very little thought at present time and requires no work on the part of the driver. Anything else, and in particular, a personal technology device like a smart phone, will require more involvement on the part of the driver.

This desire for simplicity was echoed in participants' perceptions regarding device usability and overall opinions of this particular MBUF technology solution. Again and again, participants in the MRFT expressed a desire for the technology to be integrated into the vehicle so that it would require little (if any) interaction on their part. To accomplish this would require a delicate balance of making fees and invoicing transparent to drivers while minimizing their interactions with technology. Further research is needed to fully understand the advantages and disadvantages of this approach. While a device permanently installed into a vehicle dedicated to collecting and transmitting MBUF information may provide the highest level of service to the user, these devices are not currently available and would require research, design, development, and production prior to becoming a reality.

As demonstrated in the MRFT, the use of COTS devices can add its own set of challenges. In some cases during the test, hardware or software issues hindered the system's ability to reliably capture trips. Location data is a critical component in properly assessing user fees, but in the MRFT, it appears that GPS availability was a significant system issue. Smartphones are quickly changing and improving, and the quality of GPS chips in smartphones in the near future may very well be better-suited for this kind of application, but it may be too early at this time to rely on smartphone technology to achieve the level of accuracy expected/desired for an MBUF program.

Developing a standard application for a COTS device, such as a smartphone, would allow the public to enroll without the purchase (or provision) of additional equipment. However, the challenge with allowing the use of participant-owned personal devices is that while the use of these devices can more quickly increase adoption by drawing upon the thousands of devices already in the hands of the public, it would also increase the number of both manufacturers and device models being used in the program, all requiring technical support by the administering agency.

Volume I: Background

1 Introduction

Revenue derived from fuel taxes is a crucial source of funding for state departments of transportation. However, nationally, these revenues have decreased in recent years and the U.S. Congress and many state legislatures are reluctant to increase the fuel tax.[1,2,3] Inflation, reductions in vehicle miles traveled (VMT), and increases in vehicle fuel efficiency are key reasons for this decline in fuel tax revenues.[4] Accounting for inflation, Highway Trust Fund revenues have declined 20 percent since 2006.[5] This trend is expected to continue due to new vehicle efficiency standards recently announced by the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) that require newly manufactured vehicles to be 44 percent more fuel efficient by 2016 and 120 percent more efficient by 2025.[6] States have expressed growing interest in exploring options for replacing or supplementing the fuel tax, including the possibility of implementing road user fees, specifically mileage-based user fees in some cases.

In 2007, the Minnesota Legislature appropriated $5 million from the trunk highway fund for a technology research project exploring mileage-based user fees (MBUF). The law called for a pilot project to demonstrate technologies that would allow for the future replacement of the gas tax with a fuel-neutral mileage charge.

> ***"$5,000,000 is for a pilot project to demonstrate technologies that will allow for the future replacement of the gas tax with a fuel-neutral mileage charge."***
>
> **LAWS of MINNESOTA for 2007, CHAPTER 143–H.F.No. 562**

[1] Wachs, M., "A Dozen Reasons for Raising Fuel Taxes," *Public Works Management Policy* vol. 9 no. 4 (2003), 235-242.
[2] National Surface Transportation Policy and Revenue Study Commission, *Transportation for Tomorrow,* (Washington, D.C.: s.n., 2008).
[3] Transportation Research Board, *Special Report 285: The Fuel Tax and Alternatives for Transportation Funding,* (Washington, D.C.: s.n., 2006).
[4] *Ring Fencing and Rate Setting: Policy Challenges of Road User Charging*, Presented by Travis Dunn, D'Artagnan Consulting, LLP., at 2012 MBUF Symposium, May 2012. Available at: http://www.ibtta.org/files/PDFs/Dunn_Travis.pdf.
[5] FHWA Highway Statistics, BLS.
[6] Congressional Budget Office, *How Would Proposed Fuel Economy Standards Affect the Highway Trust Fund?* May 2012. Available at: http://www.cbo.gov/sites/default/files/cbofiles/attachments/05-02-CAFE_brief.pdf

The Minnesota Department of Transportation (MnDOT) was tasked with leading the effort and this document reports the findings from the pilot project that ensued. The project is one of the first studies across the country to test MBUF concepts in practice. What makes the study unique is that it used technology as the means for assessing mileage-based user fees, and it combined this technology with other safety and mobility technologies in support of the United States Department of Transportation (USDOT's) connected vehicle and Cooperative Intersection Collision Avoidance Systems (CICAS) initiatives.

1.1 Previous and Concurrent Studies in Minnesota

MnDOT conducted two related efforts, which should be mentioned here for context. First, MnDOT conducted a series of three studies focused on public acceptance of MBUF concepts between 2007 and 2009. Research began with qualitative research to understand public opinion about a mileage-based user fee alternative to the current motor fuel tax. People interviewed included knowledgeable transportation experts as well as the general public. Eight transportation experts participated in an online bulletin board discussion about the issue and ten focus groups were held (six in the Twin Cities Metro area and two each in Duluth and Mankato), representing a total of 89 individuals who provided feedback.[7] Next MnDOT conducted 821 interviews with Minnesota drivers selected by a random sample (augmented by drivers of hybrid vehicles) to better understand their knowledge of funding of transportation issues.[8] Finally MnDOT conducted nine mini focus groups (five in the Twin Cities Metro area and two each in Duluth and Mankato) with Minnesota drivers to understand their perceptions and the level of acceptance among the Minnesota public about implementation of a mileage-based user fee.[9]

Second, MnDOT conducted a study that focused exclusively on policy issues related to mileage-based user fees. This study was led by the Humphrey School of Public Affairs at the University of Minnesota and was completed in December 2011.[10] This study overlapped with the field deployment piece of this test, which occurred between September 2011 and October 2012.

1.2 Test Objectives

The objective of the Connected Vehicles for Safety, Mobility, and User Fees project was to inform future public policy decisions regarding mileage-based user fees and connected vehicle

[7] The Dieringer Research Group, *Mileage-Based User Fee Public Opinion Study, Summary Report Phase I,* for the Minnesota Department of Transportation, August 2007.
[8] The Dieringer Research Group, *Mileage-Based User Fee Public Opinion Study, Summary Report Phase III,* for the Minnesota Department of Transportation, December 2009.
[9] The Dieringer Research Group, *Mileage-Based User Fee Public Opinion Study, Summary Report Phase II,* for the Minnesota Department of Transportation, October 2008.
[10] University of Minnesota, *Report of Minnesota's Mileage-Based User Fee Policy Task Force*, December 2011.

applications. In keeping with this objective, MnDOT sought to design an on-board equipment-based system that integrated a mileage-based user fee (MBUF) application with safety and mobility applications, and to test the system with real drivers. To this end, the test aimed to demonstrate the capability of one commercially available aftermarket device to accomplish three primary goals:

1) Assess mileage-based user fees;
2) Convey safety alerts to drivers through in-vehicle signing; and
3) Provide a means for vehicles to provide data for the purposes of generating travel times on major corridors.

For purposes of communicating with study participants, the project was termed the Minnesota Road Fee Test (MRFT), and this term is used throughout the remainder of this report.

1.3 The Project Team

In crafting the pilot test, MnDOT first formed an advisory panel that consisted of individuals representing different backgrounds and perspectives. The advisory panel included representatives from various departments within MnDOT, as well as representatives from the Minnesota Department of Public Safety (DPS), the Minnesota Department of Revenue (DOR), Wright and Hennepin Counties, and the Federal Highway Administration (FHWA) Division Office.

MnDOT conducted the project in two phases, with the purpose of the first phase being to define what the proposed system should do as well as when, where, and how the test should be conducted. To support this effort, MnDOT solicited support from a program management oversight (PMO) contractor and an evaluation contractor. Mixon Hill was selected to provide PMO support and Science Applications International Corporation (SAIC) was selected to lead the evaluation effort. Throughout this document, Mixon Hill is referred to as the “PMO support contractor” and SAIC is referred to as the “study team.”

The results of Phase I of the effort became the basis for Phase II, which involved designing and implementing the application to be used in test, and conducting the test itself. Mixon Hill supported MnDOT in developing a request for proposal (RFP) for the deployment effort and continued to support MnDOT throughout Phase II. SAIC also continued to support MnDOT throughout Phase II, leading the study’s evaluation activities. SAIC’s responsibilities included:

- Creating an evaluation plan to guide the study, which included establishing evaluation objectives and identifying required data sources and plans for data analysis.
- Recruiting study participants.
- Proposing a fee structure for the test.

- Determining the value of each participant's "start-up funds" based on their mileage during the base period (funds to prevent participants from having to pay out of pocket for invoice expenses during their time in the test).
- Implementing data collection methods per the evaluation plan including:
- Conducting participant surveys, focus groups, and interviews.
- Conducting stakeholder interviews.
- Conducting test at CICAS intersection.
- Paying participant stipends at the conclusion of their time in the test.
- Implementing analysis methods and reporting out study findings.

Battelle Memorial Institute (Battelle) was selected to design and deploy the test system. Throughout this document, Battelle is referred to as the "deployment team." Figure 3 shows the overall Minnesota Road Fee Test (MRFT) "project team" along with the roles of each team member. The roles and responsibilities of the deployment team included:

- Recommending a platform for the MRFT application.
- Designing, testing, and deploying the MRFT application and the participant web portal.
- Conducting the test, which involved an array of activities including:
- Developing operational procedures for test activities.
- Developing participant instructional materials.
- Scheduling and conducting odometer reading appointments with participants including processing user agreements.
- Ensuring that smartphones were installed and functioning properly for each driver at the start of the test.
- Training drivers on use of the smartphone and the MRFT application.
- Responding to participant service requests.
- Performing software updates as needed.
- Providing participants with "start-up funds" for payment of invoices.
- Generating participant MRFT invoices, receiving and processing payment of invoices, and managing late payments.
- Managing the participant portal.
- Providing system data to the study team.
- Reporting on deployment team activities and findings.

The University of Minnesota's Institute of Technology ensured the DSRC transmission for the CICAS test.

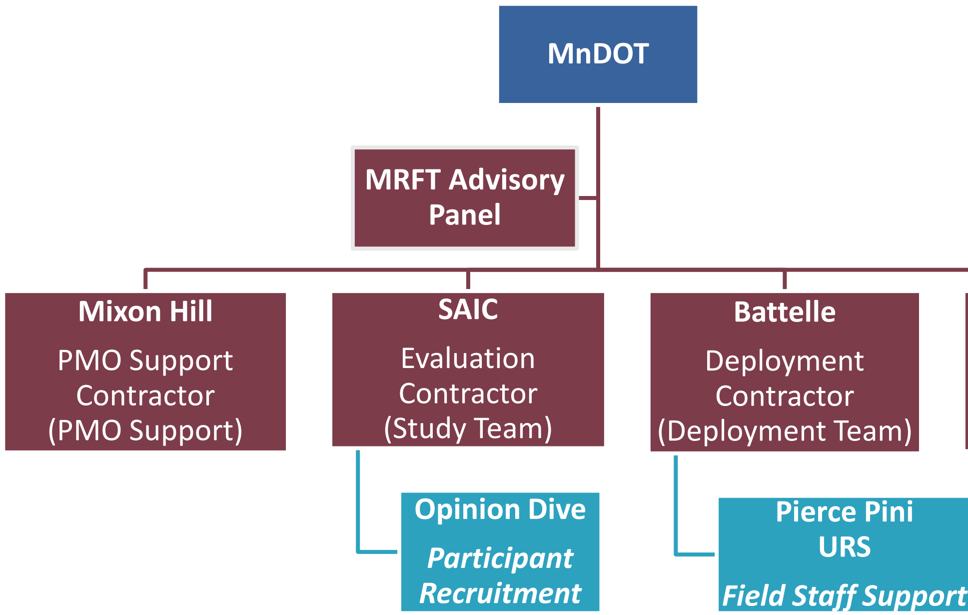


Figure 3. Minnesota Road Fee Test Project Team.

1.4 Overview of Evaluation

1.4.1 Evaluation Goals

The key goals of the evaluation were to:

- Assess the technical performance of the technology used in the test – This area of the evaluation looked at system reliability, system accuracy and precision, and opportunities for evasion and tampering, with a focus on not just the technologies and platforms used in the test, but also consideration of technologies that might be considered for future "real-world" deployments. This aspect of the test is discussed in *Volume II, Overview of Data and Technical Performance of the System*.
- Assess participant perceptions of MBUF concepts and safety technologies – A central focus of the test was to gather perceptions from the public regarding MBUF concepts, including their perceptions of a technology approach to MBUF, their perceptions of the in-vehicle safety alerts tested, and their perceptions of a system that combines the two. Although studies have been conducted of public perceptions of MBUF, this test provided an opportunity to gather feedback from drivers on issues such as privacy concerns after they had experience using an actual system. This aspect of the test is discussed in *Volume III, Driver Acceptance Assessment*.
- Investigate the mobility impacts associated with mileage-based user fees – A real-world implementation of mileage-based user fees would have some impact on drivers' travel

patterns, such as when they drive, how much they drive, and where they drive, since paying a fee based on miles driven rather than based on gallons of gas used can make drivers more aware of their driving behavior. This goal area focused on assessing whether drivers changed their driving behavior during the test as a result of paying by the mile. This goal area is discussed in *Volume IV, Assessment of Impacts on Mobility*.

- Investigate the safety impacts of the safety technologies tested – One goal of the test was to determine the impact of the in-vehicle safety alerts. This includes both driver perceptions of the alerts as well as an analysis of whether driver behavior changed as a result of the alerts. This aspect of the test is covered in two separate sections. The CICAS study, which was a limited study of seven drivers at one intersection, is discussed in whole in *Volume VI, In-Vehicle CICAS Evaluation*, and the study of driver responses to the safety alerts is presented in *Volume V, Assessment of Impacts of Speed-Related Signage on Safety*.
- Investigate the feasibility of generating travel times using data from the same device used to assess mileage fees – One goal of the pilot test was to determine whether a device designed to assess mileage-based user fees also has the potential to be used as a device to collect second-by-second data that could be used in projecting travel times. Therefore, the purpose of this goal area was for the study team to investigate the feasibility of determining travel times based on data gathered from smartphones used in the test. This goal area is discussed in *Volume VII, Assessment of Utility of Travel Time Data.*
- Document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale – This aspect of the study is important as it provides insight into the success factors and pitfalls that may be encountered in a "full-scale" deployment of MBUF (e.g., multi-jurisdiction, statewide, or multi-state), connected vehicle applications, or any combinations thereof. This goal area of the evaluation included: documenting costs associated with development and deployment; documenting the challenges and limitations encountered by the participating organizations and stakeholders and any steps that were taken in an attempt to address these challenges; and documenting success factors identified by project stakeholders that should be considered for inclusion in subsequent tests or full-scale deployments. This goal area is discussed in *Volume VIII, Operation and Administration of an MBUF Program*.

1.4.2 Key Data Sources

In assessing each of these evaluation goals, the study team utilized a number of data sources including:

- Service requests, which provided insight into the nature of the challenges drivers can face with this type of system.
- Data from the system, which allowed the team to explore driver response to the safety alerts as well as to explore changes in driver behavior resulting from the MBUF system. Data available to the team included the following:[11]
    - Number of trips recorded per day;
    - Number of trips occurring through pre-defined safety zones;
    - Number of miles driven during the baseline period in each fee category;
    - Number of miles driven during the test period in each fee category;
    - Length of each trip in miles; and
    - Second-by-second data for each trip including vehicle speed, heading, latitude, longitude, timestamp, and GPS accuracy.
- Participant perceptions as gathered through a multi-tiered approach including surveys, focus groups, and interviews.
- Stakeholder interviews, which helped the team document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale.

2 Test Design

This section presents the test design and includes a discussion of:

- The location for the test and how the study team arrived at that location;
- The fee structure used for the test and how the team settled on that structure;
- How the system worked and how the team arrived at that functionality;
- How the number of participants was determined, how participants were recruited, what the demographics were of the study group; and
- The overall schedule for the test.

The test design is discussed in additional detail in the evaluation planning document, *"Test Plans for the Minnesota Road Fee Test Evaluation*."[12]

[11] Note that these data were available for all trips, but assigning a trip to a participant was not possible unless the participant elected to provide the study team this level of visibility.

[12] SAIC, *Final Test Plans for the Minnesota Road Fee Test Evaluation*, for MnDOT, April 2011.

2.1 Test Location

There are several project goals that impacted the selection of a location for the test. The project aimed to:

- Obtain opinions and feedback from both the rural and urban residents of Minnesota.
- Test the impacts of the fee structure on the travel behavior of individual travelers (e.g., overall miles traveled, time of day of travel, number of trips, etc.). Congestion is not a concern in rural areas of the state so it was important that the study allow for testing of congestion pricing in an urban part of the state.
- Demonstrate the capability to distinguish miles driven by geographic area. This meant that it was critical that the test include one or more boundaries that are frequently crossed in order to test this capability.
- Test the feasibility of using the MBUF device as a source of data for generating travel times. In order to have a sufficient number of data points, the test needed to include drivers who travel on specific corridors on a regular basis.

Taking these project goals into account, the project team selected the greater Minneapolis / Saint Paul Metro Area as the location for the test. The high population density of the region as well as the corresponding level of traffic congestion make it a good choice for the Pilot Study.[13]

As the geographic boundary of a predefined "Metro Zone" was one of the factors used to determine the price for any given trip (as is described in Section 2.1.3), it was desirable to select a county that would provide sufficient opportunity to obtain data on commute trips that begin outside the Metro Area and require crossing into the Metro Area. Figure 4 depicts the commute patterns in the Twin Cities area.[14] As shown in the figure, among the counties surrounding the Metro Area, Wright County (shown in yellow) has the largest number of residents (49 percent) commuting into the Metro Area, and was therefore selected as the key study area for the test.

The population of Wright County is approximately 120,000 and the county covers approximately 660 square miles (136.1 persons per square mile).[15] Males and females are equally divided in the county. Approximately 80 percent of workers drive to work alone while 13 percent of the working population carpools. Approximately 5 percent of the population

[13] Metropolitan Council. http://www.metrocouncil.org/Census/KeyFacts/7-county.htm (Accessed May 28, 2009).
[14] Source: Twin Cities Metropolitan Council, http://www.metrocouncil.org/about/index.htm (Accessed September 22, 2010).
[15] United States Census, http://quickfacts.census.gov/qfd/states/27/27053.html (Accessed May 28, 2009).

works from home. In 2000, the average commute time of residents was 29 minutes, the fifth longest average commute in the state.[16]

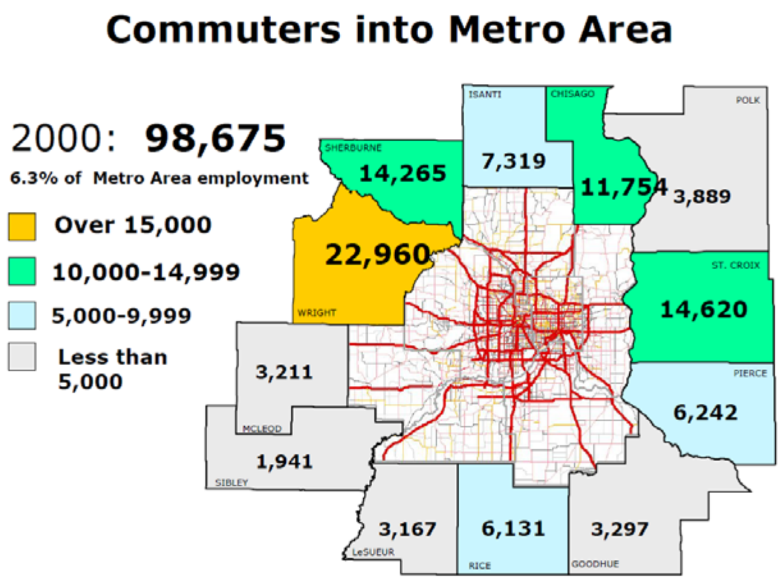


Figure 4. Number of Drivers Commuting from Adjacent Counties into the Twin Cities Metro Area.

Focusing the Pilot Study on Wright County provided a mix of urban and rural opinions as 47 percent of the county is defined as “urban” and 53 percent of the county is defined as “rural.”[17] It is important to note that Wright County’s rural residents do live in close proximity to the Metro Area, so their viewpoints may differ from those in more remote areas of the state.

2.1.1 Location of the Signage Zones, Travel Time Corridors, and CICAS Test

The project team identified a total of 98 signage zones for inclusion in the test. This included 46 school zones, 28 speed zones (areas of reduced speed), 17 curves, and a 10-mile construction zone which included 7 individual signage zones. The PMO support contractor supported MnDOT in selecting the locations and designing the boundaries of each of the zones. The primary factor that drove selection of zones was the volume of traffic through the zone as the team wanted to gather a much data as possible for analysis purposes. After identifying the high-volume locations, the PMO support contractor visited each location, determined if it was

[16] Minnesota State Demographics Center, Population Notes Minnesota, OSD-03-104, April 2003. http://www.demography.state.mn.us/DownloadFiles/CommuterPopnote.pdf (Accessed May 28, 2009).
[17] Source: City Data, Wright County, Minnesota, http://www.city-data.com/county/Wright_County-MN.html (Accessed October 21, 2010).

suitable for the study, and recorded the GPS coordinates of the proposed start/end boundary for each zone. The zone locations are provided in Appendix C.

Three corridors were identified by the project team for study as “travel time” corridors: a 1.6-mile segment of TH55 in the City of Buffalo, which is in Wright County; a 16-mile segment of TH55 in Hennepin County; and an 8-mile section of I-94 from TH 101/Main Street in Rogers to County Rd 109/Weaver Lake Road in Maple Grove. The CICAS test was conducted at an intersection in Mille Lacs County, MN.

The CICAS test was conducted at the intersection of US Highway 169 and County Road 11 in Milaca, MN which is in located to the north of Wright County as shown in Figure 5. The CICAS test is described separately in full in *Volume VI* of this document.

Figure 5. Location of CICAS Test in Milaca, MN.

Source: Google Maps

2.2 The Fee Structure for the Test

The state of Minnesota has not developed a formal policy regarding road fees, so an important element in test planning was to determine what sort of fee would be tested in the pilot. For example, would the fee include factors such as roadway type or time of day? MnDOT tasked the study team with proposing a fee structure for the test. In doing so, the team first considered MnDOT’s overarching goals for the test, which were that the participants’ experience should be as realistic as possible so as to gather feedback to inform future policy. With this in mind, it was determined that participants should:

- Pay invoices for mileage fees. The reason for this is two-fold. First, MnDOT desired to obtain some feedback from participants regarding the payment process (e.g., whether monthly invoices make sense, whether they prefer both electronic and paper mailings). Second, MnDOT wanted drivers to experience the concept of paying a fee for each mile driven rather than just seeing a bill, and to get their feedback on this concept. The deployment team generated invoices for participants based on the data collected from each participant's smartphone and provided the invoices to participants via mail and email. Participants had the option of paying invoices by mail, on the internet, or in person by credit card, PayPal, check, or cash (the cash option was available only to those paying in person). Participants paid up to six invoices during their time in the test, including a final invoice at their final in-person meeting for the miles recorded by their odometer but not by the device. The exact number of invoices varying depending on where each participant's start and end dates fell within a calendar month.
- Have access to details about how their fee was determined (i.e., have transparency in the invoicing process). MnDOT desired for participants to have the ability to view their fees on a trip by trip basis for repudiation purposes. At a minimum, participants' monthly invoices needed to be itemized by fee category. Additionally, there needed to be a way for participants to view details about their trips if they questioned their fees. The system was designed such that fees could be determined without the study team or system being able to identify or track individual users. The deployment team accomplished this by designing a system that maintained trip information on the smartphone and only sent data to the central server that was necessary for determining fees (i.e., the total number of miles within each fee category). Although the server maintained data on each unique trip (by TripId), it did not know which driver was associated with that TripId. If participants desired to view details about a specific trip, they could do so on the portal by entering the TripId for that trip. Participants did have the option of sharing all of their data with the study team (i.e., linking their name to their TripIds), and many did so. For these participants, detailed information on each trip was readily available on the portal.
- Not be "double-taxed" (i.e., not pay the gas tax as well as the fee). Since MnDOT determined that payment of mileage fees would not be linked to the gas pump in this test, participants continued to pay the fuel tax as they normally would during their time in the test. As a result, it was important that they not also pay out of pocket for their mileage fees. Therefore, the study team provided participants with funds with which to pay invoices prior to receipt of their first invoice. If any participant reached a point in the test where their fees exceeded the amount of the pre-payment they were provided,

they were not responsible for paying these additional fees. This occurred for about one-quarter of the participants.

Next, the study team determined the details of the fee structure including:

- The extent to which *pricing factors* would be incorporated into the fee.
- The *size of the fee* for each set of conditions.

When considering the extent to which *pricing factors* would be incorporated into the fee, MnDOT desired to have a fee structure that would incorporate elements that have the potential for real-world implementation while not making the structure so complicated as to confuse drivers (for example, a fee structure that changes at a county line may not be a good idea as drivers are not likely to know exactly where a particular roadway crosses a county line). Although a variety of factors were considered, including pricing that varies by roadway type, the project team settled on a fee structure that takes into account just two factors: time of day and location.

In terms of the *size of the fee*, MnDOT desired for the fee to be revenue-neutral, or essentially enough to replace the Minnesota portion of the fuel tax as it stands today. To determine what the fee size per mile would need to be in order to be revenue neutral, the study team considered the average fuel efficiency for vehicles on the road today and the current amount of the Minnesota fuel tax.

At the time of the fee structure determination, the average vehicle fuel efficiency was 20.5 miles per gallon (mpg),[18] and the Minnesota portion of the fuel tax was $0.275 per gallon. Taking these values into account, the equivalent average mileage fee rate is $0.013 per mile. Regardless of the pricing factors that came into play, this value of $0.013 per mile became the target for the *average* fee collected in the test. If a flat fee per mile were to be implemented in the real world using the average fuel efficiency of all vehicles on the road, there would be "winners" and "losers" (e.g., people who drive vehicles that are extremely fuel efficient would end up paying more, while people who drive vehicles that are not very fuel efficient would pay less than they do today). Defining a fee structure for a real-world deployment of MBUF is certainly a delicate process from a customer acceptance perspective, and probably one of the largest challenges when it comes to deploying MBUF.

The study team hypothesized that drivers might change their driving habits as a result of paying by the mile for travel (e.g., drive less or combine trips). Therefore, once it was determined that there would, in fact, be two different rates, the study team sought to determine the needed difference between the two rates such that it would likely be possible to detect a change in

[18] www.fueleconomy.gov

behavior. Based on fuel price elasticities derived from prior studies linking gas taxes and VMT, the team determined that a difference of 2 cents between the two rates would be needed in order to detect a difference in VMT (in the short term).[19] Taking this into account, the team settled on rates of $0.03 per mile for travel that is both during peak hours and in the predefined "Metro Zone" (as show in Figure 6), and $0.01 per mile for all other travel, as shown in Table 2.

The intent was that participants would not be charged for travel that occurred outside of the state of Minnesota. However, to incentivize participants to use their device as much as possible, they were charged at the higher rate (i.e., $0.03 per mile) for any miles driven without the device (later in this report these are termed "non-technology" miles). As a result, if participants drove outside of the state but did not take their device, they were, in fact, charged for those miles, and at the higher rate. Similarly, if they drove during off-peak hours without the device, they were charged at the higher rate. Part of the reason for structuring the fee in this way was to explore how an "opt-in discount model" might work (i.e., in one possible real-world solution involving a technology approach to MBUF, drivers might not be required to have the technology, but could "opt-in" to using technology, and would pay a discounted rate for doing so).

Table 2. Fee Structure for the Test.

<table>
<tr><th colspan="2">Current Driving Location</th><th>Peak Times
Monday-Friday
7AM-9AM
4PM-6PM</th><th>Off Peak Times</th></tr>
<tr><td colspan="2">Outside of Minnesota</td><td>$0.00</td><td>$0.00</td></tr>
<tr><td rowspan="2">Inside Minnesota</td><td>Outside the Twin Cities Metro Zone</td><td>$0.01</td><td>$0.01</td></tr>
<tr><td>Inside the Twin Cities Metro Zone</td><td>$0.03</td><td>$0.01</td></tr>
</table>

[19] SAIC, *Recommendations for Pilot Pricing Scheme*, Presentation to MnDOT, March 2011.

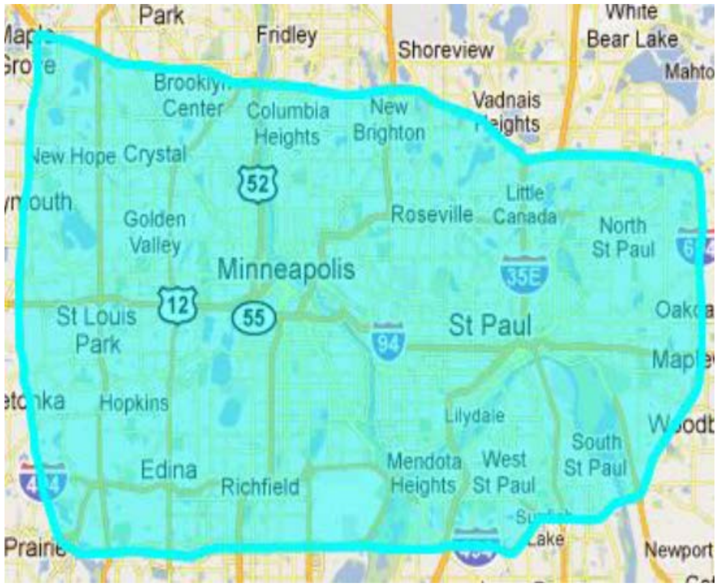


Figure 6. Boundary of "Metro Zone" (Loop formed by I-494/I-694).

Source: Google Maps

2.3 System Development

MnDOT, with support from the PMO contractor, began formulating the concepts that drove system development in Phase I. During Phase I the PMO contractor supported MnDOT in developing the ConOps, preliminary requirements, and implementation work plan for the Phase II implementation.[20,21,22]

2.3.1 Requirements Development

Development of the system concepts began with a series of workshops and interviews to assess the needs and goals to be addressed by the project. Although the workshop attendees were limited to state agency staff, participants represented perspectives of drivers; traffic managers and planners; traffic data consumers and providers; transportation operations and maintenance; state, county, and municipal road engineers; the State Department of Revenue,

[20] Mixon Hill, *Minnesota Department of Transportation, Vehicle Infrastructure Integration (VII) for Safety, Mobility, and User Fee Technical Program Management, Concept of Operations*, for MnDOT, October 2009.

[21] Mixon Hill, *Minnesota Department of Transportation, Vehicle Infrastructure Integration (VII) for Safety, Mobility, and User Fee Technical Program Management, Preliminary Requirements,* for MnDOT, October 2009.

[22] Mixon Hill, *Minnesota Department of Transportation, Vehicle Infrastructure Integration (VII) for Safety, Mobility, and User Fee Technical Program Management, Preliminary Phase II Implementation Plans*, for MnDOT, February 2009.

which is responsible for collection of fuel taxes and subsequent distribution of funds; and the State Department of Public Safety, which and collects registration and license tab fees and issues license tabs.

The PMO contractor also conducted a survey of mileage-based user fee programs and looked at similar demonstrations and applicable technologies to provide a context for the description of solutions and operational scenarios.

The system concept called for use of a consumer aftermarket in-vehicle device that would interface with back office systems via wireless and network communication. Use of dedicated short-range communications (DSRC) was specified only for the CICAS test, which involved intersection conflict warnings. It was anticipated that the aftermarket device used in the test would be either a GPS navigation device or a smartphone.

The PMO contractor then prepared a Concept of Operations (ConOps), a set of preliminary requirements to be applied in the Phase II implementation. Implementation scenarios in the ConOps described what the system should do, and the preliminary requirements set constraints on the design and operation of the overall system.

After selection of the Phase II deployment team, implementation plans followed a standard systems engineering process to specify the requirements and design. The ConOps document developed in Phase I became the basis for a revised Phase II document, with greater detail defining the types of devices to be used in the system design. The Phase II system requirements specification incorporated the Phase I preliminary requirements, new requirements derived from the Evaluation Plan criteria laid out by the study team, and detailed requirements driven by the proposed system architecture. Documents that the deployment team developed included a stakeholder requirements document,[23] a system requirements document,[24] and a system architecture document.[25]

2.3.2 Final System Design

After conducting a feasibility analysis of possible commercial off the shelf (COTS) products that met the system requirements, the deployment team settled on the Samsung Captivate™ Android smartphone with CoPilot(R) navigation software, Google Navigation, and custom in-vehicle signage and MBUF functionality;[26] a supplemental DSRC radio for the intersection safety

[23] Battelle Memorial Institute, *IntelliDrive(SM) for Safety, Mobility, and User Fee Implementation Stakeholder Requirements Document,* for MnDOT, September 2010.
[24] Battelle Memorial Institute, *IntelliDrive(SM) for Safety, Mobility, and User Fee Implementation System Requirements Document,* for MnDOT, October 2010.
[25] Battelle Memorial Institute, *IntelliDrive(SM) for Safety, Mobility, and User Fee Implementation System Architecture Document,* for MnDOT, February 2011.
[26] Battelle Memorial Institute, Presentation to MnDOT, October 20, 2010.

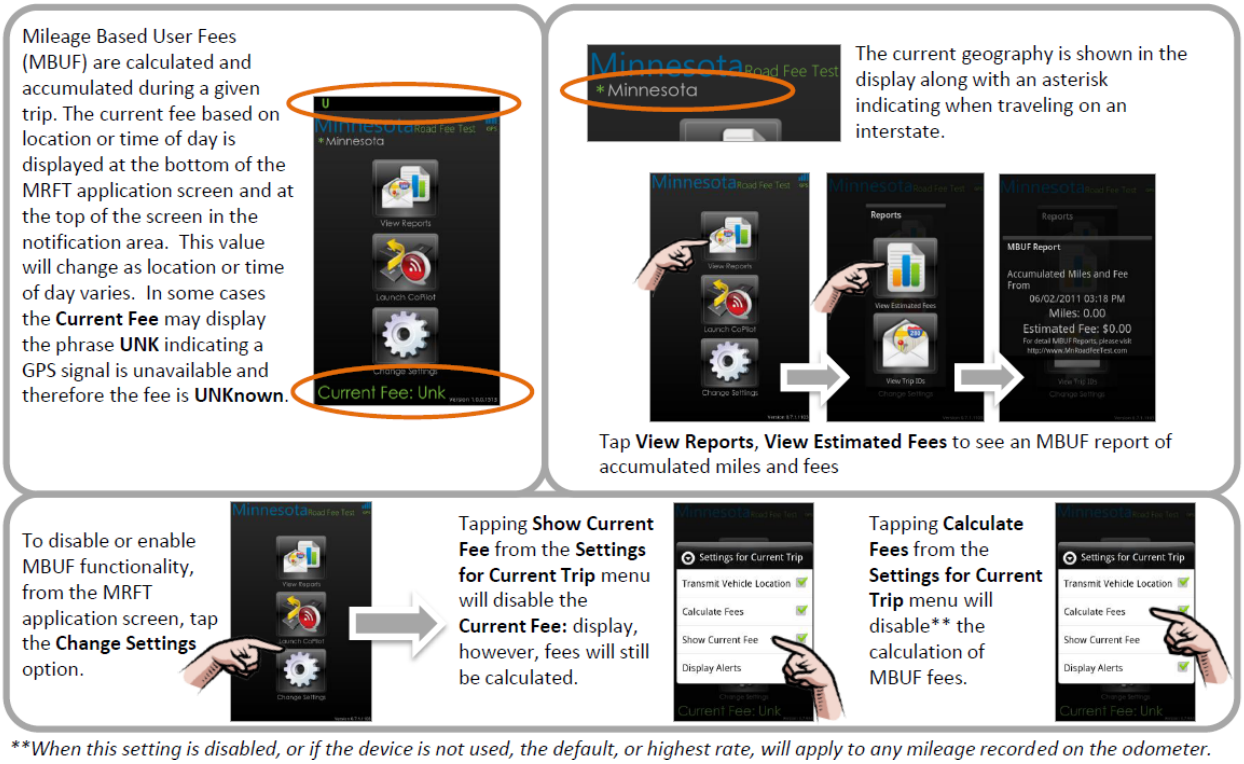
application; and back-office applications hosted in a Microsoft Windows Azure(TM) cloud services platform. For test purposes, some of the phone functionality was removed (e.g., the participant was unable to access the internet, send or receive text messages, or make a phone call). As described in the following sections, the smartphone application had two key functions that were apparent to drivers:

- Assessing mileage-based user fees; and
- Providing safety signage.

2.3.2.1 Mileage-Based User Fee Application for Smartphone

From the driver's perspective, the MBUF functionality of the application on the smartphone consisted of two aspects. First was the mileage-based user fee portion of the application, which showed the driver the current rate both at the top left of the screen and across the bottom of the screen, as shown in Figure 7. (When using the navigation feature of the phone rather than the MRFT application, the current rate still displayed at the bottom of the screen.) Second was the drivers' ability to view some details of their trips and fees, including a list of their trips, their total number of miles traveled for the month, and their total estimated fees for the month. If drivers wanted to see details of any trips, they were invited to visit the web portal.

From the study team's perspective, this application was the means for determining participant fees. Drivers did have the ability to turn off the functionality of the MRFT application, but they were informed that if they did so, they would be responsible for paying a fee for all miles traveled without the application running. These miles were assessed at their final odometer reading by comparing their total miles driven during the test period of the study to the total miles recorded on the device.



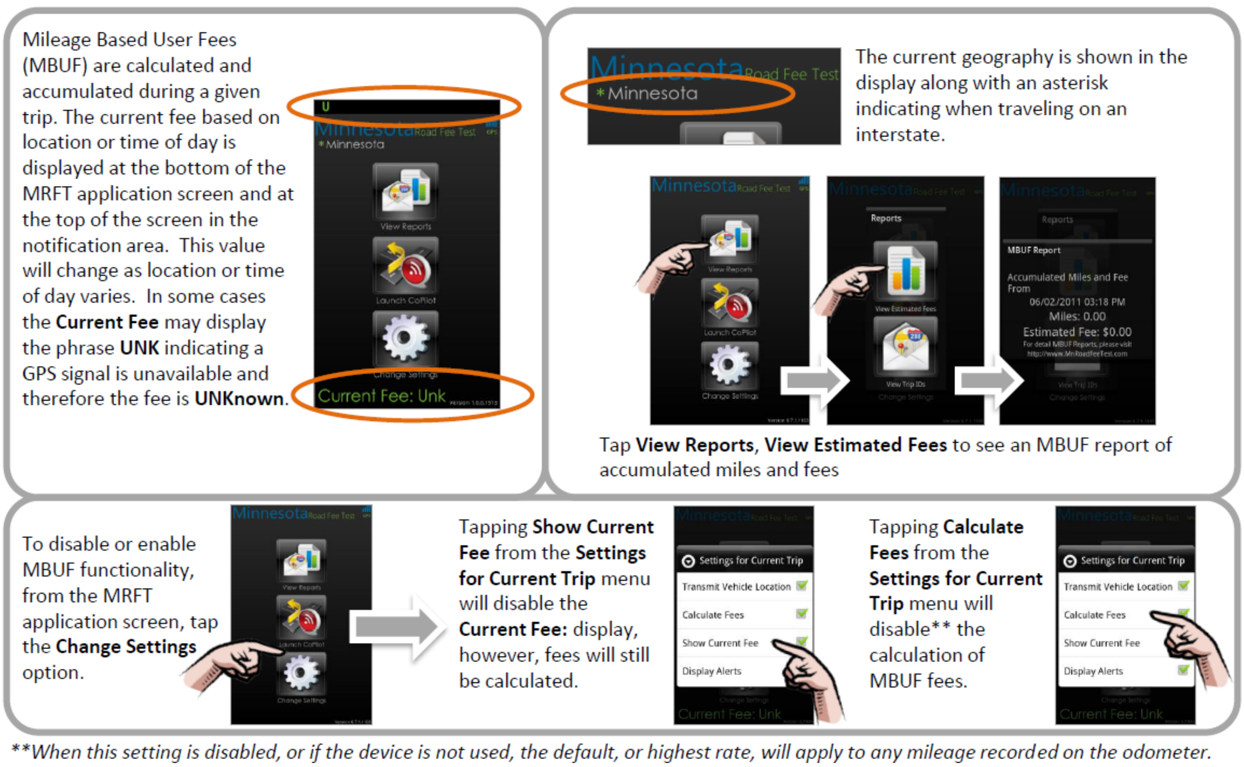


Figure 7. Educational Materials on MRFT Application Provided to Participants at Odometer Reading 2.

2.3.2.2 Safety Signage Application for Smartphone

The safety signage functionality of the smartphone application also consisted of two aspects. One aspect of safety-related signage was the CICAS signage, which was reserved for a small test of seven drivers who participated in a 1-day study. This study was conducted separately from the main test, which involved 500 participants. (The CICAS functionality of the phone is discussed separately in *Volume VI – In-Vehicle CICAS Evaluation*.) The other aspect of safety signage provided safety alerts to drivers when entering pre-defined safety zone locations throughout the Metro Area. Three primary types of safety zones were included in the test: (1) school zones, (2) speed zones (areas of reduced speed), and (3) curves. The test also included a limited demonstration of a fourth type of safety zone: a construction zone. As discussed previously, there were a total of 98 signage zones included in the test. This included 46 school zones, 28 speed zones, 17 curves, and a 10-mile construction zone, which included 7 individual signage zones. While Wave C participants experienced all four of these safety zones, Waves A and B participants did not experience construction area safety zones due to the availability of applicable MnDOT road construction projects in the vicinity of Wright County.

As shown in the print materials provided to the participants at odometer reading 2 (Figure 8), upon entering a safety zone, participants received a visual alert on the screen of their smartphone. This visual alert remained present until they exited the zone.

Participants also received a verbal announcement that they were entering safety zones (note that this message would not have been heard by participants who chose to turn down the volume on their phone). Messages were as follows:

- School zones: “School Zone Ahead - X Miles per hour.”
- Speed zones: “Speed Limit X miles per hour.”
- Curves: “Left Curve Ahead” or “Right Curve Ahead.”
- Construction zones: “Construction Zone Ahead.”

For school zones and speed zones, if the participant was traveling 5 mph or more over the speed limit at any time while in the zone, and for travel at all speeds over 5 mph in the construction zone, the visual alert would be accompanied by an audible alert in the form of a beep. Participants did have the ability to disable the safety signage functionality or to lower (or turn off) the volume of the audible alerts.

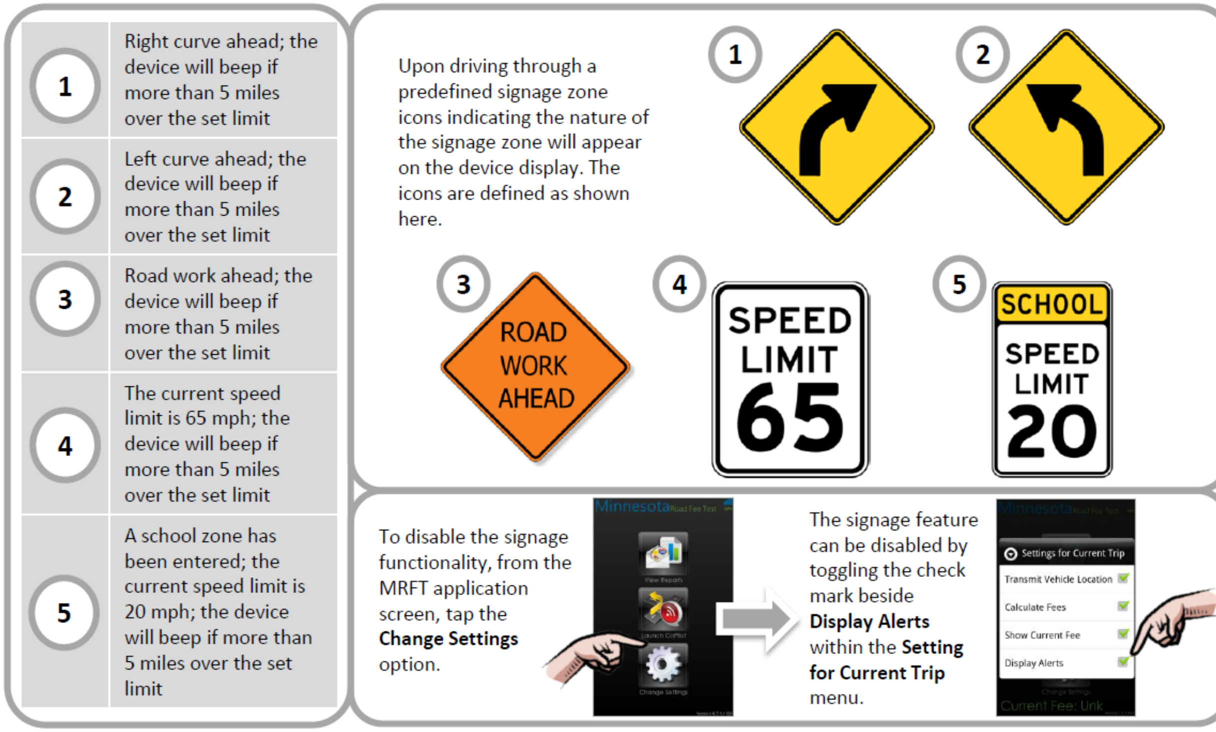


Figure 8. Safety Signage Materials Provided to Participants at Odometer Reading 2.

For regulatory signs (this applied to school zones and speed zones where speed limit signs are used), the system was designed such that the in-vehicle signage would appear when the driver passed the roadside sign. The reason for this is that the speed limit would only be enforceable after passing the roadside sign. For advisory signs (this applied to the curve warning signs and the construction zone "road work ahead" signs), the boundaries of the zones were established such that the sign would appear in the vehicle at the same time that it became visible to the driver on the roadside. The advance distance at which the signs should appear was determined based on guidance in the MUTCD. One exception was that zones were not carried across an intersection with a traffic control device (whether a traffic signal or a stop sign), even if the zone sign was still visible on the far side of the intersection.

2.3.2.3 Participant Web Portal

The system design also included development of two web portals that would be available to participants during their time in the test. First was the portal established by the deployment team. This portal is the type of portal that might be implemented in the real world should a mileage-based user fee system be implemented. The purpose of this portal was for participants to view their trips and invoices online as shown in Figure 9. The second portal was established by the study team to communicate with participants about study activities. For example, participants could view "points" they had earned to date, view information about upcoming study activities, and schedule an interview timeslot.

Figure 9. Participant Portal.

This section describes how participants were recruited, presents the demographics information for the participants, discusses participant stipends, and discusses participant study activities.

2.3.3 Recruitment Approach

Given the goals of the test, the study team determined that a sample size of 500 drivers was desired.[27] The team therefore recruited 500 drivers from the metropolitan Minneapolis-St. Paul area for the test. As was previously discussed in Section 1, MnDOT selected Wright County for the location of the test. Residents of Wright County were randomly contacted via telephone, and screened. If they met the requirements of the study, they were offered the opportunity to participate in the study.

In screening drivers, the team sought to reflect the age, gender, and income of the county population. In addition to this, the team recruited for a mix of driving levels and vehicle types (including hybrids). Participants were required to have a valid Minnesota driver's license and a vehicle with a working odometer and electrical outlet. They were also required to be the "primary driver" of a vehicle in their household (defined as the person driving that vehicle at least 90 percent of the time that the vehicle is driven). They were not eligible to participate if

[27] SAIC, *Final Evaluation Plan for the IntelliDrive for Safety, Mobility, and User Fee Evaluation, Appendix A - Sample Size Calculations*, for MnDOT, October 2010.

they or a member of their household were employed by MnDOT or a county department of transportation.

Participants were informed that the purpose of the study was to investigate a technological approach to mileage-based user fees in lieu of a fuel tax due to changing revenue needs. They were also informed that they would be provided a stipend that would reflect their level of participation, up to a maximum of $375, at the conclusion of their time in the study.

2.3.3.1 Two-Participant Households

It is important to note that the team made the decision to allow two members from a household to participate in the study so long as both drivers were over the age of 18, both were primary drivers of one vehicle in their household, and both met all screening criteria. Sixty-two percent of the 500 participants were from a two-participant household.

2.3.4 Participant Demographics

As discussed previously, the study team attempted to compile a sample that was representative of Wright County residents. Table 3 compares the sample demographics to the population of Wright County. The most notable difference between the test participants and the county population is the comparatively small percent of participants in the highest age category (66 years of age or older) and the lowest income category (less than $35,000 per year). The study team found it extremely difficult to recruit individuals in these categories. Many individuals in the lowest income category reported that they did not have a car or that they did not have the flexibility to participate in such a study, while many individuals 66 years of age and older simply were not interested in participating.

Table 3. Test Demographics Compared to Demographics of Wright County

Gender	Test	Wright County
Male	46.4%	50.2%
Female	53.6%	49.8%
Age (Years)	**Test**	**Wright County**
18-35	16.6%	22.1%
36-55	54.6%	47.7%
56-65	23.0%	15.1%
66+	5.8%	15.1%
Income	**Test**	**Wright County**
Less than $35,000	6.0%	20.7%
$35,000 - $49,000	14.0%	12.7%
$50,000 - $74,000	32.6%	23.7%
Greater than $75,000	47.4%	42.9%

Source: 2010 U.S. Census, "American FactFinder." Available at http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk

Of the 500 participants who began the test, 478 (96 percent) successfully completed all study activities. The remaining 22 participants either withdrew from or failed to complete the test. Of those who left the test, five did so for reasons unrelated to the study (e.g., one dropped out of the study for health reasons, two were unable to participate due to the fact that the on-board diagnostic (OBD-II) port on their vehicle was not functioning properly, and two had mechanical issues with their vehicles during the study and could no longer participate as a result). Seven participants indicated that they were having too many issues with their device or with scheduling odometer readings and they no longer wished to participate. The remaining nine participants dropped out for unknown reasons.

It is important to note that throughout this report, various sections will reference different sample sizes. The reason for this is that in order to maximize the sample size, the study team analyzed all data available wherever possible, even if a participant did not complete all study activities. For example, if a participant dropped out of the test after completing the first survey, that person's responses to the first survey are included along with other participants' responses to the first survey. However, for analysis of questions that appeared across multiple surveys, this participant would not be included since the person did not complete the later surveys.

2.3.5 Participant Stipends

Each study activity earned participants points, which translated into dollars at the conclusion of the study. While the maximum amount that a participant could earn was $375, the average participant received $320. In addition to the stipend, participants were able to keep the smartphone at the conclusion of the study (the deployment team removed the custom software applications that had been added for the study).[28]

2.4 Overall Test Schedule

MnDOT began preparatory work for the test in the summer of 2008. Test planning and technology development occurred over the next 3 years. Participant recruitment began in August 2011. In order to account for seasonal variations and other external factors that could affect travel behavior (e.g., changing gas prices), the study was conducted in a staggered approach with the 500 participants divided into three groups (Waves A, B, and C) as shown in Table 4. Each group participated in the test for a total of 6 months including a 2-month during the baseline period and a 4-month test period. The first group of participants (Wave A) began the test in September 2011 and the final group of participants (Wave C) ended the test in October 2012.

The purpose of the 2-month baseline period was to allow drivers to acclimate to the system and to overcome any strong initial experimental bias associated with being observed during the study. It also allowed the evaluation team to assess system learning focusing primarily on:

- Compliance with using the system and participating in the study;
- Frequency and type of service requests;
- Accuracy and reliability of system performance;
- System calibration (e.g., how often do drivers customize the system such as setting the volume and tone of an alert); and
- Initial driving behavior with respect to the system (e.g., speed adjustment in response to an alert, traveler information requests, access of MBUF information in-vehicle and on-line).

During this period, the evaluation team:

- Collected field data with the system turned on to observe initial system performance and driver behavior; and
- Conducted focus groups and interviews with drivers and stakeholders to assess initial impressions.

[28] In order that some phones could be reused for later waves, Wave A participants were provided the choice of taking the phone or $100.

Table 4. Schedule of Participants.

	2011				2012									
	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct
Wave A	Baseline		Test											
Wave B				Baseline		Test								
Wave C									Baseline		Test			

3 Participant Experience

This section describes the participant experience beginning with recruitment and ending with receipt of their stipend.

3.1 Participant Activities

Participant activities included attending in-person odometer readings, completing surveys, participating in focus groups and interviews, and writing notes in their participant journal. Each wave of participants followed the same schedule. Table 5 presents the overall schedule of participant activities for each wave.

Table 5. Timeline of Participant Activities.

Time Period	Activity	Wave A	Wave B	Wave C
Pre-Test	Participants recruited	Jun-Aug 2011	Oct-Nov 2011	Feb 2012
Baseline Period (2 months)	Participants attended OR1	Sept 12-24, 2011	Nov 16-Dec 20, 2011	Mar 12-Apr 12, 2012
	Participants completed survey #1	Oct 3-17, 2011	Dec 28, 2011-Jan 11, 2012	May 14-28, 2012
Test Period (4 months)	Participants attended OR2	Dec 13-21, 2011	Feb 13-22, 2012	Jun 18-Jul 18, 2012
	Participants completed survey #2	Dec 8-22, 2011	Mar 8-22, 2012	Jul 11-25, 2012
	Participants completed survey #3	Feb 20-Mar 5, 2012	May 23-Jun 6, 2012	Oct 3-17, 2012
	Participants participated in focus group	Feb 28 & 29, 2012	May 21 & 22, 2012	Oct 2 & 3, 2012
	Participants participated in telephone interview	Feb-Mar 2012	May-Jun 2012	Oct 2012
	Participants attended OR3	Apr 25-May 7, 2012	Jun 20-Jul 11, 2012	Sept 25-Oct 25, 2012
Post-Test	Participants received stipend	By April 30, 2012	By July 31, 2012	By Nov 30, 2012

3.1.1 Pre-Test Activities

All participants were initially approached through a telephone call by the study team's recruiter. After answering a series of screening questions and indicating that they were interested in participating in the test, they were told that they were eligible to participate and that they would need to attend an upcoming in-person odometer reading in St. Michael, Minnesota. They were also told that they would be sent a "Welcome Packet" with more information on the test and how to schedule their first odometer reading (see Welcome Packet materials in Appendix A).

3.1.2 Baseline Period Activities

The baseline period covered the first 2 months of a participant's time in the test. The purpose of this baseline period was to document the typical driving behavior of each participant so that changes in behavior resulting from the system could be assessed after the system was turned "on." This period also provided time to reduce any experimental bias that might result from participants driving differently from how they normally would. For instance, drivers might drive more slowly or more cautiously because they feel that they are being watched or evaluated.

Each participant's time in the test began with odometer reading 1 (OR1). Although the exact format of the odometer readings changed somewhat during the course of the test, they were run much like a doctor's office in that there was a sign-in sheet and a waiting room. Figure 10 shows the inside of the odometer reading offices as well as the tent that was set up outside the facility for odometer readings. While in the waiting room, participants were provided advance reading materials, allowing them to familiarize themselves with the materials before the information was presented to them by the deployment team staff members.

Figure 10. Odometer Reading.

Staff from the deployment team provided participants with all of the necessary paperwork which was packaged into an *End User License Agreement*.[29] Once the documents had been signed, the deployment team staff took note of the participant's current mileage. The team member then provided the participant with an Android smartphone (see participant smartphone kit shown in Figure 11) and instructed them on how to install and operate the phone during their time in the test. The staff member ensured that the phone was working properly in the participant's vehicle before concluding the odometer reading. Participants were instructed to carry the provided smartphone and keep it powered on while driving for all trips they made during the baseline period, even though they would not be receiving alerts on the phone or otherwise be asked to interact with it until after their second odometer reading.

[29] Battellle Memorial Institute, *End User License Agreements for Minnesota Road Fee Test, MRFT Operational Procedure*, for MnDOT, August 19, 2011.

Figure 11. Participant Smartphone Kit.

Deployment team staff also provided each participant with a small journal (Figure 12) to keep in their vehicle during the test. Drivers were under no obligation to make notes in their journal, but this allowed them an opportunity to record ideas and questions that occurred to them during their time in the test.

Figure 12. Participant Journal.

At this first odometer reading participants were informed about data privacy practices in the study and were told that they had a choice regarding whether or not they wanted to share their trip data with the study team. Trip data consisted of detailed second-by-second data representing the time and location of their trips. The system was designed such that a participant’s fees could be calculated without the study team needing to know any details about that participant's trips in order to protect privacy. Although detailed second-by-second trip data was collected for all trips, the study team did not have the ability to associate a specific trip with the participant who made that trip. However, for study purposes, the study team desired to have this ability to link trips to participants, allowing for analysis of metrics such as driver behavior in safety zones before and after the addition of the in-vehicle signage. MnDOT elected to give participants a choice as to whether or not they were willing to share their data with the study team. If they elected to share data on all trips with the team, the association of a trip to a driver occurred automatically. If they did not elect to share data on all trips with the team, their phone's MRFT application prompted them as to whether or not they wanted to "share a trip," and they had the ability to exclude select trips when presented with this option. Most participants elected to share their data with the team and all participants shared data on at least some trips.

From a participant's perspective, the only formal study activity that occurred during the baseline period was the first survey (survey #1, or the baseline survey), which took place approximately 2 weeks after OR1, as is described in *Volume I, Section 4.1.2.1*. During the 2-month baseline period they were also welcome to write down any thoughts they might have in the journal they were provided, and they were free to call the service desk at any time with questions or issues related to their device or the test. The web portal was available to participants during the baseline period, but use of the portal was not promoted at this time as participants were not being invoiced and would not have a reason to view details about their trips and invoices.

3.1.3 Test Period Activities

Odometer reading 2 (OR2) marked the end of the baseline period and the beginning of the test period for participants, a period of approximately 4 months. At OR2, members of the deployment team updated participants' devices with the custom software and then instructed participants on the use of the software. Staff members explained to participants how the fee structure worked and presented them with an example in writing. Staff members also explained that there were locations around the Twin Cities Metro Area in which they would receive safety alerts on their device and they were provided a map of the safety zone locations as shown in Figure 13.

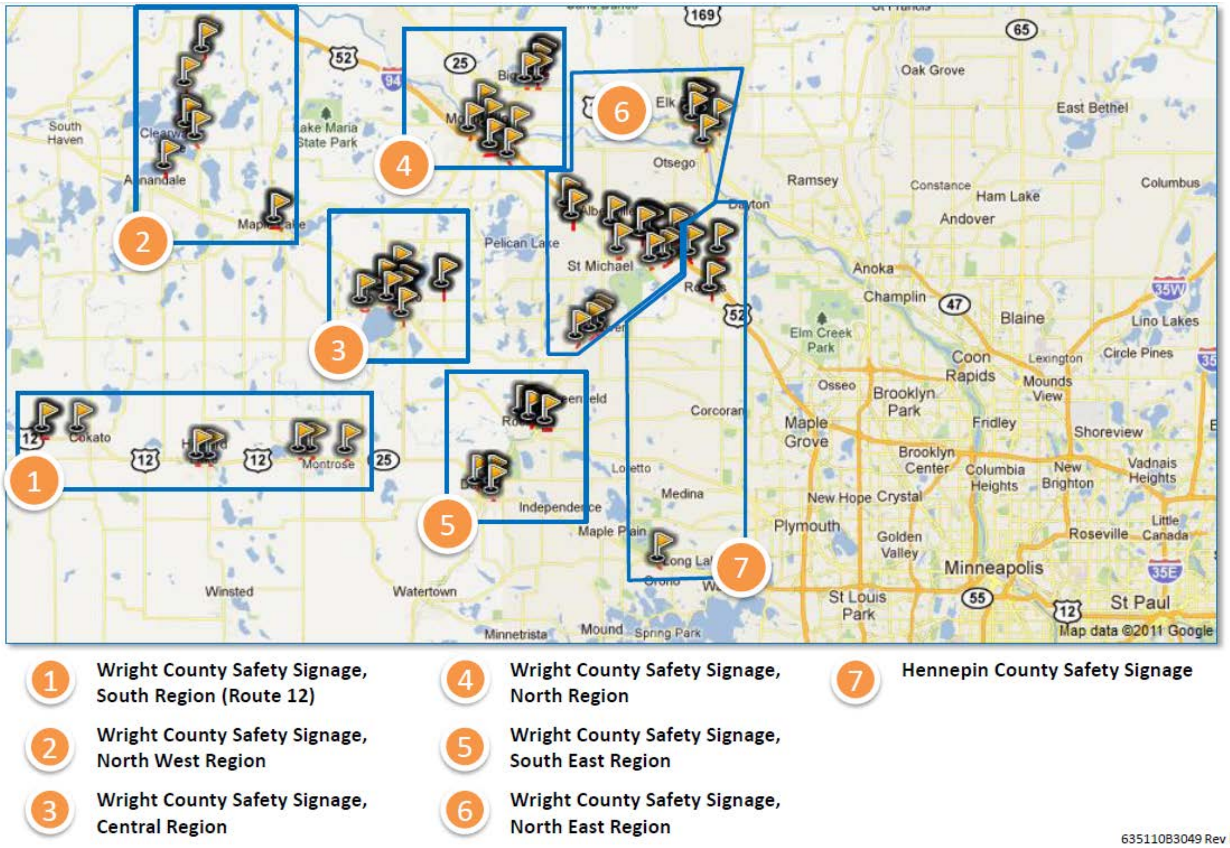


Figure 13. Map of Safety Zones Provided to Participants at Odometer Reading 2.

As was discussed in Section 2.3.2.1 and as is shown in Figure 14, the software displayed the current rate both at the top left of the screen and across the bottom of the screen when in the MRFT application (when using the navigation feature of the phone, the current rate only displayed at the bottom of the screen). When the driver entered select safety zones, the software provided the driver with safety alerts in the form of a visual alert as well as an audible alert in some cases. Safety zones are discussed in more detail in Section 2.3.2.2.

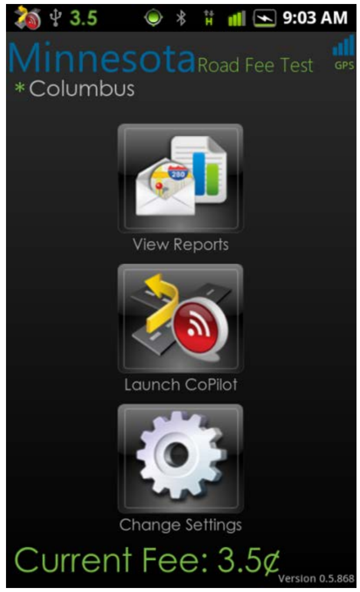


Figure 14. MRFT Smartphone Application Showing Current Fee.

During the test period there were a number of activities that participants were invited to complete. First was survey #2, which was issued to participants approximately 2 weeks following OR2. About 3 months into the test period there was the opportunity for a limited number of study participants to participate in a focus group and for all study participants to participate in a one-on-one telephone interview. Lastly was survey #3, which was issued to participants during their final month in the test. As with the baseline period, they were welcome to write down any thoughts they might have in their journal, they were free to call the service desk at any time with question or issues related to their device or the test, and they were welcome to visit the portal to view details about their trips.

During the test period, participants drove as they normally would, always seeing the current rate displayed on the device and receiving safety alerts when traveling through pre-defined safety zones. On the last day of the month (and every month thereafter), each participant received an invoice by email, and later by mail, from the deployment team. The invoice was generated based on the data collected from the participant's smartphone on how many miles were accumulated within each rate category. Participants were responsible for paying these invoices by the 14th day of the month. Once their invoice was past due they received a series of reminders from the deployment team via email and via administrative message on their smartphone device. If their invoice was more than 15 days late, their smartphone was disabled by the deployment team.

Participants had the option of paying their invoices either online, by mail, or in person. At their third and final odometer reading (OR3), they paid their final invoice, which accounted for any miles noted on their odometer that were not recorded on the device, and the deployment team provided them with the smartphone after removing the custom software.

3.1.4 Post-Test Activities

Within a month of completing the test, participants received a thank you letter and stipend by mail from the study team.

3.2 Contextual Factors Influencing the Test Experience

Although all participants were asked to complete the same activities, each participant had a slightly different experience in the test since it was a naturalistic study. Since participants were not in a controlled environment, there are a number of factors which can come into play to shape each participant's unique experience. For example, some participants experienced issues with their device while others did not; some participants had friends or family members in the study and their discussions with these individuals may have influenced their perceptions; and some participants' behavior or perceptions may have been influenced by external factors such as the state of the economy. These factors are discussed below. To the extent possible, the study team explored these factors in the analysis that follows.

3.2.1 Factors Related to Smartphone Performance

Although all participants were provided the same phone and the same software, all phones did not operate in the exact same manner. To start, the GPS quality of various phones of the same make/model can vary, and this occurred during the test. Weather was a factor as well, since battery life and smartphone functionality can deteriorate in extreme temperatures. Some Wave A and B participants experienced problems in the cold winter weather while some Wave C participants experienced problems in the hot summer weather. Participants in the first wave of the test experienced some challenges that were not experienced in later waves as the deployment team implemented a number of patches to resolve unexpected problems related to the operating system, the power port in the vehicle, and other issues. As the deployment team re-used some Wave A phones for Wave C participants, some Wave C participants experienced slower processing and other problems with these refurbished phones due to age.

3.2.2 Factors Related to Prior Experience with Smartphones

To participate in the test, participants were required to carry the study-provided smartphone and keep it powered on while driving in order to capture travel data. Although the percentage of the U.S. population owning cell phones (and smartphones in particular) is steadily increasing, and did so during this test, less than half of Americans currently own a smartphone and 15 percent do not own a cell phone at all.[30] The first group of participants began the test in

[30] Smith, Aaron, "46% of American Adults are Smartphone Owners," Pew Research Center, March 2012. Available at: http://pewinternet.org/~/media/Files/Reports/2012/Smartphone%20ownership%202012.pdf

September 2011 and the third and final group began the test 7 months later in April 2012. During a similar time period (May 2011-February 2012), the percentage of the U.S. population owning cell phones increased 4 percent and the percentage of the U.S. population owning smartphones jumped 11 percent.[31] The study team intentionally did not screen participants based upon experience with smartphones. Some participants had never operated a smartphone or cell phone. Although field staff provided technical support and distributed reference materials with troubleshooting information, some of these participants had trouble properly operating the device (e.g., accidentally turning off the GPS functionality).

3.2.3 External Factors

External factors such as the state of the economy and fuel prices can have a large impact on travel behavior. These factors could have also impacted participant acceptance of the concept of a mileage-based user fee. As shown in Figure 15, fuel prices wavered during the time participants were in the test, fluctuating between $3.11 and $3.94 per gallon, with Wave A experiencing the lowest fuel prices and Wave C experiencing the highest fuel prices. As shown in Figure 16, unemployment numbers[32] for Wright County sharply increased between December 2011 and March 2012, a time period that overlapped with Wave A and B participants. The possible impacts of these factors are discussed in the findings in later chapters.

[31] Smith, A. (March 2012).
[32] Defined by the Bureau of Labor Statistics, persons are classified as unemployed if they do not have a job, have actively looked for work in the prior 4 weeks, and are currently available for work.

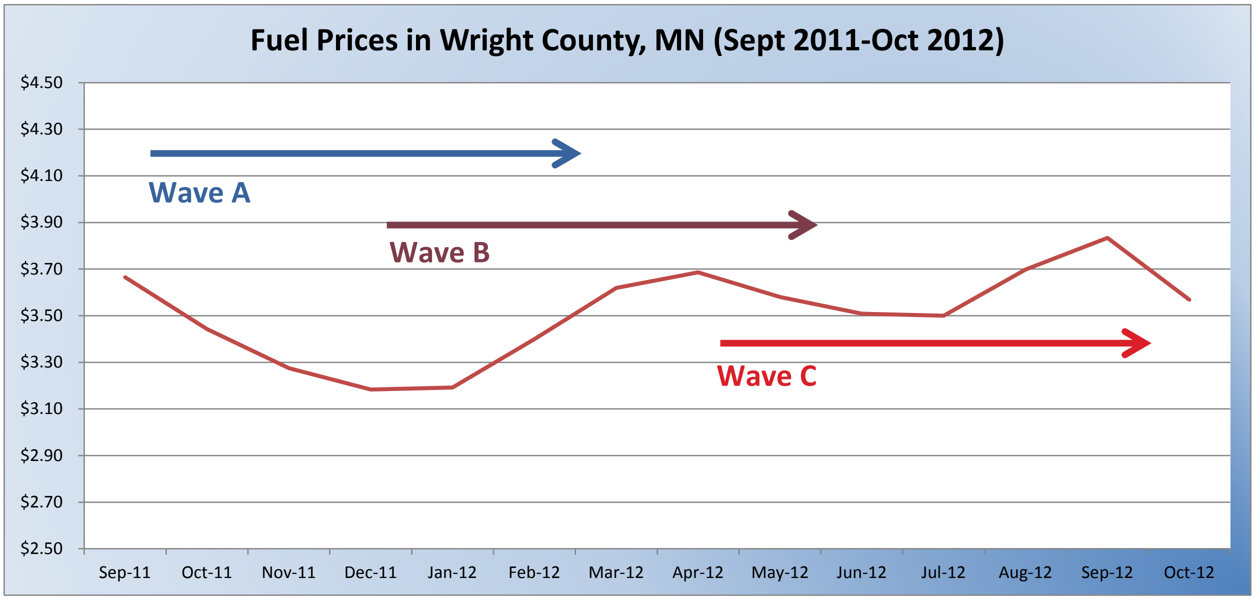


Figure 15. Wright County, MN Fuel Prices over Timeline of Pilot Study.

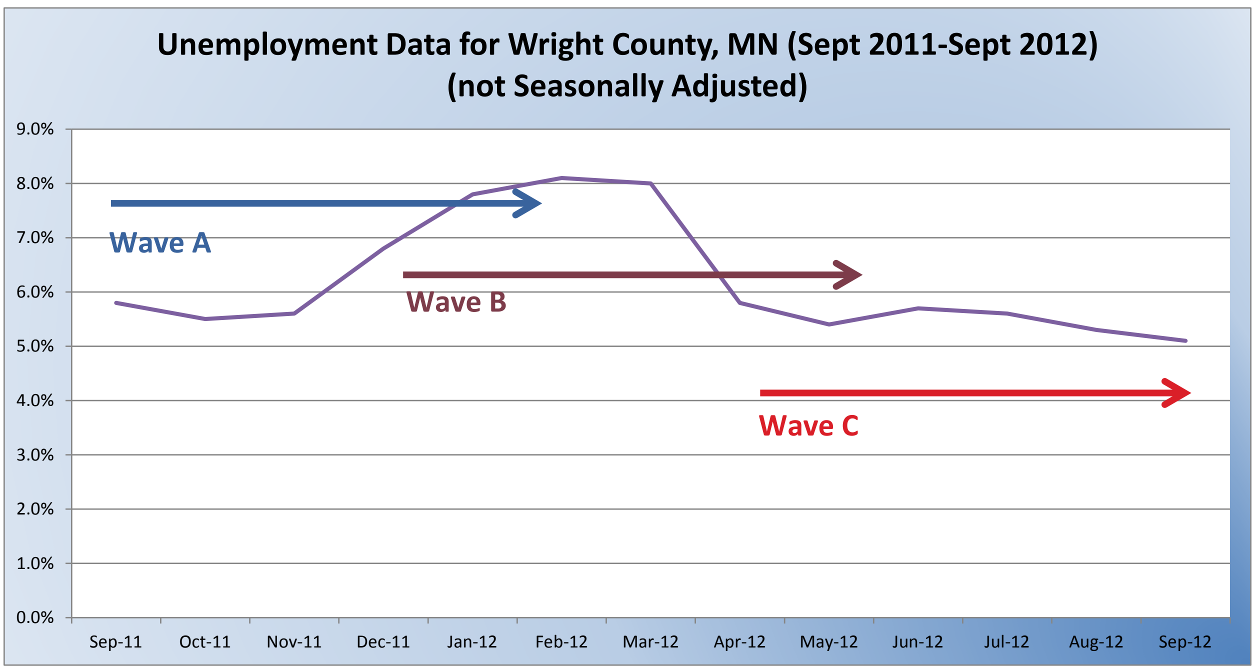


Figure 16. Wright County, MN Unemployment over Timeline of Pilot Study.

4 Evaluation Methodology

This section presents a high-level overview of the evaluation methodology. This includes a discussion of how the team collected and analyzed device data, conducted observations, gathered subjective data from participants, and collected institutional information.

4.1 Introduction

Considering the evaluation goals presented in Section 1.4, the team designed an evaluation methodology that enabled the team to gather data from a range of sources to meet the goals of the evaluation. For many goal areas, the team combined data from different sources. Table 6 shows which data sources were used to assess each goal area. The sections that follow describe the various types of data that the team used in analysis:

- Device data;
- Participant subjective data assessed through surveys, focus groups, and interviews;
- Observational data; and
- Institutional data.

Table 6. Data Sources used to Assess each Evaluation Goal.

Evaluation Goal	Data Sources
Assess participant perceptions of MBUF concepts and safety technologies	- Subjective data from participants (surveys, focus groups, interviews)
Investigate the safety impacts of the safety technologies tested	- Device data - Subjective data from participants (surveys, focus groups, interviews)
Investigate the mobility impacts associated with mileage-based user fees	- Device data - Subjective data from participants (surveys, focus groups, interviews)
Investigate the feasibility of generating travel times using the same device used to assess mileage fees	- Device data
Assess the technical performance of the technology used in the test	- Device data - Observational data (service requests)
Document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale	- Institutional information (stakeholder interviews)

4.1.1 Device Data

During the field test, the MRFT application generated a wealth of data. This data was transferred by the smartphone via its 3G mobile data network (the mobile carrier used in the test was a major carrier in this area) to the deployment team's data infrastructure. Depending on the data type, it was either transferred immediately in real-time or stored on the smartphone until transferred by the participant. The system collected three primary types of data that were used to generate the additional data and information needed to implement and run the MRFT program:

(1) Second-by-second ***trip data*** (generated by Probe Data Collection system element)[33] which provides time, location, and speed data;
(2) Event-based ***log data*** which was recorded and time stamped whenever system events occurred (generated by Logging system element);
(3) Unique trip identification numbers (TripIds) or ***TripId data***; (generated by Probe Data Collection system element); and
(4) Number of miles driven by fee category, or ***MBUF data*** (generated by MBUF Collection system element).

Trip data points were recorded every second that the MRFT application was running and a trip was underway. The GPS chip in the smartphone captured information such as vehicle speed, heading, latitude, longitude, timestamp, and GPS accuracy. Simultaneously, the system was constantly performing various status checks and updates, which were recorded as messages in the ***log data*** along with speed, latitude, longitude, and timestamp. Log messages ranged from error-related messages to system updates to system events such as a change from one fee category to another or entrance into a safety signage zone. Trip data and log data were transmitted every ten seconds. It is important to note that for a real-world deployment of mileage based user fees, trip data and log data would not need to be recorded on a second-by-second basis. This level of resolution was included in the test to support the evaluation analysis.

For every data point captured in both the trip data and log data, the trip identification number (***TripId***) was also recorded, allowing the system to generate summary information about any given trip, including the number of miles driven, location, time, GPS accuracy, and log messages. Note that although the team had access to this detail for every trip, the team was not able to associate a trip to a participant unless the participant expressly provided approval for the team to do so.

The ***MBUF data*** captured during the field test is comprised of two elements: (1) the number of miles driven and (2) how much participants owed for those miles based on the fee category where the miles were driven.

[33] Note that what is termed “trip data” throughout this report is referred to as “probe data” in the Operations Summary Report.

The deployment team provided these data to the study team via monthly reports. The team's analysis of this data is presented in *Volumes II, IV, and V.*

4.1.2 Participant Subjective Data

The study team gathered a wide range of data from participants. Data collection methods included:

- Surveys
- Focus Groups
- Telephone Interviews
- Participant Travel Journals

The team's approach to each of these activities is described in detail in the following sections: surveys, Section 4.1.2.1; focus groups, Section 4.1.2.2, telephone interviews, Section 4.1.2.3; and participant travel journals, Section 4.1.2.4). Findings gathered from these activities are presented throughout the document, but are primarily covered in *Volume III, Driver Acceptance Assessment*.

4.1.2.1 Surveys

The study team designed a series of surveys to detect changes in knowledge, perceptions, and opinions of participants as they progressed through the 6-month test:

- The study team designed the first survey (<u>Baseline</u>) to assess participants' initial thoughts and opinions. The team conducted the baseline survey approximately 2 weeks after participants joined the test, which included having their odometer read and receiving their device. The mileage-based user fee functionality on the device was not "on" during the baseline period.
- The study team conducted the second survey (<u>Novice</u>) to assess participants' initial reactions to the test device and mileage-based user fee program. The study team conducted the novice survey approximately 2 weeks after participants' second odometer reading, at which time the mileage-based user fee functionality on the device was turned "on."
- The study team conducted the third survey (<u>Experienced</u>) to assess participants' opinions regarding the test device and mileage-based user fee program at the end of their time in the test. The third survey was conducted during the final month of the test period. At this point, participants had approximately 4 months' experience using the device, with its mileage-based user fee functionality, and paying the accompanying invoices.

Participants completed the three surveys either online or by mail, depending on their preference. Only 21 of the 500 participants elected to receive a paper version of the questionnaire by the mail. The other participants completed the survey online using a web-based survey tool.

This number of participants in the test declined during the course of test as participants withdrew for various reasons, as described in Section 2.3.4. The response rate for the three surveys was as follows: the "baseline" survey received 484 responses out of a possible 500 (97 percent); the "novice" survey received 473 responses out of a possible 484 (98 percent); and the "experienced" survey received 454 responses out of a possible 481 (94 percent). It is important to note that participants were modestly compensated for each survey (approximately $25 per survey) as compensation has been shown to increase response rates and to increase completeness of responses.[34] This eagerness to participate is noted in the survey response rate.

4.1.2.2 Focus Groups

The study team conducted two focus groups with each of the three waves of participants, for a total of six focus groups. In total, 63 participants shared their thoughts and opinions through these 6 focus groups. Certain demographic criteria were established *a priori* to balance for age, gender, and income level. Participants who expressed interest were then matched to these categories on a "first-come, first-served" basis.

The focus groups with Wave A participants focused on how an MBUF program could work (e.g., how they feel the fee should be structured, how they feel fees should be collected, and how they think fees should be paid). At the end of the focus groups the team sought out their overall perceptions on MBUF and how they feel it could be implemented in the real world. The focus groups with Wave B and C were structured in the opposite way, focusing on gathering input for future messaging to the public, should an MBUF scenario ever be carried out in a real-world scenario. Toward that end, the meeting focused on how they felt about MBUF and whether their time in the test changed their opinions, what they think an effective message to the public would be, and how that message should be communicated to the public. At the end of the focus groups, the team sought out their overall thoughts on how an MBUF program could work.

The focus groups conducted with Wave A participants were structured as follows:

- *Part I - Mileage Fee Structure* - In this section, the facilitator inquired about how the fee structure worked in the test, what participants thought about it, and what other ideas they had for possible fee structures.

[34] Willimak, Diane, et. al., "Effects of a Prepaid Nonmonetary Incentive on Reponse rates and Response Quality in a Face-to-Face Survey," *Public Opinion Quarterly*, 1995, Vol. 59:78-92.

- *Part II - Fee Collection: Technology, no technology, both?* - In this section, the facilitator inquired about the system that was used to assess fees in the test, what participants thought about it, and what other ideas they had for possible ways to collect fees.
- *Part III - Payment Process: How, where, and when do you pay?* - In this section, the facilitator inquired about the approach to payment that was taken in this test, what participants thought about it, and what ideas they had to improve the process.
- *Part IV – Overall Opinions* - In this section, the facilitator asked participants about their overall opinions about MBUF.

The focus groups conducted with Wave B and C participants were structured as follows:

- *Part I - Understand the reasons for any opinion change regarding MBUF that might have occurred during their time in the study* - In this section, the facilitator asked what information, interaction, or experience led a participant to change his/her opinions, mind, or view (if any). Based on survey responses from Surveys 1 and 2, the facilitator knew which participants had changed their opinions on MBUF during their time in the test.
- *Part II - Capture the participants' opinion on what MnDOT's message should be to its audience if they were to ever to launch or initiate a user fee program* - In this section, the facilitator asked what participants would tell prospective users (other citizens) to help them understand the reasons for such a program.
- *Part III - Gain an understanding of the dynamics that occurred during participants' interactions with others (family, friends, coworkers, neighbors) during the test* - In this section, the facilitator probed on the nature of the interaction in terms of what questions were asked and what responses they gave.
- *Part IV - Capture the participants' opinion on what would be the best and most effective ways, means, and methods for MnDOT to disseminate the message if ever to launch or initiate a user fee program?* - In this section, the facilitator asked what participants felt was the best ways and methods to communicate the message.
- *Part V - Capture the participants' ideas on how would they like to see a user fee program implemented, based on their experiences during the test* - In this section, the facilitator asked how would drivers like to see a program like this implemented in the real world.

4.1.2.3 Telephone Interviews

The study team gave each participant the opportunity to participate in a telephone interview during their final month in the test. These interviews served as a mechanism for researchers to obtain additional insight into participants' perceptions. Of the 481 participants eligible for a telephone interview, 423 (88 percent) completed a telephone interview.

Interview questions asked of participants were as follows:

- Topic Area #1 - Signage Zone Experience
  - Based on your experience, can you tell me about something positive you experienced and something negative you experienced relative to the signage zone feature?
  - Overall would you say the signage zone feature was helpful? If not, why not? If so, what do you like in particular?]
    - If participant is very negative about this feature, ask if they had tried to do anything to get around the signage zone feature such as: trying to disable volume, changing routes to bypass the signage zone, putting their device under their seat, etc.
  - Additional Possible Probe Questions:
    - Where should the signs be located?
    - What should the signs look like?
    - Did your opinion of the signs change over time as you experienced them more? Why or why not?
- Topic Area #2 - Twin Cities Peak Experience
  - Did you pay attention to what the fees were in the different places you drove?
  - Did your knowledge of the varying fees change the way you drove in any way?
    - If no, probe: In this case we gave you the money to pay the invoices, but if this were coming out of your pocket, how do you think it might have affected your driving?
  - Most people are aware, in general, of how much they drive each year, but did this test make you more aware of exactly how long your trips tend to be?
  - Did it make you reconsider how you drive or did it change any of your driving habits?
- Topic Area #3 - Technology Feedback
  - Thinking about the smartphone device you used in this test, can you tell me about something positive you experienced and something negative you experienced relative to the device itself?
  - Did you think it did a good job of tallying your miles?
  - Did you trust it to work properly for your entire trip after setting it up when you started your vehicle?
  - Does this technology (or does technology in general) make you have any privacy concerns? Do you think your opinion of privacy changed over time?
    - Probe to figure out whether there is a distinction between privacy with this device versus privacy with technology in general.
- Topic Area #4 - MBUF Versus Gas Tax

- [Clarifying that they would not use the exact device or technology used in the test] Would you prefer MBUF or the gas tax? Why?
- Do you perceive that MBUF would save you money and/or does this benefit you as a driver versus being under the gas tax?
- [ASK ONLY HYBRID DRIVERS] One of the reasons we're asking about this is that cars are becoming more fuel efficient. I see you drive a very fuel efficient car. Does this influence your opinion at all?

- Topic Area #5 - Overall Experience
    - Have you talked much about the study with friends or family? If so, what kinds of things are they asking about?
    - If this kind of program were to become a reality, are there any unanswered questions in your mind that would need to be addressed?
    - Is there anything – either positive or negative – that you want to share that we haven't been able to cover during this interview?

4.1.2.4 Participant Travel Journals

The study team provided each participant a small journal to keep in their vehicles during the test. Drivers were under no obligation to make notes, but this allowed them an opportunity to record ideas and questions that occurred to them in the moment. Drivers returned their journals to the study team by providing them to deployment team members at their final odometer reading.

4.1.3 Observational Data

So that the study team would have the full context of the participant experience, the team conducted observations of three of the nine participant odometer readings and reviewed all participant service requests.

Observing participants being processed at odometer readings allowed the team to personally see the way in which the test was explained to participants and also provided the team insight into the types of questions raised by participants.

Each correspondence occurring between a participant and the deployment team's field staff was recorded as a service request. The deployment team provided details of the service requests to the study team for analysis purposes. The study team reviewed the service requests in detail to gain further insight into participant experiences and also to gain an understanding of what sorts of service request capabilities might be necessary in a real-world deployment of MBUF on a larger scale.

Information gathered through these activities is discussed throughout the various sections of the report where relevant.

4.1.4 Institutional Data

A final activity the study team completed was stakeholder interviews to gather information on institutional issues experienced in the test to document the programmatic / implementation experience of the pilot test and assess future potential and overall feasibility of deploying MBUF on a larger scale. The team conducted interviews with MnDOT, the PMO support contractor, and the deployment team.

The team's goals for the interviews were to:

1. Investigate **technical** questions related to the pilot program (e.g., understanding the system capabilities related to GPS accuracy);
2. Where possible, enumerate **costs** to operate this pilot program and identify the types of costs which may be associated with a wider, "real-world" implementation;
3. Identify potential effects on costs if alternative programs are implemented (e.g., simple odometer readings might require less equipment installation costs);
4. Identify **research lessons learned** from this pilot program (i.e., to refine conduct of further research);
5. Identify feasibility of widespread **implementation** of pilot program (i.e., MBUF COTS smart phone system) – physical, technical, marketing/messaging, operational (e.g., staffing), administrative factors:
    a. Who are partners or key players?
    b. Asses buy-in from partners and key players.
    c. What is needed in terms of processes and resources to implement program?
    d. What further investigations are needed?
6. Address issues associated with **policy** related to this pilot program and further implementation; and
7. Compare pilot program implementation to feasibility of implementing **alternative programs** indicated by users (e.g., simple odometer readings).

Findings of this activity are presented in *Volume VIII, Operation and Administration of an MBUF Program*.

5 Roadmap to the Remainder of this Report

The remainder of the report is organized as follows:

- ***Volume II - Overview of Data and Technical Performance of the System*** – This volume of the report presents findings related to system capabilities performance during the test.

- ***Volume III - Driver Acceptance Assessment*** – This volume of the report presents findings regarding driver acceptance of MBUF and the safety applications as assessed through survey, interview, and focus group findings as well as service requests. It discusses where opinions varied by age, income, or other demographics. Finally, it discusses potential barriers that could be expected in a real-world MBUF scenario based on what was observed in the test, as well as possible mitigation approaches to these challenges.
- ***Volume IV - Assessment of Impact of MBUF on Driver Behavior and Revenue*** – This volume of the report presents findings related to whether drivers in the test changed their driving behavior as a result of paying by the mile rather than for fuel. Measures include changes in total miles driven and the number of trips made as well as driver self-reports of awareness of their mileage as captured subjectively through interviews and focus groups.
- ***Volume V - Assessment of Impacts of Speed-Related Signage on Safety*** – This volume of the report presents findings regarding the impact of the in-vehicle safety alerts on drivers. The assessment includes an overall analysis of driver behavior resulting from the signs as well as a before-and-after analysis “within subjects.”
- ***Volume VI - In-vehicle CICAS Evaluation*** – This volume of the report describes how the study team conducted the CICAS test and presents the drivers’ perceptions of the in-vehicle CICAS safety alerts in concert with roadside alerts.
- ***Volume VII - Travel Time Data Utility*** – This volume of the reports discusses the utility of predicting travel times based on data captured from smartphones.
- ***Volume VIII - Operations and Administration of MBUF Program*** – This volume of the report discusses considerations in operating and administering an MBUF program in the real-world based on findings form the test.

The final volume, ***Volume IX, Findings and Recommendations,*** concludes this document with a summary of the findings including recommendations for future research.

Appendix A provides the materials the participants were provided, ***Appendix B*** provides the training materials participants were provided at OR2, ***Appendix C*** provides signage zone locations, and ***Appendix D*** provides the CICAS survey instruments.

Volume II: Overview of Data and Technical Performance of the System

1 Introduction

The system designed to support the Minnesota Road Fee Test had three key requirements:

1) Assess mileage-based user fees (MBUF);
2) Convey safety alerts to drivers through in-vehicle signing (safety signage); and
3) Provide a means for vehicles to provide data for the purposes of generating travel times on major corridors (data collection to support travel times estimates).

It is important to consider these three requirements when reviewing the design and technical performance of the mileage-based user fee system tested by MnDOT. Currently in Minnesota, a flat rate fuel tax is assessed on every gallon of gasoline purchased in the state. Just as consumers expect gas pumps to measure the number of gallons purchased accurately and reliably so that the proper amount of tax can be applied, likewise they would expect that a system designed to support an MBUF program will capture the number of miles driven accurately and reliably and apply the correct mileage fees. Along the same lines, drivers would expect a technology designed to provide in-vehicle safety alerts will be able to provide the same warning information as signs do in a manner that is reliable and accurate, with the intent of increasing safe driving behavior.

Driver response to in-vehicle safety alerts is addressed in *Volume V*. The ability of the system to provide detailed location data in support of travel time estimates is discussed in greater detail in *Volume VII*. This volume provides an overview of the system designed to support the MRFT and gives a detailed description of the data collected and its utility relative to the three system requirements listed above. Lastly, a high-level assessment of the technical performance of the system and its various functions is presented, focusing on its ability to support an MBUF program.

2 System Design and Data Collection

Volume I introduced the final system design developed for the pilot and provided an overview of the data collected on the smartphone. This section expands on the description of the system and details how the data was collected and processed to support the various functions of the field test.

2.1 System Design

The MRFT technology developed for the field test consisted of a system comprised of two major sub-systems and their supporting network connections. The two sub-systems, as defined by the deployment team, were:

1. The Infrastructure Subsystem, or the data infrastructure and its supporting server and computing services which stored the data; and
2. The In-Vehicle Subsystem, or the smartphone and its supporting hardware and software which collected all the data for the system.

The infrastructure subsystem was implemented using Microsoft Windows Azure Cloud computing services and provided data collection, analysis, and presentation capabilities. Specifically, the infrastructure subsystem hosted several services including:

- Participant Portal
- Administration Portal
- Data Repository (MBUF data)
- Trip and Log Database
- Report Generation

While performance of the infrastructure subsystem was important, Volume II focuses on the technical performance of the in-vehicle subsystem for two reasons: 1) the data sources available to the study team for analyzing technical performance primarily related to the in-vehicle subsystem, and 2) with the exception of the participant portal, participants, in general, did not interact with elements of the infrastructure subsystem. Therefore, the subsections below focus primarily on the hardware and software elements of the in-vehicle subsystem. More detail on the technical performance of the infrastructure subsystem is available in the deployment team's final report.[1]

2.1.1 In-Vehicle Subsystem Hardware

Hardware for the in-vehicle subsystem consisted of the following four elements:

- Samsung Captivate™ smartphone
- Smartphone vehicle mount
- Vehicle identification module (VIDM)
- Power management module

[1] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.

Prior to attending OR1, participants received a welcome packet in the mail which contained a flyer developed by the deployment team that described the MRFT system and the hardware items, or equipment, which they would be receiving (Figure 17).

Figure 17. Welcome Packet - In-Vehicle Equipment and System Flyer.

At OR1, a member from the deployment team instructed participants on how to mount the smartphone in his/her vehicle using either the windshield mount or vent mount, per the participant’s preference. The participant was then directed to plug the device charger into the vehicle’s power port and connect it to the smartphone. The beginning and end of a trip were defined by when power was supplied to the smartphone, mimicking the status of a vehicle’s ignition (i.e., a trip starts when the vehicle is turned on and that trip stops when the vehicle is turned off). A power management module was available for participants owning vehicles with power ports that remain active after a vehicle’s ignition is shut off. Next, the VIDM was plugged into the Onboard Diagnostic (OBD II) port beneath the steering column. The smartphone communicated with the VIDM via Bluetooth to ensure it was in the correct vehicle before starting a trip, supporting the test design that miles recorded by the MRFT application compared to odometer miles on the assigned vehicle would reflect participant technology use.

2.1.2 In-Vehicle Subsystem Software

The smartphone was the user interface for the technology and was equipped with Version 2.2 of the Android operating system (OS), which, along with custom code, provided key software services to the MRFT application as developed by the deployment team. The software package loaded on the smartphone by the deployment team consisted of seven main system elements, which are listed and described in Table 7 below.

Table 7. The In-Vehicle Software System Elements and Their Functions.

Software System Element	Function
Main	Communicated status of the MRFT application (i.e., on/off) to all other software elements and received inputs for operation of the application functions.
Positioning	Provided positioning/location information using the GPS chip in the smartphone.
Logging	Received and created log messages from other software elements, sent log messages, and handled errors.
Vehicle Communications Support	Sent data from all other software elements to the data infrastructure via the smartphone's cellular communications.
Probe Data Collection	Managed the unique trip identification numbers (TripId) created each time a new trip began and received inputs from the Positioning, Logging, and Main software elements to create second-by-second trip data which were sent to the data infrastructure.
Signage	Received inputs from Positioning, Logging, and Main software elements to determine if the smartphone was in a signage zone and displayed the appropriate sign if the defined criteria were met.
MBUF Collection	Received inputs from Positioning, Logging, and Main software elements to determine the current MBUF rate, logged miles driven in fee categories, and estimated total MBUF mileage and fee for a trip.

2.2 Data Collection

The system processes described above produced the data collected from the various MRFT functions. In summary, the system generated four primary types of data:

1. Second-by-second ***trip data*** (generated by Probe Data Collection system element);[2]
2. Event-based ***log data*** which was recorded and time stamped whenever system events occurred (generated by Logging system element);
3. Unique trip identification numbers (TripIds), or ***TripId data*** (generated by Probe Data Collection system element); and
4. Number of miles driven by fee category, or ***MBUF data*** (generated by MBUF Collection system element).

Table 8 compares the various data elements available by data type.

[2] Note that what is termed "trip data" throughout this report is referred to as "probe data" in the Operations Summary Report.

Table 8. Data Elements by Data Type.

Data Element	Trip Data	Log Data	TripId Data	MBUF Data
Fee Category				✓
Miles Driven				✓
Participant Id			✓	✓
Device Id			✓	✓
TripId	✓	✓	✓	
Latitude	✓	✓		
Longitude	✓	✓		
Speed	✓	✓		
Heading	✓	✓		
Position Time Stamp	✓	✓		
Wave Id	✓			
GPS Accuracy	✓			
Altitude	✓			
Message		✓		
Message Type		✓		
Source – Software System Element		✓		

The four primary data types collected and their utility are further explained below.

2.2.1 Trip Data and Log Data

Trip data was recorded every second that the MRFT application was running and a trip was underway. The trip data included detailed position information such as location, direction, speed, time, and GPS accuracy on a second-by-second basis, providing a wealth of driving data to the field test. Collecting this type of data for multiple drivers on a roadway creates the potential for travel information applications such as providing travel time estimates. While this functionality was not presented to participants during the field test, one goal of the pilot study was to determine whether the same in-vehicle device used to assess mileage-based user fees and to provide safety alerts to drivers also had the potential to collect second-by-second trip data that could be used to predict travel times in real-time. This topic is discussed in-depth in *Volume VII*.

Additionally, the MRFT application was constantly executing self-performance and Android OS performance checks as well as communicating with the data infrastructure to check for various updates or status changes, which were all recorded as messages in the log data. Log messages ranged from error-related messages to system updates to system events such as a change from one fee category to another or entrance into a safety signage zone. Log messages were used for system diagnostics and helped the deployment team identify problems with the smartphone hardware, software, or operating system. Trip data and log data were first cached locally on the smartphone, but were then sent as soon as possible in near real-time to the data infrastructure as long as a data network connection (i.e., cellular communications) was available on the smartphone. At least 20 seconds of trip data had to be stored on the smartphone before it would be transmitted to the data infrastructure.

2.2.2 TripId Data

At the start of a new trip, a unique TripId was assigned to the individual trip and recorded along with all second-by-second trip data points and event-based log data points captured during the trip. This data is first cached locally on the smartphone and then sent via wireless communications. Separately, on the smartphone, the TripId was associated with the relevant Participant Id and Device Id to create the TripId data. At the end of the trip, the participant had the option to save or discard the TripId data (see Figure 18). If the data was discarded, then trip and log data associated with that TripId could never be attributed to that participant. If the participant chose to save the data, then the TripId data was stored to the smartphone. Using a "reports" menu in the MRFT application, the participant then had the option to send his/her TripId data to the data infrastructure, effectively sharing it with the deployment and study teams. At that point, the TripId data could be used to associate the trip and log data to a participant. Participants who were willing to share all of their TripId data with the team had the option of forgoing the prompts at the end of each trip to save and send TripIds by electing to save and send all TripIds automatically by adjusting settings on the settings menu (see Figure 18). The deployment team's report provides additional detail on the options available to participants with regard to sharing or not sharing their data.[3]

[3] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.

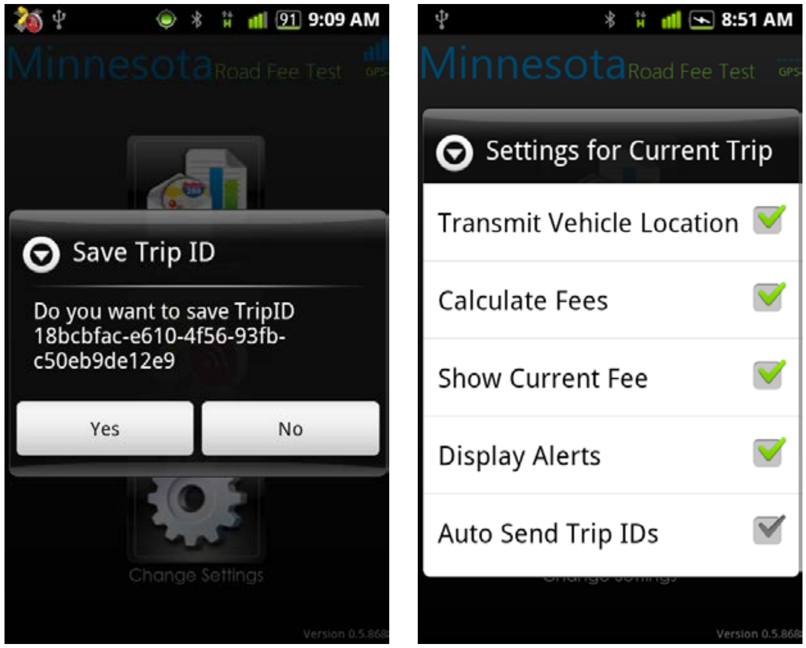


Figure 18. MRFT Application Prompt to Save TripId (Left) and Auto Send TripIds Setting Option (Right).

Additionally, sharing TripId data allowed participants to log in to the participant portal and view their list of shared trips as well as a map of each individual trip, which gave participants the opportunity for reconciliation if a participant noticed a trip was missing or recorded improperly. Alternately, if a participant chose not to save TripId data, he/she could write down the TripId before discarding it and still view trip details on the Participant Portal using the TripId as a reference number. Figure 19 below is a screenshot of a trip display provided on the participant portal for a single TripId. The position information (Latitude, Longitude, Speed, Heading, and PositionTimeStamp) from the trip data is used to produce the trip display provided on the participant portal.

Figure 19. Screenshot of Trip Display on Participant Portal.

2.2.3 MBUF Data

As mentioned in Volume I, the system was designed to protect participant privacy. The MBUF Collection software system element collected miles driven and calculated fees owed independently of the trip data and TripId data. The system element only used participant location to determine the appropriate fee category and corresponding MBUF rate at that immediate point in time. As shown in Table 8, it did not record location, time, or speed information like the trip and log data.

The system retrieved current location data every second and then determined the fee category based on location and time of day, and assigned the corresponding MBUF rate. Next, the current MBUF rate was displayed on the MRFT application in the vehicle. Simultaneously, the distance between successive location points was calculated (in miles) and added to the corresponding fee category bucket. Lastly, no less than every 24 hours, the MRFT application on the smartphone sent an accumulated mileage report to the data infrastructure containing the miles driven in each fee category bucket.

The data infrastructure then compiled the accumulated mileage reports sent by the smartphone and generated an invoice at the end of each month detailing the miles driven in each fee category, the MBUF rate for that fee category, and the total fee (in dollars) owed. Table 9 below shows the four criteria used to create the fee categories and the possible types under each, resulting in 48 different fee categories. A check mark indicates the types within each criterion where there was an applicable MBUF rate.

Table 9. Breakdown of Fee Categories.

Criteria	Types	MBUF Rate Impact?
Geography	North America	
	United States	
	Minnesota	✓
	Twin Cities	✓
Road Type	Interstate	
	Non-Interstate	
Time of Day	AM	✓
	PM	✓
	OFF	✓
Day of Week	WEEKDAY	✓
	WEEKEND	✓

MBUF data was collected in both the baseline and test periods. However, the MBUF rate was only displayed to participants on the smartphone during the test period, at which time they also began receiving invoices for their miles accumulated in each fee category along with the corresponding fee. The method for determining the MBUF fee rates during the field test was presented in *Volume I, Section 2.2*. The MBUF rates established were $0.03 per mile for travel that was both during peak hours (Monday-Friday, 7:00am-9:00am or 4:00pm-6:00pm) and in the predefined “Metro Zone” (indicated in the fee category criteria by “Twin Cities”), and $0.01 per mile for all other travel inside the State of Minnesota. Although miles outside of Minnesota were collected by the MBUF application, participants were not charged for them. Additionally, any miles recorded on the odometer and not by the MRFT application (i.e., “non-technology” miles) were charged at the higher rate, $0.03.

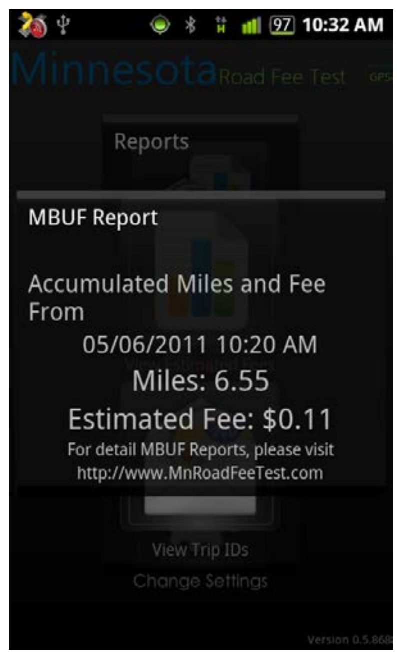


Figure 20. MBUF Application Miles Report Menu.

Participants had various options for viewing their total miles accumulated and fee throughout the test period. First, participants could view the miles driven and corresponding fee for the most recent trip completed using the report menu available on the MRFT application (see Figure 21 below).

Additional detail was available on the participant portal where participants could view a list of the MBUF charges for all trips in the current month including the number of miles by fee category along with the corresponding MBUF rate and total fee. Lastly, participants received an invoice at the end of each month that also provided detail by fee category as well as the total fee due for the month. At any time throughout the test period, participants could log in to the participant portal and view a list of all previous or outstanding invoices including the invoice date, due date, amount owed, amount paid, remaining balance, and current status (e.g., paid, past due), as well as a PDF of the invoice itself for detail by fee category.

Figure 22 below shows the Invoices menu available on the participant portal. Participants received an invoice at the end of each month in the test period and at their final odometer reading for any miles and fee accumulated since the beginning of that month. Lastly, participants received one final invoice for the number of miles recorded by their vehicle during the test period but not recorded by the MRFT application (i.e., "non-technology" miles).

Figure 21. Invoice Information on Participant Portal.

3 Summary Statistics

This section provides greater detail on the volume and use of the data captured by the smartphone, collected by the data infrastructure, and analyzed by the study and deployment teams. The MRFT field study was launched on September 12, 2011, when the first participant completed odometer reading 1, and concluded on October 25, 2012, when the last participant completed odometer reading 3 and submitted the final trip. This section presents data captured during that period of time. As explained above, some data was able to be attributed directly to participants while other data was anonymous. In the case of anonymous data, the summary information reported may include data from MRFT participants, test accounts, and "VIPs" (at times, representatives from MnDOT or the project team tested phones) without the ability to distinguish between them. In the case of shared data and MBUF data, only summary information collected from MRFT participants is reported.

Over the course of the field test, 83 percent of the trips recorded by the system were shared with the deployment team and study team.

3.1 Trip Data, Log Data, and TripId Data

The field study took place over the course of 409 days. Trip data was collected nearly every second during trips along with a wealth of system diagnostic log data, and a unique TripId was generated for every trip that took place over that period. In cases where the TripId was shared by participants, the study team could associate trip data and log data to a participant. Therefore, comparing the number of TripIds in the TripId data to the number in the trip data provides insight into the percentage of trips where participants elected to share TripId data.

Table 10 presents the total number of data points collected by each data type and a count of TripIds recorded in each dataset by the system. Of the 493,867 TripIds stored in the trip data, 408,857 (83 percent) were shared by participants and available in the TripId data.

Table 10. Data Volume by Data Type.

Data Type	Total Data Points	Count of TripIds
Associated TripId Data	408,854854	408,854854
Trip Data	660,958,334	493,867
Log Data	175,400,563	492,331

As mentioned before, the trip data contained valuable position information (i.e., location, speed, time, and GPS accuracy) for every second of every trip. With more than 660 million points collected over the course of 14 months, the position information represents a wealth of detailed travel information data across Wright County, the greater Minneapolis/St. Paul Metro Area, and beyond (discussed in greater detail in *Volume VII – Assessment of Utility of Travel Time Data*). The more than 175 million log data points generated by the system contained 165 different message types and provided detailed insight into system operation and performance.

The TripId data is associated with participants and, therefore, provides insight into the number of trips taken by each participant. Table 11 below shows a count of the total number of associated trips by wave for all participants who completed the majority of the test activities (n=481). The number of trips by wave and per participant is further addressed in the system reliability section below.

Table 11. Number of Participants and Associated Trips by Wave.

Wave	Count of Participants	Count of Associated Trips (TripIds)	Percent of Total Associated Trips	Trips per Participant
A	139	83,438	21%	600.3
B	162	97,091	24%	599.3
C	180	219,020	55%	1,216.8

3.2 MBUF Data

The MBUF data captured during the field test is comprised of two elements: (1) the number of miles driven and (2) how much fee participants owed for those miles based on the fee category in which the trip took place. This section begins with a look at the number of miles participants captured with their smartphones compared to the number of miles recorded on their vehicles, or "usage." Then, there is a discussion of the results of the process by which participants were charged and paid fees for miles driven during the test period, or "payment."

3.2.1 Usage

As described above, the MRFT application collected the number of miles driven in each fee category and reported the accumulated miles to the data infrastructure no more often than every 24 hours during the baseline and test periods. Additionally, odometer miles were recorded from participants' vehicles at each of the three odometer readings throughout the field test. The difference between OR2 and OR1 miles provided total miles driven in the vehicle in the baseline period while the difference between OR3 and OR2 provided total miles driven in the vehicle in the test period. Based on the MBUF rate and test design, only four higher-level fee categories were relevant to participants:

1. Outside Minnesota miles;
2. Inside Minnesota miles;
3. Twin Cities ("Metro Zone") – Peak miles; and
4. "Non-Technology" miles.

Any miles captured by the MRFT application on the smartphone were considered "device miles" (categories 1-3) while "non-technology" miles were those captured on the odometer but not accounted for on the MRFT application. Figure 22 below presents the total number of miles driven over the length of the field test. The figure shows percentage of miles driven in each of the categories listed above for all participants who completed the test (n=478). Figure 23 shows the percentage of participants that recorded miles in each of the categories. The Twin Cities-Peak and Non-Minnesota categories accounted for the lowest number of miles in the field test and were traveled in by a lower number of participants. However, while the Twin Cities-Peak category only represented 3 percent of miles in the test period, 75 percent of participants recorded at least some mileage in that category.

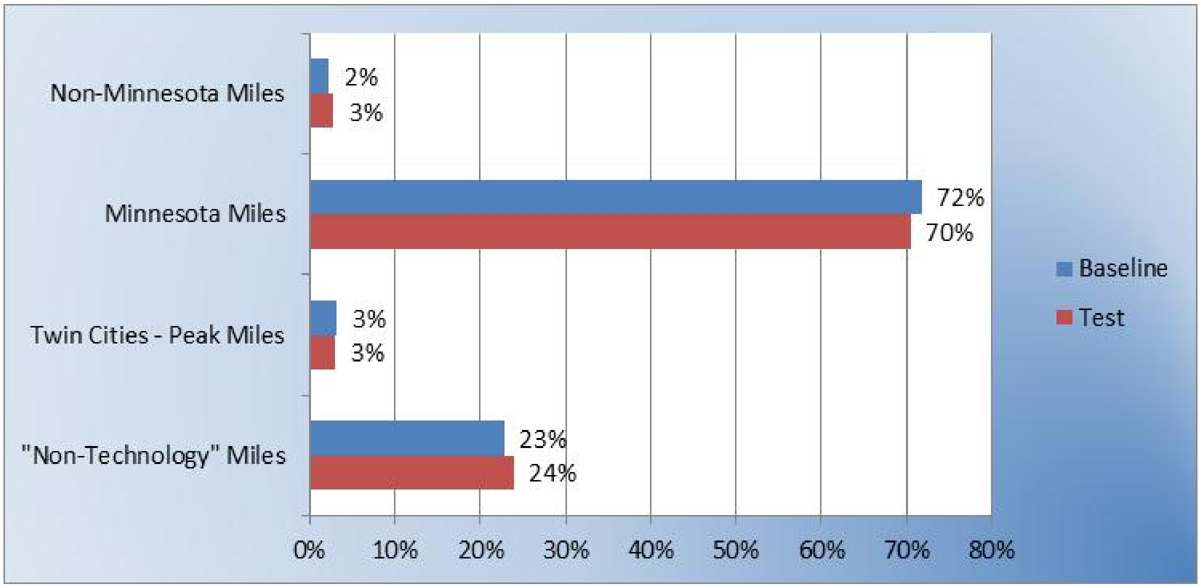


Figure 22. Percentage of Miles Driven in Each Fee Category in Baseline and Test Periods.

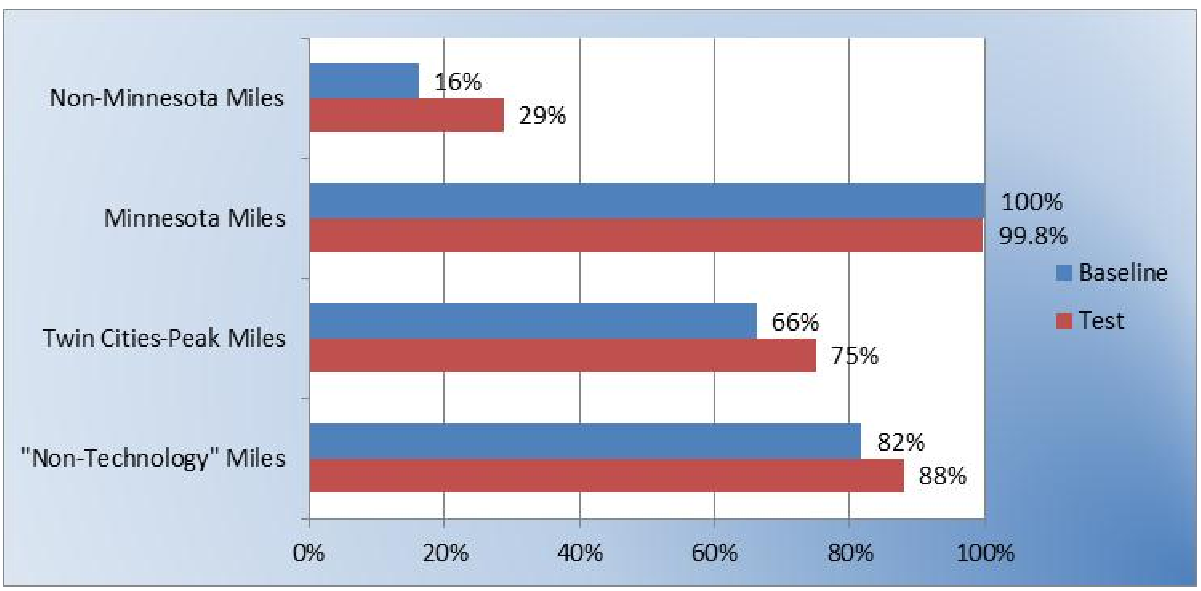


Figure 23. Percentage of Participants Experiencing Each Fee Category in Baseline and Test Periods.

As shown in Figure 22, 77 percent of miles in the baseline and 76 percent of miles in the test period were captured by the MRFT application (device miles) and odometer while the remainder were captured by the odometer only (shown as "non-technology" miles). These "non-technology" miles represented instances when participants either (a) forgot or elected not to bring the smartphone with them, or (b) the MRFT application failed to capture their mileage. When the MRFT application failed to capture their mileage this was sometimes related to user error (e.g., the participant thought they were using the device properly but they were not) and sometimes related to device issues.

Figure 24 below shows the breakdown by device and "non-technology" miles per participant (sorted by participant devices miles) and provides greater insight into what portion of total miles each represents. The figure indicates that a number of participants had a majority of miles captured by the odometer and not the smartphone whether due to scenario (a) or (b) mentioned above. One participant in particular whose device miles only represented 7 percent of total miles is a clear outlier. For the remainder of participants, device miles represented 78 percent of total miles. However, it is important to report that 47 out of 478 participants (9.8 percent) experienced more miles captured by their device than by the odometer on their vehicle. In the field study, the percentage of device miles out of total odometer miles, or "percent usage," was a metric considered for each participant. Therefore, 9.8 percent of participants experienced a percent usage above 100 percent either in the baseline or test period. Percent usage and the issue of more device miles than odometer miles are discussed in greater detail in the System Accuracy section below.

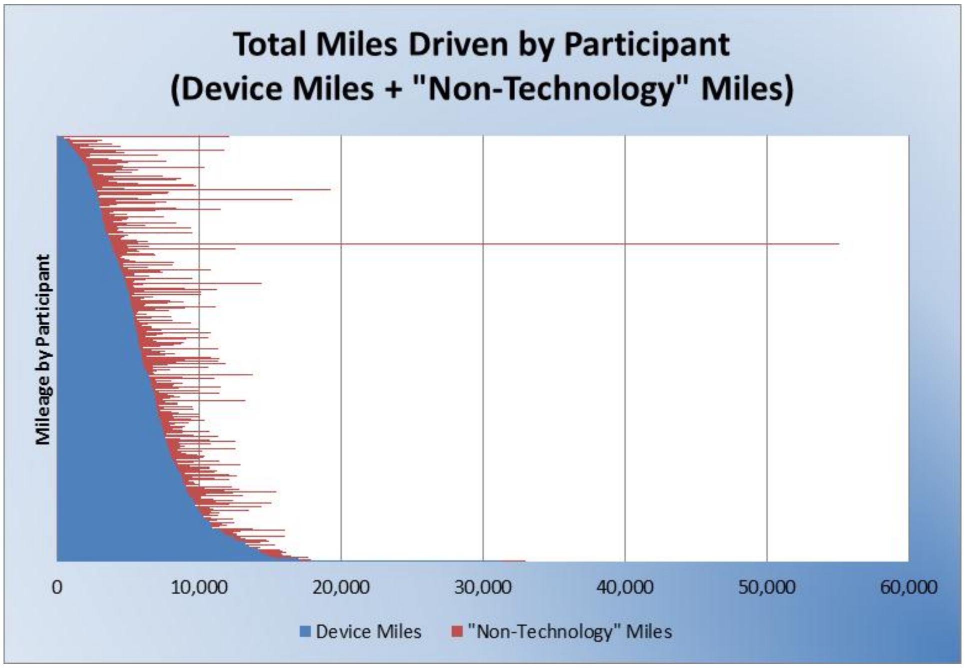


Figure 24. Total Miles Driven by Participant: Device Miles + "Non-Technology" Miles (Baseline and Test Periods).

3.2.2 Payment

Participants were charged fees during the test period on the miles driven in the categories mentioned above based on the MBUF rate for that category:

1. Outside Minnesota miles - $0.00 per mile;
2. Inside Minnesota miles – $0.01 per mile;
3. Twin Cities ("Metro Zone") – Peak miles – $0.03 per mile; and
4. "Non-Technology" miles – $0.03 per mile.

Figure 25 below shows the percentage of total dollars collected during the test period that each fee category represented. Interestingly, nearly as much fee was collected for "non-technology" miles as for miles captured by the device, 48 percent and 53 percent respectively. Figure 26 below shows that all participants drove and paid for miles in Minnesota and 88 percent had to pay for some amount of "non-technology" miles at the end of the test period.

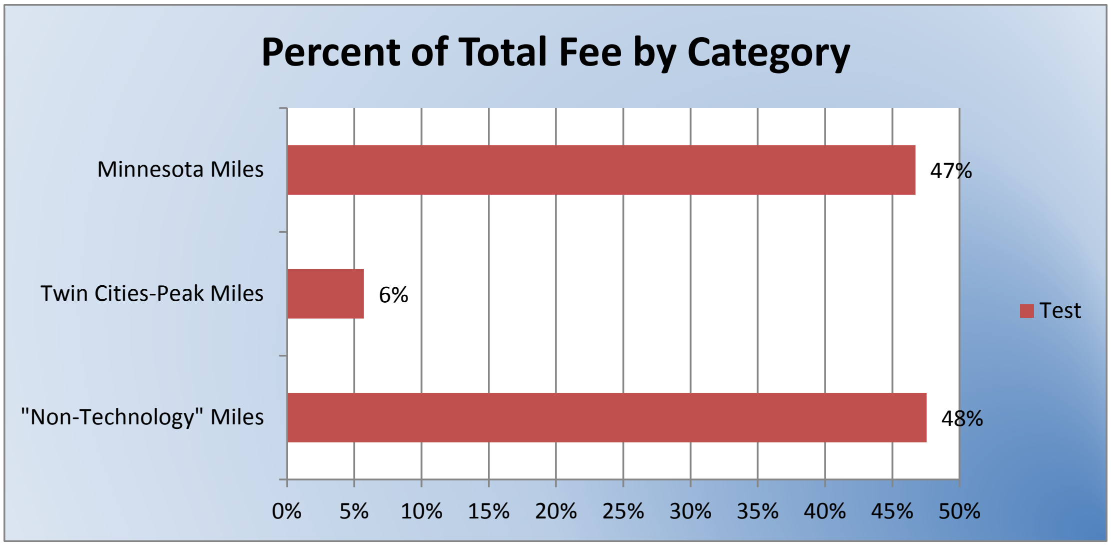


Figure 25. Percentage of Total Fee Collected by Category in Test Period.

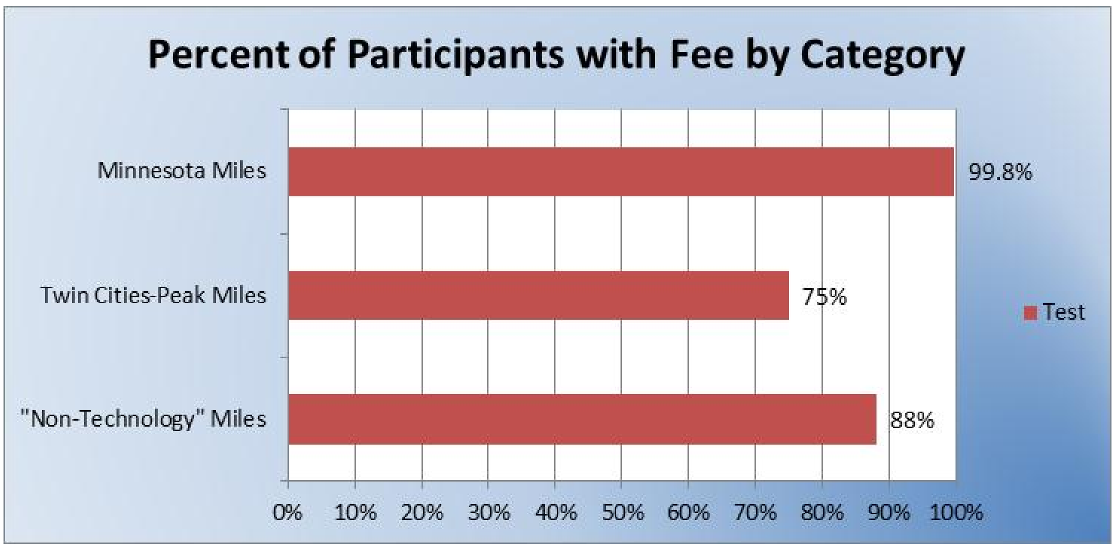


Figure 26. Percentage of Total Participants with Fee Category in Test Period.

Fees were charged to participants by invoice at the end of each month during their involvement in the test period as well as at the final odometer reading before their participation in the field test ended. In the results below, only participants who completed the field test are presented (n=478). Table 12 below shows that participants paid an average of 6 invoices at an average cost of $11.87 each.

Table 12. Summary of Invoices during Test Period.

Number of Participants	Number of Invoices	Sum of Invoice Totals	Average Number of Invoices per Participant	Average Invoice Total per Invoice
478	2,750	$32,640.05	5.8	$ 11.87

In most cases, participants received four invoices during the test period and two invoices at the final odometer reading (one for device miles in the current month and one for "non-technology" miles over the course of the test period). In a few cases, participants received up to eight invoices over the test period. This was the result of participants remaining in the field test longer than expected due to difficulty scheduling or attending their third odometer reading. These participants continued being invoiced for miles driven at the end of each month until OR3 was complete. Table 13 below shows the number of participants receiving each invoice number along with the average fee paid per invoice.

Table 13. Count of Participants by Invoice Number (n=481).

Metric	Invoice Number							
	1	2	3	4	5	6	7	8
Total Number of Invoices Issued	478	478	478	476	460	334	25	9
Average Fee per Invoice	$4.55	$11.35	$10.41	$16.39	$21.34	$7.06	$2.95	$1.13

All participants in the field test received at least three invoices over the course of the test period. In most cases, whether a participant received a fourth and fifth invoice depended on activities at OR3 (e.g., participants only received a fourth invoice if they had outstanding device miles on their smartphone at OR3 and participants only received a fifth invoice if they had to pay for "non-technology" miles accumulated during the test period at OR3). Table 13 shows that invoice 5 was higher on average across all participants. The MBUF rate for "non-technology" miles was $0.03 per mile. In the test period, "non-technology" miles represented 24 percent of the total miles driven, accounted for 48 percent of the total fee collected, and were experienced by 88 percent of participants. Therefore, it is not surprising that invoice 5 was substantially higher than the others. However, the final device miles invoice and "non-technology" miles invoice did not always correlate to invoice 4 and 55, respectively. Some participants in Wave C only received 3 invoices over the course of the test period due to the day of the month that their OR2 appointment took place. For these participants, invoices 3 and 4 were generated at OR3 for device miles and "non-technology" miles, respectively. This explains the significantly higher average for invoice 4 seen in the table.

Participants had several options for paying invoices received during the field test including:

- Check by mail;
- Online via PayPal through the participant portal; or
- In-person by check or PayPal at the MRFT office where odometer readings took place.

Figure 27 below shows how participants elected to pay for invoices and includes a count of $0.00 invoices generated (i.e., the participant either did not use their device in that month or the device was not recording their miles for some reason). Invoices 1 through 3 were paid slightly more by check than PayPal. Far more invoices were paid by check for invoices 4, 5, and

6, which can likely be attributed to those invoices being paid in person by participants at OR3. For all non-zero invoices generated during the field study, 67 percent were paid by personal check while 33 percent were paid using PayPal.

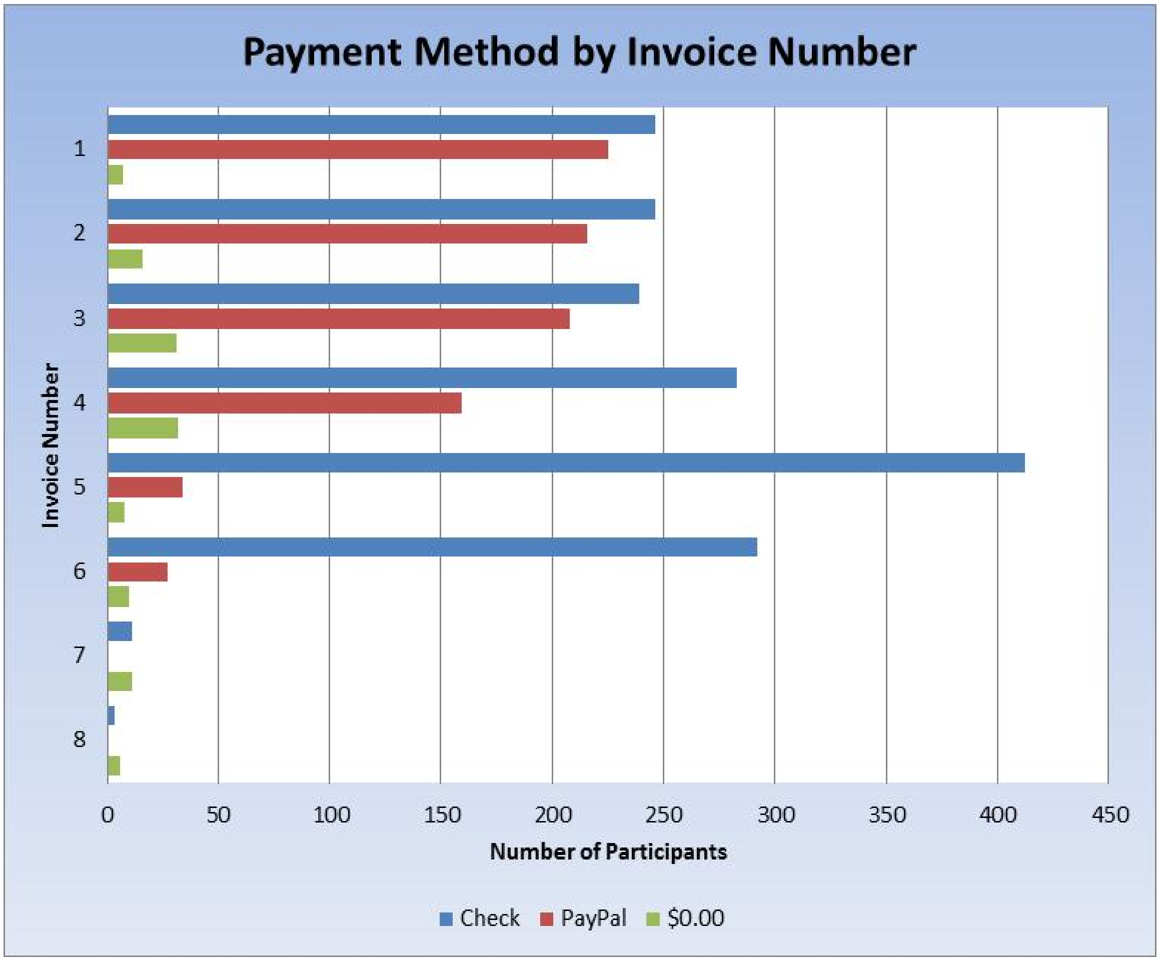


Figure 27. Payment Method by Invoice Number (n=478).

Table 14 below provides insight into the success of the field test in collecting fees from participants. The pilot study achieved a 99 percent or better collection rate for invoices 1 through 3 and 96 percent or better for invoices 4 through 6.

Table 14. Amount Due and Amount Paid by Invoice Number.

	Invoice Number (Dollars)								
Metric	1	2	3	4	5	6	7	8	Total
Amount Due	$2,176	$5,426	$4,976	$7,803	$9,816	$2,359	$ 74	$ 10	$32,640
Amount Paid	$2,176	$5,426	$4,952	$7,567	$9,534	$2,289	$ 69	$ 10	$32,023
Difference	$ (0)	$ -	$ (24)	$ (236)	$ (283)	$ (70)	$ (4)	$ -	$ (617)
Percent Paid	100%	100%	100%	97%	97 %	97%	94%	100%	98%

As mentioned, participants received invoices on the first day of each month by e-mail and were mailed a paper copy shortly thereafter. The due date for invoices was 14 days after receipt.

Invoices still outstanding after the due date were considered late. If a participant had still not paid an invoice by the end of the month, then the participant's smartphone was locked and the MRFT application or other functionality could not be used. Any miles driven when the device was locked would be recorded by the odometer and accumulated as "non-technology" miles. To unlock the phone, participants had to contact the deployment team's support line and schedule a meeting to have the phone unlocked at the MRFT field office. Table 15 below presents the payment status of each invoice by invoice number. For invoices 1 through 3, over 40 percent of invoices were paid late by participants. However, payment punctuality improved by the fourth invoice with 73 percent paying on-time. For invoices 1 and 2, 3 percent of invoices were not paid by the end of the month, resulting in a locked smartphone for those participants. The number of locked smartphones per invoice number dropped significantly from there. A total of 30 different participants in the field test experienced a locked smartphone at some point during the test. Five participants were repeat offenders with payments late enough to result in a locked device. Of those, 1 person's smartphone was locked three times.

Table 15. Payment Status by Invoice Number.

Payment Status	Invoice Number (Count of Invoices)							
	1	2	3	4	5	6	7	8
On-time	217,217	200,200	196,196	127,127	44	11	-	-
Late	1,414	1,616	55	-	-	-	--	--
Locked	247,247	262,262	277,277	349,349	456	333	25	9

3.3 Safety Signage Events

As mentioned above, the safety software system element of the MRFT application received inputs from the Positioning, Logging, and Main elements to determine if a safety alert should be displayed on the application. The project team identified a total of 98 signage zones, which included 46 school zones (covering 27 different schools), 28 speed zones (areas of reduced speed), 17 curve warning zones, and 7 zones within a 10-mile construction area. Participants received these visual safety alerts on the screen of their smartphone upon entering a safety zone, resulting in a "signage event." The safety signage functionality was a key component of the MRFT pilot study and is further explained in *Volume III*, which reports participant reactions to and perceptions of signage events, and *Volume V*, which further explains the signage functionality and investigates behavior change in response to the alerts. A summary of the signage events and participant exposure by zone type that occurred during the test period of the field test is provided in Table 16 below.

Table 16. Signage Events and Participant Exposure by Zone Type, by Number and Percent of Total Events.

Zone Type	Count of Zone Type (%Total Zones)	Zones with Events (%Total Zones of this Zone Type)	Test Period Events (%Total Events)	Participants (%Total Participants)
School	46 (47%)	45 (98%)	6,800 (2222%)	393 (81%)
Speed	28 (29%)	28 (100%)	17,458 (5858%)	462 (95%)
Right Curve	7 (7%)	7 (100%)	2,983983 (10%)	272 (56%)
Left Curve	10 (10%)	9 (90%)	3,140140 (10%)	305 (63%)
Construction	7 (7%)	1 (14%)	1818 (<1%)	11 (2%)

4 System Assessment

The study team assessed two key factors in analyzing the technical performance of the system: (1) system reliability and (2) system accuracy over the course of the pilot test. The purpose of this section is to provide an understanding of the context under which the findings in other volumes were generated. As an example, if negative reactions are presented from participants, it is important to know whether there were particular technology challenges that the participants faced which may have impacted their perceptions or behavior (versus a general lack of acceptance of MBUF policy, for example). When interpreting field test results and analysis, the study team considered the performance of the system and the challenges/issues presented in this volume.

The primary data sources for technical performance of the system were trip data, log data, MBUF data, records of service requests, and participant survey responses. Institutional and participant interview results provided additional insight.

4.1 System Reliability

As mentioned above, the smartphone and its supporting software and hardware serve as the in-vehicle subsystem designed to collect all the necessary data for the field test. The in-vehicle subsystem's ability to reliably collect and transmit that data to the infrastructure subsystem is a key component of the system design. Data loss resulting from failure to collect or transmit would directly impact the system's ability to support its three key functions for the field test: (1) MBUF, (2) safety signage, and (3) data collection to support travel time estimates. This section primarily focuses on the system's reliability in supporting the MBUF functionality required.

4.1.1 System Performance for Data Collection

As was explained in Section 2.1.2 of this volume, the in-vehicle subsystem included software and hardware that supported the MRFT application. The software contained multiple system elements that were interconnected and relied on each other for data to perform their functions. For example, the Signage software element received inputs from the Positioning, Logging, and Main software elements to determine if the smartphone was in a signage zone, and then displayed the appropriate sign if the defined criteria were met. Nearly all of the software elements including MBUF Collection, Signage, and Probe Data Collection depended on the Positioning and Logging software elements, which ultimately produced the trip and log data collected during the field test. If the position and logging information could not be captured in the trip and log data, the MBUF, safety signage, and data collection to support travel time estimates functionality likely did not perform properly either. Therefore, the trip and log data availability are a valid source for understanding system reliability.

As mentioned before, both trip and log data contain the TripId field. Therefore, identifying all TripIds recorded by the system, and determining whether trip and log data were available for each trip, provides insight into system reliability. Table 17 below shows the availability of trip and log data for all TripIds recorded by the system. Log data was available for nearly all TripIds (over 99 percent) while trip data was only available for 57 percent. This significant percentage of TripIds without trip data can mostly be attributed to instances where trips were started but the smartphone never received a good GPS signal. Any case of lost trip data would directly impact the calculation of MBUF data (i.e., miles driven and fee assessed) as well as data collection to support travel time estimates functionality, which would lower the expected number of drivers whose position data would be feeding such a system.

Table 17. Trip and Log Data Availability for All Trips during Field Test.

Data Available?	Log Data		Trip Data	
	Count of Trips	Percent of Total Trips	Count of Trips	Percent of Total Trips
No	923	0.19%	213,029	43.19%
Yes	492,331	99.81%	280,225	56.81%

As mentioned, the MRFT system relied on the in-vehicle subsystem to collect and transmit the necessary data to support the three primary functions of the application. Proper operation of the smartphone itself and other hardware associated with the in-vehicle subsystem was essential to reliably collecting MBUF fees, properly displaying in-vehicle safety alerts, and collecting data for travel time estimates. Because log data was available for nearly all trips, the study team analyzed log messages related to hardware issues to understand what percentage of trips captured by the system were impacted by these issues. One specific issue related to the in-vehicle subsystem hardware was the smartphone failing to connect to the VIDM (i.e., recognizing that the smartphone is in the correct vehicle. When this hardware failure occurred, participant trips and miles could not be captured by the MRFT application. A vehicle detection failure occurred in 35 percent of TripIds as shown in Table 18 below. This issue is discussed further below and in Section 4.1.2 in the context of service requests from participants.

Table 18. Occurrence of Hardware Issues for All Trips during Field Test.

Error Occurred?	Vehicle Detection Failure (VIDM fails to connect to smartphone)	
	Count of Trips	Percent of Total Trips
No	319,322	64.74%
Yes	173,932	35.26%

The MBUF approach selected for the Minnesota Road Fee Test elected to leverage the GPS capabilities of a widely available COTS smartphone by designing an application that could use position information from the GPS (location and time) to capture miles driven and categorize them based on various location and time criteria. Consequently, the MBUF functionality of the MRFT application relied heavily on availability of GPS data in the smartphone. The safety signage and data collection to support travel time estimates functions also relied on GPS data to determine a participant's location at any point in time during a trip. Therefore, a key measure of the system's reliability is the availability of GPS data during participant trips. The trip data and log data collected throughout the field test captured position information from the GPS on the smartphone.

The log data recorded status and error messages related to GPS availability. Three log messages in particular (listed in Table 19 below) were related to GPS availability. Forty-four percent of total log messages across all trips reported that the current fee (or MBUF rate) was unknown due to GPS error, lack of sufficient GPS accuracy, or a lost GPS signal. However, there was not an opposing log message that identified a "good" GPS signal, which may have allowed for a quantitative comparison. Because log data was only captured on an event basis, no data was captured if there was not a message to record, and log data was not necessarily evenly captured across all trips. Therefore, the GPS-related log messages simply provide examples where system diagnostics identified GPS availability issues.

Table 19. GPS-related Log Messages (Percent of Total Log Messages).

Log Message	Percent of Total Log Messages
"Current Fee is Unknown because GPS accuracy > [Int-GPSError] meters"	43.29%
"GPS Signal Lost"	0.65%
"Current Fee is Unknown because GPS accuracy > [Int-Dist] meters"	0.18%

As mentioned previously, trip data was only available for 57 percent of trips generated by the system. Of the 43 percent of trips where trip data was not available, 69 percent of the trip data loss was due to a vehicle detection failure. Trip data was only recorded if the system could both detect the device was in the correct vehicle and a valid GPS signal was found. Therefore, the remaining 31 percent of the trip data loss can likely be attributed to poor GPS signal during trips. Although the log messages associated with GPS availability cannot be extrapolated to measure the number of trips or miles impacted, the loss of trip data resulting from vehicle detection failures or lack of GPS signal during trips clearly identifies GPS availability as a significant system issue. The deployment team's report provides additional insight into the accuracy of the system as it relates to GPS connectivity and accuracy. Intermittent GPS signal was reported as a contributing factor to lower device miles compared to odometer miles collected.[4]

4.1.2 Participant-Reported Issues

The team identified system issues in a number of ways over the course of the field test. Participants reported many issues via service requests to the deployment team or on surveys, in focus groups, and during interviews with the study team. The deployment team identified other issues or problems during system testing or through analysis of the log data. The sections below report the issues encountered by participants related to system reliability. Participants were encouraged to contact the deployment team and study team during their involvement to ask questions, identify any problems or issues with the system, or provide feedback on the performance of the system. Feedback was provided primarily to the deployment team through service requests and to the study team through participant surveys. It should be noted that in some cases participants reported an issue with the device when in fact the problem was actually user error in some cases. For example, the deployment team found at times that participants accidentally turned off the data network, rendering the GPS inoperable, or that they had not ensured that their phone was charged prior to beginning a trip.

The deployment team provided an analysis of the service requests received and processed throughout the field test in their final report.[5] Table 20 below is a list of the service request (SR) categories that represent more than 2 percent of the total service requests that were not related to scheduling odometer reading appointments or other tasks necessitated by the field test.

Table 20. Number of Service Requests by Type.

Category Description	Quantity	Percent Total
General Smartphone use and operation	228	17.6%
Password reset or account verification	151	11.6%
1. Android data service auto turn-off	112	8.6%
2. Payment clarification	74	5.7%
3. Swapped device on request	53	4.1%
4. MBUF assessment questions	51	3.9%
5. Participant equipment requests	39	3.0

[4] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.
[5] Ibid.

Category Description	Quantity	Percent Total
6. Damaged car charger or power outlet	32	2.5%
7. Smartphone battery replacement	32	2.5%
8. IMEI Not Found error	30	2.3%
9. Unrecoverable data at ORs or as reported	30	2.3%
10. No or poor GPS signal	29	2.2%

Of the 12 service request categories, 7 of them relate to possible system reliability issues; these are highlighted in blue in the table above. To further understand actual issues associated with each service request category, reviewing the individual service requests related to these issues provides greater insight into what the participants were actually experiencing.

General Smartphone Use and Operation – ***"Device not Working"***

The majority of these requests involved the device freezing and shutting down at random or being unable to pick up GPS for the MRFT application, thus ultimately not recording trips properly.

General Smartphone Use and Operation – ***"Error Message"***

Many participants reported experiencing an error message. Some examples of error messages that were more commonly seen included:

- "Cellular Data Not Found: Cellular Network Has Been Disabled"
- "Sorry for the inconvenience, but the application needs to close"
- "Downloading – Do Not Turn Off Target"
- "Cell packet information is not correct"
- "Exception During Start"

General Smartphone Use and Operation – ***Trips not Recording Properly***

Participants reported issues with their trips not recording properly; these included errors when trying to send trips, TripId mileage that did not match up with actual mileage, etc.

Additional examples of service request categories related to system reliability include "MRFT issue" and "GPS issue." These issues have a direct impact on the system's ability to support its three primary functions as the data presented in the previous section suggested.

MBUF Assessment Questions and Unrecoverable Data at ORs or as Reported – ***"MRFT Issues"***

Several participants reported MRFT issues. Participants who had problems sending MRFT data reported receiving messages such as the following:

- "Current Fee: Unk"
- "Force MRFT Data Failed"

- "MRFT not able to connect – option to force close or wait"
- "MRFT data upload failed"
- "Exceeded available time"

No or Poor GPS Signal – "*GPS Issues*"

2.2 percent of service requests involved GPS issues, with the most frequent GPS issue being that the device did not have a GPS signal. Some participants experienced the error message "No GPS found, install GPS now?" indicating that the device was not recognizing their GPS. One participant reported: "I'm noticing when my car is idling that the GPS unit will stop the trip and send in a TripId. When I accelerate again, the trip is restarted."

As a result of service requests, 53 participants ended up getting a new device to solve the various issues encountered with their original device.

Many of the same issues reported in the service requests were also shared by participants in their survey responses. On the last survey completed by participants during the field test, a list of known issues was provided and participants were asked to indicate if they had experienced issues related to the items on the list. Table 21 below provides the percentage of participants who reported experiencing each issue on Survey 3. Again, several were related to system reliability (highlighted blue in the table below). Forty-four percent of participants reported perceptions that they had difficulty "obtaining a good GPS signal," again, a vital need to reliably collect MBUF fees, properly display in-vehicle safety alerts, and collect data for travel time estimates.

Table 21. Percentage of Total Participants by Survey 3 Issue Type.

Survey 3 Issue Type	Percent Total Participants (n=500)
Device powering down unexpectedly	54%
Screen goes blank unexpectedly during a trip	52%
Obtaining a good GPS signal	44%
Powering on the device in the vehicle	44%
Starting a trip (e.g., device froze at 14%)	36%
New trip starting unexpectedly	36%
Device is not recognized in the vehicle (i.e., "IMEI is not found")	29%
Data network accidentally turning off	28%
TripId Auto-Send feature is not working properly	18%
Not all trips are shown on the participant portal	18%
Receiving some other error message	16%
Logging onto www.mnroadfeetest.com	10%
Logging onto www.mymnpoints.com	9%
Other	8%
Receiving a request to set up a Google account	8%
Flight mode accidentally turning on	5%
Download mode accidentally turning on	4%

Similar to the hardware reliability data presented in the previous section, many issues reported in service requests as well as on the survey were related to the reliability of the smartphone itself and other hardware associated with the in-vehicle subsystem. Specifically, participants had issues keeping the smartphone powered and received various error messages related to the smartphone failing to connect to the VIDM or not being recognized as a registered device (i.e., "IMEI not found"). The service requests offer additional insight on these issues.

Smartphone Battery Replacement and General Smartphone Use and Operation – *"Power Issues"*

Many service requests involved power issues. The majority of power issues were one of the following:

- The device will not charge;
- The device will charge, but does not hold the charge very long;
- The device shuts down even when fully charged;
- The device shows nothing but a black screen with green battery light; and
- The device loses charge quickly.

General Smartphone Use and Operation & IMEI Not Found Error – *"Communication Issues "*

IMEI – 30 service requests (2.3 percent) involved IMEI issues. (See "device not registered").

VIDM – Service requests also involved VDIM issues. These occurred either because the VDIM was not installed, or because the VDIM was removed due to getting a new set of keys, car was taken to the shop, VDIM would not stay in, etc.

No Connection – Other service requests involved reports of "no connection." One participant indicated that the power cord was not connecting to the device. All other participants indicated that the device was saying it was not connected to the right vehicle, or that the vehicle was not registered.

These reports are clear examples of reliability issues where the system failed and did not give the participant the opportunity to use the technology to capture a trip and the corresponding MBUF miles. Instead, the miles were accumulated on the odometer and assessed as "non-technology" miles at the higher rate. In an "opt-in" or "opt-out" framework where drivers can benefit from using the technology to pay a lower rate, drivers would be forced by the technology failure to "opt-out" and pay the higher rate.

4.2 System Accuracy

Whether designed to supplement or replace existing revenue streams, an MBUF system that seeks to charge drivers by the mile must be able to capture miles driven as accurately as possible to ensure that drivers are charged correctly. Failure to accurately capture miles and charge the correct fees could have undesirable outcomes such as overpayment for drivers or revenue shortfall for collecting agencies. As with system reliability, this section primarily focuses on the system accuracy as it relates to the MBUF functionality.

4.2.1 System Performance in Data Collection

The MBUF functionality of the MRFT system is most reliant on its ability to capture miles accurately. Analyzing the characteristics of trips recorded during the field test by such metrics as trip duration (in time), trip length (in miles), and average speed provides insight into the system's accuracy. A total of 472,735 trip records were captured over the course of the study (September 12, 2011 to October 25, 2012) from participants only (i.e., trip records associated with VIP and system accounts were removed).). However, upon further analysis of the metrics identified, only 227,137 trips (48 percent) captured by the system were considered "valid" trips. The other 245,598 trips were ruled out for failing to meet one or more of the criteria listed in In addition to the various issues presented previously, the table below identifies another important system accuracy issue realized during the field test. The large number of trips less than 0.1 miles in distance (254,437) presented in the table above suggests a number of trips were started and stopped very quickly. This is likely the result of the test approach to use the vehicle ignition to determine the start/stop of a trip. As mentioned previously in the report, the smartphone was connected to a power cord which was plugged into the vehicle's power port. The large number of short distance trip is likely due to the unstable nature of the voltage coming from the vehicle's power port. More detail on this issue is available in the deployment team's report.

While algorithms could be implemented to remove invalid data, 52 percent is a significant number of total trips with unrealistic or questionable characteristics, which is reason to question the system's ability to capture miles accurately for an MBUF program.

Table 22 below. The vast majority of "invalid" trips were either too short in distance (less than 0.1 mi), too slow in average speed (less than 0.1 mph), or both. The remaining invalid records were less than 30 seconds in duration, or represented a trivially slow distance or implausibly high average speed or a trivially short distance or implausibly far distance traveled.

In addition to the various issues presented previously, the table below identifies another important system accuracy issue realized during the field test. The large number of trips less than 0.1 miles in distance (254,437) presented in the table above suggests a number of trips were started and stopped very quickly. This is likely the result of the test approach to use the vehicle ignition to determine the start/stop of a trip. As mentioned previously in the report, the smartphone was connected to a power cord which was plugged into the vehicle's power port. The large number of short distance trip is likely due to the unstable nature of the voltage

coming from the vehicle's power port. More detail on this issue is available in the deployment team's report.[6]

While algorithms could be implemented to remove invalid data, 52 percent is a significant number of total trips with unrealistic or questionable characteristics, which is reason to question the system's ability to capture miles accurately for an MBUF program.

Table 22. Criteria Used to Determine "Invalid" Trips.

Criteria	Threshold Value	Count of Trip Records Failing
Minimum Trip Duration	0.5 min	44,214
Maximum Trip Duration	1,440 min (24 hours)	33,107
Minimum Trip Distance	0.1 mi	254,437
Maximum Trip Distance	3,000 mi	0
Minimum Average Speed	0.1 mph	222,444
Maximum Average Speed	100 mph	22

Based on the issues reported by participants related to system reliability (especially those related to GPS accuracy), another metric to consider regarding system accuracy is the percentage of miles captured by the MRFT application (device miles) compared to the number of miles recorded on participants' odometers during the baseline and test periods, or percent usage. On average, 82 percent of total miles driven during the baseline period and 77 percent of miles driven during the test period were captured by the MRFT application. The missing miles can either be attributed to participants electing not to use the technology, forgetting to bring the smartphone in the car, or failure of the technology to capture the miles. The distribution of the change in participants' percent usage between the baseline and the test periods follows the relatively normal distribution as seen in Figure 28 below.

[6] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.

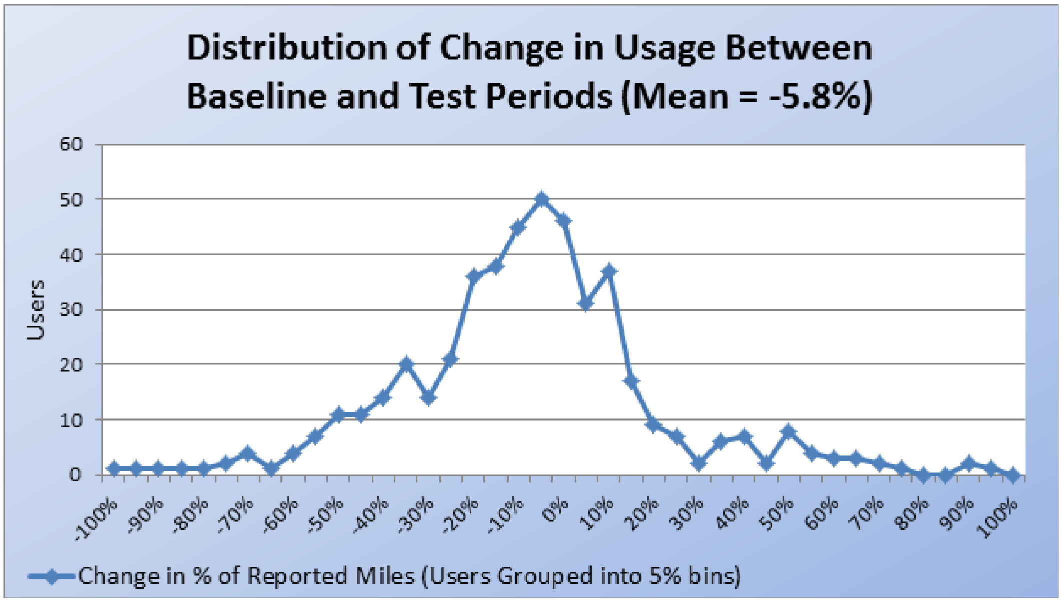


Figure 28. Distribution of the Change in Participants' Percent Usage.

As mentioned in Section 3.2.1, 9.8 percent of participants experienced a percent usage above 100 percent either in the baseline or test period. Issues around percent usage and more device miles being captured than odometer miles are related to system accuracy. One participant experienced 157 percent usage, where the MRFT application recorded 1,709 more miles than the odometer on the vehicle. It is known that odometer accuracy can range by as much as 10 percent when modifications are made to a vehicle (e.g., larger tires or wheels). However, such a substantial difference in device miles and odometer miles can only be attributed to system inaccuracy or error. Although more than 90 percent of participants' percent usage value did not exceed 100 percent, the possibility of that level of inaccuracy or error begs the question of whether a participant with a more average percent usage, such as 80 percent, truly used the smartphone 80 percent of the time, or whether the participant's usage could have been lower with the system falsely capturing an additional 40 percent in device miles.

Participant survey responses also provide some insight into the issue. On the second and third survey completed by participants, they were asked to self-report their perception of what percentage of the time they believe they brought the smartphone with them and powered it on with the purpose of capturing their miles driven. The reported percent usage (survey 3) and calculated percent usage (OR3) is plotted on Figure 29 below for all participants. Each participant is represented by both a reported and calculated data point where available along the horizontal axis. Certainly participants may have intended to use the device more than they actually did and they may have felt a need to report higher usage than what they actually did, but the graph shows that perceived percent usage varied greatly from calculated percent usage in many cases. Just as a number of participants experienced percent usage values above 100 percent, a number of participants experienced a percent usage value of less than 20 percent when their perceived usage was 80 percent or greater.

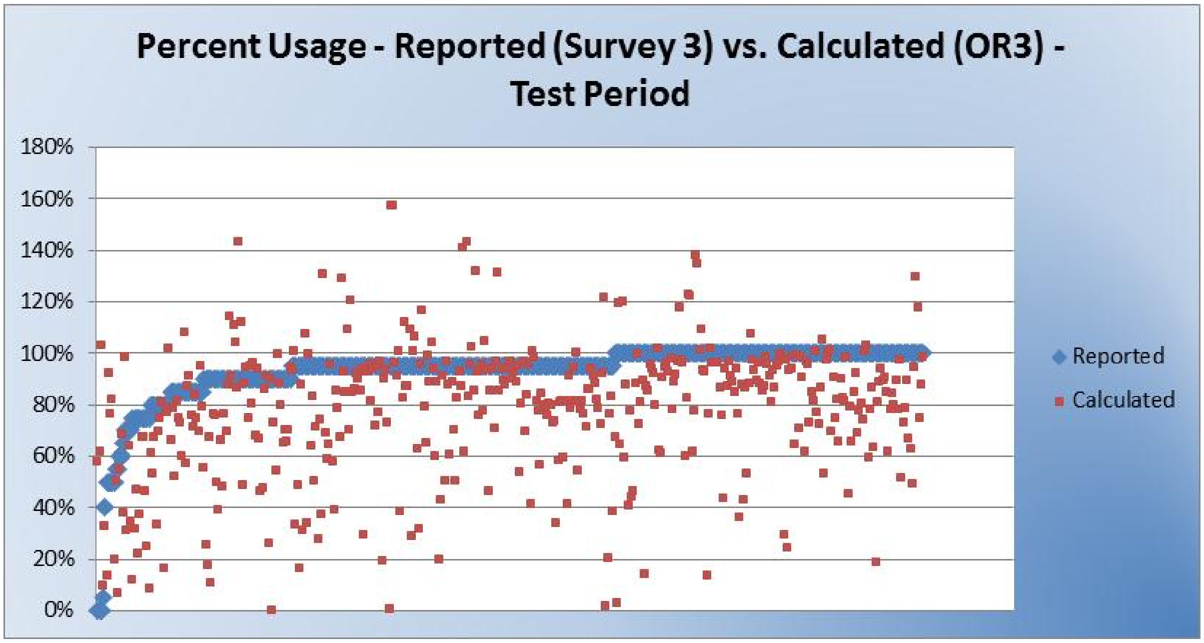


Figure 29. Percent Usage – Reported (Survey 3) vs. Calculated (OR3) – Test Period.

Regarding system accuracy, the deployment team's report includes a detailed assessment of the issue related to the difference in device miles and odometer miles collected. The report points to "instability within the Android Smartphone platform when used in combination with on-board vehicle power to cue Smartphone application behavior (i.e. trip starts and stops)" as the cause for instances where device miles exceeded odometer miles and acknowledges that the impact may have also influenced participant mileage where devices miles were equal to or less than odometer miles.[7] In summary, trips were identified where MBUF miles were double counted due to instances where multiple trips were running and accruing miles on a device at the same time. The deployment team reported that mileage for 40 percent of participants was impacted by this phenomenon.

4.2.2 Participant-Reported Issues

Section 4.2.1 introduces the issues reported by participants via service requests and survey responses. Most of the issues presented in that section would also have an impact on system accuracy, specifically in the case of GPS accuracy. Another issue directly related to system accuracy reported by participants was "trips not recording properly." Upon reviewing their

[7] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.

trips on the participant portal, several participants reported that a trip did not appear to be captured correctly.

> ***Trips Not Recording Properly***
>
> Service requests included reports of issues with their trips not recording properly; these included errors when trying to send trips and a mismatch between the displayed trip and the trip the participant actually took.

Similarly, from the survey responses, 18 percent of participants indicated they had experienced the issue, "Not all trips are shown on the participant portal." Participant reports from service requests and surveys related to trips not being captured properly suggest there is an issue with system accuracy.

5 Conclusions

The Minnesota Road Fee Test system was designed to serve three key functions during the field test: (1) assess mileage-based user fees MBUF, (2) display in-vehicle safety alerts at predetermined locations, and (3) collect data for travel time estimates. The system supported these functions by using the GPS capabilities of a widely available, COTS smartphone to collect and transmit four primary types of data: trip data, log data, TripId data, and MBUF data. A look at the system design showed how the data was collected by the MRFT application on the smartphone and how the data was then used to support the three key functions of the field test. Analysis of the data types available provided insight into the amount and type of information generated by a program designed to assess mileage-based user fees and offer safety and mobility functionality and insight into the reliability and accuracy of such a system. Key findings and conclusions regarding the overview of the data and the technical performance of the MRFT system are presented below.

5.1 Ability to Provide Key System Functions

Summary statistics of the data collected by the system were provided in this volume. As the study team did not perform independent validation and verification on the system, specific metrics on the system's ability to correctly capture miles, assess fees, or generate safety alerts are not reported. However, the summary statistics provide insight into the fact that the system did demonstrate the ability to support its intended key functions: (1) MBUF, (2) in-vehicle safety signage alerts, and (3) data collection for travel time estimates. Findings and relevant conclusions are listed below organized by the three primary functions of the system.

5.1.1 Assess Mileage-Based User Fees

The MBUF functionality of the system successfully demonstrated the ability to collect trips from participants while protecting privacy, and was used by participants during the field test. A total of nearly 500,000 unique trips were collected by the MRFT system, 83 percent of which were shared by participants with the deployment and study teams. In terms of usage, the MBUF system successfully demonstrated the ability to separate miles into fee categories based on location, type of roadway, day of week, and time of day, and to properly assess the corresponding MBUF fee. The data collected showed that the system was used by participants during the test to capture miles for fee assessment; 77 percent of total odometer miles driven by participants were captured by the MRFT application. Lastly, the system did also demonstrate the ability to generate monthly invoices for the miles driven in the various fee categories.

5.1.2 Provide In-Vehicle Safety Signage Alerts

The MRFT system demonstrated the ability to incorporate safety features into an application designed to assess mileage-based user fees. Ninety-one of the 98 signage zones included in the field test were traversed by at least one participant during the test period, resulting in over 25,000 instances during the test period where a participant received an in-vehicle safety alert.

5.1.3 Provide Data Required for Travel Times Estimates

The system successfully demonstrated the ability of the MRFT application and smartphone to serve as a means to collect data that can be used to generate travel times on major corridors. Over 660 million trip data points were collected over the course of the field study.

5.2 System Reliability and Accuracy

A detailed look at the data generated by the system along with participant reports shows recurring reliability and accuracy issues with the system. A summary of the findings follows.

5.2.1 System Reliability

The system experienced a number of challenges related to system reliability including:

- **Data loss or failed data collection –** The lower than expected availability of trip data (only 57 percent for all TripIds) suggests that the system may not have been reliably supporting the 3 key functions desired for the field test. The loss of or failure to collect trip data impacts the calculation of MBUF data (i.e., miles driven and fee assessed) as well as data collection to support travel time estimates functionality, which would lower the expected number of drivers whose position data would be feeding such a system.

- **Smartphone and hardware/software issues –** Hardware issues hindered the system's ability to reliably capture trips. Vehicle detection failures occurred for 35 percent of total trips and were the primary cause of trip data not being collected during trips (i.e., the vehicle had to be recognized in order for trip data collection to begin). With these hardware failures, the MRFT application could not properly capture participant trips and miles. Additionally, survey responses indicated 8 percent of participants reported vehicle detection and device registration issues. Service requests resulted in reports of "device not working" or that participants received an "error message." While in some cases, reported issues were likely the result of user error, the specificity of many of the participant reports with regard to error messages, the device freezing up or shutting down unexpectedly, and GPS issues suggest that the reliability of both the smartphone itself and the overall system was an issue. Additionally, 53 participants had to be provided replacement smartphones due to issues experienced with their original phone.
- **GPS issues –** The three key functions of the MRFT application relied heavily on availability of GPS data in the smartphone. Therefore, a key measure of the system's reliability is the availability of GPS data during participant trips. A GPS signal had to be available in order for trip data to be collected on the device. Second only to vehicle detection failures, poor GPS signal was the contributing factor in 31 percent of trips where no trip data was collected. Log messages supporting system diagnostics reported instances where the current fee (or MBUF rate) was unknown due to GPS error, a lack of sufficient GPS accuracy, or a lost GPS signal. The combination of these factors identifies GPS availability as a significant system issue. Providing further insight, survey responses indicated that 44 percent of participants believed to have had experienced issues with GPS signal.

5.2.2 System Accuracy

The system experienced a number of challenges related to system accuracy including:

- **Use of power-port (voltage) for trip start/stop is not reliable –** Fifty-two percent of total trips collected by the system were deemed "invalid" upon further analysis. Invalid trip records were removed for reasons ranging from the trip being too short in duration (less than 1 minute) to the trip being implausibly long in duration (over 24 hours), to the trip being too short (less than 0.1 miles), to the average speed being too high (over 100 mph). While algorithms could be implemented to remove invalid trips, such a significant percentage of total trips falling into these categories is reason to question the system's ability to accurately capture miles for an MBUF program.
- **Approach to starting/stopping trips caused inaccuracy** – Over 50 percent of total trips were deemed invalid because they were less than 0.1 miles in distance. The large number of short distance trips is likely due to the unstable nature of the voltage coming

from the vehicle's power port and suggests that the power port is not a reliable source for indicating the start and stop of trips.

- **Excess miles captured by system –** Nearly 10 percent of participants experienced a percent usage above 100 percent indicating that the system captured more miles than the vehicle odometer. While odometer accuracy can vary upwards of 10 percent, a large ratio of device miles to odometer miles, such as a value of 157 percent that was experienced by one participant, can only be attributed system inaccuracy. Multiple occurrences of inaccuracy suggest that there was a system error or issue that greatly impacted the system's ability to properly record miles traveled. Upon further analysis from the deployment team, trips were identified where MBUF miles were double counted due to instances where multiple trips were running and accruing miles on a device at the same time. 40 percent of participants were impacted by this phenomenon, greatly impacting the accuracy of the miles capture during the test.

5.3 Summary

The system designed for the pilot test was only intended to be used for a test, and therefore the robust testing and development that would occur in a real-world deployment were not conducted. While participant reports and indicators in the data did point to system reliability and accuracy issues, the system did demonstrate the ability to support its intended key functions in some capacity for all participants and in full capacity for a number of participants, allowing the study team to capture driver perceptions of a simulated real-world MBUF program.

Volume III: Driver Acceptance Assessment

1 Assessing Driver Acceptance

Failure to attain acceptance by Minnesota's citizens has the potential to be a central barrier to any new revenue concept. This acceptance can be influenced by the purpose of the concept (Why is the State collecting this revenue?) and by the specific of the revenue program (How much do I pay? How do I pay?). In the case of the MRFT, Minnesota was testing a very specific program requiring participants to have a high level of interaction with the State. As specified in Volume I, participants had to attend three in-person appointments, use a smartphone for all trips made over a period of 6 months, and pay monthly invoices. Further, because this was a pilot test, they faced additional requirements related to the research itself, such as completing surveys and interviews. All of these behaviors occurred in the context of participants' pre-existing attitudes toward taxes and fees, technology, and driving.

Any of these elements has the potential to affect acceptance of an MBUF program. It was the job of the study team to identify these elements and select a set of methods to assess participants' opinions related to the MRFT and perceptions of their own behavior, driving, and use of the smartphone. The team accomplished this through a variety of subjective data collection techniques described in greater detail in Volume I. These data sources include the recruitment screening tool, surveys, individual interviews, focus group meetings, journals, service requests, and other anecdotal observations by the study team. The analysis approach for each is described in the following sections.

1.1 Analysis of Survey Data

The largest and most comprehensive set of data is the set of **three surveys** assessing Baseline, Novice, and Experienced participant attitudes. Each driver also completed a screening questionnaire at the time of recruitment, and some of those responses are considered among the survey data. A total of 1,411 surveys were completed during the test with 484 participants completing the first survey, 473 completing the second, and 454 completing the third, a decrease the study team associated with participant attrition throughout the test period. Participants also were not required to respond to every question, and for this reason the sample size for individual questions may vary.

Responses usually took the form of a response on a Likert scale (e.g., Agree, Somewhat Agree, Somewhat Disagree, Disagree). Generally, participants were not given a "neutral" response option as it was the perspective of the study team that a neutral response was not easily interpretable in the context of the MRFT items. Instead, participants could respond "Not Sure" if they did not feel they had enough information to form an opinion or if they had not yet formed an opinion. Thus, in some cases, the survey findings will present responses of Not Sure separately from those participants who chose to express an opinion on a Likert scale. Both parametric and non-parametric statistical methods were used to address specific hypotheses about differences in responses over time (Baseline, Novice, Experienced surveys), among test waves (A, B, C), or across different demographic variables (e.g., age).

Many survey items required a "free response" text entry from participants. To facilitate analysis of text responses, the study team categorized each response with respect to topics of interest for each item. When appropriate, the number of responses was analyzed using the methods described above. In other cases, the contents of particularly relevant or interesting responses are described for discussion purposes.

1.2 Analysis of Interview and Focus Group Meeting Data

The study team held a variety of conversations with participants in the form of interviews and focus group meetings**.** The opportunity to participate in **individual interviews** was offered to all test participants, and 425 test participants completed an interview. These interviews allowed participants the chance to speak freely about their overall attitudes toward MBUF and the test. It also allowed the study team an opportunity to follow up on unique driver behavior observed during the test. Written notes were reviewed for content and are incorporated into the analysis where they provide some explanation of participants' behavior or survey responses.

A subset of test participants also had the opportunity to participate in a **focus group meeting.** A total of 63 participants completed this activity across 6 focus group meetings. Each focus group was structured around a particular discussion protocol containing questions of interest to the study team, and each meeting was conducted by a trained facilitator. This technique enabled the study team to observe focused discussions on specific issues among a smaller sample of participants. Detailed notes were taken for each meeting, and these were reviewed for content and are incorporated into the analysis where appropriate.

1.3 Analysis of Service Request and Journal Data

Finally, the study team examined detailed records of participants' day-to-day experience. Entries in driving **journals** were examined by the study team to assess their content. There was a great deal of variability in the degree to which participants made entries, with some participants making no entries and others making more irregular entries on various topics. The study team examined the 318 journals returned by the participants for content that might have implications for data analysis, such a technical problem with the device, or that might offer insight into a participant's attitudes "in the moment" as he or she used the smartphone.

Further, the study team also examined all 2,280 **service requests** collected by the deployment team. The study team categorized these into areas of interest (e.g., device issues, invoice issues) and assessed the frequency with which certain topics occurred as well as how the requests were resolved in order to create a fuller description of participants' test experience and provide context for the attitudes expressed through the survey data.

1.4 Presentation of Findings Related to Driver Acceptance

The following chapters present findings that integrate these various data sources to describe elements of driver acceptance observed in this test. Chapter 2 describes the participating driver demographics, driving experience, and experience with common technologies. These characteristics may influence some opinions and subjective data and will be included in relevant analyses. Chapter 3 assesses the participants' experience as it specifically relates to the administration of the test and interaction with the deployment team. Chapter 4 contains an overview of participant opinions and perceptions of the MBUF system, including the device, the participant portal, and the invoices. Chapter 5 described the safety signage application for the MBUF application as well as the participants' perceptions of this value-added feature. Chapter 6 discussed the main component of the test, the participants' perception of mileage fees. Finally, Chapter 7 provides an overall conclusion to this volume of participant perceptions, weaving in overarching thoughts and participant commentary or opinions to program administration and operations.

2 Driver Characteristics

Driver characteristics are those pre-existing factors such as age or driving patterns that might be related to driver attitudes toward MBUF and the smartphone and software application used in the test. In order to understand these factors, the study team examined the answers provided during participant recruitment screening and on the test surveys. The findings are reported in the following sections.

2.1 Participant Demographics

The sample of drivers who participated in the MRFT are described by demographics of gender, age, and income.

Forty-six percent of participants were men and 54 percent were women. The average age of drivers was 52 years of age (SD=8), and there was no significant difference in age between men and women ($p=0.43$). The average age at which participants first received a driver's license was 17 years of age (SD=4). Years of driving experience since receiving a license was strongly related to age ($r = 0.999$, $n=483$, $p<0.05$); older drivers had more driving experience. Thus, any relationships between age and opinions might be a result of older drivers having more driving experience.

There are several ways in which these demographics might affect participants' opinions in this test. Gender and age affects have been observed in relation to technology acceptance and usage.[1][2] For instance, in a workplace study, men's technology usage decisions were strongly influenced by their perceptions of usefulness. In contrast, women were more strongly influenced by perceptions of ease of use and social pressure, although the effect of social pressure diminished over time. When considering how age plays a role in technology usage, younger workers' technology usage decisions were more influenced by attitudes toward the technology and the costs and benefits of using it. Older workers were more influenced by social pressure and perceptions of control or difficulty in using the technology. Possible confounds were removed from these findings, including income, occupation, education levels, and prior experience with computers in general. The study team has also hypothesized that older drivers, who are more experienced drivers, are likely to believe they have an understanding of the motor fuel tax system and may express more entrenched opinions related to the present fuel tax (or be more resistant to MBUF). Thus, the present analysis will investigate whether participants differ on some opinions based on age or gender.

Additionally, because this study investigates issues related to personal finance (e.g., paying taxes and fees), the study team desired to understand how a driver's income level might influence their thinking on MBUF. As discussed in Volume I, recruitment for this complex pilot test was challenged in the area of recruiting lower income drivers. Table 23 summarizes the income brackets to which participants reported they belonged during recruitment. Because the overall number of participants in the lowest income group (less than $35,000) was 30, it will be difficult to detect a statistical effects related to income.

Table 23. Number (n) and Percentage (%) of Participants in Each Income Bracket.

Yearly Income	n (%)
Less than $35,000	30 (6%)
$35,000 - $49,999	70 (14%)
$50,000 - $74,999	168 (33%)
Greater than $75,000	237 (47%)

The most common income bracket of test participants was greater than $75,000. It might be expected that higher income drivers are more open-minded with respect to a new revenue mechanism like MBUF. Further, when developing an MBUF it is important that the fee be

[1] Venkatesh, V., & Morris, M. G. "Why Don't Men Ever Stop to Ask for Directions? Gender, Social Influence, and Their Role in Technology Acceptance and Usage Behavior," MIS Quarterly, 24, (2000), 115-139.
[2] Morris, M. G., & Venkatesh, V. "Age Differences in Technology Adoption: Implications for a Changing Work Force," Personnel Psychology, 53, (2000), 115-139.

equitable to all drivers, regardless of income. To this end, the study team studied responses of participants with lower incomes to obtain an understanding of their perceptions of the test. For this reason, lower income drivers will be considered separately in Section 6 – Perceptions Related to Mileage Fees.

2.2 Participant Driving Characteristics

Participants reported their annual mileage driven during recruitment, and this is shown in Table 24.

Table 24. Number (n) and Percentage (%) of Participants in Each Mileage Bracket.

Yearly Annual Mileage	n (%)
4,000 - 7,999	45 (9%)
8,000 – 11,999	113 (23%)
12,000 – 15,999	142 (28%)
16,000 – 19,999	89 (18%)
Greater than 20,000	111 (22%)

Participant driving behavior varied considerably from person to person at Baseline, and this is demonstrated in their commute patterns (i.e., to an office, worksite, or university). Approximately 7 percent of participants indicated that they commute 1 to 2 times per week, 54 percent indicated that they commute 3 to 5 times per week, 15 percent indicated that they commute 6 to 7 times per week, and 24 percent indicated that they do not commute at all. Figure 30 on the following page shows the home and work locations for all participants.

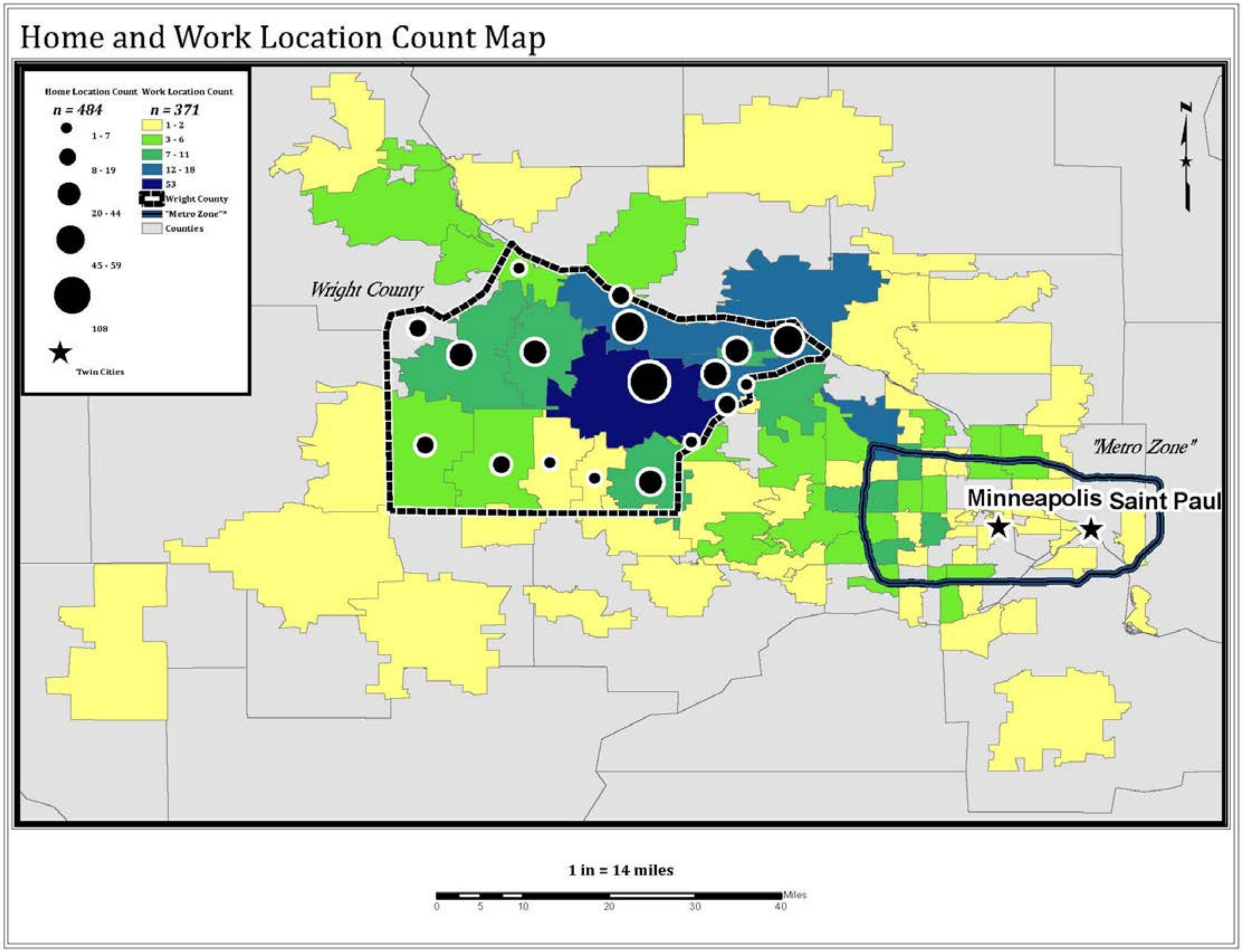


Figure 30. MRFT Participant Home and Work Locations.

All participants were required to be the primary driver of the vehicle they used during the test (defined as being the driver of this vehicle 90 percent of the time that it is driven). The average amount of time participants claimed to drive their vehicle was 92 percent (SD=10 percent). Twenty-three percent of participants responded that they were the driver of the vehicle 100 percent of the time. The remaining 77 percent of participants were given the opportunity to describe the situations in which they are not the driver. The two most common responses were that "occasionally, my spouse drives the primary vehicle without me" (75 percent) and "when we are together in the primary vehicle, my spouse usually drives" (39 percent). Other situations that occurred less commonly were that the participant's child or some other person drove the vehicle.

2.3 Experience with Technology

Because Minnesota selected a technological solution for the MRFT, it is important to assess any individual differences that might exist in participants' experience with different types of technology. In particular, the study team examined previous experience with smartphones and the Android™ Operating System (OS).

The Baseline survey asked participants about the frequency with which they used the following (Never, Less than Once a Month, 1-3 Times a Month, Once a Week, 2-3 Times a Week, or Daily or Almost Daily):

- Desktop or laptop computer,
- Tablet (such as iPad®),
- Mobile phone for calling,
- Mobile phone for texting,
- Mobile phone for Internet, or
- Social media (such as Facebook® or Twitter™).

Figure 31 shows the responses of participants to this question. The results indicate that the majority of the participants used a desktop or laptop computer, mobile phone for calling, and mobile phone for texting daily or almost daily. Tablets were the technology that the largest percentage of respondents indicated they never use, with the second largest being a mobile phone to access the internet. Interestingly, there was a near identical split between the percentage of respondents who never use social media (37 percent), and the percentage of respondents who use social media daily or almost daily (36 percent).

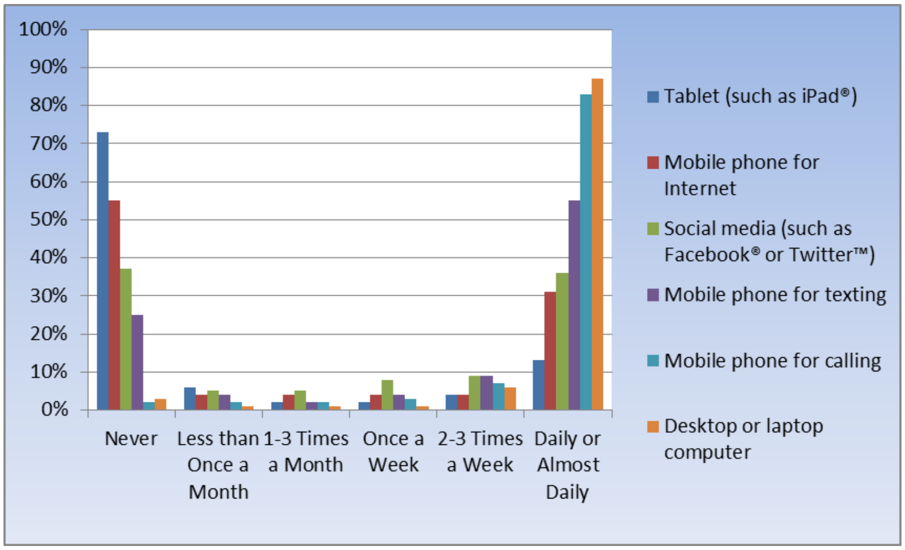


Figure 31. Baseline Participant Technology Experience (N=484).

Using responses to this question, the study team attempted to characterize drivers in terms of how broadly they were using technology at the time they entered the MRFT. The study team reviewed these responses and categorized participants as “high technology usage” (HTU) and “low technology usage” (LTU).

Participants who reported using any of the following once per week or more were considered high technology-usage participants: tablet, mobile phone for texting or internet, or social media. Participants who reported they do not use any of the above items at least once per week were considered “low technology-usage” participants for the purposes of this analysis. The study team anticipated that this categorization might reflect the degree of openness to, comfort with, or merely preferences relative to existing technologies, and might be related to perceptions of usability and trust in the MRFT application. Eighty percent of participants (n=385) were identified as high technology-usage participants and 20 percent (n=99) were identified as low-technology-usage participants. Not surprisingly, 15 of the 21 participants who requested that all contact by the study team be made via telephone or by mail rather than via email also fell into the low technology-usage category. The percentage of high technology-usage participants was higher in Wave C (84 percent) as compared to Waves A and B (77 percent in both cases), consistent with the national statistics regarding increases in cell phone and smartphone use as reported in Volume I, Section 3.2.2.[52]

As described above, there is a hypothesized relationship between age and technology. The study team was interested in exploring if participant age was a contributing factor to

[52] Raine, L. “Pew Internet Smartphone Ownership Update: September 2012,” Pew Research Center, Pew Internet & American Life Project Study, September 11, 2012. Available at: http://www.pewinternet.org/Reports/2012/Smartphone-Update-Sept-2012/Findings.aspx

participant level of technology-usage. The study team found the average age of the HTU participant was 48 years (SD=8 years), whereas the average age of the LTU participants was 58 years (SD=5 years). Although these findings show that younger respondents were more likely to use technology more often, the mean age of the two groups were not statistically different at a significance level of 0.05.

Participants were also asked about their mobile phone usage (n=284). Nearly all (98 percent) of the respondents indicated that they had owned a mobile phone prior to their involvement with the MRFT. Further, of the respondents that had owned a mobile phone, 39 percent owned or had previous experience operating a smartphone. Further emphasizing the finding above stating that Wave C had the highest percent of HTU participants, the highest percentage of participants with smartphone experience was in Wave C (52 percent) as compared to 30 percent in both Waves A and B.

Of the 108 participants who had smartphone experience, 49 percent of the respondents indicated that they had previous experience using the Android operating system, followed by iPhone at 37 percent and Blackberry at 24 percent. This translates to 18 percent of all respondents having had prior experience with the Android operating system when they began the test.

This analysis and its resultant categorization of participants will be used to assess whether experience with technologies affected drivers' attitudes toward the smartphone used in this test. Further, these findings are a useful context to view participant perceptions and opinions. More than half of the respondents had indicated that they had no previous experience operating a smartphone. For these participants, there was a learning curve to understand how to operate the smartphone used in the test before they could begin to understand how the MRFT application functioned on the smartphone. Further, these participants with no previous smartphone experience were likely less prone to review settings in the phone to ensure that the application was operating.

3 Test Experience

As discussed in Volume I Section 3, each participant had the opportunity to complete various activities throughout their involvement with the MRFT. This chapter will discuss participant perceptions of the different activities, drawing from survey responses, telephone interviews, participant service requests, and other anecdotal sources. The analysis of the participants' test experience served several purposes. First, it enabled the study team to demonstrate the kind of information participants had when they entered the test. Second, it enabled the assessment of study factors to ensure that the study itself did not interfere with the MBUF aspects of the test. Finally, participants' reactions to the test experience provided insight into how drivers might react to the administrative and operational elements of a wide scale “real-world” deployment.

3.1 Pre-existing Knowledge

The recruitment process was designed so as to obtain the participation of drivers who were representative of drivers who might one day enroll in an MBUF program in the State. Therefore, many drivers came in with little knowledge of the MBUF issue beyond their interactions with the MRFT recruiter, while others had some awareness of it from other sources. Seventy-eight percent of participants (N=379) indicated that they had first heard of the test when they were called by the recruiter while 14 percent had heard of the test through family or friends. The remaining participants indicated that they had first heard of the test through the media (e.g., television news, the radio, or the internet). Not surprisingly, the number of participant who learned about the test from their family and friends increased from the first to the final wave as more participants were involved with the test, with only 11 percent of the participants indicating that they first learned about the test from family and friends in Wave A and 21 percent indicating the same in Wave C, but there was not a statistical difference in the responses from Wave A and Wave C at a significance level of 0.05.

Experienced participants were also asked if they sought out additional information on the fuel tax and/or mileage-based user fees during the course of the test. The majority of the respondents (68 percent, n=484) indicated they had not sought out any additional information. The majority of the individuals that did not seek out additional information responded that they felt comfortable with the MRFT after having a conversation with the recruiter as the recruiter was able to answer all of their questions. Of the respondents that did seek out additional information, 50 percent did so online, and 36 percent had additional discussions to learn more about the MRFT with family and friends. The remaining participants indicated that they learned more about the test from either speaking with MnDOT or other media sources such as television or a newspaper. Many of the participants sought out information to determine if the MRFT was a legitimate study before providing their personal information.

3.2 Welcome Packet and Introductory Materials

Following the completion of the recruitment screener, the recruited participants were each sent a packet of information introducing the purpose of the test, the MRFT websites, the device, and the activities that make up the test. The majority (52 percent) of the participants indicated that they read the welcome packet cover to cover, and most of the rest (46 percent) read parts or skimmed the entire packet.

Participants were asked a number of questions on the first survey regarding their thoughts on the content included in the welcome packet. Their responses to these questions were useful in ensuring that the study team had included enough information, and the correct information, for participants, and very slight revisions were made to the welcome packet material between waves to address for any participant concerns. For example, some Wave A participants had indicated confusion between the two websites (e.g., the deployment team's participant portal, and the study team's myMNpoints website), so Waves B and C received additional guidance explaining the purpose of each website.

The vast majority of the participants found the welcome packet information both complete and useful. Only three participants (less than one percent) responded that they disagree that the welcome packet was useful in explaining the test. The participants' thoughts regarding the additional questions related to the welcome packet were similar. The question with the lowest response was "the Welcome Packet made clear to me the device I would be using in the test," where 8 participants (2 percent) disagreed and 26 (5 percent) somewhat disagreed.

3.3 Participant Activities During Appointments

The first survey included questions about the activities each participant completed during OR1 and allowed the participants to rate the activities using a scale of Very Difficult, Difficult, Neutral, Easy, and Very Easy. Similar to the positive participant responses to the questions regarding the welcome packet, the majority of the participants (greater than 75 percent) felt that the OR1 activities were either easy or very easy to complete. These include:

- *Scheduling the appointment;*
- *Finding the appointment location;*
- *Understanding the user agreements;*
- *Understanding the installation instructions;*
- *Installing the device in my vehicle; and*
- *Having my questions answered.*

As will be discussed in detail in Volume VIII, the deployment team made several changes to their operational procedures during the test to use resources more efficiently and process participants more effectively. Thus, participants in Waves A, B, and C had somewhat different experiences in how they interacted with the deployment team. For this reason, the study team assessed whether participants' perceptions of ease related to appointments was different depending on the wave. There was a significant but small negative change between the first wave and the final wave in response to ease of scheduling the appointment. Using a scale of 1 to 5, the mean response to this question decreased from 4.6 to 4.4 over the course of the test (n_{WaveA}=142, n_{WaveC}=180). A likely explanation for the decrease in average response was that during Wave C, the deployment team had Wave B active when Wave C was beginning the test, and both groups of participants communicated to the deployment team through the same e-mail address and telephone number. While there were two waves active during Wave B's OR1, there was not a significant change in survey responses between Wave A and Wave B participants. The study team hypothesizes that the lack of a significant decrease was due to Wave A being the smallest of the three waves while Wave C was the largest. What this indicates is that drivers might be very sensitive to operational procedures.

While the Baseline survey (#1) focused on an initial odometer reading and an initial experience with the smartphone, the MRFT application was not functional from the perspective of participants. The smartphone was merely being used to collect baseline driving behavior data and enabled the participants to become accustomed to using the device for trips. It was at the second odometer reading that the MRFT application became fully functional, providing MBUF and safety signage features. The study team included seven statements in the Novice survey (#2) that focused on OR2:

- *Scheduling the appointment was easy.*
- *Staff clearly explained the mileage fees pricing table (i.e., rates per mile).*
- *Staff clearly explained how mileage fee rates and fee categories are displayed on the device.*
- *Staff clearly explained where/when the mileage fee rate may change while I am driving.*
- *Staff clearly explained the invoicing process associated with mileage fees.*
- *Staff clearly explained the safety zones feature of the device.*
- *All my questions were answered.*

Participants were asked to react to each statement with one of the following responses: Disagree, Somewhat Disagree, Somewhat Agree, Agree, or Not Sure. The study team found that, similar to participant responses following OR1, nearly all of the participants (greater than 97 percent) either somewhat agreed or agreed with each question. To assess the effect of changing operational procedures, the study team compared responses for the three waves, but did not find any statistically significant differences (all p=0.05).

3.3.1 Learning How to Use the Smartphone

In addition to completing odometer reading appointment requirements (e.g., scheduling an appointment, signing user agreements), participants were also educated about the features of the MRFT application. It was during the first odometer reading when participants first received an in-person introduction to the test, received training on how to use the smartphone, and had the device installed in their vehicle.

In OR1, the deployment team sought to communicate a few basic features of the smartphone and requirements of the participants. The percentage of participants who agreed or somewhat agreed with the following statements are reported here.

- Eighty-three percent of participants reported that they understood “how trips are stored on the (smartphone).”
- Ninety-six percent of participants reported that they understood “how to charge the (smartphone).”
- Ninety-seven percent of participants reported they understood “how to power on and plug in the (smartphone) even for short trips.”

This high percentage of understanding is important as the deployment team stressed to participants the importance of routinely powering on their device regardless of the length of their trip to ensure that driving occurred with the device active in order to capture their trip information. While the participant responses indicated that they generally understood features of their device following their first odometer reading, interviews with the deployment team indicated that it was common that participants actually did not *fully* grasp how to operate the smartphone after OR1. Several times, participants came back the same day or next day to the odometer reading facility for more information on the device. It is not understood whether participants overstated their understanding of the device or if they considered multiple interactions with the deployment team as one interaction for the purpose of this survey.

The participants were also asked to rate the smartphone used in the test compared to other, similar devices they have used in the past on the following three questions: ease of installation, ease of understanding the available features, and user-friendliness. Each participant was to use a five-point scale to respond to the question with one of the following responses: Much Worse, Worse, About the Same, Better, or Much Better. Finally, participants were also given the option to respond “Not Sure” if they felt they did not have enough information. When compared for statistical significance across prior use of technology (i.e., HTU participants versus LTU participants), no significant difference in the responses was found. However, it should be noted that a large percentage of respondents indicated that they were not sure in response to each of the three questions (34, 37, and 36 percent, respectively of the 484 responses). These high percentages of not sure responses indicate that many of the participants had not had experience with similar devices prior to their involvement with the test. Comparing the responses to these three questions across the three waves again found no statistical difference in responses. However, it should be noted that while many participants in all waves had not had experience with similar technology in the past, the percentage of not sure responses for each question decreased greatly from Wave A to Wave C, again indicating that the Wave C participants had more experience with similar technology than Wave A participants.

3.3.2 Learning about the MRFT Application

During OR1, participants received materials with information on the device and its operation, but because the device was in “baseline” mode during the first part of the test and did not display any test information to the driver, there was no discussion about the actual mileage fee. To evaluate participant understanding of OR2, four statements were used to obtain participant perceptions on the materials presented during the odometer reading:

- Materials explaining the pricing table (i.e., mileage fee rates) were easy to understand.
- Materials explaining how mileage fee rates and fee categories are displayed on the device were easy to understand.
- Materials explaining the signage zones feature were easy to understand.
- Materials explaining the user interface of the device were easy to understand.

The majority of participants (greater than 88 percent) agreed or somewhat agreed to each of the questions.

Reviewing participant responses across the three waves did not find any statistically significant differences. This suggests that efficiencies in processes from the deployment team did not affect participants' experience with respect to comprehending training materials. This makes sense, as there were no specific changes in materials provided across the waves.

The study team did hypothesize that the degree to which participants were familiar with various technologies might influence their ease of understanding. When reviewing the statement "materials explaining the user interface of the device were easy to understand," a statistically significant difference was found (p-value=0.04) between the HTU participants and the LTU participants, with the latter less likely to agree (82 percent) with the statements than the former (92 percent).

3.4 Study Attrition

The number of participants who remained in the MRFT and the number that left the test may provide insight into the quality of the test experience. Participant retention in this test consisted of two components: recruitment retention and participant retention. During the recruitment process, more than 650 participants were recruited to ensure that 500 participants would be available to start the test. After a participant was recruited, he or she was sent test information and asked to schedule an odometer reading and complete their scheduled odometer reading. Potential participants were not classified as test participants until they completed their first odometer reading.

The number of participants beginning and completing the test in each Wave is presented in Table 25. Participant reasons for leaving the test varied, but were generally related to one of the following: no longer available to participate, dislike for the test device, or failure to complete test activities (e.g., paying monthly invoices or completing odometer readings).

Table 25. Test Retention.

Wave	Number of Participants That Began the Test	Number of Participants Removed From the Test	Number of Participants That Completed the Test
Wave A	146	9	137 (94%)
Wave B	165	3	162 (98%)
Wave C	189	11	178 (94%)

As shown in Table 25, Wave B obtained the highest percentage of participants that completed the test (98 percent) with Waves A and C each having a 94 percent completion rate. As noted in Volume I, of those who left the test, five did so for reasons unrelated to the study (e.g., one dropped out of the study for health reasons, two were unable to participate due to the fact that the OBD port on their vehicle was not functioning properly, and two had mechanical issues with their vehicles during the study and could no longer participate as a result). Seven participants indicated that they were having too many issues with their smartphone or with scheduling odometer readings and they no longer wished to participate. The remaining nine participants dropped out for unknown reasons. While there does not seem to be any relationship between reasons why participants opted out of the test and their test Wave, it should be noted that participants left the MRFT in both Waves A and C due to issues with their smartphone, but no participant left the test in Wave B due to issues with the smartphone. This finding is surprising, as by Wave C, the smartphones had the most updated software used in the test and the deployment team had more detailed guidance available for troubleshooting any issues.

4 Perceptions of the MBUF Features

As described in Volume I, the MBUF components were the major focus of the participants' attention in the test. These included: the smartphone MBUF interface, the participant portal, and the invoices. While each of the three components had a critical role in the participant's experience, the smartphone had arguably the biggest impact on participant perceptions as drivers interacted with it most frequently.

4.1 Smartphone Device

Because the device was to be used by participants on every trip they took over the 6-month test period, the participants became very familiar with both the operation and interface of the device. Further, due to the fact that this device was customized for this test, there was a continuous improvement process used by the deployment team that corrected small issues and challenges observed in the field by the participants.

4.1.1 Using the Smartphone

Volume II reports on the number of miles that were recorded on the smartphone and the number of miles recorded on the odometer. As noted in that volume, there is a complicated relationship between the frequency with which participants brought the smartphone on trips and used it properly (i.e., turned it on at the start of a trip) and whether the MBUF application actually captured the miles driven on that trip. There are a variety of situations where miles might be "lost." First, on the user end, participants might consciously choose to opt-out and not use the device for some trips, or they might make errors in failing to turn on the device or mount it properly for the best likelihood of obtaining a satellite signal. The MBUF application cannot capture miles if it is not used. Second, there were a variety of cases (described in Volume II) where the application may have appeared to have been working, but where it was unable to capture miles driven accurately (e.g., loss of GPS satellite link, trips not "closing" at the appropriate time).

> **"The more I have used the device, the more I have made it a habit."**

Thus, in examining self-reports of smartphone usage, it is difficult to interpret the accuracy of participants' claims. Some participants may certainly have been motivated to report a high frequency of usage since they knew the stipend would be based on this in part. However, smartphone data and anecdotal observations also suggest that many participants did make a great effort use the device regularly. Unfortunately, inconsistencies in knowing when the application was not able to collect information make it difficult to interpret self-reported usage because while the majority of the participants self-reported that they used the smartphone more than 90 percent of the time, the study team cannot confirm what percent of the time the participant had the device set up, but did not have GPS connection, and therefore the device was not recording trip information. Excerpts from the participant journals highlight this issue. After having difficulties with the device capturing their miles, a participant wrote, "we never know when it will work… phone is totally unpredictable" in regards to having difficulties with the smartphone, while another participant wrote, "not sure if all trips were recording correctly." The addition of an icon or feature on the MRFT application to verify trip information was being captured would be useful for participants to understand what trips were and were not captured. Further, this type of active feedback would allow participants a chance to correct any issues in their control (i.e., reposition the device for better GPS reception or ensure the device is plugged in) to ensure that every time the participant made a conscious effort to use the device, their trip information was captured.

Participants often noted that using the device for every trip was challenging as they had to ensure that the device was in the vehicle and powered on for every trip. Further, because the device took time before being fully powered on and having a connection established with the GPS satellites, participants often indicated the use of the device delayed the start of their trip or that the trip did not reflect the miles closest to their origin point. For example, an excerpt of a participant's journal reads, "waiting for the start-up screen is inconvenient when in a rush to get where you're going; it is hard to remember to bring every trip and hard to remember to charge." Though, with more time in the test, the act of charging and using the device appeared to have become routine. A second excerpt from the same participant's journal reads, "the more I have used the device, the more I have made it a habit."

4.1.2 MBUF Application Interface

The MBUF functionality consisted of two aspects from the driver's perspective. First, the mileage-based user fee portion of the application showed the driver the current rate both at the top left of the screen and across the bottom of the screen. Second, the ability to view some details of their trips and fees, including a list of their trips, their total number of miles traveled for the month, and their total estimated fees for the month. A screenshot of the interface is shown in Figure 32. More information of the smartphone's interface can be found in Volume I, Section 2.3.2 – Final System Design. In order to assess participant's reactions to the MBUF application, they were asked a series of survey questions about:

- Awareness of the fee information available on the smartphone;
- Understanding of why the fee value was what it was;
- Frequency with which participants pay attention to the fee while driving;
- Distraction associated with the information; and
- Usefulness of the fee information while driving.

Figure 32. Application Interface.

In the weeks immediately after MBUF functionality became available to participants, 93 percent of participants (n=473) indicated that they had noticed the mileage fee information on their smartphone; that is, they saw the fee appear while they were driving. Further, 96 percent of participants (n=470) during the same timeframe indicated that they were aware of what factors affect the mileage fee as they drive.

While most drivers indicated awareness and understanding of the MBUF features, that does not necessarily mean that they paid attention to the fee on a regular basis. Participants generally indicated that they paid attention to the fee information presented on their device and that the fee information was not distracting to them as they drove. Displayed in Table 26, as novices 80 percent of the 442 participants who had seen the fee information on their smartphone indicated that they paid attention to the fee information at least some of the time, while almost 20 percent reported paying attention to the information rarely or never.

When participants became more experienced (i.e., at the end of the test), there was a slight increase (about 8 percent) in the percentage of participants who rarely or never paid attention to the fee information on the smartphone. This decrease over time could be due to the fact that, for the most part, the fee information displayed on the smartphone rarely changed (e.g., 1 cent or 3 cents) for some drivers. Given the fee information only changes when a participant crosses the Metro Zone boundary at peak hours, as the participants spent more time with the test and became more experienced with the device, participants were likely knowledgeable as to where and when the fee information would change and therefore did not feel the need to pay as much attention to the device in order to obtain this information. Additionally, while many participants did claim to pay attention to this information with some frequency, very few reported that they found the information distracting. Almost 96 percent of participants (regardless of whether they were novices or experienced with the smartphone) reported that the fee information was only distracting some of the time, rarely, or never. Of course, drivers are often not the best judges of their own level of distraction; regardless, it is reassuring that the presence of the fee information did not cause them any discomfort.

Regardless of being novice or experienced users of the smartphone, approximately 59 percent of the participants indicated that the presentation of fee information on the smartphone was useful. It is interesting that so many drivers reported paying attention, while far fewer reported that the information was useful. One possible explanation for this is that drivers were concerned with accuracy and did indeed pay attention to make sure they were being charged correctly. However, the interface itself was relatively static and rarely changed. Thus, drivers may not have perceived there was a lot gained from the way information was presented but paid attention to make sure the fees were accurately counted.

With respect to accuracy of information, participants were asked about whether a) they believe miles were accurately counted by the smartphone and b) the subsequent fees were accurately calculated by the smartphone. The pattern of response for both questions was almost identical, and there were no significant changes in opinions as participants became more experienced. Only 18 and 21 percent, respectively, thought that the smartphone was recording miles and fees accurately. More alarming, 12 and 9 percent thought that these were rarely or never being recorded accurately. Thus, even in their earliest experience with MBUF features, a large number of participants did not trust these calculations, and further experience did not convince them otherwise. Before the smartphone determined the participant location, the fee listed on the device would read “UNK.” Through the surveys and telephone interviews, participants indicated that they were aware that when the device read a fee of “UNK,” the device had not yet located their vehicle and thus was not tracking their current trip information. While the amount of information lost to trip startup for longer trips was likely small on a percentage scale, the fact that participants saw this “UNK” fee on many of their trips likely introduced thoughts of device inaccuracy.

Table 26. Initial Participant Perception of the Mileage Fee Presented on the Device (N=442).

Question	Not At All	Rarely	Some of the Time	Most of the Time	All of the Time
I pay attention to the mileage fee rates and fee categories displayed on the device.	7%	13%	39%	29%	12%
It is useful to see the mileage fee rate and fee category as I drive.	19%	19%	24%	21%	17%
I find the mileage fee information distracting.	60%	27%	9%	3%	1%
I believe mileage is accurately counted by the device.	8%	4%	27%	43%	18%
I believe mileage fees are accurately calculated on the device.	6%	3%	26%	44%	21%

4.1.3 Issues and Challenges

As long as the smartphone was properly mounted in the vehicle, the smartphone would power on and power off with the participant’s vehicle. However, due to the wide range of vehicles used in the test, some participants’ smartphones had to be manually powered on and powered off to collect trip information. Further, the deployment team had challenges with some vehicles that had features to increase fuel efficiency, such as lower power output from the alternator when idling. In these instances, the lower power level would cause the smartphone to end the trip as if the vehicle was powered off. More information regarding smartphone and MRFT application operation can be found in Volume II.

While the smartphone was to be in the participant’s vehicle and powered on for each of their trips, the smartphone was also to be taken out of the vehicle for various reasons. For example, Wave A and B participants were active during the winter months and were instructed to remove their smartphone from the vehicle if the vehicle was to be parked for extended periods of time in freezing temperatures. Extended exposure to cold weather often affected smartphone performance and could prevent the smartphone from operating properly.

On the second survey, the participants had an opportunity to discuss any issues they had with the smartphone. The majority of the respondents indicated that they had issues with:

1. Powering on the device in the vehicle,
2. Obtaining a good GPS signal,
3. Starting a trip (e.g., device froze at 14%),
4. New trip starting unexpectedly, and
5. Device powering down unexpectedly.

Through discussions with participants, many indicated that the smartphone would often take longer than expected to power on when beginning their trip and that they sometimes had to reboot the smartphone to have it fully powered on. The issue with obtaining a good GPS signal seemed to be less a function of the participant or the smartphone than it was a function of the participant's location; many times participants who garaged their vehicle would indicate that their smartphone would not be able to capture GPS reception until they were en route on their trip. A participant provided the following example during the telephone interview: the participant's commute was about 6 miles and it generally took about 6 minutes to complete; however, the smartphone typically took about 3 minutes before it registered his location. As a result, for the first 3 miles of his commute, when the smartphone had not yet obtained GPS reception, he was charged the higher, "non-technology" rate of 3 cents a mile, because his trip information was not yet being tracked. For the final 3 miles of his commute, the smartphone obtained GPS reception and the participant was charged 1 cent per mile. In this scenario, the participant's daily one-way commute totaled 12 cents (9 cents for the first 3 minutes and 3 cents for the final 3 minutes) while the trip should have only totaled 6 cents (1 cent per mile for 6 miles). In this extreme scenario, the participant was charged a fee that is 100 percent higher than what it should have been due to delay with acquiring GPS signal. For participants who routinely took short trips, this issue could have caused a large percentage of the participant's trip information to be lost over the course of the 4-month test period.

Starting a trip was listed by participants as a common issue, and this issue was more common during Wave A where, when the smartphone had very poor reception, a glitch in the smartphone's software could cause the smartphone to hang when starting a trip. The deployment team corrected this issue for Waves B and C. The final two issues both relate to the smartphone operating unexpectedly (e.g., starting a new trip or powering down). While these unexpected issues were more challenging for the deployment team to isolate and mitigate, discussions with the participants showed that potential causes of these issues could relate to how the smartphone was mounted in the vehicle. For example, some participants indicated that due to their vehicle's configuration, it was difficult to securely mount the smartphone, and sometimes the power cable would be bumped by either the driver or passenger and this could cause the smartphone to reboot and begin a new trip.

Participants were again asked to voice their thoughts on smartphone issues during the third survey. The issues that the majority of the participants indicated that they had experienced were:

1. Powering on the device in the vehicle;
2. Obtaining a good GPS signal;
3. Device powering down unexpectedly; and
4. Screen goes blank unexpectedly during a trip.

Three out of the four issues listed above were identical to the issues reported in the second survey. The issue that only appeared on the third survey was "screen goes blank unexpectedly during a trip." Participants indicated that at seemingly random times during their driving experience, the smartphone's screen would shut off and the smartphone would become unresponsive. The remedy for this issue would be to reboot the smartphone, but due to the random/inconsistent nature of this issue, it was challenging for participants and the project team to understand exactly what caused this issue. In addition to the isolated nature of these issues, there was also a communications challenge due to the different terminology that participants and developers used. For example, participants would report something to the effect of, "the smartphone flickered and the green battery showed up and now the screen is dark," and field staff would have to go through several iterations of questions to determine the actual problem when the issue may have been a simple one that could have been resolved in a matter of minutes if the participants had been able to articulate their situations with more technical precision.

Participant interviews shed further light on their perceptions of the smartphone. Fifty-seven percent of participants believed that the smartphone accurately captured their trip information. Similarly, 54 percent of the respondents trusted that the smartphone would operate properly once they began their trip.

The study team also reviewed service requests submitted to the deployment team to provide a fuller story on the participant interaction and understanding of the smartphone used in the test. Of the 500 participants in the MRFT, 28 percent submitted service requests due to their smartphone malfunctioning, 23 percent due to power issues with the smartphone (e.g., smartphone losing charge quickly), 21 percent due to an error message displayed on their smartphone, and 12 percent due to trips not being properly recorded. Further, 8 percent of the participants submitted a service request that resulted in a new smartphone being issued to the participant. A critical consideration when reviewing the percent of participants that submitted a service request related to the smartphone is to consider that these values represent those individuals who 1) perceived that their smartphone was malfunctioning, and 2) took the time to submit a service request and have the issue resolved. There may be other participants that did not submit a service request because they did not understand that their smartphone was malfunctioning or did not take the time to attempt to resolve any perceived issues.

4.2 Participant Portal

Participants were also offered the opportunity to access the participant portal to learn more about the test as well as view information about their involvement in the test (e.g., invoices, list of mileage charges, list of trips, etc.). It was not until after OR2 when most of this information would become more useful to the participants. Understanding participant perceptions of the participant portal is useful because, if an MBUF program were to become a reality, the public would likely require a mechanism to review their MBUF-related information. As designed for the MRFT, the participant portal provided participants access to information regarding their invoice, the MBUF fees, and trip information as well as guidance such as smartphone troubleshooting and frequently asked questions.

4.2.1 Invoice Information

While the participants received a copy of each month's invoice both through the U.S. Postal Service as well as electronically via e-mail, they were also offered the opportunity to review all of their invoices through the participant portal. About half of the novice participants indicated that they had accessed the participant portal to view their invoice information early in the test period (e.g., novice) while 61 percent of participants indicated that they had used the participant portal to view their invoice information by the end of the test period (i.e., experienced). It is not surprising that not all participants used the participant portal to access their invoice because participants were not required to view an invoice on the participant portal to successfully pay their invoice. Interestingly, although fewer than two-thirds of participants indicated using the portal to view invoices, when asked about the utility of viewing invoices on the participant portal, 95 percent (n=186) of the experienced participants somewhat agreed or agreed that it is useful to have the ability to view invoice material on the portal.

4.2.2 Fee Information

Along with the participants' invoice information, participants are able to view information on fee charges for the current month, separate from their invoices. Similar to viewing "usage," such as data usage on a personal mobile device, this information allowed participants to review their monthly driving habits and estimate their monthly invoice before the end of the month when the invoice was issued. Nearly half of the novice and slightly more than half of the experienced respondents indicated that they had seen a list of mileage fee charges on the participant portal. When taking into account that the funds to pay the monthly invoices were provided to the participants by the study team, and coupling that with the fact that viewing this fee information is not required to complete the test, it is easy to deduce why about half of the respondents indicated that they did not access the fee information on the participant portal. Of the experienced participants who did view the fee information, 90 percent indicated that they somewhat agreed or agreed that it was useful to be able to view fee information on the participant portal.

4.2.3 Trip Information

The participant portal allowed participants to view their trips in two ways: through a list or through a map. About half of the novice participants and 55 percent of the experienced participants responded that they had viewed a list of trips on the participant portal, while 36 percent of the novice and 38 percent of the experienced respondents indicated that they had viewed their shared trips in the form of a map on the participant portal. For many of the same reasons above (i.e., participants were not required to view their trips to complete the test), it is not surprising that a low percentage of the participants accessed this information. However, reviewing survey responses indicates that participants did enjoy the ability to view their trip information on the participant portal as a mechanism to determine if their device was accurately recording miles. The team believes that if the participants were paying the invoices with their own money, it is likely that many more participants would have logged in to review trip information before paying their invoice. Of the experienced respondents who had viewed the trip information, 90 percent (n=129) responded that they somewhat agreed or agreed that it was useful to be able to view individual trips that were recorded by selecting a TripId on the portal.

4.2.4 Participant Guidance

The final type of activity that a participant could access through the participant portal was viewing guidance for the test. Of the different types of activities, respondents were least likely to view this information on the participant portal. Nearly 28 percent of the novice and 31 percent of the experienced respondents indicated that they had seen the guides and videos, while about 42 percent of both the novice and experienced respondents indicated that they had seen the frequently asked questions. The fact that the majority of novice and experienced respondents did not see the guides, videos, or frequently asked questions on the participant portal is surprising as one common comment from participants was that they would have preferred more troubleshooting documentation or videos. It is possible that while the participants indicated that they had wanted more guidance information, they had not taken the time to research what was available to them. A second possibility is that although the availability of this information was provided to the participants during the odometer reading, the amount of other information they were provided related to the smartphone may have caused participants to focus on the technology and forget about the guidance.

4.3 Invoicing

Participants were invoiced for their road fees on a monthly basis following OR2. This section will discuss participant perceptions of the invoice process in terms of invoice delivery and invoice presentation.

4.3.1 Invoice Delivery

As discussed in Volume I, a major responsibility of each participant was to pay the monthly road fee invoice. While Volume I, Section 3.1.3 – Test Period Activities discusses the methods participants could use to provide the deployment team with a payment, this section of the report discusses participant thoughts and perceptions of the invoicing process.

The second survey discussed how participants would prefer to *receive* their invoices. The participants could respond that they preferred to receive the invoice online, through a paper copy sent in the mail, or both. There was almost an even division among the participant responses to the three questions with the majority responding that they preferred to receive both. Forty-two percent of respondents preferred to receive both a paper and online copy of the invoice, 32 percent preferred to receive only an online copy, and 26 percent preferred to receive only a paper copy.

The third survey asked how participants would prefer to *pay* their invoices. Forty-four percent of the experienced participants preferred to pay the invoice by check through the mail, 35 percent preferred to pay online using PayPal, and 18 percent preferred to pay electronically from their bank account. Only two participants responded that they would prefer to pay in person. The study team did not call out specifically the option of paying by credit card since this was not an option given to participants in the test, but eight participants stated that they would prefer to pay online via credit or debit. Since these participants specifically did not select PayPal, even though this is a means for paying online via credit card, one can infer that they are not comfortable with this method of payment. These findings are similar to the actual percentages of methods used by the participants. The deployment team reported that 34 percent of the participants paid by PayPal, whereas 66 percent paid by check or credit card by mail or by check, credit card, or cash in person. The differences between the participant perception and actual payments during the test were that the participants were not offered an opportunity to pay directly from their bank account; all electronic payment in the test would have been through PayPal or by credit card.

The third survey also asked participants to respond to four statements gauging the participants' perceptions on invoicing, considering both paper invoices and electronic invoices. The statements and responses can be seen in Table 27. The majority of the participants agreed to each of the four questions.

Table 27. Distribution (row percentages) of Survey 3 Responses to Invoicing, by question (N= 454).

Question	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Not Sure
The paper invoices I received were sent to me in a timely manner.	21%	11%	11%	52%	5%
After receiving the paper invoices, I had enough time to pay my bill.	22%	11%	9%	51%	7%
The online invoices I received were sent to me in a timely manner.	3%	2%	7%	75%	13%
After receiving the online invoices, I had enough time to pay my bill.	3%	4%	10%	68%	15%

When comparing the responses regarding receiving paper versus electronic invoices, more participants responded that they disagreed that they received the paper invoice in a timely manner and that they had enough time to pay their bill after receiving the paper invoice when compared to electronic invoices. This difference in opinions can be explained by how each of the two invoices were distributed. As discussed in Volume I, Section 3.1, electronic invoices were automatically distributed via e-mail in the early morning on the first of the month. Paper invoices were compiled by hand after the electronic invoices became available on the first of the month. Because of the manual process and potential delays through the Postal Service, paper invoices could have arrived to the participant's address with little time to submit a payment by its due date on the 15th.

4.3.2 Invoice Presentation

The majority of the novice participants either somewhat agreed or agreed to each of the invoice presentation-related statements, and both the statements and distribution of responses can be seen in Table 28.

Table 28. Survey 2 Perception of Invoice Presentation (N=338).

Question	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Not Sure
The invoice was presented in a way which was easy to read.	1%	3%	14%	80%	2%
I understood the way my invoice was calculated.	2%	3%	15%	76%	4%
The invoice reflected the	2%	4%	15%	63%	16%

Question	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Not Sure
charges I expected to see.					
I believe the invoice accurately reported the number of miles I traveled during my trips.	5%	7%	23%	50%	15%
I believe the invoice accurately reported my accumulated fees based on the miles that my device recorded.	3%	3%	19%	61%	14%

While participants mostly agreed or somewhat agreed with each of the invoice presentation-related statements, three of the five received a higher percentage of not sure responses (nearly 15 percent). These statements were:

- The invoice reflected the charges I expected to see;
- I believe the invoice accurately reported the number of miles I traveled during my trips; and
- I believe the invoice accurately reported my accumulated fees based on the miles that my device recorded.

Each of these three questions relates to the number of miles recorded by the smartphone. One concern discussed with participants during the telephone interviews and at the focus groups was that the invoices were difficult to audit because all trip information was grouped based on the fee assessed (e.g., all trips throughout the month made outside of the Metro Zone were aggregated together). Aggregating all of the trips by fee category allowed the invoices to be concise and protected participant privacy, but made it difficult for participants to determine if their invoices were accurate. An excerpt from a participant's journal further emphasizes this point: "[t]he list of charges is confusing: too many different categories. It's hard to tell where each day's new charges show up."

It was often easy for participants to realize that their smartphone was not functioning properly if their invoice displayed no or very few miles, but due to this aggregation of trips, it was more difficult for the participants to realize that the smartphone was capturing and invoicing more miles than they had actually traveled. Few participants disputed invoices because the funding used to pay the invoices was "not their money." Most complaints were at the final odometer reading; participants generally did not call in a service request for their invoice unless their invoice read $0.00.

Further, as noted in Section 4.1.3, some participants did not believe the smartphone accurately captured their trip information, but without manually logging each trip, they had no way to determine which trips were captured and which trips were missed. Participants indicated that one way to improve the invoice would be to include a section of the invoice that listed each trip taken with time and date to allow the participants to review their driving behavior and ensure it was accurate.

Participants were again asked to react to the statements presented in Table 28 during the final survey, and similar responses were received. The experienced respondents answered the questions as follows:

- Ninety-two percent of the participants somewhat agreed or agreed with the statement “the invoice is presented in a way easy to read”;
- Ninety percent somewhat agreed or agreed with the statement “I understood the way my invoice was calculated”;
- Seventy-eight percent somewhat agreed or agreed with the statement “the invoice reflected the charges I expected to see”;
- Sixty-seven percent somewhat agreed or agreed with the statement “I believe the invoice accurately reported the number of miles I traveled during my trips”; and
- Seventy-eight percent somewhat agreed or agreed with the statement “I believe the invoice accurately reported my accumulated fees based on the miles that my device recorded.”

Much like the percentage of participants responding with an opinion, the percentage of participants who responded that they were not sure to each of the questions above remained nearly the same. For the final three bulleted items above, the percent of participants that were not sure decreased from 16, 15, and 14 percent in the second survey to 14, 12, and 11 percent, respectively, in the final survey. Again, these percentages of participant responses are likely explained by the participants’ inability to easily audit invoices without taking detailed notes of their daily trips.

5 Perceptions of the Safety Signage Functionality

5.1 Introduction to the Safety Signage Functionality

The safety signage application that the deployment team developed for the phone consisted of two aspects. One aspect of safety-related signage was the CICAS signage, which was reserved for a small test of seven drivers who participated in a 1-day study. This study was conducted separately from the main test, which involved 500 participants. (The CICAS functionality of the phone is discussed separately in *Volume VI – In-Vehicle CICAS Evaluation*.) The other aspect of safety signage provided safety alerts to drivers when entering pre-defined safety zone locations throughout the Metro Area. Three primary types of safety zones were included in the test: (1) school zones, (2) speed zones (areas of reduced speed), and (3) curves. The test also included a limited demonstration of a fourth type of safety zone: a construction zone. As discussed previously, there were a total of 98 safety zones included in the test. This included 46 school zones, 28 speed zones, 17 curves, and a 10-mile construction zone which included 7 individual signage zones. This chapter will discuss participant opinions and perceptions about the in-vehicle safety signage system as demonstrated in the test.

Upon entering a safety zone, participants received a visual safety alert on the screen of their smartphones. This visual alert remained present until they exited the zone. For school zones and speed zones, if the participant was traveling 5 mph or more over the speed limit at any time while in the zone, the visual alert would be accompanied by an audible alert in the form of a beep. Participants did have the ability to disable the safety signage functionality or to lower (or turn off) the volume of the audible alerts.

5.2 Visual Safety Alerts

For regulatory signs (this applied to school zones and speed zones where speed limit signs are used), the system was designed such that the in-vehicle signage would appear when the driver passed the roadside sign. The reason for this is that the speed limit would only be enforceable after passing the roadside sign. For advisory signs (this applied to the curve warning signs and the construction zone “road work ahead” signs), the boundaries of the zones were established such that the sign would appear in the vehicle at the same time that it became visible to the driver on the roadside. The advance distance at which the signs should appear was determined based on guidance in the MUTCD. One exception was that zones were not carried across an intersection with a traffic control device (whether a traffic signal or a stop sign), even if the zone sign was still visible on the far side of the intersection. While Wave C participants experienced all four of these safety zones, Waves A and B participants did not experience construction area safety zones due to the availability of applicable MnDOT road construction projects in the vicinity of Wright County. In the case of school zones, these alerts appeared regardless of time of day.

5.2.1 Participant Perception on Frequency and Location

The visual safety alerts were experienced by nearly all participants. Shortly after OR2, 84 percent of the novice respondents indicated seeing the visual safety alert at least once, and this increased to 94 percent of the experienced participants, indicating they had seen a visual safety signage alert by the end of the test. Because it was neither feasible nor desirable to have alerts displayed on the smartphone for all traffic control devices in the County, the project team selected 98 locations dispersed around the County. Considering driving habits of some of the low-mileage participants in this test, coupled with the locations of the safety zones, it is not surprising that not all respondents indicated having experienced a visual safety alert.

Wave C participants were asked about the location they experienced the visual signage alerts. The most commonly observed visual safety alert was for reduced speed zones, where 73 percent of novice (n=141) and 84 percent of the experienced (n=150) respondents indicated they had seen this type of alert on their smartphone. Further, the majority of respondents in both the second and third survey (62 and 72 percent, respectively) indicated that they had experienced a visual safety alert in a school zone. Less than half of the respondents (36 percent in survey 2 and 49 percent in survey 3) indicated that they had experienced a visual safety alert approaching a curve. Finally, the construction area alert was not displayed prior to the second survey, but in the third survey 12 percent of the respondents indicated that they had experienced the alert.

5.2.2 Comprehension

Nearly all of the respondents who had seen the visual safety alerts reported that they somewhat agreed or agreed that they knew why the alerts were displayed (97 percent), that the alerts were easy to read (98 percent), and the alerts were easy to understand (99 percent). These findings are not surprising given that the alert displayed on the smartphone was identical to the traffic control device installed alongside the roadway at the same location where it was displayed in the vehicle.

While respondents' level of technology-usage seemed to slightly affect the percent of participants somewhat agreeing or agreeing to each of the three statements, both the HTU and LTU participants overwhelmingly responded somewhat agree or agree to each of the three statements, and further analysis did not find any statistical significance at a significance level of 0.05 between the two groups' responses. The largest difference was observed among experienced users, where 98 percent of the HTU participants (n=336) believed that the safety zone alerts were easy to read, while 95 percent of the LTU respondents (n=82) indicated the same.

Nearly all of the respondents who had seen the visual safety alerts reported that they understood why the alerts were displayed and that they were easy to read and understand.

Discussions with participants through the telephone interviews further emphasized that participants easily understood what the visual safety alert was representing; however, participants indicated that at a few locations throughout Wright County, the safety alerts seemed to be presented in incorrect locations. Review of these instances led the deployment team to modify one signage zone due to an incorrect speed limit being presented; however, other instances where the visual safety alerts were being presented at what the participants thought were incorrect locations (e.g., visual alert starting after the participant was already in the designated zone) seemed to be a function of the smartphones' GPS and the delay in obtaining the participants' location. That is because the smartphone only refreshed its location every second, so a participant could be driving into a safety zone for nearly a full second before the alert is issued (i.e., 66 feet into the zone if traveling at 45 mph).

5.2.3 Requested Improvements

For the purpose of this study, participants could not easily disable the visual safety alerts from appearing on their screen. However, through survey responses and telephone interviews, disabling or modifying where and when the visual safety alerts were displayed was a common request. For instance, some participants noted that they had a safety zone on their daily commute, so at least twice each day they would see that same visual safety alert. Similarly, other participants noted that the alerts were most useful in locations that they were not familiar with, and that these participants would prefer an option that disabled the visual safety alert from being displayed in a specific zone after a set number of trips through that zone. Participants indicated that they found great utility in the reduced speed visual safety alert, but many indicated that they would prefer an advanced warning that they were entering a reduced speed area ahead to provide adequate time to slow to adhere to the posted speed limit. Another common request heard in both the surveys and the telephone interviews was to disable the school zone signage alerts during hours when children are not present. As designed in the test, these school safety zone alerts were shown to the participants regardless of the time of the day when the participant drove through a school safety zone, although the speed limit was only enforceable when children were present. While not specifically asked during the surveys, anecdotal findings from the telephone interviews indicate that overall, participants found the visual safety alerts to be the most distracting during the nighttime hours when the glow from the visual safety alert would illuminate the cabin of their vehicle.

5.2.4 Acceptance

The acceptance of the visual safety alerts was evaluated through survey responses in three aspects: perceived driver distraction, perceived usefulness, and participant opinion on the ability to disable the alert. Understanding participant opinion on both driver distraction and alert usefulness is critical to designing future value-added features like in-vehicle safety alerts. Near the end of the test, 60 percent of the experienced respondents indicated that they somewhat agreed or agreed that the visual safety alerts were distracting, a slight increase of 3 percent from their novice responses. Also, 70 percent of the experienced respondents indicated that they somewhat agreed or agreed that the visual safety alerts are useful tools for drivers, a decrease from 72 percent from the responses given when the participants were novices. Responses to the final metric, the percentage of participants that would prefer to disable the visual safety alerts, also grew over time from 42 percent of the respondents indicating they somewhat agreed or agreed as novices, to 50 percent agreeing near the end of the test.

Results from these three survey statements generally indicate a trend where the participants found the visual safety alerts less useful and more distracting over time. This trend in participant responses likely relates to the finding that many participants believed these alerts most useful in unfamiliar areas. Over the course of the test, participants were likely subjected to the same safety zones several of times, and, depending on the location of the safety zone, the frequency with which they had seen it, or the attitudes of drivers toward their own driving skill, this repetition could become frustrating to the driver. Table 29 reviews the responses to the visual safety alert survey statements by technology usage. Interestingly, the HTU participants were more likely to find the visual safety alerts to be distracting as well as more likely to prefer to disable these alerts, regardless of being a novice or experienced user of the MRFT application.

Table 29. Acceptance of Visual Safety Alerts by Technology-Usage.

Question	Technology-Usage (Survey 2)		Technology-Usage (Survey 3)	
	High (N=314)	Low (N=74)	High (N=336)	Low (N=82)
	Somewhat Agree or Agree		Somewhat Agree or Agree	
I found the safety zone alert(s) distracting when they appeared.	58%	50%	61%	52%
I think the safety zone alerts are a useful feature for drivers.	73%	73%	70%	70%
Personally, I would prefer to disable the safety zone alert feature.	43%	34%	51%	45%

5.3 Audible Safety Alerts

Audible safety alerts were experienced when a participant was traveling at a speed greater than or equal to 5 miles per hour above the posted speed limit in a safety zone. While the image displayed for the visual safety alert differed with each type of safety zone to correspond with the type of zone, the audible alert tone was the same regardless of the type of zone (i.e., a "beep" that occurred when a driver exceeded the speed limit by 5 miles per hour or more in the zone).

5.3.1 Participant Perception on Frequency and Location

The audible safety zone alerts were experienced by nearly all of the participants during their time in the test. Near the end of the test, 90 percent of the experienced respondents indicated that they had experienced an audible safety zone alert, up from 74 percent of the respondents during their novice survey responses. These numbers are similar, but slightly lower than the percentage of respondents experiencing the visual safety alert. It is not surprising that the number of respondents indicating that they had experienced the audible alert was less than the number of respondents indicating that they had experienced a visual safety alert, given the fact that the alerts were only sounded when the driver exceeded the posted speed limit by 5 miles per hour or more.

Also similar to the responses to the visual safety alert, the location where most respondents indicated experiencing the audible safety zone alert was in a reduced speed zone. Of the 147 Wave C participants that were asked (Waves A and B were not asked this question), 82 percent of the experienced respondents indicated that they had heard an audible alert in a reduced speed safety zone, and 78 percent of the respondents experiencing an audible alert in a school zone. Only 8 percent of the experience respondents experienced the audible alert in a construction area, but this low percentage of respondents with experience in a construction area is not surprising given the location and the duration of the construction activities.

5.3.2 Comprehension

Similar to the visual safety alerts, the majority of the respondents somewhat agreed or agreed that they understood why the audible safety alerts occurred and that the audible safety alerts were easy to hear, with 95 percent of the experienced respondents responding this way to both statements. Table 30 further reviews responses by level of technology-usage. As with responses for the visual safety alert, there was no observed statistically significant difference between the two groups' responses. Also, as with the responses to the visual safety alerts, the high technology-usage participants were slightly more likely to somewhat agree or agree to each of the two questions.

Table 30. Audible Safety Alert Comprehension by Level of Technology-Usage.

Question	Technology-Usage (Survey 2)		Technology-Usage (Survey 3)	
	High (N=279)	Low (N=65)	High (N=324)	Low (N=78)
	Somewhat agree or Agree		Somewhat agree or Agree	
I understood why the safety zone "beep(s)" occurred.	95%	94%	96%	95%
The safety zone "beep(s)" were easy to hear.	95%	92%	96%	95%

5.3.3 Requested Improvements

In general, participants voiced more concern regarding the safety zone audible alerts than they did for the visual safety alerts. The majority of the respondents indicated that they believed the audible safety alerts were distracting and that they would have preferred to disable them. Some participants indicated that they turned the volume either down or off on the smartphone in order to circumvent these alerts. As discussed regarding visual safety alerts, many participants indicated that they disliked the fact that, although reduced speed limits in school zones are only enforced when children are present, the smartphone application emitted audible regardless of the time of the day or day of week. In other words, if the usual posted speed limit in a school zone was 40 mph but the speed limit when children are present was 25 mph, any time the participant drove through this school zone at 30 mph or greater, regardless of time of day or day of week, they would be provided an audible alert. Other requested improvements involved the tone or frequency of the audible alert and varied from participant to participant (e.g., some participants indicated that they would prefer a brief tone to alert them of the upcoming safety zone, others indicated that they would prefer to remove the tone and have only voice commands). Allowing the participants to customize the alert for their individual preference would assist in addressing many of these comments.

5.3.4 Acceptance

The acceptance of the audible safety alerts was evaluated through survey responses in three aspects: if participants believed that the alert was distracting, if participants believed that the alerts would be useful for drivers, and if participants would disable the signage alert in their own vehicle. By the end of the test, although the majority of the respondents thought that the audible alerts were distracting and would prefer not to have them in their own vehicles, the majority of the respondents thought that the audible alerts were useful for drivers in general.

Sixty-six percent of the experienced respondents indicated that they somewhat agreed or agreed that the audible alerts were distracting, and 51 of the experienced respondents indicated that they somewhat agreed or agreed that they would prefer to disable the audible alerts. On the other hand, 65 percent of the experienced respondents indicated that they somewhat agreed or agreed that the audible alerts were useful for drivers. It is interesting that while the respondents generally disliked the audible signage alerts, they felt they are useful for drivers in general. This finding emphasizes a common statement made by participants when discussing the safety alerts: “I do not need this feature, but I could see how others would.”

When reviewing the responses to the audible safety alerts by technology-usage level, the study team found that while the response rates were similar, the respondents classified as high technology-usage respondents indicated in both the novice and experienced surveys that they were more likely to find the audible safety alerts distracting and they were more likely to prefer to disable the audible safety alerts than the low technology-usage respondents.

> ***"I absolutely love the [safety signage alerts]. I think everyone should have it."***

5.4 Perceptions on Overall Safety Signage Utility

While the surveys asked participants for their thoughts or opinions on the safety signage application, these questions were generally focused on either the visual or audible aspect. The telephone interviews allowed the participants to discuss the overall impact that the safety signage application had on their driving as well as their opinions on the overall utility of the function. Of the 423 participants interviewed, 61 percent indicated that they thought the signage alert application was a useful feature, 33 percent did not believe the signage alert application was useful, and 6 percent were not sure if they thought it was useful or did not have an opinion. For instance, one participant was quoted as saying, "I absolutely love the [safety signage alert function]. I think everyone should have it." Many others indicated that this feature was a useful reminder, was especially useful in areas they were not familiar with, and assisted in lowering their driving speed in areas of reduced speed. Two common responses by participants who did not find the overall safety signage application useful were that drivers should be paying attention to the road and should see the traffic control devices instead of paying attention to the smartphone, and that the feature was a nuisance as they were already familiar with the area and the traffic control devices in that area.

6 Perceptions Related to Mileage Fees

6.1 Introduction of the Mileage Fees

As discussed in *Volume I: Background*, revenue derived from fuel taxes is a crucial source of funding for all state departments of transportation. Nationally, these revenues have decreased in recent years and both state legislatures and the U.S. Congress are reluctant to increase the fuel tax. As a mechanism to supplement the current fuel tax, several states are investigating the use of mileage-based user fees. For the purpose of this test, participants experienced a mileage-based user fee that was structured around location and time of day.

In selecting a fee structure for the test, MnDOT wanted an easy-to-understand structure that incorporated elements with the potential for real-world implementation. MnDOT settled on a mileage-based fee determined by time of the day (i.e., peak or off-peak), and location (i.e., inside or outside a predefined Twin Cities “Metro Area”) as shown in Table 31. The amount of the fee was determined such that it would approximate the Minnesota portion of the fuel tax for the average driver.

Table 31. Fee Structure for the Minnesota Road Fee Test.

Current Driving Location		Peak Times (Weekdays 7-9AM and 4-6PM)	Off Peak Times
Outside of Minnesota		$0.00 / mile	$0.00 / mile
Inside of Minnesota	Outside the Twin Cities Metro Zone	$0.01 / mile	$0.01 / mile
	Inside the Twin Cities Metro Zone	$0.03 / mile	$0.01 / mile

6.2 Perceptions of the Fuel Tax

Participants completed the first survey nearly 2 weeks after beginning the test. The goal of the initial survey was to capture drivers’ initial thoughts as they began the test. An important aspect of the first survey was to capture participant thoughts on the current fuel tax. The study team intentionally did not ask participants about the Federal tax as the premise of this study was that the user fee would replace the state portion of the fuel tax only. The survey also did not ask participants to estimate the state fuel tax per gallon because previous MnDOT public opinion research concluded that the general public could not accurately estimate the fuel tax.

6.2.1 Prior Understanding of Fuel Tax

Table 32 captures the responses from 484 participants highlighting the respondents’ prior understanding of the fuel tax. The responses show an even divide among participants regarding whether or not they were aware of the amount of fuel tax. Of the 484 participants who responded, 46 percent disagreed or somewhat disagreed that, “prior to my enrollment in this test, I was aware of the amount of the Minnesota fuel tax collected per gallon,” while 44 percent agreed or somewhat agreed. However, it is important to note that looking at each end of the spectrum (i.e., agree and disagree), more participants responded that they disagree (37 percent) than agree (21 percent). The percentage of participants indicating that they were aware of the amount of the fuel tax was higher as compared to prior studies that have shown that the public is generally not aware of the amount of the fuel tax. It is highly possible that participants in this test sought out additional information on the fuel tax after joining this test or that they had an idea of what the tax was, but did not know the exact amount. The majority of the participants responded positively to each of the other statements regarding the fuel tax, with 75 percent of participants responding either somewhat agree or agree to the statement "fuel tax revenue benefits me as a driver."

Table 32. Initial Thoughts on the Fuel Tax (Survey 1), N=484.

Question	Disagree	Somewhat Disagree	Somewhat Agree	Agree	Not Sure
Prior to my enrollment in this test, I was aware of the amount of the Minnesota fuel tax collected per gallon.	37%	9%	23%	21%	10%
I know how fuel tax revenue is used.	16%	11%	40%	25%	7%
Fuel tax revenue benefits me as a driver.	2%	4%	31%	44%	18%
The fuel tax is assessed in a way that is fair to all drivers.	6%	15%	27%	26%	26%
The fuel tax amount is too high.	7%	10%	23%	21%	38%

When considering the lower income participants in this test (income less than $35,000 per year), two of the questions above have particular value: "the fuel tax amount is too high" and "the fuel tax is assessed in a way that is fair to all drivers." Only 15 participants in the lowest income bracket expressed an opinion on the question regarding the amount of the fuel tax (13 responded Not Sure) and 17 participants in the lowest income bracket expressed an opinion (11 responded Not Sure) on the question of fairness. Although a small number (n=28), these lower income participants responded similarly to all other participants to "the fuel tax is too high"; 39 percent of the low income and 44 percent of all other participants somewhat agreed or agreed with the statement. However, when reviewing the question regarding fairness, only 36 percent of the low income participants somewhat agreed or agreed that the fuel tax is fair to all drivers compared to 54 percent of all other participants. These responses show that while low income participants may have felt similar to other participants in their response to the question asking if the fuel tax is too high, these participants seem less likely to believe that the fuel tax is assessed in a way fair to all drivers. Participant opinion on the fairness of mileage-based fees is further discussed in Section 6.4.2.

6.3 Perception of the Fee Structure

During the baseline period of the test, participants had no knowledge of the fee or the fee structure that the study team would be assessing. It was at the second odometer reading where the fee amount and fee structure were revealed to the participants. At this same time, staff provided training materials about the fee and gave participants examples of what the fee would be in different times and locations as they drive. For example, staff explained the difference between both peak hours and off-peak hours as well as inside and outside of the Metro Zone. Approximately 2 weeks following the participants' second odometer reading, they had the opportunity to complete the second survey, which included questions regarding both the fee and fee structure.

6.3.1 Perceptions on Fee Amount

The amount of the fee was determined such that it would approximate the Minnesota portion of the fuel tax for the average driver (i.e., the amount the average Wright County resident would pay in State fuel taxes to drive one mile). The second survey asked participants to consider their thoughts at the start of the test and to select one of three statements that best describes their opinion of the mileage-based user fee in the test: "The mileage fee rates are higher than I expected them to be," "The mileage fee rates are lower than I expected them to be," or "The mileage fee rates are about what I expected them to be." Of 467 responses, 53 percent indicated that the fee rates were about what they expected, 30 percent responded that the rates were lower than they expected, and 17 percent responded that the fees were higher than expected.

Many of the participants living in the rural areas of Wright County may have little reason to commute into the Twin Cities areas during peak times if their place of employment was not in the Twin Cities. In an effort to determine if there was a difference in responses between those participants who would regularly experience the peak fee with those who would not, the study team reviewed the responses of the Twin Cities commuters against those who do not commute into the Twin Cities during peak periods, and these responses can be seen in Figure 33.

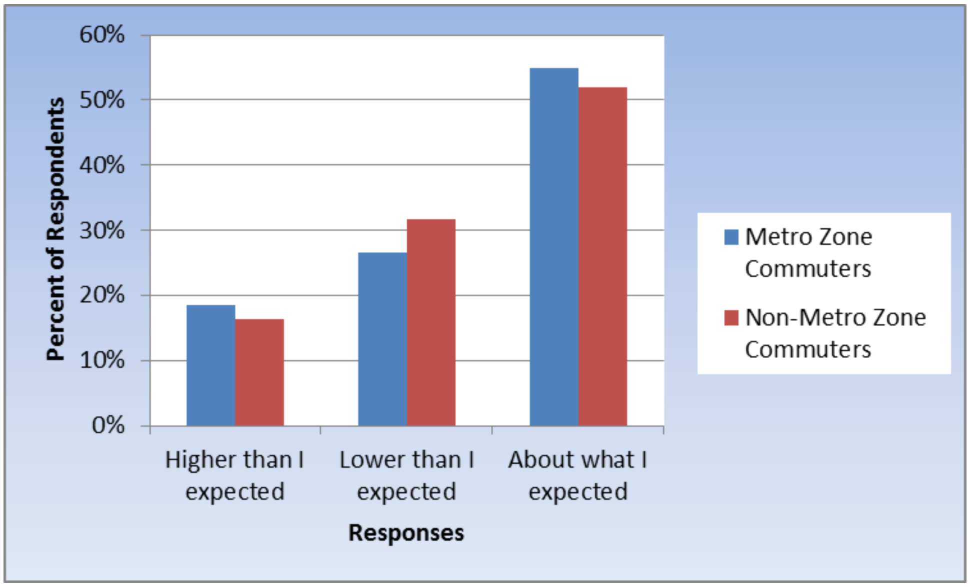


Figure 33. Participant Perception on Mileage Fee Amount ($n_{commuter}$=343, $n_{non\text{-}commuter}$=124).

Of the 343 respondents identified as not routinely commuting in the Twin Cities area (non-Metro Zone commuters) during peak times, 52 percent indicated that the fee rates are about what they had expected, 32 percent indicated that the rates were lower, and 16 percent indicated the fee rates were higher. A similar response was found for those participants who do routinely commute during peak hours: 55 percent of the 124 respondents indicated the fee rates were about what they expected, 26 percent indicated the fee rates were lower, and 19 percent indicated the fee rates were higher. While a greater percent of the peak commuters found the fee rates higher than expected, there was not a statistical difference between the responses of the two groups.

Reviewing by participant income level, the study team again found similar responses. Considering the participants in the lowest income bracket, of the 26 responses, 62 percent indicated the fee rates were about what they expected, 30 percent indicated the fee rates were lower than expected, and 8 percent indicated the fees were higher than expected.

6.3.2 Perceptions on Time of Day and Location Charges

Participants were asked their opinion about both the peak period and the location fees in the Twin Cities area. Participants favored the increased fee for travel inside the Twin Cities area more than they did an increased fee during peak hours. Of the 473 responses received, about half of the respondents (51 percent) agreed that both are appropriate, with an additional 4 percent somewhat agreeing or agreeing that charging different rates during peak hours is appropriate (55 percent total), and an additional 13 percent somewhat agreeing or agreeing that charging different rates in the Twin Cities area is appropriate (64 percent total). Nearly one-quarter (23 percent) did not feel that either pricing scheme was appropriate, and 8 percent were not sure about either scenario. As shown in in Table 33, opinions were divided among the remaining 18 percent of respondents. It is important to note that the participants all lived outside the Metro Zone. Although some participants traveled there regularly for their commute, many never had reason to, especially during peak hours when the fee was higher. These driving habits may have impacted their acceptance of one or both pricing scenarios.

It is important to note that no information was provided to participants to educate them on possible reasons for structuring the fee in this way. Participants' responses and perceptions reflect their own interpretation of the reasons for such a structure. Telephone interviews with participants shed more light on their perceptions. Participants seemed to understand the focus on funding infrastructure construction and maintenance, so not surprisingly they saw a link between traffic volumes and infrastructure needs, but they did not necessarily see a reason for time-of-day pricing. This link between traffic volumes and infrastructure needs was so strong that many participants thought it appropriate to charge more per mile for travel within the metro area. In one participant's words, "there are more vehicles in the Twin Cities area and thus more damage to the infrastructure." Without education on this, few participants seemed to understand the intent of a fee structure linking both time of day and location. Participants often expressed concern that the damage done to the road was not a factor of the time of the day and therefore charging a higher fee dependent on the time of the day was less acceptable.

Table 33. Opinions on Appropriateness of Fee Varying by Time of Day or Metro Zone, N=473.

Question	Number of Participants	Percent of Participant
Both are appropriate	239	51%
Neither are appropriate	109	23%
"Not sure" if either are appropriate	37	8%
Metro Zone is appropriate / Peak Hours is not appropriate	57	12%
Metro Zone is appropriate / "Not sure" about Peak Hours	6	1%
Peak Hours is appropriate / Metro Zone is not appropriate	20	4%
Peak Hours is appropriate / "Not sure" about Metro Zone	3	0.6%
"Not sure" about Metro Zone / Peak Hours is not appropriate	2	0.4%

6.4 Perceptions of the Mileage Fees

While there were select questions asked on multiple surveys throughout the test, one set of questions was asked on each of the three surveys, and this set of questions was developed to assess the participants' opinions on mileage fees as well as any changes that occurred over time. Specifically, the questions assessed participant understanding of opinions on the fairness of mileage fees and on the operational aspects of mileage fees. Further, this section also discusses participant thoughts and opinions on their preference between the fuel tax or a mileage fee.

6.4.1 Participant Understanding

Table 34 highlights participants' responses to the questions related to their understanding of both the fuel tax and mileage fees over the three surveys, where the sample size for Wave A was 484, Wave B was 473, and Wave C was 454. When combining the disagree and somewhat disagree responses as well as the somewhat agree and agree responses, several trends can be observed. First, survey responses show that as time passes, the respondents' rate of agreeing with each statement increases. For example, in the first survey, 87 percent of the respondents somewhat agreed or agreed that they understood the reasons for considering replacing the fuel tax with a mileage fee. In the final survey, this percentage increased to 91 percent. A similar, but opposite trend can be seen for the disagree and somewhat disagree responses. Finally, the percent of respondents that indicated they are not sure of their response also decreased for both statements over time, with the most substantial decrease found in the statement "I understand how mileage fee revenue would be used"; 19 percent of the respondents were not sure in the first survey, but this rate decreased to 6 percent in the final survey. Each of these trends indicates that as participants spent more time with the test, they became more knowledgeable about both the fuel tax as well as mileage fees.

Table 34. Participant Understandings of Mileage Fees Over Time (nBaseline= 484 / nNovice= 473 / nExperienced= 454).

Question	Participant Experience	Disagree or Somewhat Disagree	Somewhat Agree or Agree	Not Sure
I understand the reasons for considering replacing the gas tax with a mileage fee.	*Baseline*	6%	87%	7%
	Novice	8%	89%	3%
	Experienced	7%	92%	1%
I understand how mileage fee revenue would be used.	*Baseline*	18%	63%	19%
	Novice	15%	76%	9%
	Experienced	17%	78%	5%

Telephone interviews also shed more light on the participant understanding of mileage fees. While participants generally understood the concept of mileage fees (i.e., the more miles you drive, the higher your monthly invoice), there was often misunderstanding on how mileage fees would impact the participants. For instance, it was not uncommon for a participant to indicate they thought that a mileage-based fee would end up costing them more than the fuel tax simply because they are a high-mileage driver. These participants did not seem to fully grasp that while high-mileage drivers would pay more mileage fees than low-mileage drivers, they are currently paying more fuel tax than their lower mileage counterparts. These participants understood that the amount of fees they pay is a function of how much they drive, but did not appear to realize that the difference between the cost of the fuel tax and mileage fee is a function of their vehicle's fuel economy (at least as laid out in the MRFT, where fuel economy was not a factor in the fee structure).

Further, both in the telephone interviews and during the focus groups, participants indicated that the ability to relate a mileage fee to a participant's everyday life was desired by participants to better enhance their understanding of this type of fee. Participants indicated that while the guidance material provided during the test that showed how to calculate a mileage fee was useful, participants would like to see examples describing the monthly fuel tax spent by a typical family compared to the typical mileage fees that same family would spend. For example, participants indicated that they would prefer detailed scenarios (e.g., a family of four with two cars each traveling 12,000 miles annually currently spends $X on the fuel tax and would spend $Y under this a mileage-based user fee with this fee structure) rather than simply a description of the fees and how they are calculated. Very few participants indicated on the telephone interviews that they had taken the time during the test to calculate the amount they were spending in fuel tax and to compare that amount with their monthly invoices.

6.4.2 Mileage Fee Fairness

To evaluate the participant perception of mileage fee fairness, the study team asked participants to respond to two survey statements, and these responses are presented in Table 35. Unlike participant responses to the statements concerning their understanding of mileage fees, trends over time were not as evident. As with the previous statements, the percent of respondents who indicated they were not sure decreased over time; however, even during the final survey, one out of five respondents were unsure if mileage fee revenue would benefit them as a driver. The percentage of respondents indicating that they were not sure if a mileage fee would be assessed in a way that is fair to all drivers decreased from 33 percent in the first survey to 11 percent in the final survey. It is likely that participants' responses to these two questions were linked; a program that would not assess their fees in a fair way would not benefit them as a driver.

Interestingly, the percentage of respondents disagreeing or somewhat disagreeing increased over time, as did the percentage of participants somewhat agreeing or agreeing. While it seems contradictory that these responses could both increase over time, this change indicates that the participants who in the beginning of the test were unsure, began to form opinions over time. By the end of the test, the majority of participants responded that they somewhat agreed or agreed with both statements regarding mileage fee fairness.

Table 35. Participant Perception of Mileage Fees Fairness Over Time ($N_{Wave\ A}$= 484 / $N_{Wave\ B}$= 473 / $N_{Wave\ C}$= 454).

Question	Participant Experience	Disagree or Somewhat Disagree	Somewhat Agree or Agree	Not Sure
Mileage fee revenue would benefit me as a driver.	*Baseline*	21%	50%	29%
	Novice	20%	55%	25%
	Experienced	24%	56%	20%
A mileage fee would be assessed in a way that is fair to all drivers.	*Baseline*	23%	44%	33%
	Novice	31%	51%	18%
	Experienced	33%	56%	11%

Further, it is important to gauge perceived fairness of a mileage-based fee by the lower income participants. When considering the statement “a mileage fee would be assessed in a way that is fair to all drivers,” of the 26 experienced lower income participants, 54 percent somewhat agreed or agreed. Fifty-six percent of all the other experienced participants responded in the same way. Thus, this small sample of lower income drivers reveals that they do perceive that MBUF could be fair to all drivers. However, a large proportion of them (n=7) still were Not Sure.

6.4.3 Mileage Fee Operations

The final three statements to which participants were asked to respond over the course of the three surveys focused on participant opinions on operational aspects of mileage fees, including the measurement of miles, the calculation of fees, and the ease of paying invoices. As seen in the two previous examples, the percent of respondents indicating they were not sure decreased over time. As shown in Table 36, participant responses to statements about the operational aspects received the largest decrease in not sure responses over time, specifically the statement, “It would be easy to pay invoices for mileage fees,” where nearly half of the respondents were unsure at the beginning of the test, but nearly all of the respondents had an opinion near the end of the test. These findings are not surprising as at the beginning of the test, not many of the operational specifics were explained in detail to the participants. There was a large decrease in not sure responses between the first and the second surveys, and this was the exact time that participants attended their second odometer reading and deployment staff provided further guidance and training.

In regard to the statement that mileage would be accurately counted and used to calculated fees, by the end of the test 56 percent of the participants indicated that they somewhat agreed or agreed and 34 percent of the participants disagreed or somewhat disagreed. Reasons for nearly a third of the participants not agreeing that the mileage fees would be accurately counted may be related to some smartphone and GPS issues experienced throughout the test (see Section 4.1.3 for more information on smartphone issues experienced by participants).

By the end of the test, 75 percent or more of the participants agreed that it would be easy to understand how a mileage fee is calculated as well as that it would be easy to pay invoices for mileage fees. Again, these responses should not be surprising as a good deal of time was taken to explain to participants how the fees were calculated as well as to provide various options to pay invoices.

Table 36. Participant Perception of Mileage Fees Operations Over Time (nBaseline= 484 / nNovice= 471 / nExperienced= 454).

Question	Participant Experience	Disagree or Somewhat Disagree	Somewhat Agree or Agree	Not Sure
Mileage would be accurately counted and used to calculate fees.	*Baseline*	22%	38%	40%
	Novice	30%	56%	14%
	Experienced	34%	56%	10%
It would be easy to understand how a mileage fee is calculated.	*Baseline*	17%	44%	39%
	Novice	11%	81%	8%
	Experienced	14%	79%	7%
It would be easy to pay invoices for mileage fees.	*Baseline*	25%	29%	46%
	Novice	16%	75%	9%
	Experienced	16%	81%	3%

6.4.4 Changes to Driver Behavior

One interesting aspect of a technology approach to mileage-based fees is that congestion pricing can be introduced (i.e., fees can be used as a strategy to reduce peak period congestion). To assess the effect of participant opinions of mileage fees on driving behavior, the study team analyzed participant trip data. The results of this analysis are presented in Volume IV. Participants also discussed their thoughts during the telephone interview. Most participants indicated that they continued to drive as they normally would throughout the test because the invoices were paid with funding provided by the study team.

As put by one participant, "when I was working with your money, it was easy to not care." However, several participants made interesting comments regarding the test's effect on their driving habits. For instance, one participant indicated the test was, "an eye opening experience; I am a stay at home mom, but through this test I found I actually drove more miles than my husband who commutes five days a week." Similar comments regarding the amount of miles driven were provided by another participant: "I was surprised. I knew I drove an amount [of miles], but when you see it on paper it's surprising."

> ***"[the test was] an eye opening experience; I am a stay at home mom, but through this test I found I actually drove more miles than my husband who commutes five days a week."***

In addition to raising awareness of how many miles participants were traveling, involvement with the test raised participant awareness of how many trips they were taking. For example, one participant noted during the telephone interviews that the vast majority of his miles occur on his commute, but the test, "surprised [him with] how many short trips he was making." Further, some participants indicated that a mileage fee would make them more aware of their trips and help prevent making the "extra trip" by considering chaining together their shorter trips into one larger trip where possible.

Others indicated that due to outside factors (e.g., the high cost of fuel) they already were conscious of their driving habits and already drive as little as possible. For example, one participant noted that, "we have a tendency to plan well before we get into the truck and do not drive any unnecessary trips. It is 20 miles from my home to the grocery store and my truck gets only 16 miles to the gallon." Location of employment was another point commented on often. Some participants thought it was a fairness issue to charge a higher fee during peak periods in the Metro Zone because this fee structure punished drivers who had to drive during those times into the Twin Cities for work. As put by one participant, "it does not cost more to buy gas between 4:00PM and 7:00PM, so it should not cost more to drive. [A mileage-based user fee] should not be penalizing the working people for driving during the hours that they have to drive."

6.4.5 Participant Preference

While the surveys asked participants their thoughts on the fuel tax and mileage-based user fees, the telephone interviews allowed researchers to ask if, given the participant's experience in the test, they would prefer to pay mileage-based fees as a replacement for the fuel tax. Participants were quite divided on this question, with 155 participants (37 percent) indicating that they would prefer to pay a mileage-based fee as a replacement to the current fuel tax, 201

(48 percent) indicating they would prefer to continue to pay the fuel tax instead of a mileage-based fee, and 64 (15 percent) responding that they did not have an opinion or were not sure of their preference. Participants indicated numerous reasons for preferring a mileage-based fee, including that a mileage fee ensured that everyone paid their "fair share." Of the participants who indicated that they would prefer to continue to pay the fuel tax, common reasons were that a mileage fee highlighted the amount of money being paid each month in taxes while the fuel tax "hid" the cost in the price of a gallon of gas, and paying a monthly invoice was "just one more bill." The undecided participants indicated that they had not determined if a mileage fee would save them money or that it would depend on how a state would implement a mileage-based user fee system.

The fact that nearly 40 percent of respondents preferred a mileage-based user fee over the fuel tax at the end of the test is quite positive given that the majority of these participants were unaware of the idea of a mileage-based user fee prior to the start of this test and that this concept was completely new to them. As mileage-based fee studies continue and the public becomes more aware of mileage-based user fees, it is likely that the public will become more accepting of the concept.

7 Conclusions: Identification of Factors that Might Influence Acceptance of Road User Fees

MnDOT was authorized by the State Legislature to investigate implementation issues related to instituting an alternative mechanism for generating transportation revenue. To meet this goal, MnDOT identified a set of program characteristics which could potentially be part of such a program. This included factors like:

- An opt-in discounted fee concept;
- Flexible fee rate structures; and
- Location-based services for improved operations (i.e., congestion pricing and travel time data) and safety (i.e., safety signage).

A robust implementation of a program with these characteristics required MnDOT to select a technology-rich approach and ultimately to select a GPS-based commercial-off-the-shelf (COTS) device to deliver MBUF and other features. MnDOT also selected particular fee rates estimated to be a revenue-neutral replacement of the fuel tax and particular fee categories (e.g., in/out of Metro zone, peak/off-peak hours). Finally, MnDOT relied on a deployment team to develop and implement administrative and operational procedures in the field.

Any of these factors, the program's high-level characteristics, or the specific implementation approach have the potential to influence driver acceptance. This chapter summarizes what the study team learned about participant reactions to these factors in the MRFT. It also contains a discussion of issues that might be barriers to acceptance and provides recommendations for mitigating these barriers to acceptance.

7.1 Summary of Findings

The participants in the MRFT varied in demographic composition, in driving characteristics, and in terms of their experience with different technologies. Because it will be important for Minnesota or any state to develop effective communications strategies, it will be important to consider whether drivers with different characteristics vary in terms of the information they seek or the concerns they have.

One area of interest is how different subgroups of the population might respond to a technological solution. When reviewing participant responses by technology use (e.g., high-technology use or low-technology use), the study team found that while the users with more experience to technology generally understood the smartphone as well as the instruction and guidance information, there was little difference in perceived understanding of the actual operation of the MRFT application. This finding shows that while guidance may need to be tailored to individuals without much experience with similar technology, once these individuals overcome the initial hurdle they will be able to properly maintain and operate the technology.

Another area of interest is whether the type of driver a person is will influence perceptions of a road user fee program. Responses from participants in this test found that there was not a significant difference in opinions regarding fee structure from those who regularly paid a higher monthly fee in the MRFT to those who did not. However, when considering the fee structure, more participants favored varying the fee rate by location rather than time of the day.

Personal finance issues, particularly one’s income level, have the potential to influence perceptions of a new fee structure. Findings indicate that while regardless of income level 44 percent of the participants believe that the fuel tax is too high and that higher income participants were more likely to agree that the fuel tax is fair to all drivers. When reviewing responses to the mileage-based fees, both the low income and high income drivers believe a mileage-base fee would be assessed in a way that is fair to all drivers. Further, regardless of income level the majority of the participants believed that the mileage-based user fees in this test were about what they expected they should be.

Participants reported a generally high level of satisfaction with the service they received during the MRFT. Nearly all participants agreed that scheduling the odometer reading appointment was easy, the staff clearly explained all materials, and the staff successfully and fully answered all questions. Further, many participants wrote in additional comments recognizing the odometer reading staff for their understanding of the program as well as their ability to relay that information to the participants and answer any questions they had.

In general, participants both understood the reasons for replacing the fuel tax with a mileage-based user fee and thought the fee levels presented in the MRFT were reasonable. The majority of the respondents in the MRFT indicated that they thought the test fees used in the MRFT were about what they would have expected a mileage-based fee to be, and few respondents indicated that the fees were higher than they expected. However, some participants did have misunderstandings of how much a mileage-based fee would cost them based on their personal driving habits. For example, it was not uncommon for a participant to indicate they thought that a mileage-based fee would end up costing them more money than the fuel tax simply because they are a high-mileage driver; these participants did not seem to consider that high-mileage drivers consume more fuel than low-mileage drivers and thus also pay higher amounts in fuel taxes. Additionally, participants reported that they would like to see examples describing the monthly fuel tax spent by a typical family compared to the typical mileage fees the same family would spend. For example, participants indicated that they would prefer detailed scenarios (e.g., a family of four with two cars each traveling 12,000 miles annually currently spends $X on the fuel tax and would spend $Y under a mileage-based fee scenario) rather than simply a description of the fees and how they are calculated.

While drivers thought that the fee rates and categories made sense and were appropriate in some cases, they did question the ability of the technology to collect and calculate invoices accurately. In two separate surveys, nearly 20 percent of the participants indicated that they believed the technology was accurately capturing their trip information all of the time, while nearly 10 percent indicated that they thought that the technology was rarely or never capturing their trip information correctly. While participants indicated that correct calculation and proper enforcement are fairness issues related to a mileage-based fee, they also understood that this is a test. Participants in this test, especially those living in more rural areas, welcomed the idea that a mileage-based user fee would allow an agency to determine road usage more accurately and thus distribute funding for maintenance more accurately.

Drivers had mixed reactions to the presence of the safety alerts. Nearly all respondents indicated that they understood both what the safety alerts represented as well as why the safety alerts occurred in the different areas they drove. While the majority of the participants responded that the visual and audible alerts were useful tools for drivers, about half of respondents indicated that they would prefer to disable both the visual and audible safety alerts. Telephone interviews with participants found that participants often drove through the same signage zone numerous times each week, or even each day, throughout the test. This repetition of safety warnings likely caused an increase in responses to those participants that would like to disable the signage. In a real-world deployment, providing participants flexibility to customize safety alerts (e.g., location, volume, tone, etc.) would likely enhance participant acceptance.

Finally, the study team wanted to know, if put in the position of making a choice, where would participants stand on the issue of changing the current transportation revenue mechanism? Participants were asked about their preferences with respect to alternative transportation funding mechanisms. Fifteen percent did not articulate a preference, and the remaining participants were split in terms of preference for continuing with a motor fuel tax approach (37 percent) and a new mileage-based user fee approach (48 percent). Not only did a large percentage of the participants indicate that they preferred MBUF as opposed to the fuel tax, but there are an additional 15 percent of undecided participants in this test that that may also prefer MBUF in the future. A completely new concept, such as an MBUF, may take some time for participants to become familiar and comfortable with. As agencies move forward and MBUF is further publicized, it is likely that more individuals will feel comfortable with and prefer MBUF.

The following sections expand upon these findings and present several areas which might pose a risk to driver acceptance in a real-world deployment.

7.2 Operational Procedures

MRFT participants were generally satisfied with the operational procedures and the service provided by the deployment team. That said, participants frequently reported that elements of the process would not be acceptable if this was not a test. For example, while participants were aware that the smartphone used in the MRFT was a test device specifically for the MRFT, many participants discussed the "hassle" of bringing their device in and out of the vehicle (e.g., for theft prevention or to ensure proper operation during winter months), and interacting with the smartphone to ensure that their trip information was being recorded. Of course, drivers frequently bring mobile devices into their vehicles. However, for these participants the smartphone did not serve as a replacement of their personal technology. For example, a driver who typically carried her own Android™ phone with her for mobile calling and texting, would also have to bring the test Android™ with her. In a real-world deployment, these concerns could be mitigated with the use of applications that download to a personal device or a system that would be integrated into the vehicle that did not require participant interaction.

Further, while participants generally agreed that the invoices clearly presented the information about how many miles and what fees they were being charged for each month, participants often indicated that it was difficult to audit their invoices. The invoices were designed to protect user privacy by aggregating miles into fee categories. However, presenting the invoices in this way was challenging because if a participant took a trip that had both peak and off-peak miles, the mileage for that trip would be broken into the two bins. In order to audit their invoices, participants would have had to record not only their trip mileage, but also the mileage they traveled within the different fee categories. To mitigate this concern, further user testing should be completed to understand how best to present invoices in order both to protect user privacy and to ensure that the invoices are useful to the user.

This test also highlighted the advantages and disadvantages of using a COTS smartphone to collect trip information and assess mileage-based user fees. For a number of reasons both user- and technology-related, participants felt that in some cases trip information was not captured, and in other cases, that the technology captured more miles than the participant traveled. In both instances the user would be charged more than they should; if the device does not capture all of the user's miles, the missing miles are assessed at the higher rate. Conversely, if the device records too many miles, users are charged for extra miles which they did not travel. To mitigate this issue, future research and development must be conducted to review and establish GPS performance issues, add programming strategies to account for lost mileage due to GPS connection issues, and ensure that the platform used is stable in various climates. Further, more testing must be done on the user end to ensure that the device can be operated without issue by the general public.

7.3 Data Practices

At its inception, MnDOT and the project team were very concerned about developing policies and procedures that would ensure the privacy of test participants. This is evident in the study procedures used, but also in the software development requirements of the test. Specifically, criteria were established that would create a firewall between data collected and accessed by the study team (which included GPS location data) and the information that was accessible to MnDOT and the deployment team (as described below and in Volume II).

Generally, participants demonstrated clear awareness that they regularly provide data about themselves to many entities already, including the State, vendors and online businesses, mobile phone companies, social media, location based applications like mapping software, and others. Sharing private data was not the issue in their minds. Rather, they were concerned about the ability of the State to *secure and protect* this information. User privacy is a major concern when considering any type of application that uses driver behavior to perform a function or provide a service (in this case, tally mileage and present opportunities for safety and travel time data to be presented to drivers). To protect participants' privacy, the study team did not have the ability to link a specific trip to an individual participant unless the participant explicitly granted researchers permission by selecting an option within the MBUF application on the smartphone. For participants who elected not to share trip information, researchers could still assess the number of miles driven in each of the rate categories over a given 24-hour period, but the participant's trip data (i.e., second-by-second location data) could not be associated with the individual participant. Most participants opted to share their information for the test even though many admitted that they might not be comfortable doing so outside of a study.

The study team specifically did not ask about “privacy” early in the test as the team did not want to draw participants’ attention to privacy issues if they did not already have concerns. While participants were not asked any privacy-related questions during the three surveys, each participant was offered a telephone interview during which privacy was addressed, and the focus group sessions (also held at the end of the study) included a topic on privacy. During both the focus group sessions and the one-on-one telephone interviews, the interviewer asked the participants whether the technology used in the test caused them any privacy concerns when thinking about a real-world deployment of MBUF. If privacy concerns were expressed, the interviewer explored to understand whether these concerns were specific to the smartphone or whether they were concerns that apply to a technology solution in general.

Interestingly, participants in the MRFT were not concerned about privacy per se. Generally, they demonstrated clear awareness that they regularly provide data about themselves to many entities already, including the State, vendors and online businesses, mobile phone companies, social media, and location based applications. Sharing private data was not the issue in their minds. Rather, they were concerned about the ability of the State to *secure and protect* this information from others with harmful intentions. For example, during a discussion on security in the focus groups, participants indicated that they would prefer that application show in some way that their information is secured. Specifically, participants brought up the example of online shopping and that while they do not understand how their information is secured, they understand that when shopping online, they should look for the Hypertext Transfer Protocol Secure (HTTPS) to ensure that the vendor is properly securing their personal information.

Of the 423 participants interviewed, 32 percent noted that they had concerns about user privacy while 65 percent indicated that they did not Many participants noted that they have “nothing to hide” as a reason why they do not have any privacy concerns regarding this type of technology. During the interviews, researchers asked participants if they had discussed their participation in the test with family and friends, and if so, what some of the main topics of discussion, reactions, or concerns were. Of the 423 participants interviewed, 21 percent responded that major concerns noted by family and friends included the topic of user privacy.

Although participants shared a number of concerns with the team regarding the smartphone itself (e.g., accuracy, reliability, etc.), privacy was not among them. While the results of these interviews may seem surprising when reviewing previous publications, these interviews took place at the end of the test, when participants had been using the smartphone for approximately 4 months, likely indicating that experiencing a technology solution first-hand can mitigate many of the reported privacy concerns of the public. The recruitment screener did discuss participant privacy, so it may be possible that potential participants with strong privacy-related concerns did not join the study.

Further, participants concerns' regarding privacy were not necessarily related to the fact that their trip data were captured, but were more in line with (1) how a mileage-based fee program would be implemented, (2) who is receiving this data, and (3) how can the public be ensured that the data will be kept safe.

When discussing privacy, focus group participants indicated that they did have an understanding that location data is, or could be, captured through the use of their personal mobile phones. However, owning a mobile phone is something the participant could end using at any time. An MBUF program mandating that the driver use a technology that tracked their trips would cause more unease than a program drivers could opt into.

Another concern voiced by focus group participants was how collected trip data would be used. Participants indicated that while they believe and would like their trip information to be used to better assess what roads should receive infrastructure improvements and additional maintenance, they would not like their trip information being shared with private companies that could profit from the information.

Lastly, the safety of trip data was a two-fold concern of participants during the test. First, participants noted that they would like to be assured that their data would be protected from individuals who may be able to compromise the system to use the data for malicious purposes. Second, participants indicated that they would need to be assured that there would be no way to tamper with the smartphone in order to "cheat" the system and pay less than they were supposed to. A selling point of a mileage-based fee program to many participants is that it allows the State to assess road usage more accurately; if it was perceived that individuals could exploit the system, it would devalue this selling point.

7.4 Costs to Administer and Operate

Two components critical to a successful mileage-based fee program would be the administrative and operational aspects of the program. The overall goal of any mileage-based fee program would be to generate additional revenue to support State and local transportation infrastructure. For this type of program to be successful, the program would have to consist of lean and low-cost processes to ensure that the maximum amount of revenue generated could be applied to the infrastructure in need. Additionally, a mileage-based fee program would require interaction with the traveling public (e.g., invoicing), and thus would require a customer service component. This section discusses participant input on these and other operational aspects of a mileage-based user fee program.

In order to maximize the amount of revenue applied to infrastructure, the cost to operate the program would need to be minimized. While the participants were not directly questioned on their opinions about the cost of operating a mileage-based fee program during the surveys, participants often volunteered their thoughts on this topic during the focus group and interviews. Administrative costs were one of the major concerns voiced by many of the participants during both the interviews and the focus groups. Many participants felt that due to bureaucratic inefficiencies, it would be too costly to implement a mileage-based user fee at the state level. Of the 200 respondents who indicated that they would prefer the fuel tax over a mileage-based fee, 27 percent indicated that the invoicing process for a mileage-based fee program is a major concern of theirs. These participants discussed invoicing from numerous angles. Primarily, many of the participants preferred the fuel tax because it removed the invoicing component of the mileage-based user fee. These respondents generally felt the fuel tax was cost effective because it removed the overhead associated with sending invoices, processes invoices, collecting late payments, and enforcing violators.

However, some participants did offer up ways to mitigate some challenges of invoicing and billing. For instance, a participant during the focus groups mentioned that the state should consider a program where the users “pre-fund” their account and the program automatically deducts from this amount as they drive. Once the user’s account level reaches a critical amount, additional funds are requested. This method would assist in reducing the number of non-paying users as well as remove the hassle of “having to pay another bill” at the end of the month.

Further, uncertainties as to how a mileage fee program would be implemented also concerned participants. Some questioned whether the state would issue the hardware or the public would be required to purchase the hardware. If these features would come standard in new vehicles, participants questioned how older vehicles would be retrofitted.

7.5 Customer Service

Customer service is a critical component to the end user experience on a mileage-based fee program, especially if technology is used to track participant trips. During the focus groups, participants indicated that for a mileage-based fee program to be a success, it would have to have dedicated customer service personnel to assist the public with any issues. Respondents also expressed uncertainties about enforcement for a mileage-based fee program, with a common question being, “if in the real world my device was malfunctioning, would that mean I would not be able to drive until it was fixed?” On the same topic, if a smartphone or other hardware was used to track trips, how would the participant ensure that the smartphone was functioning properly? Waiting until the end of the month each month to receive an invoice to find out that the device was not working properly would be frustrating to the user. In this case, the user would require a mechanism to dispute the charge, and again this would require additional staff and costs to the State to operate.

7.6 Value-Added Services

As demonstrated in the MRFT, the deployment of an MBUF using in-vehicle technology provides MnDOT opportunities to improve safety and mobility on the roads through the use of in-vehicle safety alerts. Participants in the MRFT did not necessarily understand or appreciate the combination of MBUF and in-vehicle signing. However, to maximize participant exposure to the safety alerts during the test, participants had little choice to when, where, or what safety alerts they would experience. In a real-world application, the ability to allow flexibility to where users could tailor these alerts to their own driving style may increase user acceptance. For example, while in the MRFT a participant may travel through the same safety zone multiple times a day or week and each time receive an alert. While this repetition was useful for the both the deployment and study teams, it may not have been as useful for the participant as over time they would be accustomed to the characteristics of the location and would no longer require the alert. If in the real-world users had the ability to determine areas where they would and would not receive the alerts, it is likely that they would have found more utility in the function. Further, the involvement of an in-vehicle technology to implement an MBUF, the State is opening avenues for additional and currently unknown opportunities for interacting with the traveling public to improve driver safety.

Further, in-vehicle technology offers MnDOT the chance to provide wider coverage of and more precise travel time data to assist drivers in real time. Since participants did not actually receive travel time data via their smartphones, it was difficult to fully assess their reactions to it. In focus groups meetings, some participants expressed they do use traveler information to commute, and would be interested in better information. However, many drivers do not commute, and while they could imagine the usefulness of the information, it was not personally relevant. Thus, improved traveler information probably only is a “selling point” to certain segments of the population.

7.7 Road User Fees

One of the objectives of the MRFT was to determine if individuals will accept MBUF as a new revenue concept. Results from the MRFT are promising with many individuals acknowledging that they actually prefer an MBUF fee rather than the fuel tax. Further, there were a subset of individuals in this test that did not state a preference of either an MBUF or the fuel tax, and given time and experience these individuals could ultimately be swayed to prefer an MBUF.

However, because of the many uncertainties still surrounding MBUF (e.g., what device would be used? How would out-of-state drivers be handled?), participants want to see how an MBUF would work in the real world. As more States begin to research and implement MBUF programs and the public become more familiar with the operation of such programs, many of these questions will be answered. Other participants in this test do not currently see the need for an MBUF program, but many of these reasons could be considered short-sighted (e.g., “it will be years, if ever, before hybrid vehicles achieve enough market penetration to affect the fuel tax”), or only a temporary fix for a longer term issue (e.g., “if the State requires additional funding, why not just raise the fuel tax?”). With continued research, education, and demonstration, this test shows that the public could begin to understand and possibly accept that an MBUF is an effective strategy for addressing potential transportation revenue shortages.

Volume IV: Assessment of Impact of MBUF on Driver Behavior and Revenue

1 Introduction

The intent of mileage based user fees (MBUF) in the present demonstration was to generate revenue comparable to the fuel tax. While this sounds like a simple exercise, it actually has many complexities associated with identifying the appropriate fee amounts and pricing schemes to ensure comparable revenue while accounting for driver reaction to the test system and pricing structure. There are many different approaches that might have been taken in designing an MBUF approach. However, the approach selected in Minnesota for this demonstration created a high level of transparency for participant drivers. These drivers had a great deal of opportunity for insight into how the system assessed fees through access to a location and time-based pricing structure and feedback through the smartphone interface, website portal, and invoicing. They also might have experienced increased awareness of their driving behavior and its effect on their personal finances compared to the fuel tax.

The pricing structure selected for the MRFT was but one of many that could be determined through policy debates within Minnesota, but in its most simple interpretation it demonstrates an effort to provide comparable revenue as would be assessed in the MN fuel tax. Thus, this volume will describe the amount of "revenue" assessed through this one prototypical pricing structure with the understanding that this structure was for demonstration purposes only and could be changed based on different transportation objectives.

Because pricing can be anything that policy dictates, looking at the final "revenue" value is not terribly useful. Thus, this volume will focus more on describing how important it is to understand the driving population in determining such a structure, and to look at the complex interactions of a transparent system and pricing structure with individual driving behavior. The intent of mileage based user fees (MBUF) in the present demonstration was to generate revenue comparable to the fuel tax. While this sounds like a simple exercise, it actually has many complexities associated with identifying the appropriate fee amounts and pricing schemes to ensure comparable revenue while accounting for driver reaction to the test system and pricing structure.

It is likely that drivers might change their driving behavior to some degree under a mileage-based user fee scenario. Depending on how a state or locality structured the fee, this could include changes in how many miles drivers travel, when they travel, and how many trips they take. Understanding the impact on travel of various fee structures is necessary to accurately project revenue from an MBUF program. This information would also inform policy decisions about various fee structures (Would congestion pricing be effective? How much would it reduce travel in peak periods?).

Specific policy decisions would influence how and to what extent MBUF would affect travel behavior, including:

- How the system is implemented (i.e., if fees are tallied via a real-time system that collects and displays information to the driver, if fees are simply assessed through an odometer reading, or if drivers are given a choice between these options).
- The fee amount relative to how much a motorist might otherwise pay under the fuel tax (or how much the fee is independent of the fuel tax if the fuel tax remains in place in parallel with MBUF).
- How the pricing scheme is structured (i.e., whether the fees vary based on time of day, geographic region or jurisdiction, facility type, etc.).
- The way in which the fee is presented to the driver and how this affects their perception of cost (e.g., costs indicated on their gas pump receipts may be more or less salient than an annual registration fee).

Even in the absence of any of these factors, simply paying a fee based on miles driven rather than based on gallons of gas used can impact travel behavior as drivers become more aware of how many miles they drive and how many trips they make. The recent Portland, Oregon MBUF study found that participants who were assessed a different fee based on zone and time of day made changes in their travel patterns including: driving less often during the peak periods (and more often during the "shoulder" periods immediately before and after the peak periods), shifting to other modes such as public transit, driving outside of the "congestion zone" to avoid higher fees, and making fewer trips in general. The Portland study also found that the group charged a flat per-mile fee that was equivalent to what they would have paid under the gas tax model reduced total miles driven by 12 percent.[1]

Additionally, an evaluation goal of the Minnesota Road Fee Test was to investigate the mobility impacts of the system implemented, focusing on an assessment of the impacts associated with the MBUF functionality. Since policy decisions about how MBUF would work in Minnesota were not specified prior to the MRFT, various test designs were considered before the MRFT approach was selected for the pilot study (as presented in Volume I, Section 2 and described below):

[1] Whitty, J.M. "Oregon's Mileage Fee Concept and Road User Fee Pilot Program." Salem Oregon Department of Transportation, (2007).

- MRFT participants had the option to “opt-in” or “opt-out” of using the smartphone and the MRFT application to have their miles captured and corresponding fees assessed. Any miles not captured by the device were assessed at their final odometer reading.
- The fee structure used in the field test was designed to match the fuel tax in Minnesota as closely as possible, using daily miles driven by participants in the baseline period to estimate expected daily miles driven in the test period.
- While the MBUF system demonstrated the ability to assess fees based on various factors (geography, road type, time of day, and day of week), participants paid fees based on miles in four categories: (1) Non-Minnesota miles - $0.00 per mile, (2) Minnesota miles – $0.01 per mile, (3) Twin Cities-Peak miles - $0.03 per mile, and (4) “Non-Technology” miles - $0.03 per mile. The higher rate for miles driven during peak periods in a higher congestion area was implemented to test congestion pricing as a strategy to reduce peak period congestion.
- The MBUF rate and accumulated fee were presented to MRFT participants in multiple ways. The MBUF rate was displayed to participants on the smartphone during the test period while a trip was underway. Additionally, participants could view information about their total fees on a menu in the MRFT application or in their invoices detailed on the Participant Portal.

Volume III of this report presented user perceptions and feedback on the MRFT system implemented as well as the overall MBUF concept. This volume focuses on the driving and payment data: the number of miles driven, the amount of fees paid, the number of trips made, and the demographics of the participants involved in the study. The results of the study as they relate to the test design above are presented by comparing driver behavior during the baseline period (during which no MBUF rates were shown, no fees were assessed, and no invoices were paid), to the test period, during which participants experienced a simulated real-world MBUF program involving each of those activities. Findings are organized based on the three types of analyses performed to further investigate the mobility impacts of an MBUF program:

- Driver response to the MBUF Concept,
- Driver response to Fees and Congestion Pricing, and
- Revenue Comparison between MBUF and Fuel Tax.

In summary, this volume **assesses travel choice** in terms of number of trips, number of miles, and the corresponding fee for any indication of driver response or behavior change resulting from exposure to the MBUF concept and its various elements.

2 Driver Characteristics

Driver characteristics were presented in Volume III, Section 2. With respect to mobility, factors such as age, gender, or income could affect a driver's response to an MBUF program. Additionally, a driver's commute pattern is an important factor to understand when considering a behavior change related to MBUF. Commute miles may or may not account for a significant portion of a driver's total miles, and commute direction, distance, and flexibility may influence the way a driver responds to an MBUF program. These driver characteristics are presented below and are referenced throughout this volume to investigate potential differences in behavior change based on these pre-existing factors.

2.1 Participant Demographics

Figure 34 below presents the three primary demographics collected prior to the start of the field test during participant recruitment. As presented in Volume III, 46 percent of participants were men and 54 percent were women. The average age of drivers was 52 years of age (SD=8), and there was no significant difference in age between men and women (p=0.43). Nearly half of participants (48 percent) fell into the highest income bracket at $75,000 and above. It should be noted that, because the overall number of participants in the lowest income group (less than $35,000) made up only 6 percent of all participants, it will be difficult to detect statistical effects related to income.

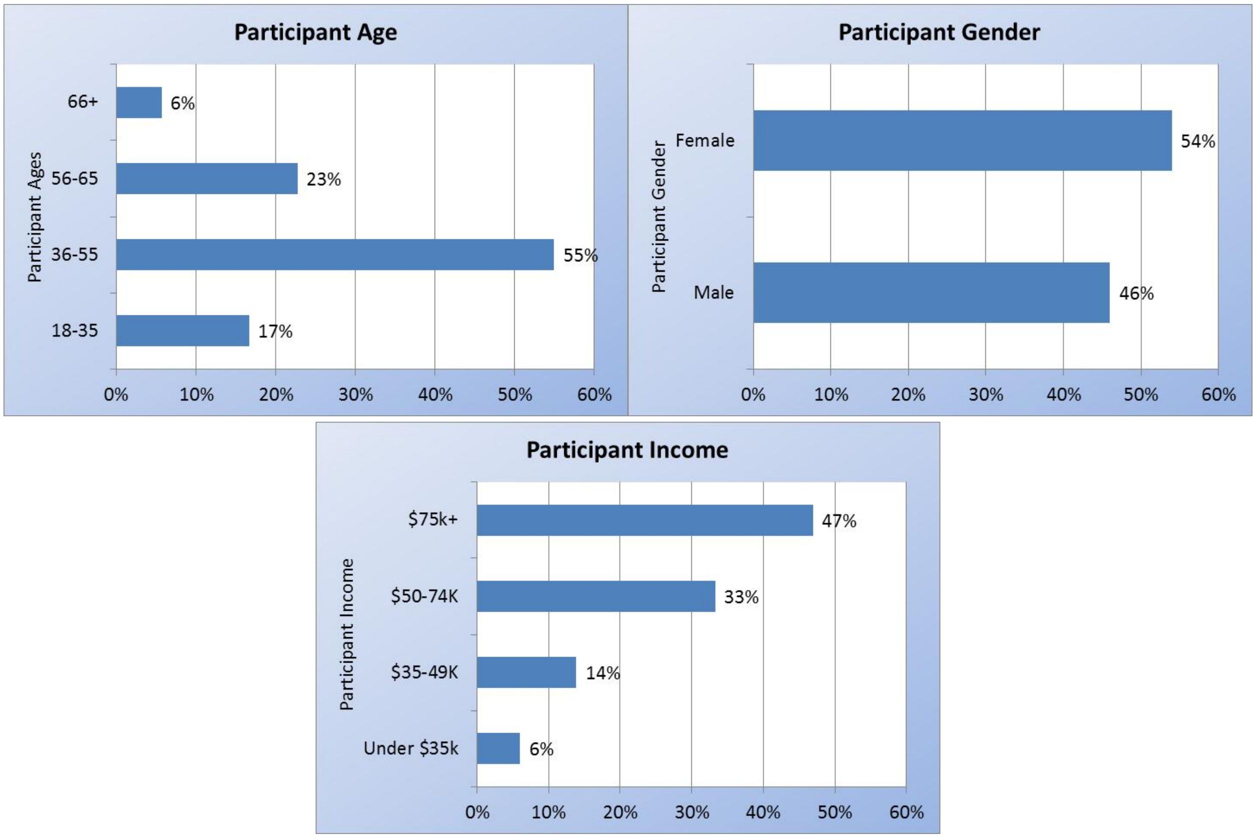


Figure 34. Participant Demographics - Age, Gender, and Income

Volume III detailed several ways demographics might affect participants' opinions including:

- Gender and age effects in relation to technology acceptance and use
- Income level effects in relation to feelings toward an MBUF program.

These same demographic effects could influence participants' travel behavior and are considered in the sections that follow.

2.2 Participant Commute Patterns

As reported in Volume III, Section 2, participant driving patterns varied considerably from person to person. Seven percent of participants indicated that they commute 1 to 2 times per week, 54 percent indicated that they commute 3 to 5 times per week, 15 percent indicated that they commute 6 to 7 times per week, and 24 percent indicated that they do not commute at all. For those who did commute, commute distance, direction, and length of commute (in time) were important factors for the study team to consider due to the congestion pricing element of the field test. The fee assessed for miles driven depended first on whether participants were in the State of Minnesota and second on whether they were in the Twin Cities metro area during a peak period. The Twin Cities metro area was defined by the "Metro Zone" boundary (as described in Volume I, Section 2.2), and the peak periods were defined as Monday through Friday, 7:00am-9:00am and 4:00pm-6:00pm. Therefore, with respect to participant commutes, it is important to understand participants' general home and work locations relevant to the "Metro Zone" boundary where a higher MBUF rate was assessed. Figure 35 below presents the home and work locations for all MRFT participants (also presented in Volume III, Section 2.2). The scaled black dots on the figure indicate the number of participants that live within each of the zip code boundaries inside Wright County, while the shaded colors indicate the number of participants that work within each zip code boundary identified on the map.

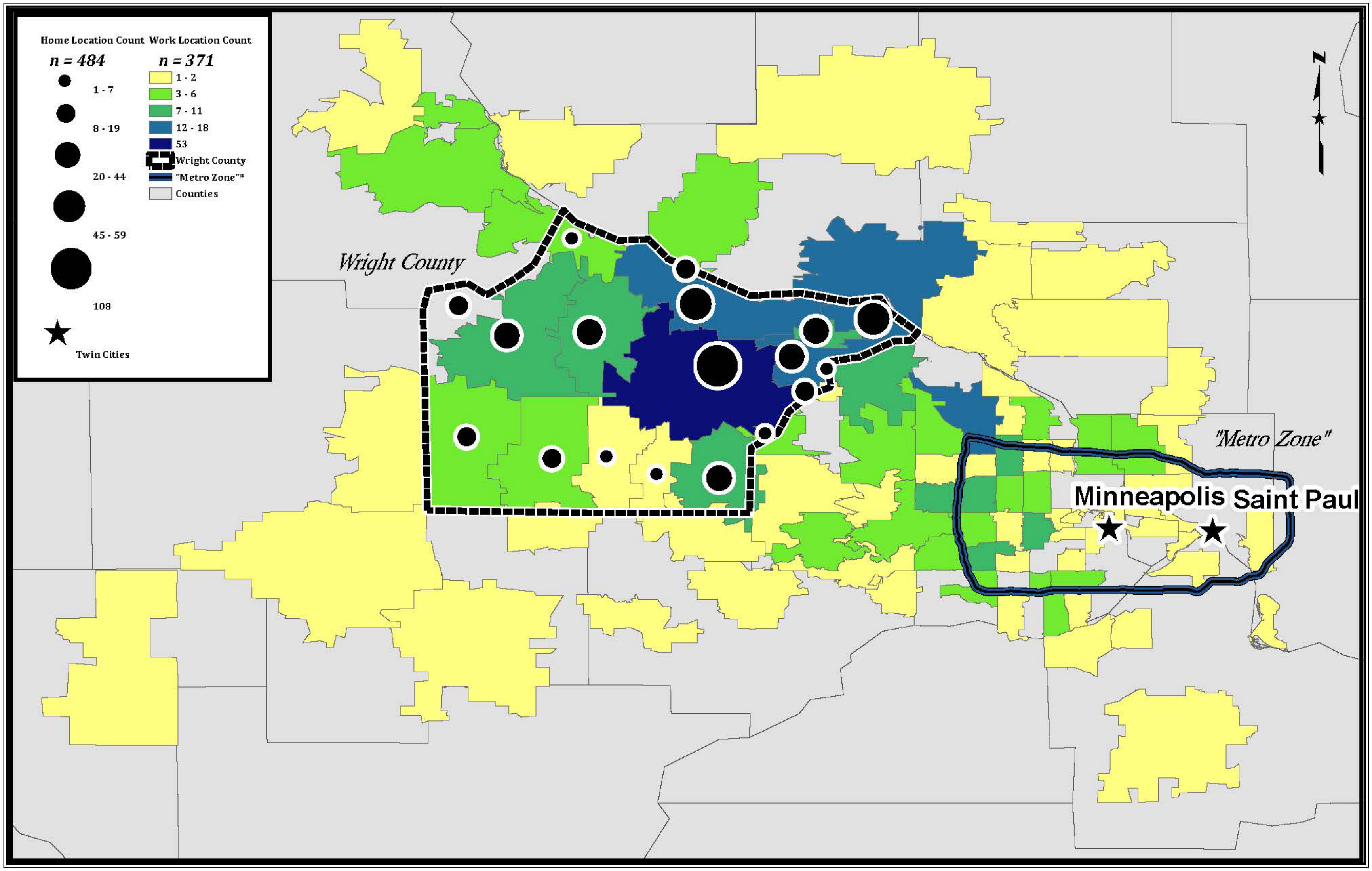


Figure 35. MRFT Participant Home and Work Locations.

For regular commuters, commute miles can represent a significant portion of the total miles driven over the course of a year. Therefore, considering participants' typical daily commute distance provides insight into whether or not behavior change was impacted by commute behavior. For those who reported a regular commute (i.e., generally to the same work location, more than one day per week), Table 37 below presents a breakdown of participants by daily commute distance.

Table 37. Participant Commute Distance (n=371).

Daily Commute Distance (miles)	Count of Participants (Percent Total)
1 – 10	108 (29%)
10 – 20	76 (20%)
20 – 30	79 (21%)
30 – 40	59 (16%)
40 – 50	31 (8%)
50 or greater	18 (5%)

Due to the congestion pricing element of the field test, commute direction is another interesting factor to consider. Figure 36 through Figure 41 on the following pages provide maps showing the general direction in which participants commuted by connecting their home ZIP code to their work ZIP code. Note that, because work ZIP codes were requested rather than addresses in order to protect privacy, and because participants' actual commute routes are unknown, the commute direction maps only provide a visual for how far and in what general direction participants commuted.

The color of the line corresponds to the number of participants that travel between the two zip codes, providing insight into commute patterns of the MRFT participants. While 371 participants are represented in the table above, it is important to note that only 289 participants are represented in the figures below due to the fact that a number of participants commuted within the same zip code, which is not represented in the figures. Due to the distance between Wright County and the Twin Cities Metro Area, very few participants with short commutes (less than 20 miles) crossed into the "Metro Zone" during their commute (only 2 participants). For participants with longer commutes, nearly 100 participants commuted into or through the "Metro Zone" as part of their regular commute.

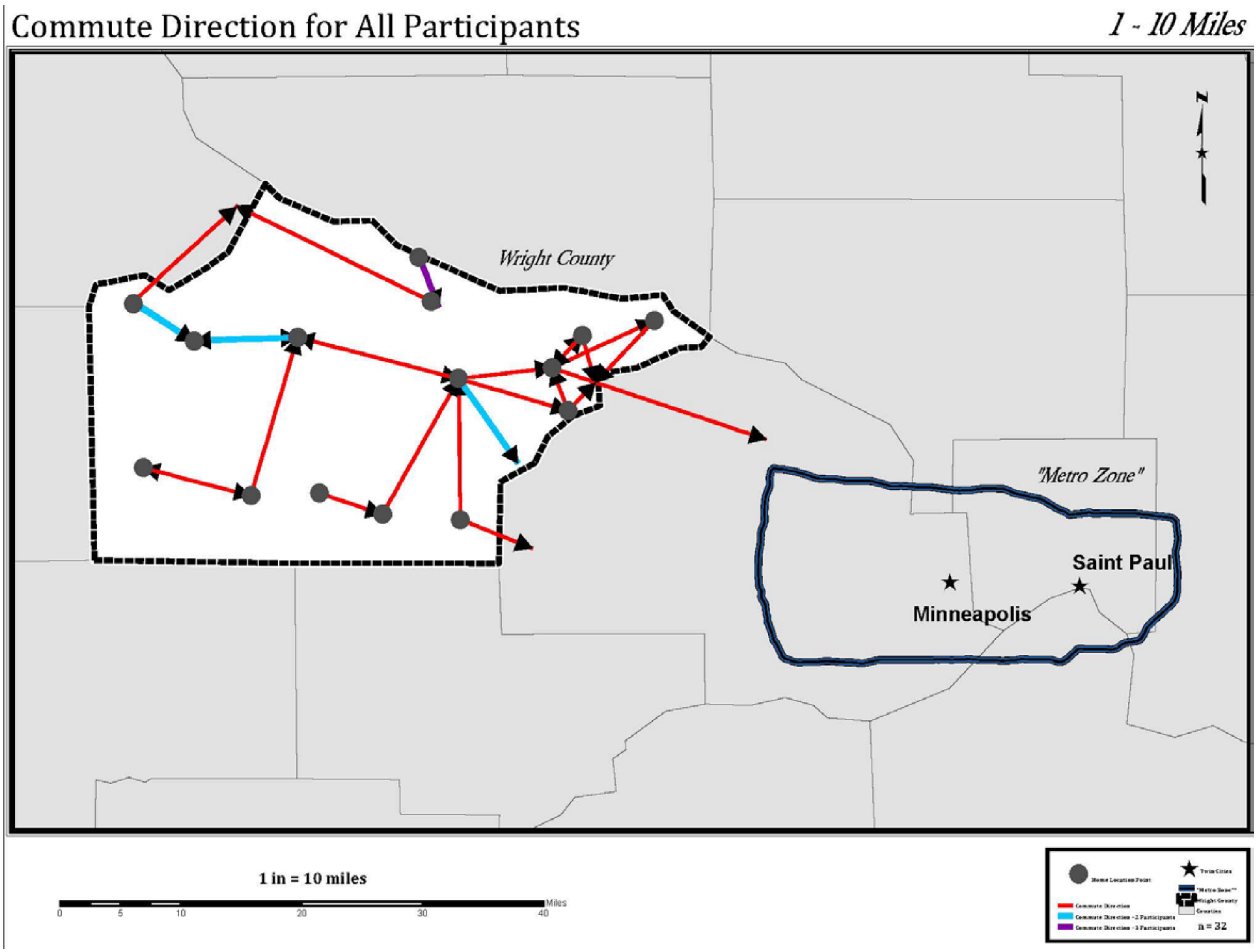


Figure 36. Commute Direction for MRFT Participants – 1-10 Miles.

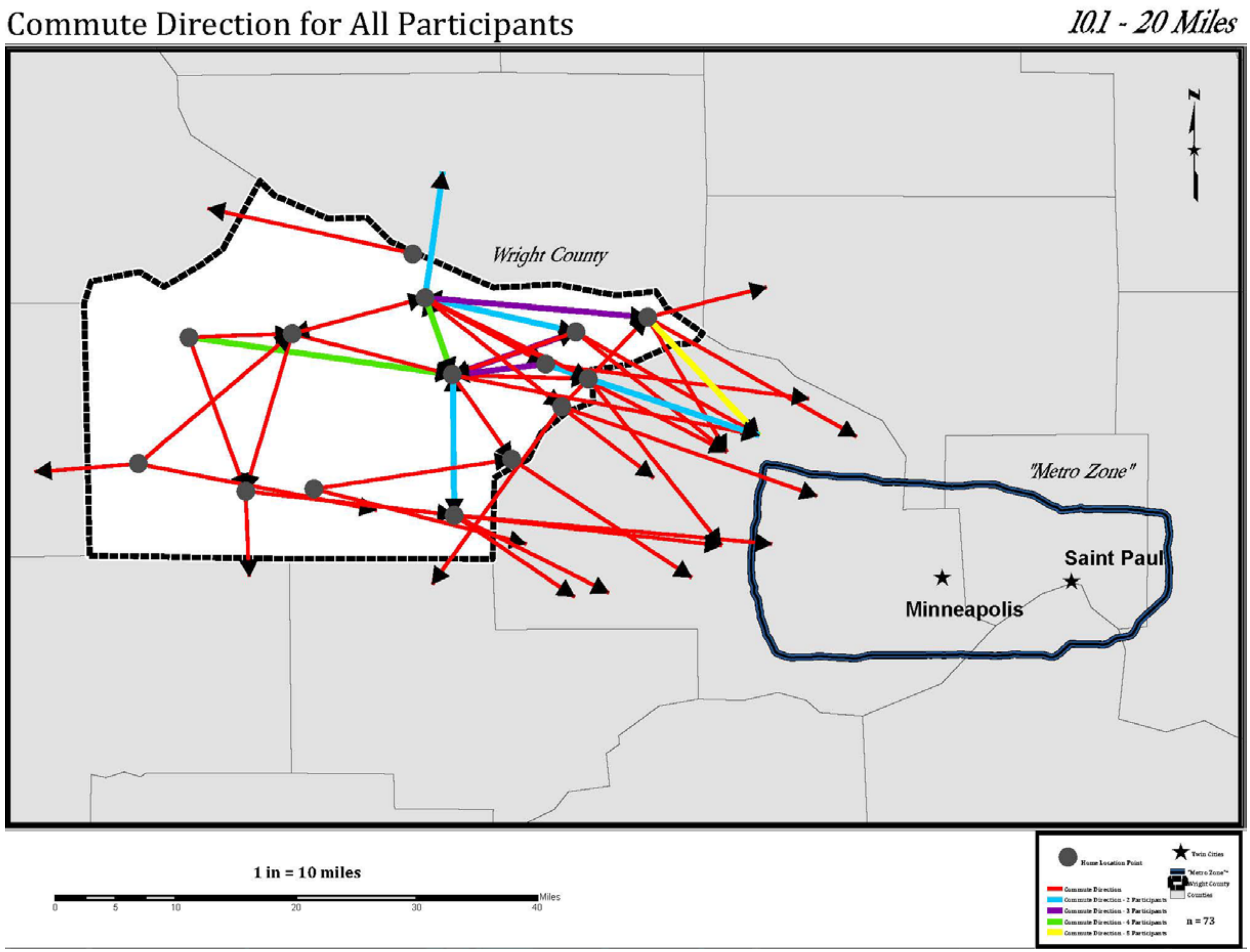


Figure 37. Commute Direction for MRFT Participants – 10-20 Miles.

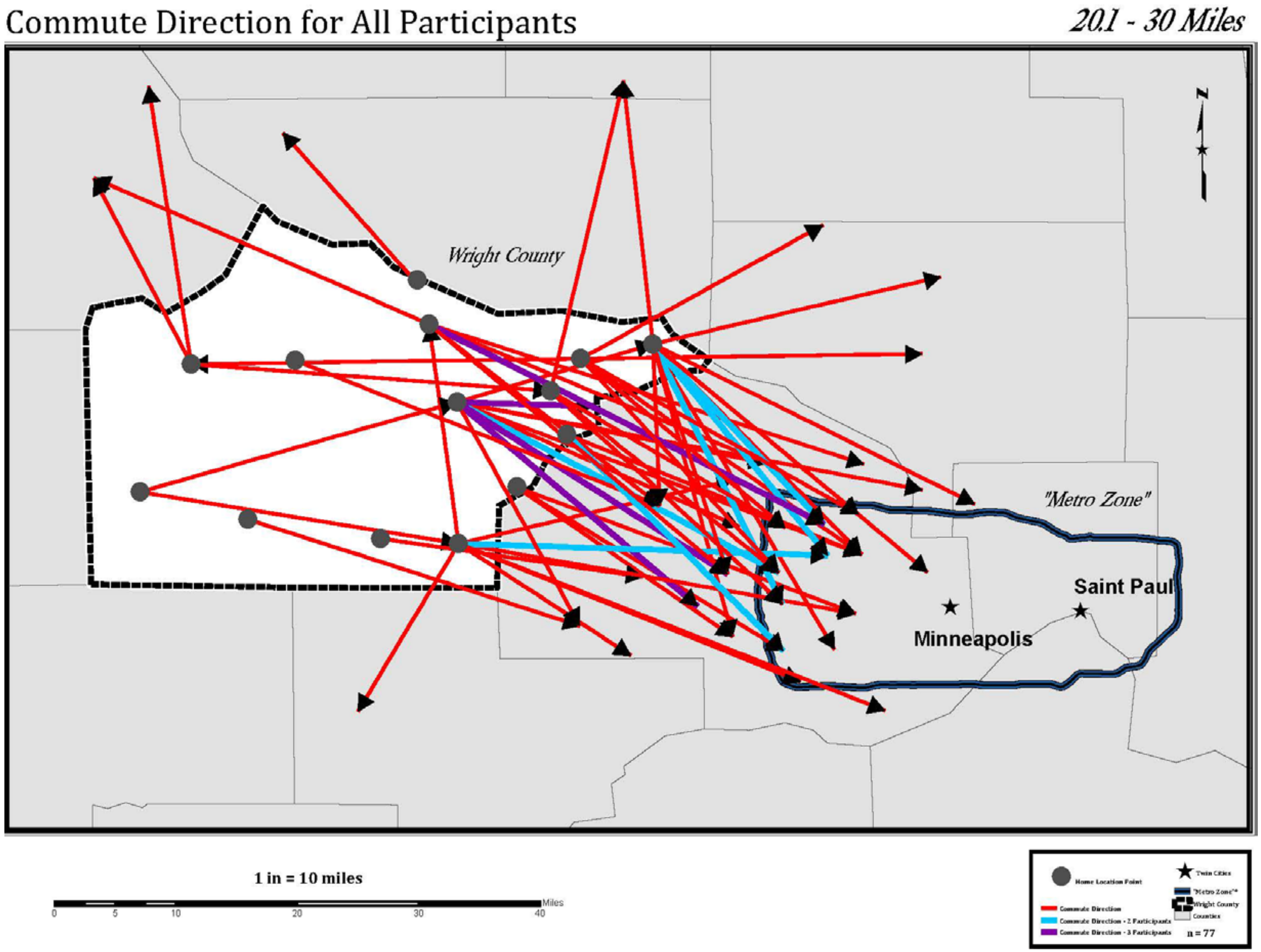


Figure 38. Commute Direction for MRFT Participants – 20-30 Miles.

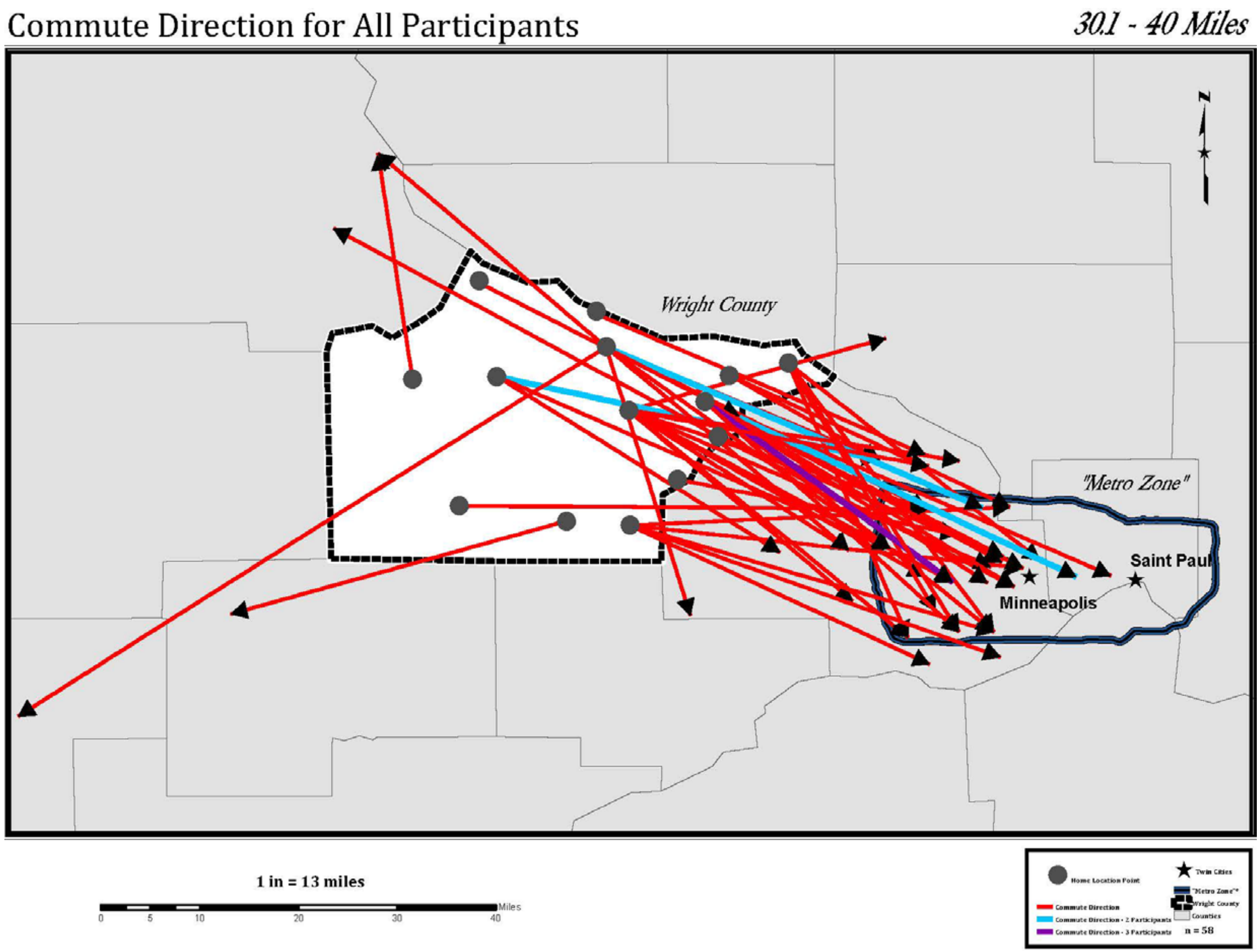


Figure 39. Commute Direction for MRFT Participants – 30-40 Miles.

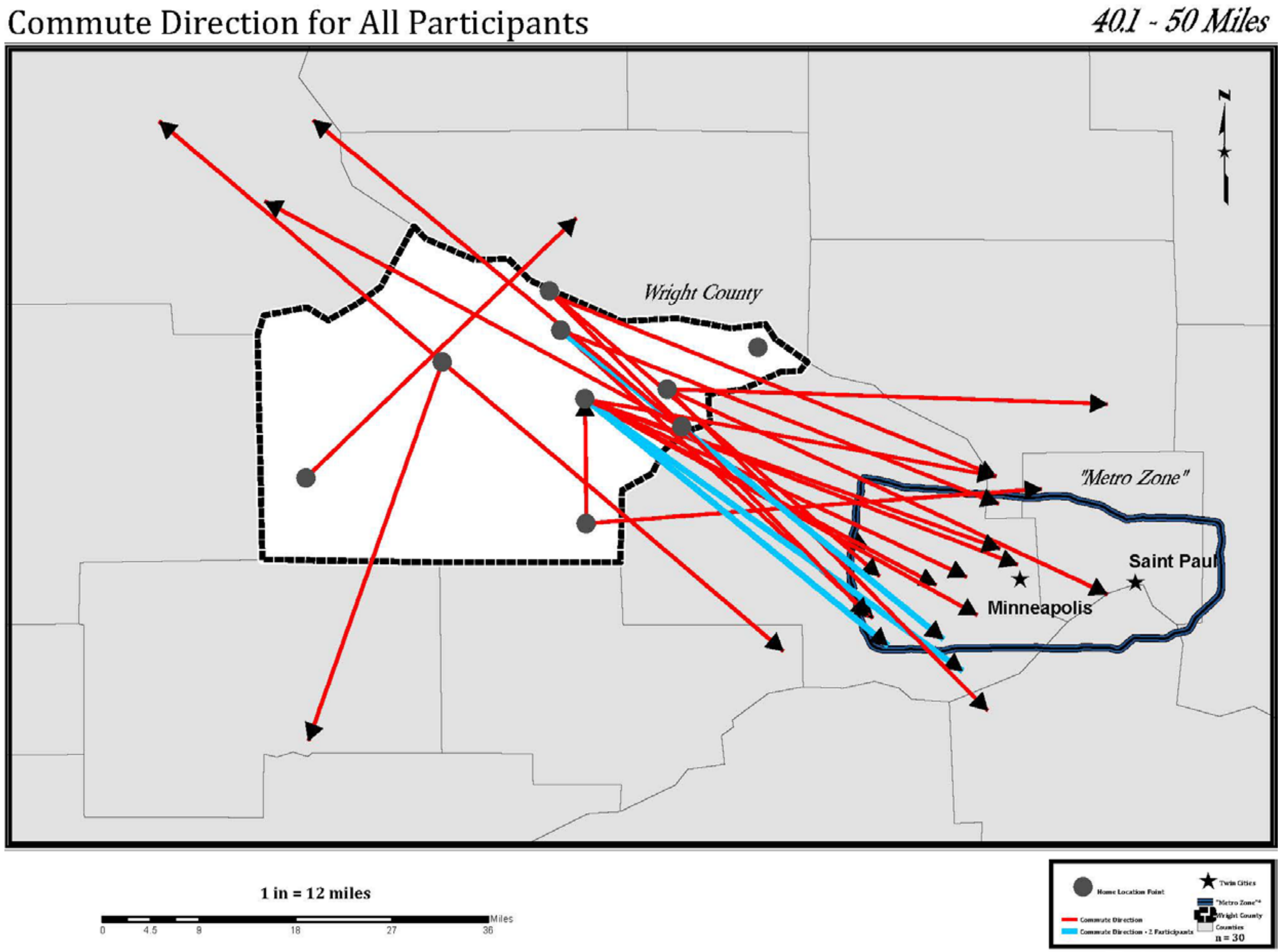


Figure 40. Commute Direction for MRFT Participants – 40-50 Miles.

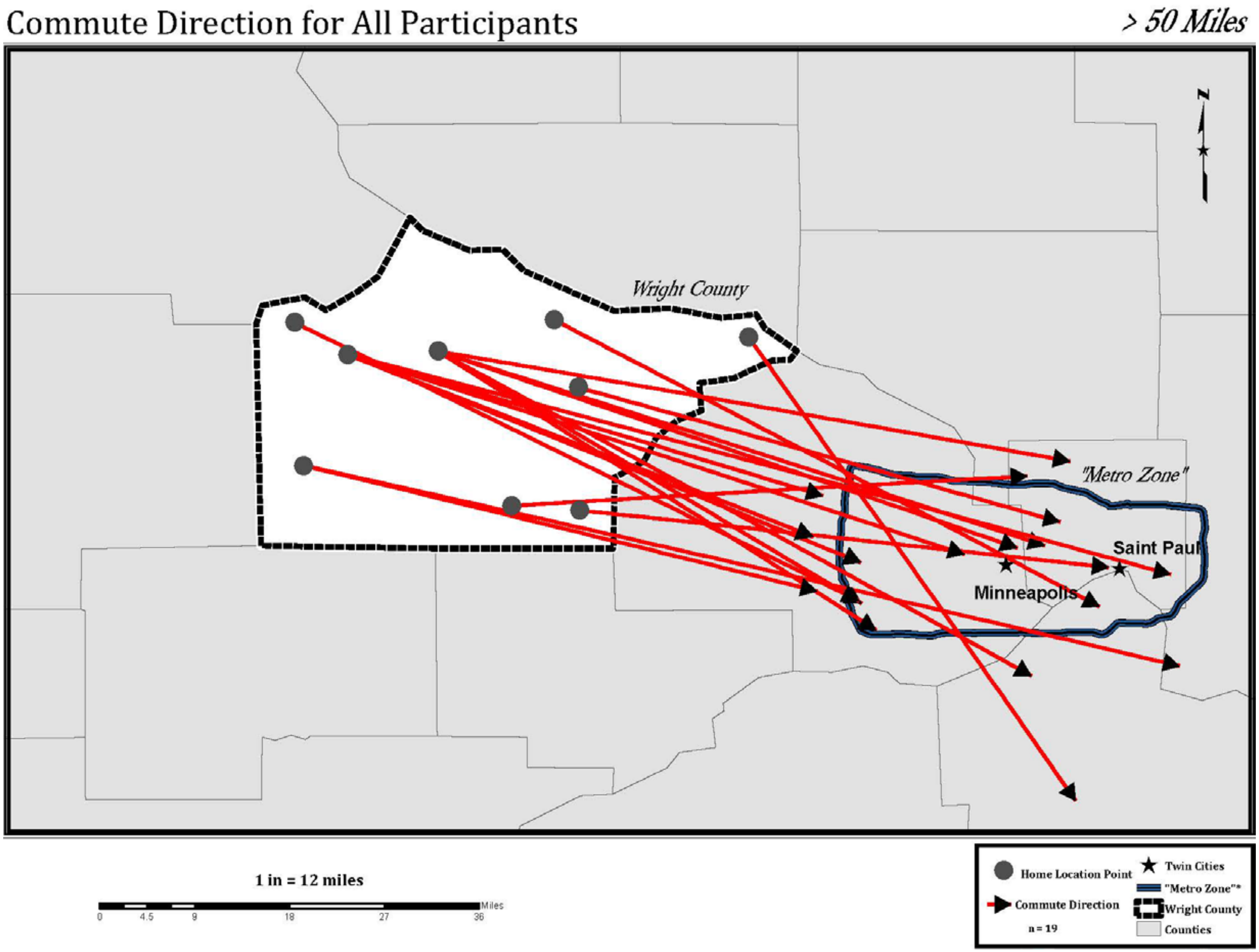


Figure 41. Commute Direction for MRFT Participants – Greater than 50 Miles.

3 Driver Response to MBUF

The design of the Minnesota Road Fee Test split participants' involvement into baseline and test periods, allowing for the comparison of a "before" condition to an "after" condition. During the baseline period, participants were simply asked to bring the smartphone and use the MRFT application for all trips taken over the course of 2 months. Then, during the test period, participants were exposed to the MBUF concept through the display of the current MBUF rate on the MRFT application during all trips, and were assessed fees for miles driven by fee category at the end of each month. Despite the difference in participant experience between the baseline and test periods, the same data was generated and collected with respect to number of trips taken and number of miles driven by fee category for both the baseline and test periods. Comparing the data collected in the "before" condition to that collected in the "after" condition provides insight into driver response to the MBUF concept implemented in the test period and any resulting behavioral change.

Two primary metrics related to the MBUF concept provide insight into driver response. First, the change in the average number of miles driven by day between the two conditions may indicate that a driver became more aware of the number of miles they drive as a result of being in the test or as a result of seeing fees in real-time on the smartphone. Furthermore, since a cost element was introduced with variable fees (i.e., drivers were charged by the mile and charges were higher in the Metro Zone during peak periods), changes in miles driven within the higher-rate fee categories could indicate that drivers were more aware of when/where they drove and made adjustments accordingly to reduce their fees.

Second, whether a change in mileage and fee is observed or not, trip characteristics may provide further insight into driver response to the MBUF concept. As discussed in Volume II, the MRFT system allowed participants to review details of their trips taken. This feature may have made some participants more aware of the total number of trips they make, as well as the length of their trips. Changes in trip characteristics between the two conditions, such as trip length, may indicate a driver response to the MBUF concept. Driver response to the MBUF concept is presented separately by each of the two metrics in the sections below.

3.1 Change in Mileage Captured and Fee Assessed

In considering driver response, what follows is a summary of the MBUF data captured during the field test, followed by a breakdown of the mileage captured by the participant demographics, and commute distance presented in the previous section.

3.1.1 Summary Statistics

Table 38 and Table 39, below, present a summary of the captured mileage for all participants during the baseline and test periods as well as overall. There appears to be a negligible difference between the baseline and test periods in terms of miles captured by the device, with miles driven in Minnesota representing 93 percent of total device miles. As first presented in Volume II, "non-technology" miles accounted for 24 percent of the total miles driven and represented 48 percent of the total fee collected in the test period. The reason the non-technology miles accounted for such a high percentage of the total fee collected was that there were issues with the device that were not apparent during the course of the test. As a result, many drivers had miles driven that were not accounted for on the device, for which they had to pay at the higher "non-technology" rate of $0.03 per mile at their final odometer reading.

As shown in the tables, a comparison of the total miles captured by the field test (i.e., device miles plus "non-technology" miles) yields a higher number than the total odometer miles recorded at the three odometer readings conducted during the field test, an overage of 2.8 percent in the baseline and 1.9 percent in the test period. This, as presented in Volume II, is the result of participants who experienced their devices collecting more miles than the odometer on their vehicles, pointing to possible system accuracy issues. Volume II of this report and the deployment team's report address the system accuracy issue of device miles being double-counted during the field test, which explains the overages presented in the table below.[54]

Table 38. Summary of Mileage Captured during Field Test.

Metric	Baseline	Test	Total
Average Days in Test (Percent of total days)	62 (34%)	118 (66%)	180 (100%)
Non-Minnesota Miles (Percent of total device miles)	32,144 (3%)	68,335 (3%)	100,479 (3%)
Minnesota Miles (Percent of total device miles)	1,019,241 (93%)	1,767,657 (93%)	2,786,898 (93%)
Twin Cities-Peak Miles (Percent of total device miles)	44,064 (4%)	72,238 (4%)	116,302 (4%)
Device Miles (Percent of total miles captured)	1,095,449 (77%)	1,908,230 (76%)	3,003,679 (76%)
"Non-technology" Miles (Percent of total miles captured)	324,116 (23%)	599,559 (24%)	923,675 (24%)
Total miles Captured = Device + "Non-technology" miles	1,419,566	2,507,789	3,927,355
Total Odometer Miles	1,379,433	2,461,321	3,840,754
Percent Difference	2.8%	1.9%	2.2%

[54] Battelle Memorial Institute, *Operations Summary Report for the Minnesota Road Fee Test*, Prepared for MnDOT, February 2013.

Table 39. Summary of Fee Assessed during Field Test

Metric	Baseline*	Test	Total
Non-Minnesota fees – $0.00/mi (Percent of total device fees)	-	-	-
Minnesota fees – $0.01/mi (Percent of total device fees)	$ 10,192 (86%)	$ 17,677 (89%)	$27,869 (89%)
Twin Cities-Peak fees – $0.03/mi (Percent of total device fees)	$ 1,322 (11%)	$ 2,167 (11%)	$ 3,489 (11%)
Device fees (Percent of total fees captured)	$ 11,514 (54%)	$ 19,844 (52%)	$31,358 (53%)
"Non-technology" fees – $0.03/mi (Percent of total fees captured)	$ 9,723 (46%)	$ 17,987 (48%)	$27,710 (47%)
Total fees captured = Device + "Non-technology" fees	$ 21,238	$ 37,830	$59,068

*Note – No fee was collected during the baseline period. Values presented in the table above in the Baseline column represent what would have been assessed had the MBUF functionality been active.

It is important to note that the dollar values provided in Table 39 differ from those presented in Volume II of this report and represent the revenue that would have been generated had all miles captured by the device and all miles captured by the odometer only ("non-technology" miles) been assessed on invoices provided to participants. In the field test, participants were provided a stipend to pay for MBUF fees. The total stipend per participant was determined based on their daily mileage rate in the baseline and extrapolated out to the length of the test period to cover their fees, with the assumption that baseline mileage would be similar to test mileage per day. If a participant used all of their stipend to pay fees, they would no longer be invoiced for the remaining device miles or "non-technology" miles. Table 39 is intended to present what would have been collected had all miles been assessed based on the actual mileage data captured during the field test versus the invoice data presented in Volume II, which is intended to present exactly what was assessed and collected during the field test.

One observation from Table 41 should be highlighted. The "revenue" generated during the test period equated to almost $38,000 across 478 individuals. This means that an average cost to a drivers participating in field test was about $0.66 per person per day or less than $20 per month. In the context of typical utility bills, this amount could be perceived to be quite consistent or even on the lower side.

The baseline period and test period were approximately 2 months and 4 months in duration, respectively. Therefore, comparing the baseline to the test period results requires calculating the average number of miles driven and average fee assessed <u>per day</u> during each period. Table 40 presents the average miles per day in the baseline and test periods. The first row in the table represents the average per day of total miles measured from participants' odometers. The second row represents the total miles captured by the device including those where a fee was not assessed (i.e., miles outside of Minnesota).

The third row represents only fee miles captured per day. Fee miles are those miles captured by the device (excluding non-technology miles) for which a fee was actually assigned (i.e., all miles in Minnesota). Fee miles are important to look at because they represent the miles for which drivers had the potential (if they paid attention) to see the cost associated with driving behavior. Seeing this cost could have led to a behavior change.

Comparing the baseline and test periods, there was an average of a 9 percent reduction in device miles driven per day and a slightly greater reduction in fee miles of 9.6 percent, but only a 2.5 percent reduction when looking at total miles traveled as recorded from participant odometers. The fact that the change in odometer miles (which can be viewed as “ground truth” in terms of the true change in miles driven) was much less than the change in device miles, exemplifies the point that a change in device miles is not a completely accurate indicator of behavior change. The significant change between baseline device miles and fee miles per day and test device miles and fee miles per day could have resulted from any number of factors. Possible factors include participants electing to opt-out and pay higher “non-technology” fees instead of carrying the device with them at all times. System reliability and system accuracy issues discussed in Volume II could also play a role in the smaller percent change in odometer miles but larger percent change in device and fee miles. Power and battery issues began to plague Wave B and C participants towards the later part of their test periods, likely reducing the number of miles captured by the device. A number of other external factors could contribute to the difference between “ground truth” shown through odometer miles and the test results shown through device and fee miles. It is important to consider the existence of these external factors while assessing the impact of MBUF on behavior change and revenue throughout the remainder of this volume.

Table 40. Average Miles per Day – Overall (n=475).

Metric	Miles per Day Baseline	Miles per Day Test	Percent Change
Odometer Miles	45.0	43.9	-2.5%
Device Miles	37.1	33.8	-9.0%
Fee Miles	36.0	32.5	-9.6%

Because this section of the volume is focused on analyzing driver response to the MBUF concept where fees were assessed and a greater percent change was identified, only average fee miles per day (i.e., device miles which were assessed at a rate greater than $0.00) are presented from here forward. Additionally, comparing the daily amount of fee that would have been collected in the baseline period to the daily amount of fee that was collected in the test period provided another layer of insight into driver response to the MBUF concept. Table 41 below shows that the percent change in the daily amount of fee collected between the baseline and test periods was -9.9 percent.

Table 41. Average Fee per Day - Overall (n=475).

Metric	Fee per Day Baseline	Fee per Day Test	Percent Change
Fee	$0.39	$0.35	-9.9%

The small difference between the percent reduction in daily fee miles and daily fee between the baseline and test periods indicates that the change may have been the result of participants becoming more aware of their total mileage and cannot necessarily be attributed to a driver response or sensitivity to the amount of fee assessed. The following sections further analyze the reduction in daily fee miles compared to daily fee to assess whether any discernible differences were observed for certain participant demographics or commute patterns.

3.1.2 Summary by Demographic

To understand how participant demographics may have impacted driver response to the MBUF concept, the study team looked at the average fee miles per day and average fee per day by demographic as shown in Table 42 and Table 43 below. Participants in all age categories with the exception of those over the age of 66 drove fewer daily fee miles and paid less daily fees during the test period. Those over the age of 66 actually drove a greater number of daily fee miles and paid more daily fees during the test period. However, the trend in the data suggests that as you get older, you are less likely to decrease your miles (and fees assessed) while using the MBUF system. Perhaps, the younger that drivers are, the more likely they are to be price-sensitive and shift their behavior so that the number of miles they drive decreases as a result of seeing the fee assessment on a regular basis (i.e., on the device).

Table 42. Average Fee Miles per Day by Age.

Age Group (n)	Miles per Day Baseline	Miles per Day Test	Percent Change
18-35 (n=79)	33.7	28.6	-15.2%
36-55 (n=261)	39.0	34.5	-11.6%
56-65 (n=108)	32.5	31.2	-3.8%
66+ (n=27)	27.4	30.0	9.5%

Table 43. Average Fee per Day by Age

Age Group (n)	Fee per Day Baseline	Fee per Day Test	Percent Change
18-35 (n=79)	$0.37	$0.31	-16.1%
36-55 (n=261)	$0.43	$0.37	-12.0%
56-65 (n=108)	$0.34	$0.33	-3.2%
66+ (n=27)	$0.28	$0.31	10.1%

Table 44 and Table 45 below show that both male and female drivers drove fewer fee miles per day and paid fewer fees per day during the test period than during the baseline period. However, the percent change from the baseline to test period was somewhat larger for male drivers. Again, the difference in percent change between daily fee miles and daily fees does not point to a driver response to fee assessed.

Table 44. Average Fee Miles per Day by Gender.

Gender (n)	Miles per Day Baseline	Miles per Day Test	Percent Change
Male (n=222)	38.4	34.0	-11.4%
Female (n=253)	33.9	31.2	-7.8%

Table 45. Average Fee per Day by Gender.

Gender (n)	Fee per Day Baseline	Fee per Day Test	Percent Change
Male (n=222)	$0.42	$0.37	-12.0%
Female (n=253)	$0.36	$0.33	-7.8%

As shown in Table 46 and Table 47 below, participants in the $35-49k annual income bracket showed the least change in daily fee miles and daily fee during the test, perhaps indicating a regular, inflexible, commute to work. The other 3 income brackets all decreased daily fee miles and daily fee in the test period. Additionally, no discernible difference between percent change in fee miles per day and fee per day by income level was identified.

Table 46. Average Fee Miles per Day by Income.

Income Bracket (n)	Miles per Day Baseline	Miles per Day Test	Percent Change
Under $35k (n=26)	27.7	25.2	-9.3%
$35-49K (n=66)	28.9	28.8	-0.2%
$50-74K (n=153)	36.5	32.2	-12.0%
$75k+ (n=230)	38.6	34.6	-10.2%

Table 47. Average Fee per Day by Income.

Income Bracket (n)	Fee per Day Baseline	Fee per Day Test	Percent Change
Under $35k (n=26)	$0.28	$0.26	-8.2%
$35-49K (n=66)	$0.30	$0.30	-1.5%
$50-74K (n=153)	$0.40	$0.35	-13.4%
$75k+ (n=230)	$0.41	$0.37	-9.8%

3.1.3 Summary by Commute Distance

Comparing daily fee miles and fees in the baseline and test periods by commute distance does not shed any particular light on participant behavior (see Table 48 and Table 49). Participants with the shortest commutes, 0 to 10 miles, and mid-range commutes, 20 to 40 miles, showed a decrease in daily fee miles of 10-12 percent. Participants with the longest commute increased their daily fee miles by 7 percent during the test period. Similar percent changes in daily fee miles and daily fees suggest participants were not sensitive to fees collected but instead may have just become more sensitive to their total mileage.

Table 48. Average Fee Miles per Day by Commute Distance.

Commute Length (n)	Miles per Day Baseline	Miles per Day Test	Percent Change
0-10 mi (n=103)	27.0	24.2	-10.4%
10-20 mi (n=76)	35.3	34.1	-3.2%
20-30 mi (n=78)	41.1	36.5	-11.2%
30-40 mi (n=58)	47.6	41.8	-12.2%
40-50 mi (n=31)	49.2	47.7	-3.2%
Over 50 mi (n=17)	59.6	63.8	7.0%

Table 49. Average Fee Miles per Day by Commute Distance.

Commute Length (n)	Miles per Day Baseline	Miles per Day Test	Percent Change
0-10 mi (n=103)	$0.27	$0.24	-12.3%
10-20 mi (n=76)	$0.34	$0.34	-1.0%
20-30 mi (n=78)	$0.46	$0.40	-12.5%
30-40 mi (n=58)	$0.56	$0.48	-14.7%
40-50 mi (n=31)	$0.55	$0.52	-5.4%
Over 50 mi (n=17)	$0.66	$0.70	5.6%

Relevant to commute distance, towards the end of the baseline period during the field test, the study team assessed each participant's mileage (as recorded by the device to date), and identified each participant as a "high mileage" or "low mileage" driver. These mileage categories provide further insight into whether overall mileage has an impact on driver response to the MBUF concept. Figure 42, below, compares average daily fee miles between high mileage and low mileage participants. Average daily fee miles decreased by 16 percent for high mileage participants and increased by 5 percent for low mileage participants in the test period, showing that average daily mileage may be a factor in a participant's awareness of their total mileage. As presented in Figure 43, percent change in average daily fee by mileage category yielded only a percent lower for high mileage participants and a percent higher for low mileage participants, suggesting neither low nor high mileage participants showed sensitivity to the amount of fee assessed.

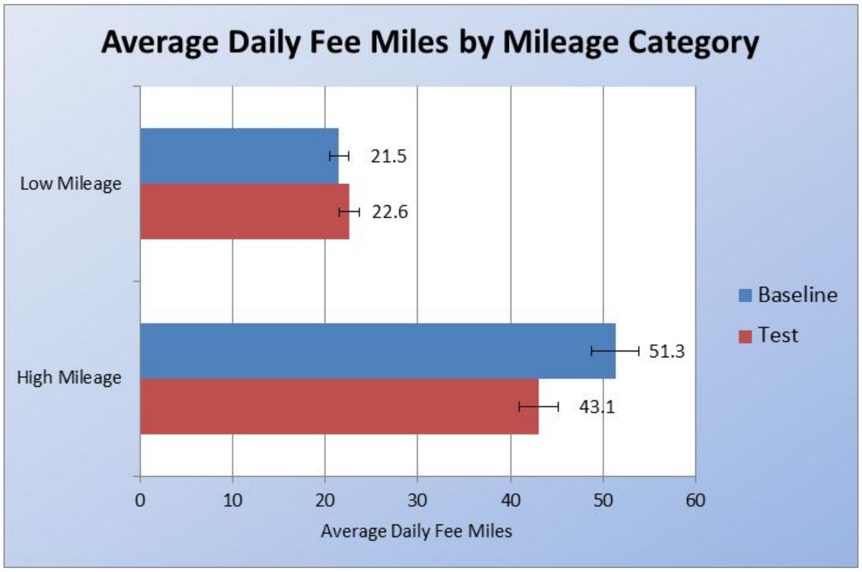


Figure 42. Average Daily Fee Miles - High vs. Low Mileage Participants.

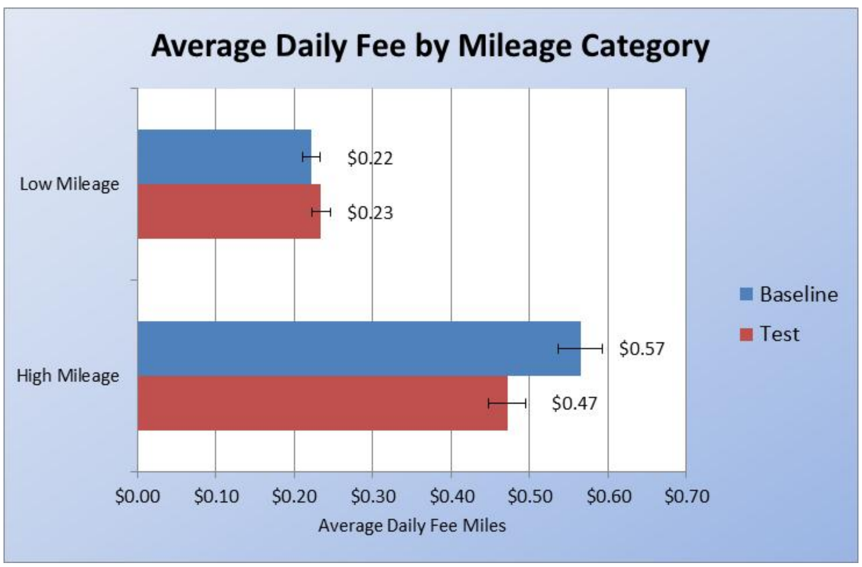


Figure 43. Average Daily Fee - High vs. Low Mileage Participants.

3.2 Change in Trip Characteristics

While an overall reduction in daily fee miles was observed between the baseline and test periods, evaluating the results by participant demographics and commute distance did not offer much additional insight into the reasons for this change. As mentioned above, trip characteristics are an additional metric that may provide insight into driver response to the MBUF concept. Specifically, changes in trip duration and distance between the baseline and test periods are presented in the sections below as a possible indication of driver response to the MBUF concept. This section focuses on identifying changes in driver behavior, which may have been the result of more efficient travel in response to the MBUF concept, such as trip chaining (i.e., accomplishing in one trip what may have previously been split into multiple trips). In this section, a summary of the trip data captured during the field test is provided followed by a closer look at the trip data by mileage category where a difference in trip characteristics was observed. Results are not presented for participant demographics and commute distances as no additional insight was gained from a look at these factors.

Figure 44 and Figure 45 below present a summary of trip characteristics captured during the field test in terms of the range of trip distances and durations observed. The results indicate that 63 percent of trips were 10 miles or less in distance and 61 percent were 20 minutes or less in duration, indicating that the majority of trips captured during the field test were likely local trips made by participants.

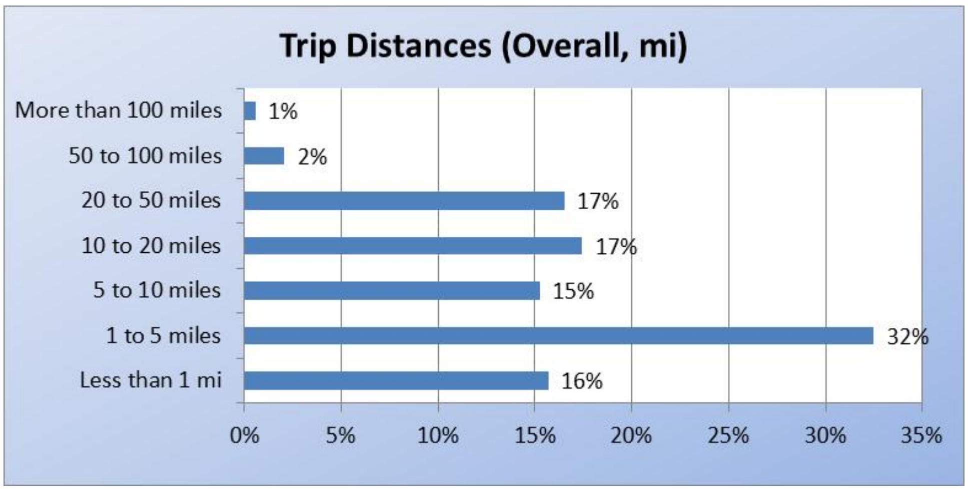


Figure 44. Summary of Trip Distances for All Trips during Field Test.

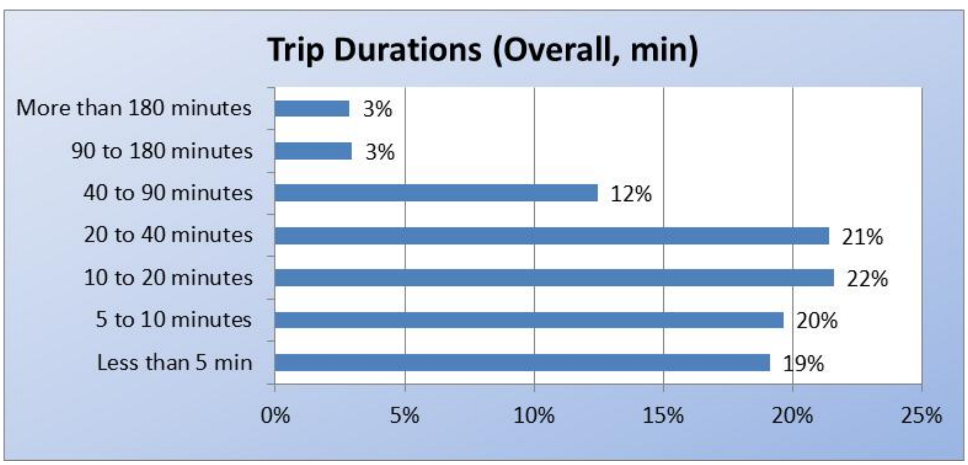


Figure 45. Summary of Trip Durations for All Trips during Field Test.

A comparison of high mileage drivers and low mileage drivers by trip distance and trip duration provides additional insight into driver response to the MBUF concept. By examining the specific trip data in Figure 46 and Figure 47 below, other trends became apparent:

- Trips made by high mileage participants during the test period were of longer distance and longer duration than those made during the baseline period, indicating a likelihood of trip chaining.
- Trips made by low mileage participants during the test period were shorter in distance and (oddly) slightly longer in duration than trips made during the baseline period.

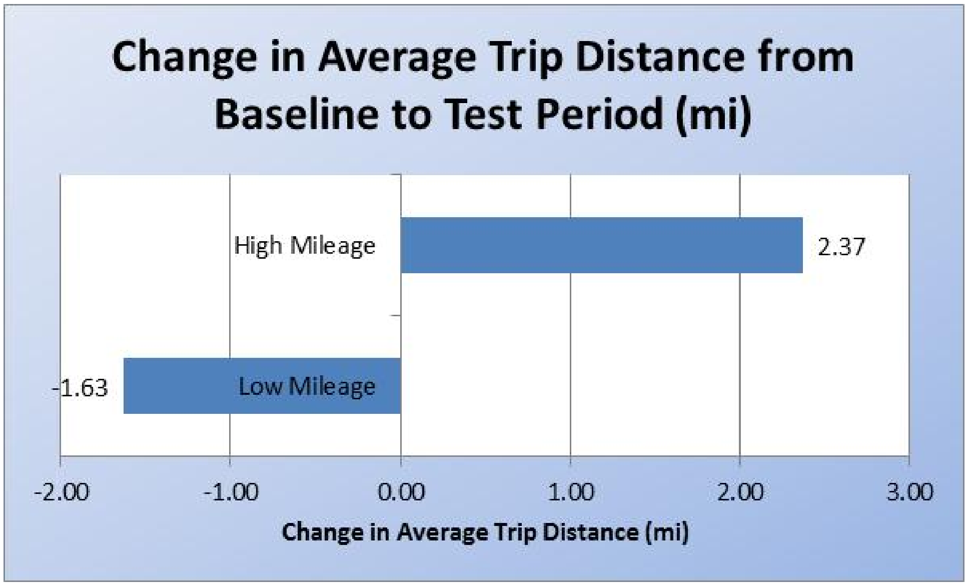


Figure 46. Change in Average Trip Distance from Baseline to Test Period.

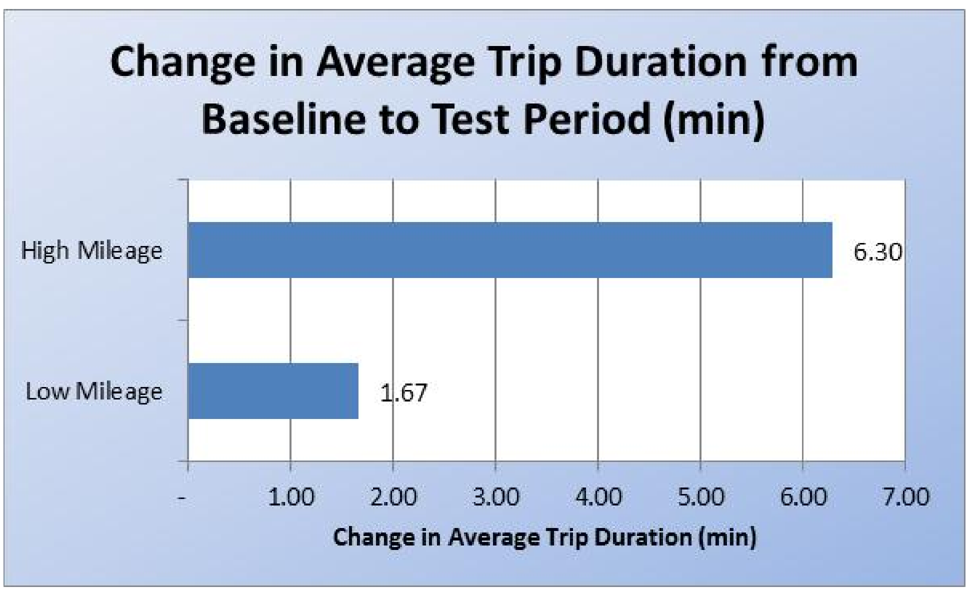


Figure 47. Change in Average Trip Duration from Baseline to Test Period.

Because specific information about the details of trip (e.g., distances and durations) could not be attributed to individual participants in all cases, it is difficult to make conclusive statements regarding specific participant's changes in behavior. However, for higher mileage participants, the combination of longer average trip durations, longer average trip distances, and reduced average daily mileage suggest that these participants continued to make their relatively long commutes to and from work, but reduced the number of additional short trips. Less short trips suggests that instances of trip chaining may have occurred in response to the MBUF concept. Supporting this theory, some participants directly spoke of trip chaining in interviews, indicating that the mileage fee made them more aware of the trips they made during the test and helped prevent them from making the "extra trip." One specifically mentioned that they found themselves considering chaining together their shorter trips into one larger trip where possible. As put by one participant, "If I would be running out to do something, I would plan more ahead or try to get my errands done in one trip versus [making trips] two or three times a week."

4 Driver Response to Fee Structure

Similar to Section 3 above, data collection during both the baseline and test periods permitted a comparison between the "before" and "after" condition for any indication of driver response or behavior change resulting from the specific elements of the pricing structure of the MBUF concept.

By designing a fee structure that included the Twin Cities-Peak fee category, the field test allowed for a look at the impacts of location and time of day pricing on the travel behavior of individual travelers (e.g., overall miles traveled, time of day of travel, number of trips, etc.). Because a number of MRFT participants commute into the "Metro Zone," the field test allowed for an assessment of this sort of fee structure in an urban part of the state, where congestion is most prevalent. As mentioned earlier, participants driving into the "Metro Zone" boundary during peak periods (Monday through Friday, 7:00am-9:00am and 4:00pm-6:00pm) accrued miles in the Twin Cities-Peak fee category and were charged a higher MBUF rate of $0.03 per mile.

A change in the fee miles and fees assessed in the Twin Cities-Peak fee category between the baseline and test periods may suggest a driver response to the location and time of day pricing element of the field test. As reported in Section 3.1.1, there appeared to be a negligible difference between the baseline and test periods in terms of percentage of device miles and fees assessed in the Twin Cities-Peak fee category. The category represented only 4 percent of total device miles and 11 percent of the total fee collected for all participants. However, this number represented all drivers, many of whom never encountered the Twin Cities-Peak fee category due to the nature of their daily travel.

When considering driver response to the location and time of day pricing elements of the test, the study team considered only those participants who recorded at least 1 mile in the Twin Cities-Peak fee category each during both the baseline and test periods, a total of 273 participants (57 percent of total participants). Looking only at fee miles captured and fees assessed in the Twin Cities-Peak fee category by this subset of participants, overall results from the field test suggest a 16 percent decrease in both fee miles per day and fee per day across the subset of participants. (Because $0.03 per mile is the only rate used on Twin Cities-Peak miles, the percent change is the same for fee miles and fee per day.) It appears that the pricing elements of the test may have made participants more aware of their total mileage driven during peak hours in the Twin Cities area and resulted in a decrease of miles driven in that fee category in an effort to reduce fees. However, as mentioned before, the significant number of "non-technology" miles assessed during the field test where a participant either elected not to use the device or the device failed to capture miles driven is likely an influencing factor in this apparent behavior change, so it is impossible to clearly ascertain that the change in miles recorded was truly a behavioral change. Participant interviews do provide anecdotal input on the question of whether the pricing elements affected participant travel. One participant did report changing their behavior, saying, "[The fee was] more expensive during rush hour traffic, so I would avoid it." Another participant reported that she did not change her driving behavior as a result of the test but that she would definitely consider changing her routes to save money in the real world. But more often than not, participants reported that they did not change their behavior, as they did not need to drive in the Metro Zone during peak periods very often. These individuals reported that thought they would change their travel patterns if they drove in a time or location that was priced higher: "I probably would [change my driving behavior], because we find that where we live we can adjust for traffic at certain times. So if we knew it was different prices [at different times of day or in specific locations], we'd probably adjust [our driving];"and "… if I got a job downtown, then I probably would take mass transit more [often]."

Table 50. Daily Twin Cities-Peak Fee Miles – Overall (n=475).

Metric	Baseline	Test	Percent Change
Fee miles per day	2.52	2.13	-15.6%
Fee per day	$0.08	$0.06	-15.6%

5 Revenue Comparison – MBUF versus Fuel Tax

Although policy decisions on how a mileage-based user fee may generate revenue have yet to be made, the Minnesota Road Fee Test required that some fee structure be developed that was realistic in its scale while being largely non-controversial, as well as simple, so as to be easily understood by drivers. The test fee structure sought to be an approximate replacement to the state fuel tax currently in place (and did not include, any element of the federal motor fuel tax).

The fee structure used in the MRFT was just a mechanism for conducting the test and not the subject of the test. Many other elements could have been incorporated into pricing including type of vehicle, fuel efficiency category, or road type (freeway or arterial). While the study team was not testing the fee structure used in the MRFT it is still important to demonstrate how this or any fee structure can affect revenue and meeting revenue goals. A key element driving the consideration of an MBUF program is the effect of increased fuel efficiency on fuel tax revenues. Because increased fuel efficiency reduces the ratio of fuel tax revenues to the number of miles driven, participants' fuel efficiency is a logical metric for comparing MBUF revenues to fuel tax revenues. Thus, in this section, fuel tax revenue will be compared with MBUF revenue as experienced in the test. It is important to note that this comparison of revenues looks only at fees miles captured by the device, essentially ignoring the "opt-in" or "opt-out" approach of the field study where drivers could elect not to use the device, with the knowledge that they would pay for those miles at the higher "non-technology" rate. The reason these non-technology fee miles and associated fees are excluded from this analysis is that due to technical challenges with the device (see Volume II), there were a large percentage of "non-technology" miles assessed during the test.

Table 51 tallies fees paid by the participants for device miles and compares these values to participants' estimated fuel tax costs for the same number of miles (based upon participants' estimated fuel efficiency inferred from the vehicle year, make and model reported during participant recruitment). Fuel tax estimates are based upon Minnesota's $0.285 per gallon fuel tax rate as of December 11, 2012.[55]

Table 51. MBUF Revenue versus Fuel Tax Revenue by Participant Fuel Efficiency.

Fuel Efficiency (number of participants)	Test Period Daily Average		MBUF Fees vs. Fuel Tax (Test Period)	
	MBUF	Fuel Tax	Avg. Difference (Daily)*	Percent of participants paying more in Fuel Tax than MBUF
10-15 mpg (25)	$0.20	$0.47	($0.27)	100.0%
15.1-20 mpg (168)	$0.26	$0.51	($0.25)	99.4%
20.1-25 mpg (202)	$0.29	$0.43	($0.14)	100.0%
25.1-30 mpg (49)	$0.30	$0.37	($0.07)	100.0%
30.1-35 mpg (23)	$0.32	$0.33	($0.01)	60.9%
35.1-40 mpg (1)	$0.54	$0.52	$0.02	0.0%
Over 40 mpg (7)	$0.29	$0.20	$0.09	0.0%

*Negative values imply that users paid less under the usage based fees than they would have paid in estimated fuel taxes.

Essentially all participants whose vehicles achieved less than 30 miles per gallon (combined city and highway) incurred lower fees than they would have paid in fuel taxes. Participants with fuel efficiency of 30-35 miles per gallon paid more 60.9 percent of the time. All participants with fuel efficiency of over 35 miles per gallon paid more in mileage-based user fees than they would have under the current fuel tax.

[55] Minnesota Department of Transportation, *History of MnDOT Revenue Changes, Motor Fuel Tax Rates per Gallon: Minnesota:* http://www.dot.state.mn.us/about/pdfs/historychart.pdf

As shown in Table 52 below, based on participants' total fee miles and estimated fuel efficiency, it can be estimated that participants would have paid approximately $33,000 in fuel taxes for all fee miles recorded during the test period. When considering miles recorded on the device only, participants incurred slightly less than $20,000 (20 percent less) in mileage-based user fees; when considering all miles driven (including those not recorded on the device), participants incurred approximately $25,000 (14 percent more) in fees.

Table 52. Total MBUF Revenue vs. Estimated Fuel Tax Revenues based on Miles Driven by Participants in the Test Period.

Revenue Source	Device Miles (excluding "non-technology" miles)	All Miles (including "non-technology" miles)*
MBUF	$ 19,844	$ 37,830
Fuel Tax	$ 24,944	$ 33,266
Difference	**- 20%**	**+ 14%**

*Note that these fees represent more miles than were reflected on participants' odometers in some cases due to issues with the device during the test that were not apparent at the time.

This difference may seem surprising, as MRFT fees were designed to approximate the Minnesota fuel tax and be revenue neutral. While the fees themselves were merely illustrative and seem to have appeared reasonable to participants, the reason the MBUF revenue deviated from the fuel tax revenue relates to the fact that MnDOT did not force drivers to use the device all the time. As a result of this "opt-in" "opt-out" approach, in establishing a fee structure for the test that would be revenue neutral, it was necessary to estimate the percentage of the time participants would elect not to use the device (whether intentionally or by forgetting to bring it or use it). In this initial revenue-projection exercise, which established the fee structure of $0.01 and $0.03, the team elected to estimate non-device usage at 15 percent. In actuality, however, non-device usage was higher, at 24 percent. Our estimate was relatively close. However, even a deviation of this size has the ability to affect the revenue projections substantially.

6 Conclusions

Looking at the miles that were captured on the device, it appears that there was a 10 percent reduction in miles driven between the baseline and test periods. However, looking purely at miles recorded on the odometer, which can be considered "ground truth" for a true change in miles driven, there was actually only a 2.5 percent reduction in miles driven. The percent reduction that would have occurred in a real-world scenario is likely somewhere between these two values.

One factor limiting the measured change in miles driven was that due to the geographic boundary established for the "Metro Zone" and the commute patterns of the participants (details that were unknown at the study start), very few participants had a need to drive many miles in the higher rate category. Drivers would have likely had a stronger response (in terms of reduced miles driven) had they experienced the higher rate category on a more regular basis.

Another factor is the human element related to paying a bill every month rather than at the gas station. Whether due to drivers opting-out of using the device or due to device issues, most participants ended up paying a large portion of their total fees at their final odometer reading when the deployment team invoiced them for any differences in miles measured on the device and their odometer. As a result of this, drivers were not receiving the immediate hit of a monthly invoices reflecting the actual amount of miles they drove that month in every case. Drivers may very well have had a stronger reaction (seen in terms of a reduction in miles driven) had they been receiving larger invoices each month along the way.

A final point is that drivers in the study did not always have the choice of opting-in to using the device. There were certainly times for many participants where the device was not working (whether due to a user error or a system error) and they were forced to forfeit the discounted rate for these miles and pay at the higher non-technology rate. This points to the importance of accuracy and reliability in a system such that drivers can trust that they will have control over the opt-in/opt-out process.

What all these findings demonstrate is that the fee structure interacts with driving behavior in often surprising ways. These is some evidence that drivers became more aware of their driving behavior and may even have reduced the length of their trips in some cases as a result of using the MBUF application. What makes this most interesting is that the overall amount paid by drivers was quite small (averaging $20 per monthly invoice, with even the highest mileage drivers were only paying about $0.66 per day in fees). However, even though the amount of fees was small compared to typical personal expenses, there were still “winners” and “losers” in terms of comparing an MBUF scenario to the current fuel tax system. It appears that drivers with vehicle fuel efficiency levels over 30 mpg often saved money each month under the MBUF system, whereas drivers with higher fuel efficiency levels (under 30 mpg) paid more under the MBUF system.

One lesson learned as part of the field test is that the rate setting process is very complex and an area that is still not well understood in this context. Comparing the revenue generated by the simulated real-world Minnesota Road Fee Test to the revenue that would have been generated from the state fuel tax for the same number of miles provides insight into some of the considerations associated with designing a fee structure. The primary reason why MBUF “revenue” was not matched to gas tax revenue was that there was insufficient information at the planning stage about how and where participants would drive (and therefore what percent of their miles would be in the higher fee category). This demonstrates the complexity of designing a fee system for real-world users who may not use the device all the time or who may “opt-out” of using it altogether.

Volume V: Assessment of Impacts of Speed Related Signage on Safety

1 Introduction

One goal of the test was to determine the impact of the in-vehicle safety signage alerts. This included both driver perceptions of the alerts as well as an analysis of whether driver behavior changed as a result of the alerts. Participant perceptions and feedback regarding the safety signage alerts are presented in Volume III while this volume analyzes and reports the findings from the objective safety alert data collected by the system for trips through signage zones.

As described in the Volume I, Section 2.3, the safety signage functionality of the Minnesota Road Fee Test (MRFT) application provided safety signage alerts to drivers when entering pre-defined safety signage zone locations throughout Wright County. Three primary types of safety zones were included in the test: (1) school zones, (2) speed zones (areas of reduced speed), and (3) curve warning zones. The test also included a limited demonstration of a fourth type of safety zone: a construction zone. The project team identified a total of 98 signage zones, which included 46 school zones, 28 speed zones (areas of reduced speed), 17 curve warning zones, and 7 zones within a 10-mile construction area. Participants received a visual alert on the screen of their smartphone upon entering a safety zone. This visual alert remained present on the screen until the driver exited the zone. In school zones and speed zones, if the participant was traveling 5 mph or more over the speed limit at any time while in the zone, the visual alert would be accompanied by an audible alert in the form of a beep. Speed was checked by the system every second to determine when the beep should be activated or deactivated at any point inside the zone. Participants did have the ability to disable the safety signage functionality or to lower (or turn off) the volume of the audible alerts.

For regulatory signs (which included school zones and speed zones where speed limit signs are posted), the system was designed to coordinate in-vehicle and roadside safety information, so that the in-vehicle visual alert was displayed at the same time the roadside sign was passed on the road since the speed limit would only be enforceable after passing the roadside sign. For advisory signs (which include curve warning zones and the construction zones), the boundaries of the zones were established such that the sign would appear in the vehicle at the same time that it became visible to the driver on the roadside. The advance distance at which the signs should appear was determined based on guidance in the Manual on Uniform Traffic Control Devices (MUTCD). One exception was that zones were not carried across an intersection with a traffic-control device (a traffic signal or a stop sign), even if the roadside sign relevant to the signage zone was still visible on the far side of the intersection.

The PMO support contractor assisted the Minnesota Department of Transportation (MnDOT) in selecting the locations and designing the boundaries of each zone. The primary factor that drove selection of zones was the volume of traffic through the zone as the team wanted to gather as much data as possible for analysis purposes. After identifying the high-volume locations, the PMO support contractor visited each location, determined if it was suitable for the study, and recorded the GPS coordinates of the proposed start/end boundary for each zone. The zone locations identified for the field test are provided in Appendix C.

Figure 48 below is a satellite view of a school zone identified as a signage location in the field test. The yellow line shown on the map represents the boundary of the signage zone, which is defined by four GPS coordinates in each corner of the rectangular shape that covers the roadway.

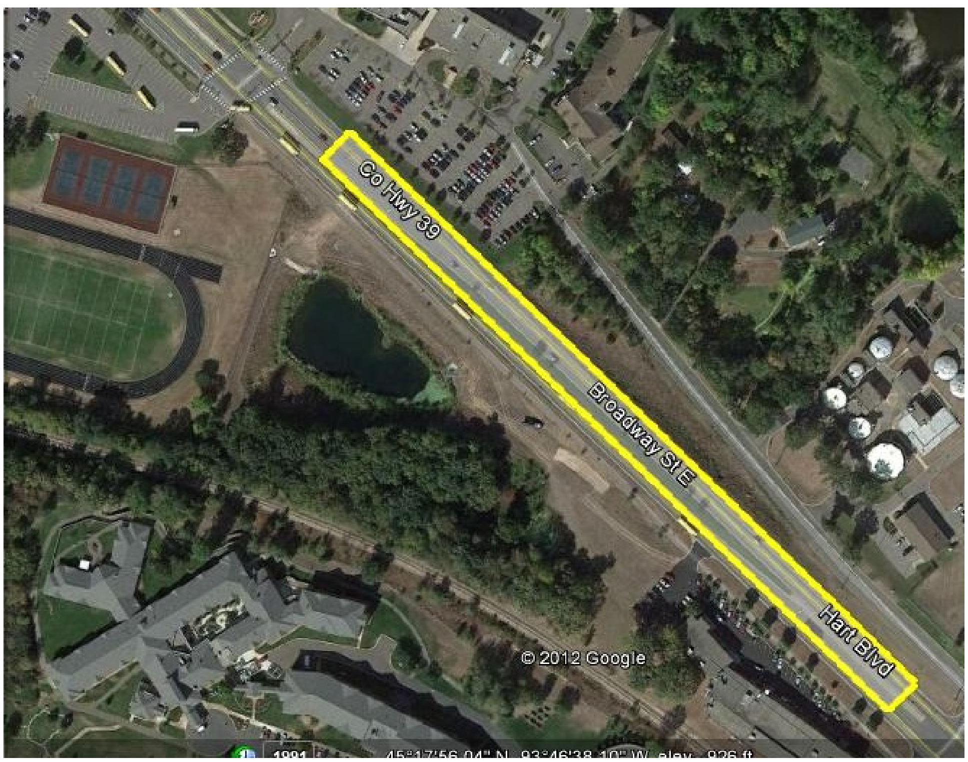


Figure 48. Satellite View of Example Signage Zone Boundary.

The signage functionality of the MRFT application used the second-by-second location information within the trip data collected by the system to determine when a participant's device entered a GPS boundary defined as a signage zone. Upon entering the zone, the visual alert (matching the roadside sign) was displayed on top of any other information on the MRFT application (see Figure 52). The participant's location was then checked against the zone boundary every second to verify the visual alert should continue being displayed. It is important to reflect on the system reliability and accuracy issues presented in Volume II as a lack of GPS signal would directly impact the signage functionality of the system. Due to the signage system's dependence on GPS location, a lack of GPS signal (or an intermittent GPS signal) would prevent alerts from being displayed properly, or at all, in safety signage zones. The analysis approach identified in this volume considered the impacts of poor or erratic GPS signal and focused on analyzing events where signage functionality worked properly.

2 Overview/Multi-Zone Analysis

Of the 98 safety signage zones, all zones with the exception of 1 curve zone, 1 school zone, and 6 of the 7 zones within the construction area were traversed by at least 1 participant during the test period across all waves over the course of the field test. Table 16 below shows that while speed zones only represented 29 percent of the total zones, 58 percent of the total signage events occurred in that zone type. Of the five zone types, speed zones were also traversed by the greatest percentage of participants (95 percent) with school zones (81 percent), curve warning zones (63 percent), and construction zones (2 percent) experiencing lower exposure. It is important to remember that in-vehicle safety signage alerts were only given when passing through school zones between the hours of 7 AM and 7 PM. No other zone types were time-constrained.

Figure 49. Example of In-Vehicle Safety Visual Alert – Curve Warning Zone.

Table 53. Signage Events and Participant Exposure by Zone Type.

Zone Type	Count of Zone Type (%Total Zones)	Zones with Events (%Total Zone Type)	Test Period Events (%Total Events)	Participants (%Total Participants)
School	46 (47%)	45 (98%)	6,800 (22%)	393 (81%)
Speed	28 (29%)	28 (100%)	17,458 (58%)	462 (95%)
Right Curve	7 (7%)	7 (100%)	2,938 (10%)	272 (56%)
Left Curve	10 (10%)	9 (90%)	3,140 (10%)	305 (63%)
Construction	7 (7%)	1 (14%)	18 (<1%)	11 (2%)

Signage zones varied slightly in length (miles) and the amount of time it took to travel through a zone.

Table 54 below presents the average length (in miles) and average amount of time elapsed (seconds) traveling through signage zones during the test period of the study by zone type. School zones were longer and took more time to traverse on average than the other zone types. The average travel time through a signage zone for all zone types was less than a minute.

Table 54. Average Zone Length and Time Elapsed by Zone Type.

Zone Type	Average Zone Length (miles)	Average Time Elapsed (seconds)
School	0.35	00:38.4
Speed	0.15	00:15.7
Right Curve	0.18	00:12.4
Left Curve	0.19	00:12.8
Construction	0.33	00:24.4

As shown in Figure 50, exposure to the different types of zones varied across participants, but nearly all participants (97 percent) traversed at least one type of signage zone during the test period. Forty-three percent of participants experienced all four of the key signage zone types. The fifth type of zone, the construction zone, was only active for the latter part of the test period for Wave C participants, so very few participants experienced that zone type.

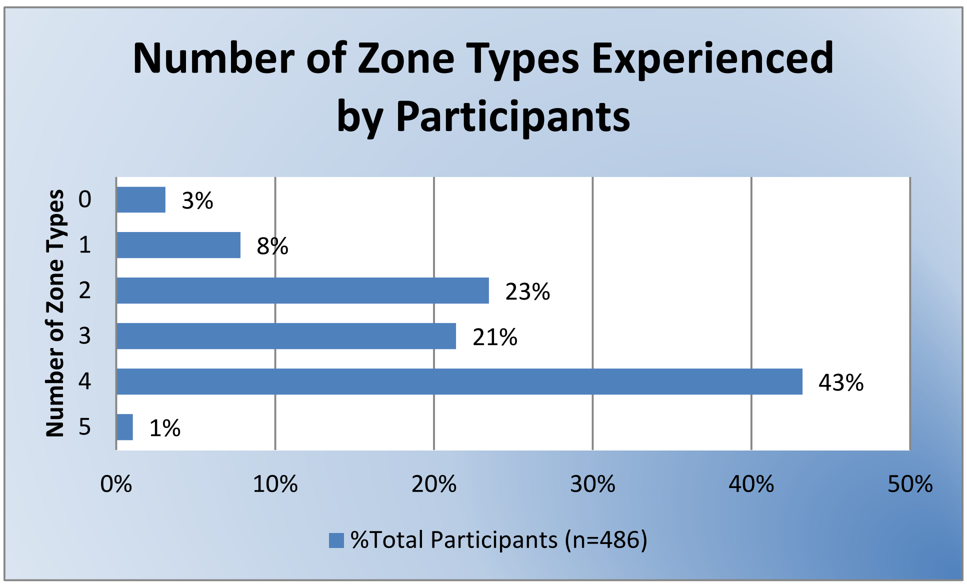


Figure 50. Number of Zone Types Experienced By Participants (n=486).

Participants experienced varying levels of exposure to signage zones throughout the test period. A total of 30,354 signage events occurred across all zones during the test period with an average of 337 signage events per zone and a maximum of 2,014 events (7 percent of total signage events) in the "busiest" zone. Most of the signage zones were visited at least once during the test period (90 of the 98 zones, or 92 percent) and the average zone was traversed by 55 participants. The most heavily-traveled zone was experienced by over half of the participants (51 percent).

Most participants experienced not only different zone types, but also different zones. The average participant drove through 11 different zones during their 4 months in the test period. The greatest number of zones traversed by a single participant was 33 (34 percent of total zones). Participants experience an average of 1.3 zones per trip with one participant traveling through 24 different signage zones (24 percent of all zones) in a single trip. The 30,354 signage events that occurred in the test period were spread across 22,826 different trips. Table 55 below summarizes these zone exposure statistics for the test period by metric.

Table 55. Summary Statistics for Zone Exposure.

Metric	Average	Minimum	Maximum (%Total)	Sum (%Total)
Events per Zone	377	0	2,014 (7%)	30,354 events
Participants per Zone	55	0	250 (51%)	471 participants (97%)
Zones per Participant	11	0	33 (34%)	90 zones (92%)
Zones per Trip	1.3	0	24 (24%)	22,826 trips

The second-by-second trip data collected throughout the field test allowed the study team to analyze each participant's travel through the signage zones both during the baseline period when no in-vehicle safety signage alerts were displayed to drivers and during the test period when safety signage functionality was activated and visual alerts were shown in-vehicle to participants. This comparison allowed the study team to understand the number of trips through signage zones by each participant over the course of the field test (shown in Table 56), regardless of whether the signage functionality was activated or not.

The opportunity to compare baseline and test trips allowed the study team to analyze trips through signage zones for any indication of a driving behavior change in response to the in-vehicle safety signage alerts.

Table 56. Number of Signage Events by Zone Type (Baseline vs. Test).

Zone Type (Count)	Baseline Period Events (%Total Column)	Test Period Events (%Total Column)	Total Events (%Total Column)
School (46)	4,750 (24%)	6,800 (22%)	8,838 (23%)
Speed (28)	11,510 (57%)	17,458 (57%)	22,083 (58%)
Right Curve (7)	1,753 (9%)	2,938 (10%)	3,780 (9%)
Left Curve (10)	1,980 (10%)	3,140 (10%)	3,803 (10%)
Construction (7)	- (0%)	18 (<1%)	18 (<1%)

3 Approach

In analyzing driver response to in-vehicle safety signage alerts, the first step was to identify the desired effect that the alerts would have on driver behavior. For example, the study team hypothesized that participants entering regulatory zones such as school zones would decrease speed upon entering the zone. To understand whether this behavior occurred, the study team needed to design a test that differentiated between the hypothesized behavior and other less desirable behaviors, such as speeding through a school zone. The second-by-second speed information collected by the system provided a wealth of data for analyzing driver behavior in signage zones. Figure 51 below is an example speed profile for a single trip through a signage zone that plots speed versus time and identifies data points collected "prezone," or before entering the signage zone, "inzone," and "postzone," or points collected after exiting the signage zone.

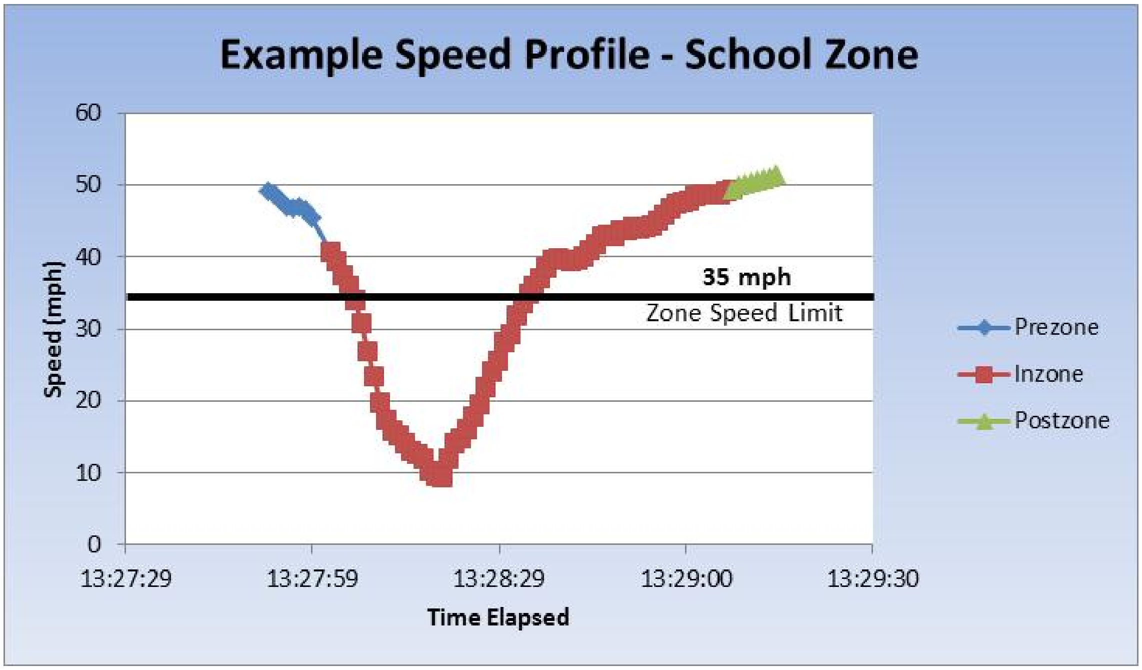


Figure 51. Example Signage Zone Speed Profile - School Zone.

Taking the available speed profile data into consideration, the study team realized the need to identify "points of interest" within and throughout a signage zone which were ideal for detecting possible behavior change. For example, regulatory zones have an enforceable speed limit, and it was expected that drivers would slow down to a speed at or below the zone's posted speed limit upon entering the zone. Therefore, the signage zone entry point where the safety alert was first displayed in the vehicle was of particular interest. Analyzing a driver's speed profile data before and after the entry point to a signage zone provided insight into the safety alert's immediate impact on a driver's speed and speed limit compliance.

The study team elected to perform a regression analysis on the speed profile data for all trips using a step function as the model. If drivers were slowing down, speeding up, or maintaining a constant speed while traveling across the point of interest, then the speed profile would fit the model well. The regression analysis produced four key metrics, which allowed the study team to focus on trips where a desired behavior change could have occurred:

- **R-squared value** (goodness of fit) – a value that indicates how well the speed profile fit the step function model;
- **Before model speed** – average speed prior to the point of interest for each signage zone;

- **After model speed** – average speed after the point of interest for each signage zone; and
- **Transition time** – a value that indicates whether the change in speed occurred before or after the point of interest.

Using the zone entry point as an example, the study team established a set of regression criteria that a trip had to meet in order to be included in the behavior change analysis for a given point of interest.

1. The speed profile had to fit the step function model well enough to achieve an r-squared value of 0.7 or better. This removed speed profiles with variable behavior at the zone entry point, so instances where drivers may have slowed down then sped up or come to a stop prior to entering a signage zone were not considered in the analysis as outside influences such as traffic congestion may have impacted their behavior beyond the in-vehicle safety alert.
2. The transition time had to be positive, indicating that the driver response occurred after the signage zone was entered and a visual safety alert was displayed in the vehicle. A negative transition time would indicate the driver response occurred prior to the visual alert being displayed, possibly the result of the driver responding to a roadside sign before the in-vehicle alert was even provided.

The point of interest was the basis for how many data points were included in the regression analysis. In the case of the zone entry point, the number of data points equivalent to 10 seconds or 200 meters (lower number of points prevailed) prior to the zone entry point were analyzed before the point of interest, then the equivalent number of data points were analyzed after the point of interest to produce the regression analysis metrics. In summary, the regression analysis served as a tool for identifying the trips where a behavior change was most likely to have occurred. In cases where a behavior change did appear to occur, the study team conducted a paired two-tail t-test to assess the statistical significance of the behaviors that were compared. Each test for statistical significance reported in the Results section that follows, includes the means for each compared behavior (e.g., baseline behavior compared to test behavior), the degrees of freedom (df), the t statistic (t stat), and the p-value for the data analyzed. The results of the t-tests are presented in the following format: t (df) = t stat, P = p-value.

Using the data made available by this approach, the study team identified three key types of analysis to perform in order to better understand driver response to the in-vehicle safety alert functionality of the MRFT system.

- First, the team looked at **driver behavior at the zone entry point where all participants would have received a visual alert**. As discussed, the point of interest was the zone entry point, and the regression analysis compared data points before and after the participants entered the signage zone to identify behavior change. For this analysis the team focused on comparisons of driver behavior without the alerts (baseline period trips) to driver behavior with the alerts (test period trips). Although drivers were presented with visual alerts in all zones, this analysis focuses on driver response to visual alerts in speed zones and school zones. Curves are excluded from this analysis as curve warning signs are advisory in nature and the desired behavior in a curve is for the driver to slow down prior to entering the curve rather than immediately upon entering the area of reduced speed. The team hypothesized that drivers would be: (a) more inclined to reduce their speed when entering signage zones than they were without the in-vehicle visual alerts, and (b) more compliant with the speed limit than they were without the in-vehicle visual alerts. In this analysis, the team excluded 20 individuals who reported on survey 3 that they had not seen a signage zone icon on their device, as well as 1 individual who requested help from the deployment team to deactivate the signage function of the MRFT application on their smartphone. One caveat with this analysis is that, unlike an audible alert that can be heard regardless of where the device is in the vehicle or regardless of which direction the device is facing, the smartphone has to be positioned in such a way that the driver can see the screen for the visual alert to have any effect. It should be noted that the study team unfortunately has no way to know for certain which drivers kept their smartphones in a position in which they would be able to see the visual alert.

- Second, the team looked at **driver behavior at the point where drivers first received an audible alert** (i.e., the "point of interest" in this case). For this analysis, the team focused only on test period data and looked at comparisons of driving behavior before and after the point where the driver received their first audible alert in a given zone. Since drivers were presented with audible alerts only in zones with regulatory signs, this analysis applies only to speed zones and school zones. The point at which the audible alert was triggered varied by driver, and drivers who always drove within 5 mph of the posted reduced speed limit are not included in this analysis as they would have never heard an audible alert. For audible alerts, the team hypothesized that drivers would: (a) reduce their speed immediately after receiving an alert, and (b) maintain a lower speed throughout the rest of the zone to avoid further alerts. In this analysis the team excluded 19 individuals who reported on survey 3 that they had not heard their device "beep" in a signage zone, as well as 8 individuals who reported in participant interviews that they had muted the volume on their phone, presumably because they found it distracting or not useful.
- Lastly, the team looked at **driver behavior through signage zones from entry point to exit point**. In this case, the point of interest was the entire length of the signage zone.

The regression analysis identified whether there was a behavior change somewhere within the zone. For this analysis, the team focused on comparing driver behavior without the alerts (baseline period trips) to driver behavior with the alerts (test period trips). The team hypothesized that drivers would be more compliant with the speed limit throughout the length of the zone when provided an alert. This applies to all zone types, but the focus is slightly different for curves since each curve safety zone ends where its corresponding curve begins. As a result, the intended behavior in a curve zone is for the driver to slow down prior to reaching the curve or exit point of the signage zone, whereas in the other zones the intended behavior is for the driver to drive more slowly through the entire safety signage zone.

Figure 52 below shows a diagram of a signage zone as it relates to the various points of interest and the method by which drivers were notified about the zone. Results of these driver behavior analyses are presented in the following section.

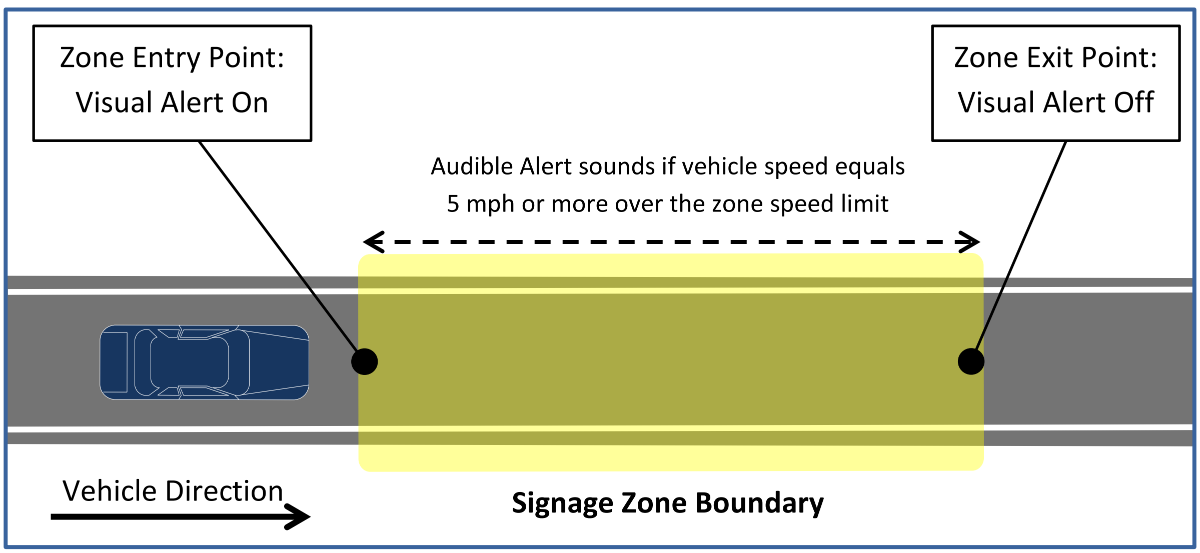


Figure 52. Diagram of a Signage Zone.

4 Results

As mentioned above, the study team focused on three different types of safety signage zone analysis to determine whether a behavior change occurred in response to the in-vehicle safety signage alerts. These analyses include:

- Analysis of Driver Behavior at Visual Alert Point,
- Analysis of Driver Behavior at Audible Alert Point, and
- Analysis of Driver Behavior through Signage Zones (from Entry Point to Exit Point).

Each section below first explains the metrics analyzed to identify driver response to the safety signage alerts, and then details the analysis approach, and lastly, presents the findings.

4.3 Analysis of Driver Behavior at Visual Alert Point

Although drivers were presented with visual alerts in all zones, this analysis focuses on driver response to visual alerts in speed zones and school zones. As mentioned before, curves are excluded from this analysis because they are advisory in nature. The focus of this analysis is comparing driver behavior without the alerts (baseline period trips) to driver behavior with alerts (test period trips). It should be noted that, in some cases, the driver would have received an audible alert in conjunction with the visual alert. The team hypothesized that drivers would be: (A) more compliant with the speed limit than they were without the visual alerts, and (B) more inclined to reduce their speed when entering zones than they were without the visual alerts. The metrics used to analyze driver behavior at the zone entry point are presented in Table 57. The rows in the table highlighted blue indicate desired behavior types.

To be included in this analysis, participants must have had a minimum of three trips each in the baseline and test periods, and their number of baseline trips and test trips must not have differed by a factor of more than seven. A factor of seven was selected as it appeared to remove outliers which would too heavily weight either baseline or test trips when comparing averages for the purpose of identifying behavior change. Additionally, only trips where a visual alert was displayed at the entry point of the signage zone were considered. In some longer zones, participants could have entered the zone from a side street or driveway, in which case their behavior at the visual alert point would vary significantly from a participant traveling at speed on a roadway when entering the zone (i.e., a driver may be increasing speed from a stop if entering a zone from driveway). The resulting analysis included 227 participants across a total of 3,156 baseline trips and 2,347 test trips in 67 different signage zones.

Table 57. Metrics for Driver Behavior at Visual Alert Point.

Behavior Category	Baseline Metric Result (+ or - result)	Test Metric Result (+ or - result)	Behavior Change Indicator [Baseline Metric minus Test Metric] (+ or - result)	Description of Participant Behavior Change	Type
Speed Limit Compliance (A) Metric A – vehicle speed after entering signage zone minus zone speed limit	Compliant (-)	Compliant (-)	Positive (+)	more compliant in test period than baseline period	1-A
			Negative (-)	less compliant in test period than baseline period	2-A
	Compliant (-)	Speeding (+)	Negative (-)	shift from compliant in baseline period to non-compliant in test period	3-A
	Speeding (+)	Compliant (-)	Positive (+)	shift from non-compliant in baseline period to compliant in test period	4-A
	Speeding (+)	Speeding (+)	Positive (+)	non-compliant in baseline and test periods with improved compliance in test period	5-A
			Negative (-)	non-compliant in baseline and test periods with declined compliance in test period	6-A
Change in Speed Across Zone Entry Point (B) Metric B – vehicle speed after entering signage zone minus vehicle speed before entering signage zone	Slow Down (-)	Slow Down (-)	Positive (+)	decrease in speed after entering zone in baseline and test periods with a greater decrease in test period	1-B
			Negative (-)	decrease in speed after entering zone in baseline and test periods with a greater decrease in baseline period	2-B
	Slow Down (-)	Speed Up (+)	Negative (-)	shift from an decrease in speed after entering zone in baseline period to an increase in speed in test period	3-B[56]
	Speed Up (+)	Slow down (-)	Positive (+)	shift from an increase in speed after entering zone in baseline period to an decrease in speed in test period	4-B
	Speed Up (+)	Speed Up (+)	Positive (+)	increase in speed after entering zone in baseline and test periods with a greater increase in baseline period	5-B
			Negative (-)	increase in speed after entering zone in baseline and test periods with a greater increase in test period	6-B

[56] Trips where Metric B was greater than 0 mph indicated that participants were increasing their speed when the visual safety alert was displayed in the vehicle. It is likely most of these behavior types were the result of a driver stopped in traffic or accelerating from a stop prior to entering a safety signage zone or a driver who was intentionally ignoring the alerts altogether. These trips were excluded from the analysis to prevent a negative influence on the speed metric averages calculated across all trips resulting from these types of trips with outside factors. Therefore, although Behavior Types 3-B and 6-B may have occurred in the test, they will not show up in the analysis results.

4.3.1 Speed Limit Compliance at Zone Entry Point

4.3.1.1 Analysis Method

After excluding data for particular drivers and trips as described previously (e.g., participants reporting that they had not seen a signage zone on their device), the team analyzed each driver's behavior individually upon entering the signage zone for all the baseline trips and test trips. For each driver the team calculated two values:

1) The average difference between speed and speed limit just after entering the zone for <u>baseline period trips</u>.
2) The average difference between speed and speed limit just after entering the zone for <u>test period trips</u>.

The team calculated these average values for each participant and labeled the corresponding behavior as either "compliant" (at or below the posted speed limit) or "speeding" (higher than the posted speed limit). The team then assessed the difference between the baseline and test periods for each participant to see if there was a positive or negative change in behavior. Even drivers who showed the same behavior in both the baseline and test periods (e.g., speeding on average in both) could exhibit a positive change in the test period compared to the baseline (e.g., if the driver was speeding both with and without the alerts, but their average speed was lower when presented with alerts, there was still a positive change in behavior). The team then classified each participant's behavior change as one of six "types," labeled Type 1-A though 6-A, in Table 57. The team looked at what the overall change was across the entire group and then focused specifically on types 4-A and 5-A, as these represent the most desired change in behavior.

4.3.1.2 Findings

Looking at all participants (regardless of whether they had a positive or negative change in behavior), drivers on average were not compliant with the speed limit after crossing the zone entry point whether an alert was present or not, but their speed was lower when they received a visual alert (behavior change type 5-A). In fact, drivers exceeded the speed limit by 4.4 mph on average in the baseline and by 3.8 mph on average in the test period. This reflects an overall average reduction in speed of 0.6 mph. Although the team did find this change to be statistically significant ($t\ (226) = 2.48$, $P = 0.014$), there appeared to only be a slight improvement in speed limit compliance at the zone entry point.

As shown in Table 58 below, assessing behavior on the participant level indicates that the most common behavior changes across all participants were types 5-A and 6-A. Eighty-four percent of drivers were not compliant with the speed limit in the baseline or the test period (types 5-A and 6-A); however, 51 percent did become more compliant in the test period compared to the baseline period with the presence of the alerts, but were still speeding overall. Eight percent of drivers were speeding on average in the baseline period, but changed their behavior and were compliant on average in the test period.

Table 58. Change in Average Speed at Zone Entry Point for Speed Zones and School Zones (Baseline vs. Test Periods).

Behavior Type	Avg. Diff. btwn Speed and SL, Baseline Period (mph)	Avg. Diff. btwn Speed and SL, Test Period (mph)	Change in Speed Limit Compliance [Baseline – Test] (mph)	Number (%) of Participants	Number (%) of Trips
1-A	-1.42	-2.59	+1.16	2 (1%)	28 (1%)
2-A	-3.32	-2.08	-1.24	6 (3%)	72 (1%)
3-A	-1.73	+4.46	6.19	10 (4%)	171 (3%)
4-A	+3.87	-1.48	+5.35	17 (8%)	336 (6%)
5-A	+5.72	+3.24	+2.48	116 (51%)	2,845 (52%)
6-A	+4.14	+6.49	-2.36	76 (33%)	2,051 (37%)
Overall	**+4.42**	**+3.84**	**+0.59**	**227**	**5,503**

When considering how many participants exhibited a behavior change that is desired (i.e., behavior types 4-A and 5-A, where drivers were not previously compliant with the speed limit and the presence of the alert increased their compliance), 59 percent of the participants responded in this way. For these participants, their average travel speed exceeded the speed limit by +5.4 mph in the baseline and by +2.6 mph in the test period. This reflects an overall average reduction in speed of 2.8 mph. This difference in speed is statistically significant ($t(131) = 15.36$, $P < 0.001$).

4.3.2 Change in Speed across Zone Entry Point

4.3.2.1 Analysis Method

After excluding data for particular drivers and trips as described previously, the team looked at driver behavior for each driver individually at the zone entry point for all the baseline trips and test trips. For each driver the team calculated two values:

1) The average change in speed prior to entering the zone and after entering the zone during the baseline period.
2) The average change in speed prior to entering the zone and after entering the zone during the test period.

The team then looked at the change between the baseline and test periods for each driver to see if there was a positive or negative change in behavior. For any drivers who exhibited the same behavior change type across both baseline and test periods, the team looked further to identify whether a positive change occurred (e.g., if the driver was increasing speed both with and without the alerts, but their total increase in speed was lower when presented with alerts, there was still a slightly positive change in behavior).

After calculating these values for each driver in the baseline and test periods, the team labeled each driver's behavior as either "speeding up" or "slowing down" as they crossed the zone entry point. The team then labeled each participant as exhibiting one of six behavior change "types," named Type 1-B though 6-B, as was shown in Table 57. The team focused on types 1-B, 4-B, and 5-B, as these reflected the most desired changes in driver behavior.

4.3.2.2 Findings

Looking at all participants (regardless of whether they had a positive or negative change in behavior), on an average trip, drivers decreased their speed upon entering the zone both in the baseline and test periods, but the reduction in speed was greater in the test period when the alert was present (behavior change type 1-B). On average, drivers slowed down 4.0 mph in the baseline and 6.1 mph in the test period when crossing the zone entry. This reflects an overall average reduction in speed of 2.1 mph. This difference in speed was found to be statistically significant ($t\ (226) = 9.28$, $P < 0.001$).

As shown in Table 59, by looking at behavior on the participant level, it can be seen that the only behavior changes exhibited by drivers were types 1-B, 2-B, and 4-B. Ninety-four percent of participants fell into either 1-B or 2-B (i.e., even without an alert they did decrease their speed upon entering the zone), with 78 percent of these slowing down more when presented with an alert and 22 percent slowing down less with the alert.

Table 59. Average Change in Speed across Zone Entry Point for Speed Zones and School Zones (Baseline and Test Periods).

Behavior Type	Average Change in Speed, Baseline Period (mph)	Average Change in Speed, Test Period (mph)	Difference in Speed Change (mph)	Number (Percentage) of Participants	Number (Percentage) of Trips
1-B	-3.63	-6.26	2.63	158 (70%)	4,033 (73%)
2-B	-7.44	-5.50	-1.93	52 (23%)	1,146 (21%)
4-B	+2.83	-6.17	9.00	17 (7%)	324 (6%)
Grand Total	**-4.02**	**-6.08**	**2.06**	**227**	**5,503**

When considering how many participants exhibited the most desired behavior change (i.e., behavior type 4-B where drivers increased their speed upon entering the zone in the baseline, but slowed down upon entry in the test period), only 7 percent of the participants responded in this way. These participants increased their speed by an average of 2.8 mph in the baseline while they decreased their speed by 6.2 mph in the test period. This reflects an overall average reduction in speed change of 9.0 mph. This average difference in speed change between the baseline and test conditions was found to be statistically significant ($t\ (16) = 11.05$, $p < 0.001$).

4.3.3 Speed Profile – Response to Visual Alert

Speed limit compliance after entering the signage zone and change in speed across the zone entry point were the two metrics used to identify a change in driver behavior in response to the visual safety signage alerts. For each metric, participants' total trips in the baseline and the test periods were compared and a behavior change type was assigned to the participant. While these metrics and their corresponding behavior change types were analyzed for statistical significance separately, identifying which participants exhibited the most desirable behavior change for both metrics provides further insight into how drivers responded to the visual safety signage alerts. In Table 57 where the behavior change types were initially presented, types 4-A and 4-B together represent the most desired combination of behavior change in response to the safety signage alerts. Participants labeled with both behavior change types were speeding after entering the zone and even speeding up across the zone entry point in the baseline period, but showed a behavior change in the test period by slowing down across the zone entry point and complying with zone speed limit after entering the zone. In total, only 3 participants exhibited this level of behavior change in the field test. Figure 53 below presents a speed profile for all trips traveled through a single speed zone by one participant. The comparison of the baseline period behavior to the test period behavior clearly shows an improvement in speed limit compliance and a reduction in speed.

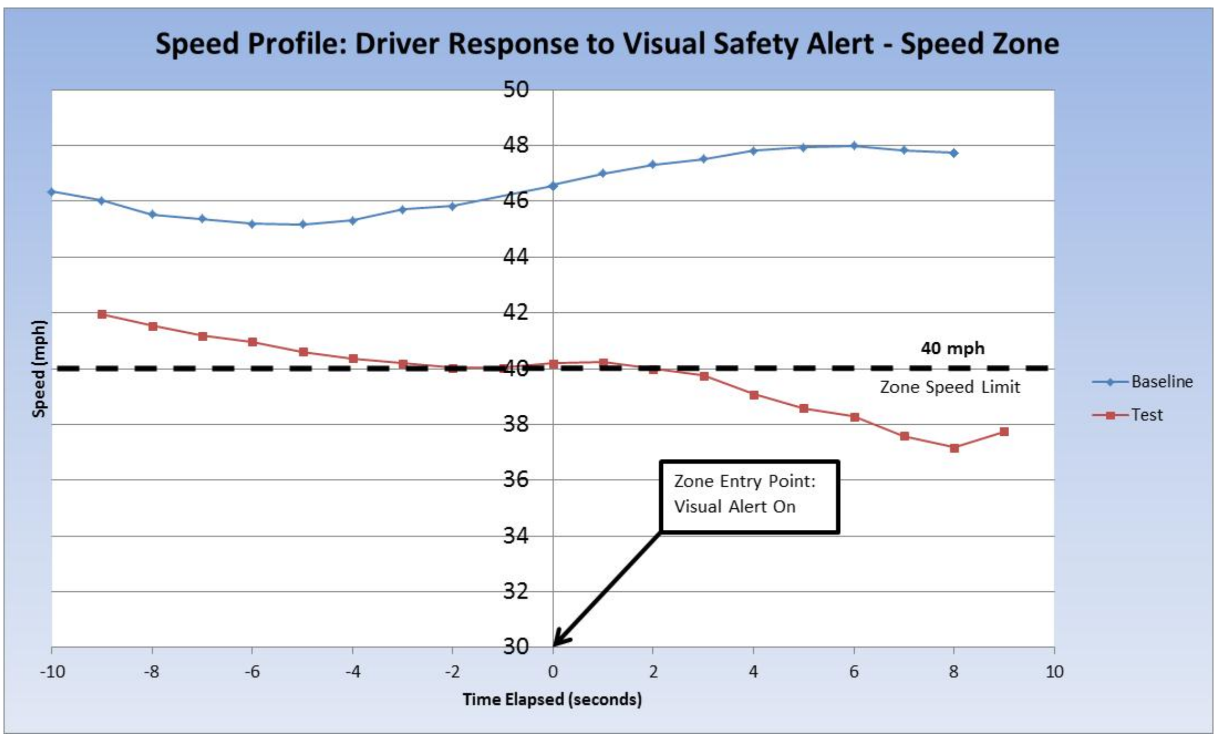


Figure 53. Speed Profile - Driver Response to Visual Safety Alert.

4.4 Analysis of Driver Behavior at Audible Alert Point

For this analysis the team focused only on test period data and looked at comparisons of driving behavior before and after the point where the driver received their first audible alert in a given zone. Since drivers were presented with audible alerts only in zones with regulatory signs, this analysis applies only to speed zones and school zones. The point at which the audible alert was triggered varied by driver, and drivers who always drove within 5 mph of the posted zone speed limit are not included in this analysis as they never would have been presented with an alert. The team hypothesized that drivers would: (a) reduce their speed after receiving an audible alert, and (b) be more compliant with the speed limit than they were before the audible alert was given.

To be included in this analysis, participants must have had at least 3 trips where an audible alert was received during the trip. The resulting analysis of driver behavior included 247 participants across a total of 2,210 test period trips in 55 different signage zones.

4.4.1 Change in Speed in Response to Audible Alert

4.4.1.1 Analysis Method

After excluding data for particular drivers and trips as described previously (e.g., drivers who reported having muted the volume on their device, trips that are unable to be linked to a driver), the team looked the behavior of each driver individually at the point where that person first received an audible alert. Note that the location of the initial audible alert point varies with each trip, as the audible alert only exhibits when the driver is exceeding the posted speed limit by 5 mph or more. If the driver is exceeding the posted speed limit by 5 mph or more upon entering the zone, the location of the initial audible alert point coincides with the zone entry point. In some instances the initial audible alert point was well into the signage zone. For the sample analyzed, described in the section above, drivers received the audible alert at the zone entry point for 95 percent of trips where an audible alert occurred during the test period. Because audible alerts only sounded when drivers were exceeding the posted speed limit by 5 mph or more, all drivers included in this analysis were exceeding the speed limit just prior to receiving an alert.

The team looked at each driver's average speed just prior to and just after the initial audible alert point to determine if drivers increased or decreased their speed upon receiving the alert, and if they decreased their speed, whether they decreased it enough to be compliant with the speed limit. The team then classified each change as one of three "types," labeled Type 1-C though 3-C, as shown in Table 60 below.

Table 60. Metrics for Driver Behavior at Audible Alert Point.

Behavior Category	Behavior Change Indicator: ["Prior to Alert" minus "After Alerts" Metric] (+ or - result)	Description of Participant Behavior Change	Type
Speed Limit Compliance Across Audible Alert Point (C)	Positive(+), Slowing Down	shift from non-compliant before alert to compliant after alert	1-C
Metric C – vehicle speed before/after receiving audible alert minus zone speed limit	Positive (+), Slowing Down	non-compliant both before and after alert with improved compliance after alert	2-C
	Negative (-), Speeding Up	non-compliant both before and after alert with reduced compliance after alert	3-C

4.4.1.2 Findings

Looking at all participants (regardless of whether they had a positive or negative change in behavior), drivers on average were still not compliant with the speed limit in the time period immediately following receipt of the audible alert, although drivers did decrease speed (change type 2-C). On average, drivers exceeded the speed limit by 11.6 mph (+/- 9.9 mph) before receiving the alert and by 5.9 mph (+/- 13.2 mph) after receiving the alert. This reflects an overall average reduction in speed of 5.6 mph. This change was found to be statistically significant (t (246) = 28.67, P <0.001).

As shown in Table 61, by looking at behavior on the participant level, it can be seen that the most common behavior change was type 2-C with 95 percent of participants falling into this category.

Table 61. Average Change in Speed Limit Compliance upon Receipt of Initial Audible Alert.

Behavior Type	Speed Limit Compliance, Before Alert (mph)	Speed Limit Compliance, After Alert (mph)	Difference in Speed (mph)	Number (Percentage) of Participants	Number (Percentage) of Trips
1-C	9.99	(2.06)	12.05	12 (5%)	66 (3%)
2-C	11.69	6.21	5.48	229 (93%)	2,104 (95%)
3-C	9.72	11.30	(1.59)	6 (2%)	40 (2%)
Grand Total	**11.56**	**5.93**	**5.93**	**227**	**5,503**

When considering how many participants exhibited a behavior change that is desired (i.e., behavior types 1-C and 2-C, where drivers decreased their speed upon receipt of the alert), nearly all participants responded in this way (98.1 percent). These participants exceeded the speed limit by an average of 11.6 mph before receipt of the alert and by an average of 5.8 mph after receipt of the alert. This reflects an overall average reduction in speed of 5.8 mph. This difference in speed is statistically significant (t (240) = 31.13, P < 0.001).

When looking at speeds before and after the alert, on average, drivers were traveling 48.8 mph before receiving the alert and dropped to 43.1 mph after receiving the alert. This reflects an overall average reduction in speed of 5.7 mph. This change was found to be statistically significant (t (240) = 31.13, P <0.001). Interestingly, although drivers did decrease their speed in response to the alert, most drivers did not decrease their speed enough to avoid the audible alert altogether. Figure 54 below supports this finding and provides further insight by presenting the average amount of time in percent that participants received the audible alert while traveling through a signage zone. The majority of participants (55 percent) received the audible alert for 75 percent or more of their travel through the zone.

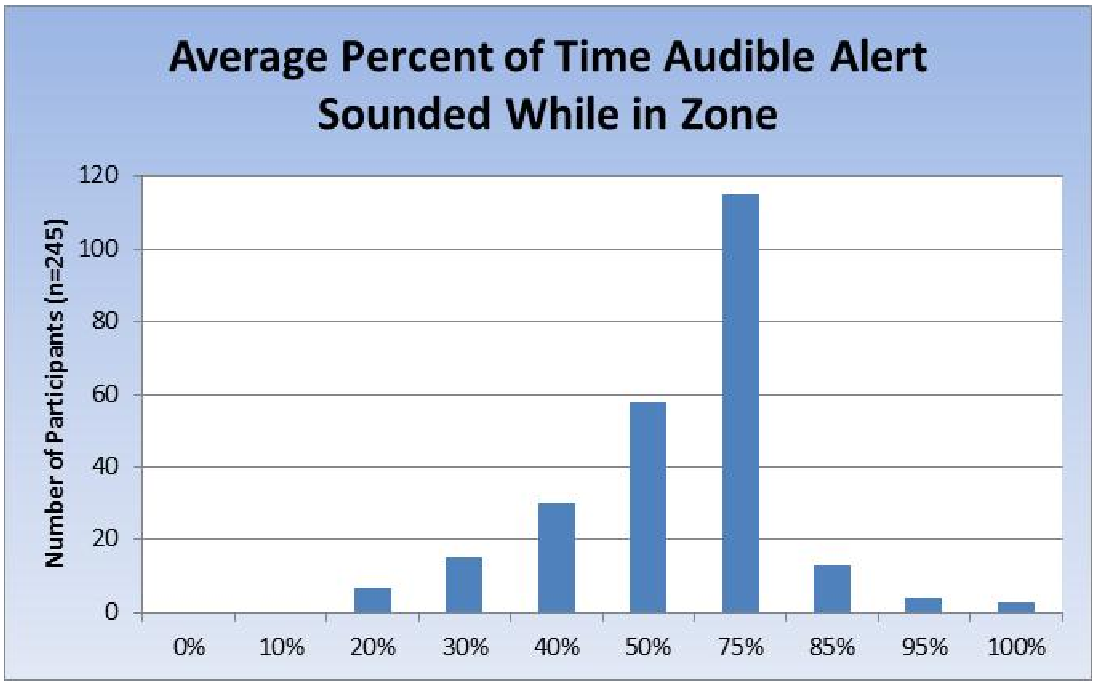


Figure 54. Average Percent of Time Audible Alert Sounded While in Zone

4.4.2 Speed Profile – Response to Audible Alert

Speed limit compliance after receiving an audible alert and change in speed across the audible alert point were the two metrics used to identify a change in driver behavior in response to the audible safety signage alerts. In test period trips, participants' behavior before the audible alert was given was compared behavior after the alert was given and a behavior change type was assigned to the participant. In Table 60, where the behavior change types were initially presented, type 1-C represented the most desired behavior change in response to the audible alerts. Participants labeled with this behavior change type were speeding prior to the audible alert point, but showed a behavior change after the audible alert sounded by slowing down across the audible alert point and complying with zone speed limit. As presented above, a total of 12 participants exhibited this behavior in the field test. Figure 55 below presents a speed profile for a trip in the test period where a participant received an audible alert while traveling through speed zone. Although the participant did not lower his/her speed to below the speed limit until nearly the end of the zone, the comparison of the before alert behavior to the after alert behavior clearly shows an improvement in speed limit compliance and a reduction in speed in response to the audible alert.

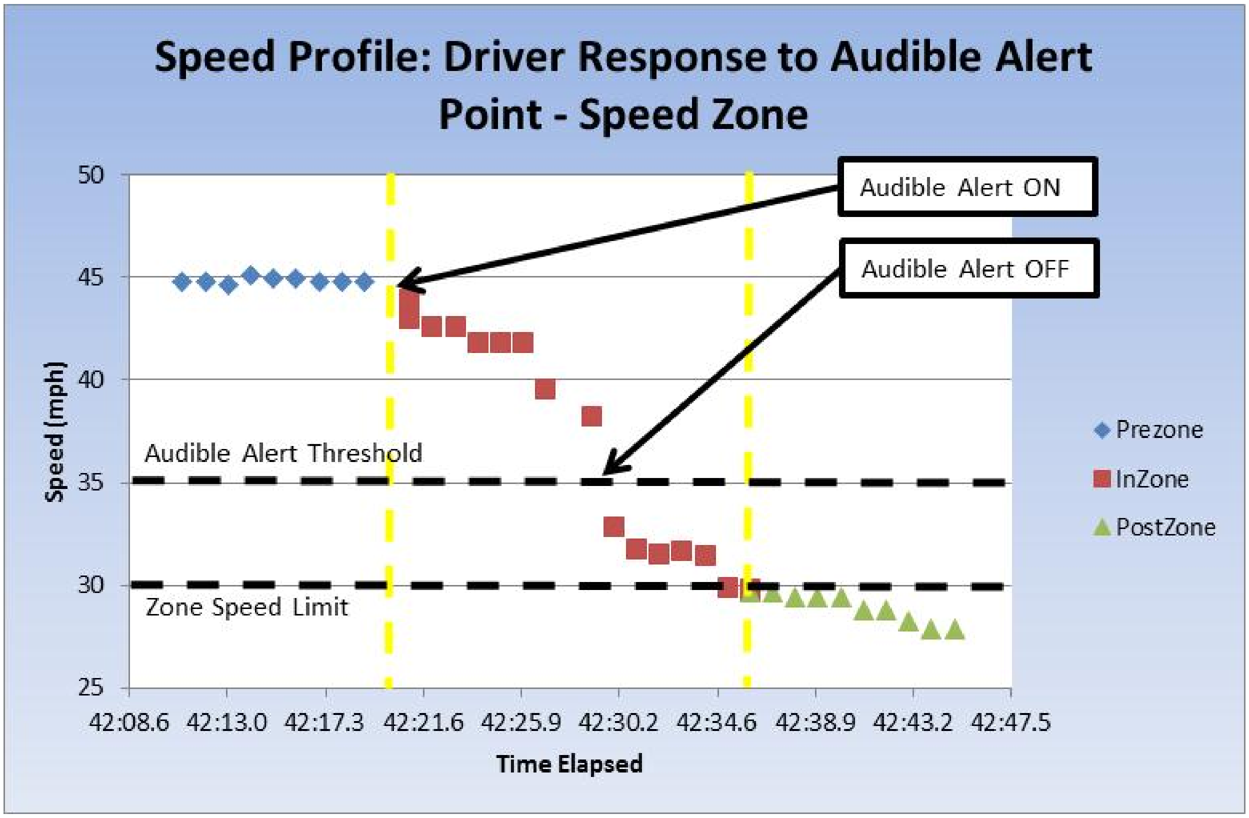


Figure 55. Speed Profile - Driver Response to Audible Alert Point

4.5 Analysis of Driver Behavior through Signage Zones (from Entry Point to Exit Point)

In this analysis, the team again excluded 20 individuals who reported on survey 3 that they had not seen a signage zone icon on their device, as well as 1 individual who requested help from the deployment team to deactivate the signage function of the MRFT application on their smartphone. The team focused on comparisons of driver behavior without the alerts (baseline period trips) to driver behavior with alerts (test period trips). The team hypothesized that drivers would be more compliant with the speed limit throughout the length of the zone when provided an alert. This applies to all zone types, but the focus is slightly different for curves since each curve signage zone ends where its corresponding curve begins. As a result, the desired behavior in a curve zone is for the driver to slow down prior to reaching the curve, whereas in the other zones the intended behavior is for the driver to slow down while in the signage zone. Curve zones are advisory in nature and provide a suggested speed before entering a curve. Therefore, the study team analyzed speed limit compliance throughout the entire zone for regulatory zones and analyzed change in speed throughout the entire zone for curve warning zones.

4.5.1 Speed Limit Compliance through Regulatory Zones

4.5.1.1 Analysis Method

To be included in speed limit compliance analysis for regulatory zones, participants must have had a minimum of three trips each in the baseline and test periods, and their number of baseline trips and test trips could not differ by a factor of more than seven. The resulting analysis of driver behavior included 227 participants across a total of 3,156 baseline trips and 2,347 test trips in 67 different signage zones.

After excluding data for particular drivers and trips as described above, the team assessed overall speed limit compliance by analyzing the average percentage of time that a participant was driving above the speed limit through the entire zone. Each participant's average percentage in the baseline was compared to their average percentage in the test period. Participants were found to show (1) no change in percent speeding, (2) an increase in percent speeding, or (3) a decrease in percent speeding in the test period compared to the baseline period. The latter was the most desirable behavior change.

4.5.1.2 Findings

Looking at all participants (regardless of whether they had a positive or negative change in behavior), drivers on average did show a decrease in the percent of time that they were speeding while traveling through an entire signage zone. On average, drivers were speeding 74 percent of the time in the baseline period before receiving the visual alerts in the test period and reduced the percentage of time they spent speeding to 71 percent after receiving audio and/or visual alerts, an overall reduction of 3 percent. This change was found to be statistically significant ($t(226) = 2.95$, $P = 0.004$).

As shown in Table 61, by looking at behavior on the participant level, it can be seen that the most common behavior change was a decrease in the percentage of time spent speeding through a signage zone in the test period when compared to the baseline period, with 57 percent of participants falling into this category.

Table 62. Average Change in Percentage of Time Speeding Through Signage Zones.

Behavior Type	Average Change in Percent Time Speeding	Average Percent Time Speeding, Baseline Period	Average Change in Percent Time Speeding	Number (%) of Participants	Number (%) of Trips
No change	0%	100%	0%	1 (<1%)	14 (<1%)
Percent Speeding Increased	-12%	67%	-12%	94 (42%)	2,178 (40%)
Percent Speeding Decreased	+14%	80%	+14%	128 (57%)	3,287 (60%)
Overall	**+3%**	**74%**	**+3%**	**223**	**5,479**

The participants who showed the desired behavior change of reducing the amount of time spent speeding through the signage zones exhibited an average time spent speeding of 80 percent before receipt of the alert and an average of 65 percent after receipt of the alert. This reflects an overall average reduction in percentage of time spent speeding of 14 percent. This difference is statistically significant (t (226) = 2.95, P = 0.004).

4.5.2 Change in Speed through Curve Warning Zones

4.5.2.1 Analysis Method

As mentioned before, curve warning zones were treated differently due to the fact that they are advisory in nature and do not have a zone speed limit associated with them. The in-vehicle visual alert (which matched the roadside sign) was simply a right or left arrow indicating a right or left curve ahead. The goal of providing an in-vehicle safety alert to drivers ahead of curves is not to get them to comply with a speed limit, but rather to ensure that they reduce their speed at some point prior to reaching the curve. The boundaries for curve warning signage zones were set to begin and end prior to the actual beginning of the curve on the roadway. Drivers received the visual alert for curve zones as close to the sight distance for the roadside sign as possible. Similar to the zone entry point analysis presented previously, the regression analysis applied to curve zones will consider the before and after speed across a point of interest. In this case, the point of interest is the entire curve signage zone. The results of the regression analysis will identify trips where drivers slowed down at some point while in the signage zone prior to exiting the curve signage zone and entering the actual curve. This analysis will use the same Type-B behavior change metrics as shown in Table 57 for the zone entry point analysis. However, again, this analysis considers speed across the whole zone, not just across the zone entry point.

The change in speed analysis for curve warning zones included 30 participants across a total of 191 baseline trips and 302 test trips in 7 different signage zones. Due to the low number of curve warning zones and events through these zones, the requirements for participants to be included in the analysis were relaxed slightly compared to the other analyses. Participants had a minimum of two trips each in the baseline and test periods, and their number of baseline trips and test trips did not differ by a factor of more than seven.

4.5.2.2 Findings

Looking at all participants (regardless of whether they had a positive or negative change in behavior), on an average trip, drivers decreased their speed at some point in the curve zone both in the baseline and test periods, but the alerts seemed to have an opposite (but minor) effect on drivers as the reduction in speed was greater in the baseline period when the alert was not present (behavior change type 2-B). On average, drivers slowed down 3.4 mph in the baseline and only 3.2 mph in the test period. This reflects an overall average reduction in speed of 0.2 mph. However, this difference in speed does not appear to be statistically significant, (t (29) = -0.58, P = 0.565).

As shown in Table 59, by looking at behavior on the participant level, it can be seen that the only behavior changes exhibited by drivers were types 1-B and 2-B. For each behavior type, participants were slowing down across the entire signage zone in the baseline, which is certainly a positive behavior. However, 53 percent continued slowing down but slowed down more in the test period in response to the visual alert (type 1-B) while 47 percent continued slowing down in the test period but slowed down less when the visual alert was displayed (type 2-B).

Table 63. Average Change in Speed across Entire Signage Zone for Curve Warning Zones (Baseline and Test Periods).

Behavior Type	Average Change in Speed, Baseline Period (mph)	Average Change in Speed, Test Period (mph)	Difference in Speed Change (mph)	Number (Percentage) of Participants	Number (Percentage) of Trips
1-B	-3.46	-4.30	+0.84	16 (53%)	298 (60%)
2-B	-3.35	-1.94	-1.40	14 (47%)	195 (40%)
Overall	**-3.41**	**-3.20**	**-0.21**	**30**	**493**

Because types 1-B and 2-B involved drivers slowing down in both the baseline and test periods, there is no indication that a more desirable behavior change occurred in the test period when visual alerts were present compared to the baseline condition. Therefore, no additional calculations or statistical tests were performed regarding driver response to curve warning zones. In effect, it appears there was little to no improvement in behavior for this zone type, as drivers were already performing as expected in both conditions.

4.6 Analysis of Construction Zones

The process for identifying a construction zone to demonstrate during the test involved finding a location that was not only active during the timeframe of one or more active waves of participants, but also was located in close proximity to the study participants, who lived in

Wright County. Due to the fact that most construction zones are active for limited periods of time, it was difficult to identify a “good” construction zone for study purposes. One construction zone was finally included in the test and was active for the final 4 weeks of the Wave C participants’ time in the test. Due to the configuration of the work zone and the multiple access points from which participants could enter the construction zone, the construction zone included 7 distinct signage zones. Only 11 participants drove through the signage zone during the course of the test, so the study team has not analyzed driver data to present here.

However, much can be learned from the project team’s experience in deploying safety signage zones in a construction zone. Considerations, challenges, and lessons learned when deploying in-vehicle safety signage alerts for a construction zone include the following:

- Identifying exact signage locations can be difficult as construction activities can change daily and even hourly, requiring signage to be relocated and making it difficult to get information quickly enough from the on-site construction workers to ensure that the zones are current. Also, construction workers can sometimes move signs a short distance without realizing the repercussions.
- Identifying timing of the overall construction zone can be difficult as construction plans change quite often due to weather events.
- A common complaint with construction zones is that reduced speed limits are posted regardless of whether workers are present. Implementing a dynamic in-vehicle system poses an opportunity to address challenges like this by having “active hours” established in the system or by having the construction engineer update the current status through an electronic system that feeds the in-vehicle devices. However, this can be difficult to do, so the current challenge will likely still exist.
- Technology is available that can wirelessly transmit the exact location of a sign or construction barrel using GPS. While expensive, a safety alert system similar to the one deployed in the field test could benefit from real-time access to these locations, especially in the more dynamic construction zones.

5 Summary of Findings

Both visual and audible alerts appear to have improved speed limit compliance and reduced driver speeds, with drivers showing a greater reduction in speed when presented with audible alerts. The most significant effect was among drivers who were previously increasing their speed upon entering the zone.

- **Analysis of Driver Behavior at Visual Alert Point indicated positive behavior change with regard to speed limit compliance.** Drivers on average were not compliant with the speed limit at the zone entry point whether a visual alert was present or not, but they did appear to lower their speed slightly when an alert was present. Although the result was found to be statistically significant, there appeared to only be a slight improvement in speed limit compliance at the zone entry point of less than 1 mph. However, 59 percent of drivers who were not previously compliant with the speed limit did show a positive behavior change by becoming more compliant (although still above the speed limit) in the test period. For these drivers, the presence of the alert lowered their speed by an average of 2.8 mph. Looking at individual participants (regardless of whether they had a positive or negative change in behavior), drivers decreased their speed upon entering the zone both with and without the presence of the alert, but the reduction in speed was greater when the alert was present (a 2.1 mph greater reduction in speed). For the 8 percent of drivers who previously increased their speed upon entering the zone, but who slowed down upon entry when alerts were present, there was a much larger impact, with an overall average reduction in speed of 9.0 mph.
- **Analysis of Driver Behavior at Audible Alert Point identified positive change with regard to reduction in speed in response to audible alert.** Of drivers who were traveling at least 5 mph over the speed limit and who received an audible alert, 98 percent decreased their speed after receiving the alert, although they continued to drive faster than the speed limit. On average, these drivers lowered their speed by 5.8 mph. Interestingly, although drivers did decrease their speed in response to the alert, most drivers did not decrease their speed enough to avoid the audible alert altogether. Additionally, 55 percent of participants received the audible alert for 75 percent or more of their travel time through the zone.
- **Analysis of Driver Behavior through Signage Zones indicated a positive behavior change in regard to percent of time driving above the speed limit through signage zones.** The study team also analyzed speed limit compliance throughout the entire zone for regulatory zones and analyzed change in speed throughout the entire zone for curve warning zones. In regulatory zones, drivers on average did show a slight decrease in the percent of time that they were driving above the speed limit while traveling through an entire safety signage zone from 74 percent of time in the baseline period to 71 percent of time in the test period. For individual participants that showed a decrease in percent of time speeding through the zone, there was average reduction of 14 percent less time speeding in the test period compared to the baseline where drivers were speeding 85 percent of time through the zone. In curve warning zones, on average, drivers slowed down 3.4 mph in the baseline and only 3.2 mph in the test period across the entire

signage zone, an overall average reduction in speed of only 0.2 mph. However, this change was not found to be statistically significant.

In summary, audible alerts appeared to have a much larger more significant impact on driver behavior than visual alerts. It was found that in most cases participants were not compliant with the posted zone speed limit upon entering a signage zone and were found to remain above the speed limit for most of their time traveling through the zone. In cases where an audible alert was received for traveling 5 mph or more above the zone speed limit, participants appeared to respond to the audible alerts but did not lower their speed enough to become compliant. The majority of participants that received audible alerts initially continued receiving them for 75 percent of their travel through a zone. While fewer cases were observed where participants did become speed limit compliant, both the visual alerts and audible alerts did appear to provoke participants lower their speed overall. It is important once again to point out the impact of the system reliability and accuracy issues identified in *Volume II*. While the analysis approach identified in this volume accounted for GPS issues and positive behavior change appeared to occur, signage functionality is dependent on reliable GPS signal to consistently and accurately present safety signage alerts.

Volume VI: Assessment of In-Vehicle CICAS Safety Alerts

1 Introduction

This section of the report describes the Cooperative Intersection Collision Avoidance Systems test conducted as part of the larger Minnesota Road Fee Test.

1.1 Background on Cooperative Intersection Collision Avoidance Systems

More than 60 percent of fatalities from stop-sign related collisions occur in rural areas and cost nearly $30 billion each year.[1] One way the U.S. Department of Transportation (USDOT) is working to improve safety at intersections is through the Intelligent Transportation Systems Joint Program Office's (ITS JPO) Cooperative Intersection Collision Avoidance Systems (CICAS) initiative. The concept of CICAS is to communicate messages between vehicles and the roadside to warn drivers about unsafe conditions. One type of CICAS system is CICAS Stop Sign Assist (CICAS-SSA) which uses dedicated short-range communication (DSRC) to provide a warning to drivers when an unsafe gap condition occurs in approaching traffic at a two-way stop-controlled intersection. A CICAS-SSA system is expected to be more effective than traditional methods, such as larger stop signs, flashers, and pavement markings, to warn drivers on the major road of entering vehicles. These more traditional traffic control devices have not proven to address the safety problem. Although the traditional methods can be effective at reducing the incidence of collisions with vehicles entering from the minor road, they can also result in an increase in the number of rear-end collisions on the major road.[2]

In their efforts to reduce fatalities and serious injuries caused by lateral crashes at unsignalized rural intersections, Minnesota has been one of the pioneers in testing CICAS-SSA technologies. Minnesota Department of Transportation (MnDOT) has tested CICAS-SSA at select intersections to date, each of which have known sight distance limitations or other characteristics including high travel speeds on the primary roadway which have led to elevated collision rates.[3]

---

[1] Minnesota Department of Transportation, *Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) Concept of Operations*, 2008. http://www.dot.state.mn.us/guidestar/2006_2010/cicas/CICAS_SSA_ConOps_FINAL_3_18_08.pdf

[2] Gorjestani, et al., *The Design of an Optimal Surveillance System for a Cooperative Collision Avoidance System – Stop Sign Assist: CICAS – SSA Report #2,* ITS Institute of the University of Minnesota, 2008, p. 2. http://www.dot.state.mn.us/guidestar/2006_2010/cicas/CICAS-SSA%20Report%202.pdf

[3] Rakauskas, M., Creaser, J., Manser, M., Graving, J., & Donath, M., *Validation Study – On-Road Evaluation of the Cooperative Intersection Collision Avoidance System – Stop Sign Assist: CICAS-SSA Report #5,* ITS Institute of the University of Minnesota, 2009. http://www.its.dot.gov/research_docs/pdf/cicas_tech_doc5.pdf

The Intelligent Transportation System (ITS) Institute of the University of Minnesota has led previous efforts to design and evaluate various components of CICAS-SSA and this study builds on those efforts. The first efforts focused on technical aspects including the timing schema for messages and the optimal detection system, which ultimately supported the development of an algorithm to identify unsafe gap conditions.[4,5] Later efforts focused on considerations for implementation, including gap acceptance behaviors, the comprehension and placement of roadside Driver Infrastructure Interfaces (DIIs) and the verification of simulated and assumed benefits of these signs.[6,7,8] The CICAS-SSA Concept of Operations developed by MnDOT included provisions for a Driver Vehicle Interface (DVI) to display messages to drivers from inside vehicles, but few of the previous research efforts have focused specifically on field testing these components of the CICAS-SSA system. [9]

1.2 Goal and Rationale

The purpose of this study was to complement MnDOT's previous research on driver comprehension and use of DVIs. Conducting the test in conjunction with the Minnesota Road Fee Test presented an opportunity to demonstrate that an in-vehicle device used to assess road user fees can also be effective at providing safety alerts to motorists. The intersection of US Highway 169 (US-169) and County Road 11 (CR-11) in Milaca (Mille Lacs County) was chosen for the study, where an elevated incidence of collisions led to the installation of four DIIs to assist traffic from the minor road (CR-11) in performing crossing and turn maneuvers safely (see Figure 56 and Figure 57 below which show the DVI and DII). The infrastructure was installed approximately 1 year before this study was conducted, and consequently, most local drivers have at least some familiarity with the DII display. Since the in-vehicle signage was meant to

[4] Gorjestani, et al., *The Design of an Optimal Surveillance System for a Cooperative Collision Avoidance System – Stop Sign Assist: CICAS – SSA Report #2,* ITS Institute of the University of Minnesota, 2008, p. 2. http://www.dot.state.mn.us/guidestar/2006_2010/cicas/CICAS-SSA%20Report%202.pdf

[5] Gorjestani, et al., *Alert and Warning Timing for CICAS-SSA – An Approach Using Macroscopic and Microscopic Data: CICAS-SSA Report #1*, ITS Institute of the University of Minnesota, 2008. http://www.its.umn.edu/Publications/ResearchReports/reportdetail.html?id=1958

[6] Gorjestani, et al., *Macroscopic Review of Driver Gap Acceptance and Rejection Behavior at Rural Thru-Stop Intersections in the US - Data Collection Results in Eight States: CICAS-SSA Report #3*, ITS Institute of the University of Minnesota, 2010. http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=1962

[7] Creaser, J., Manser, M., Rakauskas, M., & Donath, M., *Sign Comprehension, Rotation, Location, and Random Gap Simulation Studies: CICAS-SSA Report #4,* ITS Institute of the University of Minnesota, 2008. http://www.its.dot.gov/research_docs/pdf/cicas_tech_docrpt4.pdf

[8] Rakauskas, M., Creaser, J., Manser, M., Graving, J., & Donath, M., *Validation Study – On-Road Evaluation of the Cooperative Intersection Collision Avoidance System – Stop Sign Assist: CICAS-SSA Report #5,* ITS Institute of the University of Minnesota, 2009. http://www.its.dot.gov/research_docs/pdf/cicas_tech_doc5.pdf

[9] Minnesota Department of Transportation, *Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) Concept of Operations*, 2008. http://www.dot.state.mn.us/guidestar/2006_2010/cicas/CICAS_SSA_ConOps_FINAL_3_18_08.pdf

augment the drivers' experience in the context of the existing road signs, the study team focused recruitment on individuals who lived in the immediate vicinity of the intersection and who were already familiar with the roadside DIIs. As such, the study team could isolate the DVIs as the independent variable. That is, there would not be novelty associated with the roadside signs. Drivers would use them as they normally would.

Figure 56. View of DII in the Median of US-169 from Westbound Approach.

Figure 57. View of DVI in Conjunction with DII in the Median of US-169 from Eastbound Approach.

On behalf of MnDOT, Science Applications International Corporation (SAIC) conducted this study with the goal of evaluating drivers' preliminary reactions to the in-vehicle signage in conjunction with the information from the DIIs. The study focused on driver acceptance of the system as well as driver perceptions of the system's usefulness and accuracy. The scope of this project was limited to a small-scale field test, aimed at collecting foundational information needed to support subsequent research. The selected participants completed test runs of a prescribed route in their own vehicles, equipped with a temporarily-installed DVI, and accompanied by a researcher who provided navigational guidance and collected verbal feedback during the test. Additionally, the participants completed a short exit survey and interview to comprehensively document their feedback.

2 Approach

The following section describes how participants were selected for the study, and provides an explanation of equipment installation and operation as well as the methods of data collection employed by the study team.

2.1 Participants

The study team recruited participants through targeted mailings and phone calls to residences proximate to the intersection. The team screened applicants who responded to recruitment materials to exclude minors, drivers with unfavorable driving records, and transportation professionals. All other screening criteria focused on compliance with state auto-liability insurance requirements and possession or authorized use of a vehicle with a functioning power outlet (to enable installation of the test equipment).

A sample size of seven participants was determined be adequate to support the scope and schedule of the study, and the team selected three male and four female applicants to participate, all of whom use the intersection regularly. None of the applicants were under the age of 35, attributable to the predominant demographic of the residents directly adjacent to the intersection, and therefore age was not controlled for in the study. Further research may be necessary to determine the use and acceptance of the in-vehicle device by a wider audience, including younger users and drivers who are naïve to CICAS-SSA messaging systems.

2.2 Equipment

As previously stated, the test site was outfitted with a roadside CICAS-SSA system approximately a year before this study was conducted and this system remains operational at the time of the report printing. The in-vehicle system was temporarily installed in participants' cars for the duration of their test runs and was subsequently removed. The following is a description of the equipment deployed at the intersection and used for the vehicle installations; additional information about the equipment can be found in the CICAS-SSA Concept of Operations.[10]

The selected test site is configured for Roadside Computed Alerts and Warnings, where the messages are generated by detection and processing equipment on the roadside and then transmitted to the Driver Infrastructure Interface (DII) and Driver Vehicle Interface (DVI) for display. At the roadside, there are four DIIs which are changeable message signs used to display various alert and warning messages to drivers. As shown in Figure 58, two DIIs are positioned in the median of the intersection, each angled to face vehicles on one of the two minor street approaches, while the other two signs are positioned on the sides of the major road, angled to face vehicles in the median. The signs in Figure 58 are colored white and gray to denote which direction of traffic they are facing. The white signs face the westbound traffic while the gray signs face the eastbound traffic. As shown in Figure 60, the message displayed

[10] Minnesota Department of Transportation, *Cooperative Intersection Collision Avoidance System – Stop Sign Assist (CICAS-SSA) Concept of Operations*, 2008.
http://www.dot.state.mn.us/guidestar/2006_2010/cicas/CICAS_SSA_ConOps_FINAL_3_18_08.pdf

on each interface is dependent on whether the driver is at the stop sign or in the median. Both the top and bottom portions of the sign are brightly illuminated when a driver is at the stop sign as both pieces of information affect their decision about gap acceptance. The signs visible from the median show the same information; however the bottom portion of the sign is dimmed to draw attention to the top half of the sign which contains the information they need to make a decision about gap acceptance.[11]

The four DIIs are connected through the Roadside Interface to the Local Safety System, where detection data (from radar detectors) feeds into the CICAS-SSA computer to identify unsafe gap conditions and activate the messages on the DII.

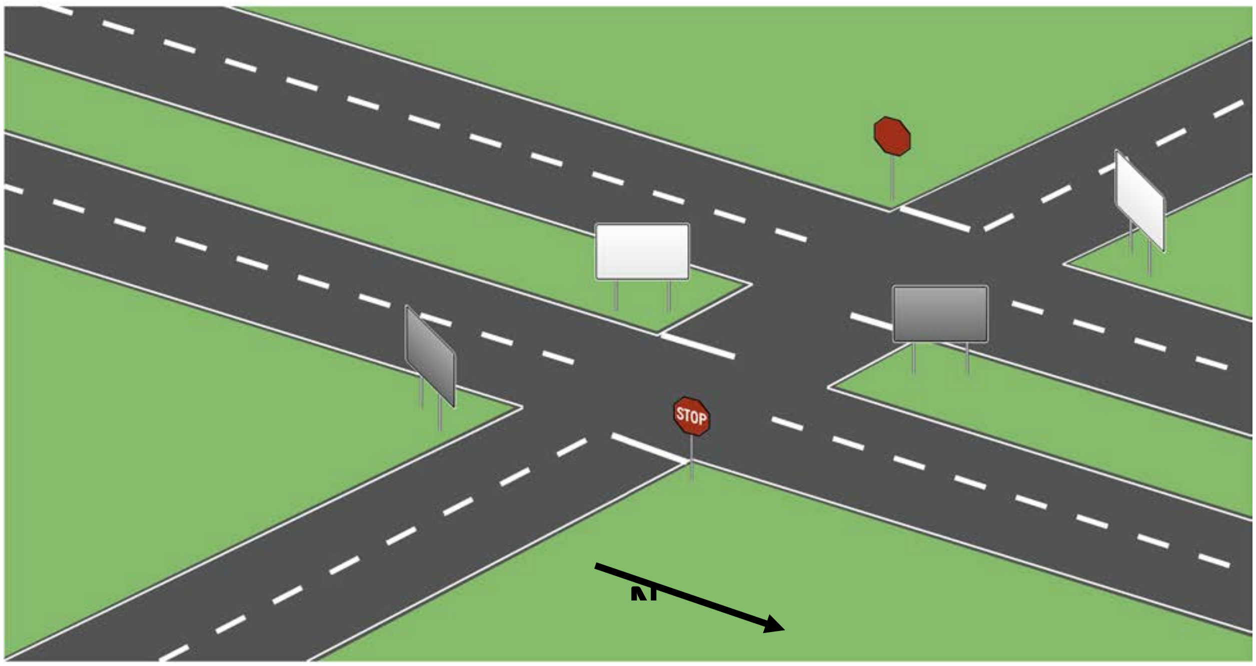


Figure 58. Intersection Schematic and Sign Locations.

[11] Creaser, J., Manser, M., Rakauskas, M., & Donath, M., *Sign Comprehension, Rotation, Location, and Random Gap Simulation Studies: CICAS-SSA Report #4,* ITS Institute of the University of Minnesota, 2008. http://www.its.dot.gov/research_docs/pdf/cicas_tech_docrpt4.pdf

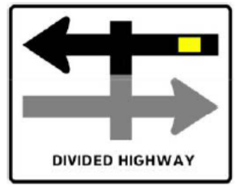
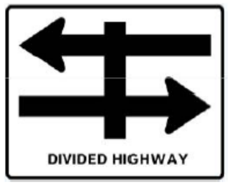
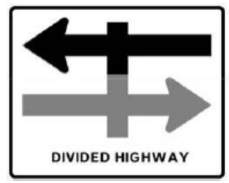
	Driver at Stop Sign		Driver in Median	
Intended Meaning	**Alert Condition**	**Sign Message**	**Alert Condition**	**Sign Message**
Do Not Enter	Traffic detected within threshold for near and far lanes		Traffic detected within threshold for far lanes*	
Do not cross or turn into far lanes; may be ok to enter near lanes	No traffic detected for near lanes. Traffic detected within threshold in far lanes		Traffic detected outside threshold in far lane	
Proceed with Caution	No traffic detected for near and far lanes.		No traffic detected within threshold for far lanes	

Figure 59. Signage Displayed on the DII.

The in-vehicle system used for this study receives messages through DSRC and displays them on the DVI simultaneously with the messages on the DII. A DSRC radio on-board unit was installed into and powered by the vehicle, providing connectivity to the roadside infrastructure through a magnetically-mounted external antenna. An Android Smartphone was used as the DVI, with Bluetooth wireless connectivity to the on-board unit. The Smartphone was temporarily mounted by a small suction cup to the center of the windshield.

2.3 Research Design

The test procedure for this study involved participants driving three times on a prescribed route that was configured to allow the driver to experience multiple approaches in which a CICAS-SSA alert or warning would be generated. This prescribed route was comprised of six different movements at the intersection including a westbound and eastbound through movement, as well as a left turn from each of the four approaches (see schematics in Appendix D for further details). The test was scheduled for a Saturday, when traffic was expected to be consistent across the scheduled test period. Participants completed the study individually, accompanied by a test conductor who provided navigational guidance and collected verbal feedback throughout the drive.

The test was completed in the participants' vehicles, to eliminate any confounding effects of driving an unfamiliar vehicle on their ability to focus on the newly-installed equipment. Participants were asked to drive normally around the route while "thinking-aloud" to explain what information they were using to make decisions, either from the DII, DVI or their own visual inspection of traffic. Additional feedback was collected at the end of the test runs, through an exit survey and short interview, while the equipment was uninstalled from the vehicle.

Several considerations for risk mitigation were included in the design of this study, including the selection of local residents as participants who would be more familiar with the intersection's sight limitations than naïve drivers. Additionally, participants were asked to operate their vehicle in a normal and responsible manner and instructed to discontinue the think-aloud protocol or use of the CICAS-SSA information if they felt it created an excessive driving burden. The staging area was stationed apart from live and parking lot traffic to ensure safety before and after the test, and participants were asked to remain in their vehicles for the duration of the test. Finally, drivers were screened to self-certify a minimum driving record, to exclude applicants with excessive moving violations or Driving-Under-the-Influence (DUI) charges in the past 3 years.

2.4 Data Collection

The data collected in this study was subjective, obtained through three different forms of participant feedback: (1) a think-aloud protocol during the test runs, (2) a written survey upon completion of the test runs, and (3) a short interview to conclude the study. Although the primary goal of the study was to understand drivers' preliminary reactions to information provided by the DVI, the DII was providing information simultaneously so the study team collected feedback regarding both the DVI and the DII in the exit survey and interview, and both will be addressed in the Findings section of this report.

For the duration of the test runs, participants were asked to "think-aloud" as they navigated the prescribed route, explaining their decision making process as they made driving decisions, and identifying their use of the roadside signage, the in-vehicle display and their own visual inspection of traffic. The written survey determined their preferred source of information and their opinion on whether the messages were easy to understand, distracting and/or useful, and if they would prefer not to have them altogether. Finally, the test conductor asked the participant several follow-up questions regarding their initial impressions of the sign, their perceptions of the accuracy of the information, and their opinions on the location or placement of the in-vehicle display. All forms of participant feedback were considered in the analysis and the survey materials are contained in Appendix D.

The think-aloud protocol was used to collect real-time feedback of participant use of the signs, and was recorded as an audio file for reference during analysis. Participants' attitudes toward the CICAS-SSA system were made evident by this activity, which provided a preliminary understanding of driver use and acceptance of the information.

The survey aimed to determine whether use of the information varied by approach and by source, asking drivers to rate how much they relied on each source of information (the roadside display, the in-vehicle device, or their own visual inspection of traffic) for each scenario in the prescribed route. Additional questions were posed regarding more general impressions, including whether information from the roadside and in-vehicle displays was easy to understand, distracting, useful, and desirable.

Lastly, the exit interviews were conducted to fill gaps in participant feedback, to determine whether the placement of the in-vehicle device was desirable, and to collect any additional feedback the participants thought was relevant.

3 Findings

The following section describes the findings of the study in terms of signage comprehension, use of the signs, and general attitudes and opinions expressed by the participants. For each component of the study, separate feedback was collected regarding drivers' reactions to the DVI and the DII, and will be compared in the analysis. Overall, responses to specific questions regarding the two sources of information were very similar with a slight preference for the information from the roadside. Several participants explicitly stated that they thought they could become more comfortable using the in-vehicle device if it was in their car all the time.

3.1 Signage Comprehension

In 2008, the ITS Institute of the University of Minnesota reported on experiments with different permutations of the alert and warning messages to maximize sign comprehension. Results of the icon design deployed at the test site reflected mixed results, with higher comprehension of the red, prohibitive icon displays than the yellow, alert icons, but little critical confusion with any of the icons.[12]

The feedback collected from this study was not specific to different messages on the displays, but instead focused on more general comprehension of the information provided by the signs. The results of the survey were consistent with the findings of the 2008 report, where a large

[12] Creaser, J., Manser, M., Rakauskas, M., & Donath, M., *Sign Comprehension, Rotation, Location, and Random Gap Simulation Studies: CICAS-SSA Report #4*, ITS Institute of the University of Minnesota, 2008. http://www.its.dot.gov/research_docs/pdf/cicas_tech_docrpt4.pdf

majority of the participants agreed that both the in-vehicle and roadside messages were easy to understand. Several participants stated in the in-vehicle discussion and closing interviews that they had very little trouble understanding the roadside displays when they were first introduced and that familiarity with the roadside DII made it easy to understand the information from the DVI, although one participant strongly asserted that the signs were both confusing and distracting.

With respect to the roadside DIIs, several participants noted that they were not sure which of the two roadside displays [facing them] they were supposed to look at and the test conductors noted that at least two of the participants consistently referenced the DII on the far side of the road instead of the nearer display intended for the current maneuver. This tendency highlights a potential advantage of the information provided from the DVI, because the driver is given only the information relevant to the maneuver indicated by their current location.

3.2 Sign Usability

Previous research has examined the impact of sign usage on driver performance, with respect to specific measures of gap acceptance and time to complete maneuvers, as well as usability defined as "the degree to which drivers perceive that the sign is reliable, trustworthy, useful, satisfying, and the degree to which the sign promotes safety."[13] No quantitative performance measures were included in this assessment; however participant feedback from the think-aloud protocol offered much information regarding drivers' perceptions of the reliability, trustworthiness, and use of the signs; additionally the survey and interview questions provided information about the drivers' perceptions of the usability of the signs.

3.2.1 Reliability

Feedback regarding the reliability of the information from the signs was collected throughout the test runs and from the survey questions asking how much drivers relied on each source of information to make their decisions. In cases where the participants' attitudes were less clear, follow up questions about whether the information was accurate, reliable and trustworthy were posed in the interview.

None of the participants expressed distrust for the information from the signs, or stated that they thought the information was inaccurate, however every participant visually verified traffic before proceeding into the intersection throughout the study. Participant commentary and test conductor observations during the test runs support the conclusion that none of the

[13] Rakauskas, M., Creaser, J., Manser, M., Graving, J., & Donath, M., *Validation Study – On-Road Evaluation of the Cooperative Intersection Collision Avoidance System – Stop Sign Assist: CICAS-SSA Report #5*, ITS Institute of the University of Minnesota, 2009. http://www.its.dot.gov/research_docs/pdf/cicas_tech_doc5.pdf

drivers fully relied on information from the displays to make decisions, but rather they used the information to support decisions to avoid inadequate gap acceptance based on their own judgment, which aligns with the intended purpose of the system. Researchers did note an instance in which the system did not detect the presence of an opposing vehicle, but since drivers were not fully relying on the information from the displays to make decisions, none commented on this. This circumstance occurred when the driver was in the median of the intersection and an approaching vehicle on the mainline slowed to make a right turn. The reason the vehicle was not detected in this circumstance is that the system was not designed to detect vehicles travelling as speeds below 25 miles per hour as they are no longer deemed a threat.

Participants' survey responses to the questions about reliability consistently demonstrated a preference for information from the roadside over the in-vehicle display, and all of the drivers expressed a heavy reliance on their own visual inspection of traffic. The degree to which drivers might rely on information from the in-vehicle device, absent a roadside display, cannot be determined from this study and may merit further investigation.

3.2.2 Use and Usefulness

The test conductors observed that most of the participants referenced the signs during the test runs more than they indicated in the survey, and similarly, more participants agreed that the information from the in-vehicle device was useful than admitted to using the device themselves. This disparity may be associated with the age group of the participants, supported by the finding asserted in the CICAS-SSA field evaluation conducted by the University of Minnesota in 2009, that older drivers may be less likely to report using the sign.

No substantial variation in sign usage by approach is evident from the survey results or test conductors' observations; however at least two of the drivers demonstrated notably increased use of the information from the in-vehicle display throughout the course of the test runs as they became more familiar with the device.

When asked about the placement of the DVI in the vehicle, several participants stated that they would prefer it be mounted in a different location, either to make it easier to reference or to make it less obstructive. Future research and deployment efforts may benefit from consideration of alternative placement for the in-vehicle display.

3.3 Discussion and Implications

The findings of this study both demonstrate the potential benefits of the vehicle-based CICAS-SSA system and highlight potential areas for future research. The participants' general consensus that the DVI is useful illustrates that this system has potential to reduce crashes at this and similar intersections through widespread use of DVIs to warn drivers of insufficient gaps.

The consensus on the DVI's usefulness forms the basis for continued development and assessment of human factors considerations that might promote acceptance and use of the device by a broader base. The focus of the following discussion will emphasize discoveries from this small-scale study that merit further examination.

A key constraint of this study was the limited available age demographic that met the research design qualifications. Recruitment of local drivers who were familiar with the intersection was necessary for the controlled variables of the test. Inclusion of drivers who were naïve to the existing infrastructure would have prevented the results from focusing on initial reactions to the in-vehicle device. Additional studies designed for a wider demographic, including drivers who are naïve to the information from the CICAS-SSA may provide additional insights into the findings of this study.

Another constraining factor was the need to maintain operation of the DII signage during the study, which prevented participants from reacting only to the in-vehicle device. Because the study was conducted in live traffic, temporary suspension of information from the DII would have imposed a potential safety risk to drivers who were not participating in the study. To address this constraint, the project introduction and feedback mechanisms were tailored to emphasize reactions to the in-vehicle device and to elicit comparative preferences between the roadside and vehicle based systems. Participant familiarity with the information from the CICAS-SSA system facilitated the focus on the drivers' preference for the source of information, which was simultaneously broadcast on both displays. Although the feedback from this study provides preliminary insight into drivers' use and acceptance of the in-vehicle device, the general preference for information from the roadside display may be attributable to the participants' familiarity with the infrastructure. Additional research to surveyed participants on their preference for information from the roadside or the in-vehicle display, experienced in isolation, would also provide additional insight into the potential market for the DVI system. Furthermore, a study designed to determine if some market penetration of a DVI deployment might provide the same or more safety benefit than the roadside infrastructure could be used by policy makers in future CICAS-SSA investment decisions.

Provided additional resources, future research efforts might survey a wider demographic of participants, including drivers who are naïve to the existing roadside infrastructure, to gauge broader market potential for a voluntary deployment, and test the DVI in isolation from the DII to further quantify the relative potential of roadside versus in-vehicle deployment to support future policy decisions.

Volume VII: Assessment of Utility of Travel Time Data

1 Introduction

Although real-time travel time information generated from the smartphones used in this test was not presented to study participants, one goal of the pilot was to determine whether the same in-vehicle device used to assess mileage-based user fees and to provide safety alerts to drivers also has the potential to be used as a way to gather data that can be used to estimate travel times. Therefore the goal of this part of the evaluation was to investigate the feasibility of using second-by-second data from participant smartphones to determine travel times.

1.1 Data Informing Travel Times

The data informing travel times is trip data that was recorded every second that the MRFT application was running and a trip was underway. The trip data included detailed position information such as location, direction, speed, time, and GPS accuracy on a second-by-second basis, providing a wealth of data. During the course of the 13-month study, more than 660 million probe data snapshots were captured across 280,225 trips. Of these trips, only 276,850 are presented in the analysis that follows, as the deployment team excluded some trips due to the fact that there were equipment malfunctions that occurred that were not evident during the study, causing some trips not to start or end correctly (e.g., multiple trips were strung together into one trip).

1.2 Location of Study Corridors

MnDOT selected three travel time study corridors for the pilot, including a freeway and two arterials. In selecting arterial segments, the team identified corridors for which MnDOT had existing data that could be used for comparison purposes. MnDOT determined that data was available for two segments of Trunk Highway 55 (TH55), one in Wright County (in the City of Buffalo) and another in Hennepin County. Since data is available for all Minnesota freeways from continuous count stations, when identifying a freeway study corridor, the project team took into account which segment of freeway would be expected to be the most heavily traveled by study participants. The freeway segment expected to be the most heavily traveled by participants was Interstate 94 (I-94) to the northwest of the Metro Area.

The three corridors that were identified as the "travel time study corridors" for purposes of this study were:

- Corridor 1 - A 16-mile segment of TH55 in Hennepin County from Arrowhead Drive near Hamel to N 7th Street in Minneapolis;

- Corridor 2 - A 1.6-mile segment of TH55 in the City of Buffalo / Wright County that runs from Central Avenue / TH25 to County Road 34 / 10th Street; and
- Corridor 3 - An 8-mile section of I-94 from TH 101/Main Street in Rogers to County Rd 109/Weaver Lake Road in Maple Grove.

The location of the three corridors in relation to Wright County and the Twin Cities Metro Area are shown in Figure 60.

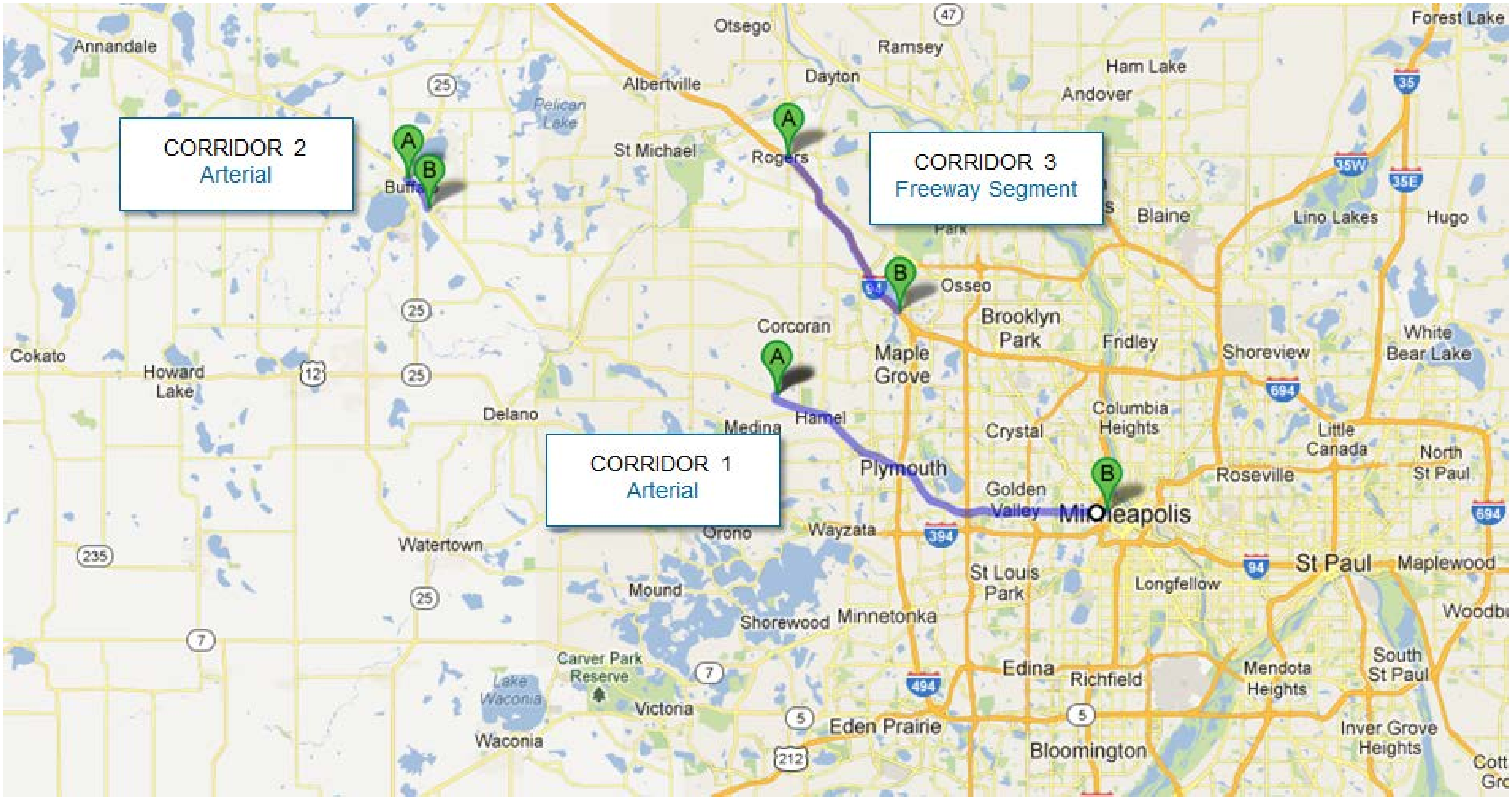


Figure 60. Location of Three Travel Time Study Corridors in Relation to the Twin Cities Metro Area.

Source: Google Maps

1.3 Role of the Deployment Team and Study Team

The deployment team's role in this portion of the study was to determine travel times from the trip data. The study team's role was to compare these travel times to those available from historic MnDOT data and to discuss the differences as well as the benefits and drawbacks of various types of travel time measurement and calculation. Section 2 presents the results of the deployment team analysis and Sections 3 and 4 discuss findings and conclusions.

2 Deployment Team Analysis

The deployment team's reporting requirements related to travel times were prescribed in the project's system requirements document which was produced early in Phase II.[1] These requirements called for determining point-to-point travel times for each corridor as well as a variety of metrics for shorter segments of each corridor. It is important to note that the travel times were to be calculated after the fact, rather than in real-time.

The deployment team divided each corridor into segments, and for each segment, they provided the start and end times of each trip through that segment as well as summary statistics for each segment. The summary statistics by segment included the number of vehicles traversing the segment, and the average, minimum, and maximum travel time across the segment. The deployment team prepared a report[2] that included this information. The highlights of the summary statistics generated by the deployment team follow.

In preparing summary statistics, the deployment team divided each corridor into short segments; identified the start and end location of each segment; looked for any trips that crossed both locations, taking note of the entering time stamp and the exiting time stamp; and determined the travel time for that trip across that segment of the corridor, excluding any segment trips that were greater than 10 minutes in length.

An example of the summary statistics included in the deployment team's report is presented in Table 64. As seen in the table, the average, maximum, and minimum travel times are provided for all trips occurring through each segment on the dates and times specified. In the example shown in Table 64, the values represent all trips occurring during AM peak hours (6:30am-8:30am) during the month of May 2012. The table reflects a total of 30 hours across 15 separate AM peak periods.

[1] Battelle Memorial Institute, *IntelliDrive(SM) for Safety, Mobility, and User Fee Implementation System Requirements Document,* for MnDOT, October 2010.
[2] Battelle Memorial Institute, *Minnesota Road Fee Test Travel Time Report,* for MnDOT, November 2012.

Table 64. Example Summary Statistics from Deployment Team Travel Time Analysis (Statistics for Eastbound Travel on I-94 During AM Rush in May 2012).

Segment	Count of Trips	Average Travel Time (min)	Maximum Travel Time (min)	Minimum Travel Time (min)
1	103	0.75	9.22	0.37
2	146	0.44	0.83	0.35
3	151	0.46	1.95	0.33
4	153	0.48	2.02	0.37
5	155	0.57	3.35	0.35
6	162	0.62	2.33	0.33
7	163	0.58	2.13	0.35
8	167	0.64	2.55	0.32
9	171	0.68	2.57	0.37
10	172	0.66	2.85	0.35
11	170	0.73	2.87	0.33
12	170	0.66	5.00	0.28
13	167	0.99	7.08	0.35
14	195	0.74	1.90	0.37
15	197	0.69	2.52	0.38

For Corridors 2 and 3 it is important to note that the average travel times reported by the deployment team reflect the average across the peak periods occurring on 15 separate days over the course of a month's time. The AM peak on I-94 is 2 hours in length and the PM peak is 3 hours in length. Consequently, the average values for AM peak hours represent the average of all trips occurring over a total of 30 hours, and the average values for PM peak hours represent the average of all trips occurring over a total of 45 hours.

The travel times reported for Corridor 1 are more accurate as they reflect travel times on just three distinct days, and the deployment team reported the travel times separately by day. However, traffic conditions can vary quite significantly even over the course of a 2- or 3-hour period, so travel time values are typically viewed in 15-minute increments.

It also should be noted that the sample size varies across segments. In the example shown above for the freeway segment, one segment's average travel time represents only 103 trips while another segment's average value represents nearly double the number of trips, at 197. Sample sizes were much lower for the arterial corridors.

Since the deployment team did not calculate the travel time for any given corridor in total, no actual maximum or minimum travel times for a corridor can be reported here. However, the study team has summed the "average travel time" values for each of the segments that comprise each corridor to report an average travel time for each corridor based on the deployment team's analysis. These values are reported in the following sections, which discuss each corridor individually.

2.1 Corridor 1 – TH55 in Hennepin County (Arterial)

Corridor 1 was defined as a 16-mile segment of TH55 in Hennepin County from Arrowhead Drive near Hamel, to N 7th Street in Minneapolis. Posted speed limits along the corridor vary from 30 mph to 55 mph:

- Arrowhead Drive (west of Hamel) to Douglas Drive N. (just west of TH100) – 55 mph;
- Douglas Drive N to N Thomas Avenue (just east of Wirth Lake) – 50 mph;
- N Thomas Ave to West Lyndale Avenue (just west of I94) – 40 mph; and
- West Lyndale Ave to North 7th Street – 30 mph.

The corridor is shown in

Figure 61

Figure 61Figure 61 below. For analysis purposes, the deployment team divided the corridor into 35 segments.

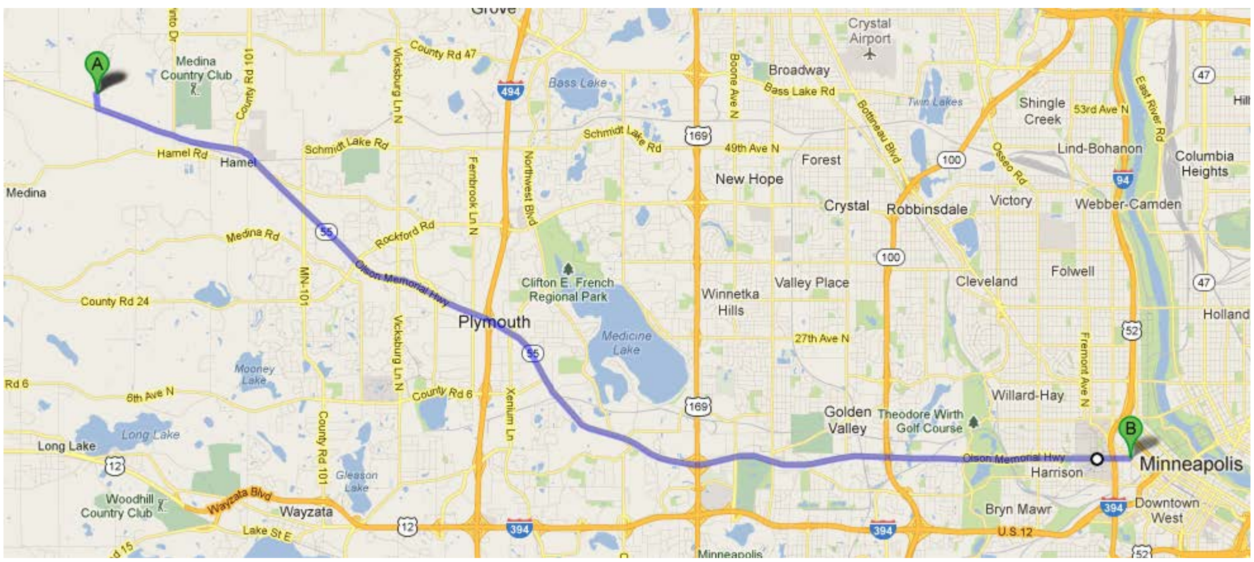


Figure 61. Location of Corridor 1 (16-mile segment of TH55 in Hennepin County).

Source: Google Maps

For this corridor, MnDOT had data available from travel time runs conducted on nine dates from February to May 2012 during AM and PM peak hours (6:00am-8:30am and 3:00pm-5:30pm). The deployment team selected three of these nine dates to be used for comparison purposes. The dates/times and directions of travel analyzed from participants are listed in Table 65 below, along with a comparison of the average travel time for the corridor based on the sum of the reported average travel times for the segments and the travel time reported from the MnDOT travel time runs conducted on these same days (note that there were no travel times available for many of the segments in each case). Since deployment team data was not available for all segments, the study team reduced the travel times reported from the MnDOT travel time runs proportionately to match the deployment team data.

Table 65. Summary of Deployment Team Data for Corridor 1.

Day/Date	Time Period	Direction	Average Travel Time from Deployment Team (sum of reported segment averages)	Travel Time Reported from MnDOT Travel Time Runs
Wednesday, February 29, 2012	AM Peak Period (6:00am-8:30am)	Eastbound	13 min 5 sec *(n varies by segment between 1 and 9)*	36 min 46 sec *(n=1)*
		Westbound	11 min 30 sec *(n=1)*	18 min 2 sec *(n=1)*
Tuesday, March 6, 2012	PM Peak Period (3:00pm-5:30pm)	Westbound	7 min 5 sec *(n varies by segment between 1 and 8)*	9 min 33 sec *(n=3)*
Thursday, March 15, 2012		Eastbound	11 min 28 sec *(n varies by segment between 1 and 3)*	14 min 38 sec *(n=3)*

Despite that fact, as seen in the table above, the travel time values from the deployment team data are significantly lower during the AM peak as compared to those reported from MnDOT's travel time runs. The reasons for the inaccuracies in the estimations are unclear. One challenge with the data is certainly the low sample size. The travel time runs conducted by MnDOT represent just one data point for each of the AM peak period values and three data points for each of the PM peak period values. The deployment team values represent between one and nine data points depending on the segment. The low sample sizes are exacerbated by the fact that trips span across a 2.5-hour peak period, and travel times can vary greatly across a peak period.

Another reason for inaccuracy is that, from a closer look at the deployment team's presentation of travel time data, it appears that there was typically a small amount of time "lost" between each segment due to the way in which the data was processed into segments (i.e., if a vehicle travelled both segments 1 and 2, the timestamp identified for the time they left segment 1 was typically several seconds before the time at which they were identified as entering segment 2).

A closer look at one example trip illustrates the extent to which this "lost time" impacted one trip. The example vehicle traversed segments 3 through 13 of the corridor, entering segment 3 at 3:28:01 PM and exiting segment 13 at 3:35:47 PM. Figure 62 below shows a depiction of this example trip, with the vehicle path shown in white and the missing segments highlighted in red. By simply subtracting the start time from the end time, it appears that it took this vehicle 7 minutes and 46 seconds to traverse approximately 5.5 miles of the corridor, a travel time that is 29 percent greater than the travel time that was reported based on the travel time for this trip across each segment individually (6 minutes 2 seconds). This “lost time” clearly accounted for a portion of the travel time inaccuracy, but could not have accounted for all of the inaccuracy.

Figure 62. Missing Segments in Example Eastbound Trip on Corridor 1, Segments 1-13.

Source: Google Earth

The study team looked at the deployment team data to identify any instances where a vehicle traversed consecutive segments in an attempt to quantify the amount of this “lost time.” The results of this analysis showed that 7 seconds were lost between segments on average (n=257). With this arterial being comprised of 35 segments, there are 34 opportunities for this loss of time between segments. Consequently, an average of 7 seconds lost between each segment could account for a total time loss of 3 minutes 44 seconds across the length of the 16-mile corridor. However, even this large amount of “lost time” does not appear to account for the low travel times reported during the AM peak period.

2.2 Corridor 2 – TH55 in Wright County (Arterial)

Corridor 2 was defined to be a 1.6-mile segment of TH55 in the City of Buffalo / Wright County running from Central Avenue / TH25 to County Road 34 / 10th Street. The posted speed limit along this length of TH55 is 45 mph. The corridor is shown in Figure 63 below. For analysis purposes, the deployment team divided the corridor into 6 segments.

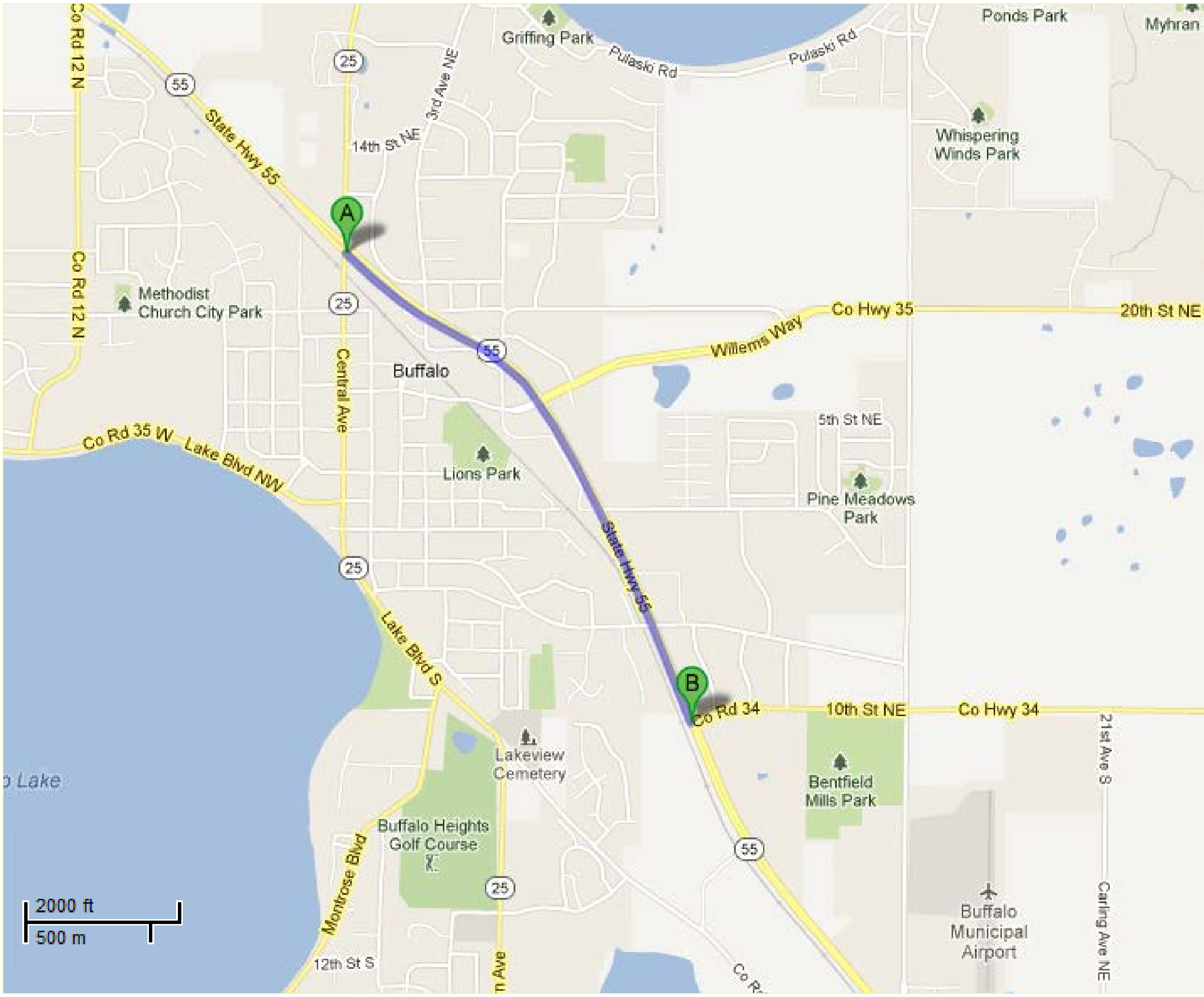


Figure 63. Location of Corridor 2 (1.6-mile segment of TH55 in Wright County).

Source: Google Maps

For this segment, MnDOT had data available from travel time runs conducted in late summer/early fall 2010. Although the exact dates of data collection were unknown, it is known that the data were collected during peak hours (6:30am-8:30am and 3:00pm-6:00pm) on mid-week weekdays (Tuesdays-Thursdays). For this corridor, the deployment contractor focused analysis on the time periods with the highest concentration of participants traveling the corridor. The highest travel month of the study period was May 2012. Consequently, the deployment team focused on this month of travel data, analyzing data for all mid-week weekdays (Tuesdays-Thursdays) in May 2012, a total of 15 days. The dates/times and directions of travel analyzed are provided in Table 66 below, along with a comparison of the average travel time for the corridor based on the sum of the reported average travel times for the segments and the travel time reported from MnDOT's travel time runs.

Table 66. Summary of Deployment Team Data for Corridor 3.

Day/Date*	Time Period	Direction	Average Travel Time from Deployment Team (sum of reported segment averages)	Travel Time Reported from MnDOT Travel Time Runs
Tues-Thurs in May 2012 for deployment team data (15 days in total) **Tues-Thurs in late summer/early fall 2010 for MnDOT data**	AM Peak Period (6:30am-8:30am)	Eastbound	2 min 38 sec *(n varies by segment between 14 and 35)*	4 min 43 sec *(n=10)*
		Westbound	2 min 36 sec *(n varies by segment between 3 and 16)*	4 min 43 sec *(n=10)*
	PM Peak Period (3:00pm-6:00pm)	Eastbound	3 min 51 sec *(n varies by segment between 18 and 55)*	5 min 24 sec *(n=10)*
		Westbound	3 min 50 sec *(n varies by segment between 11 and 117)*	5 min 14 sec *(n=10)*

*Note that the dates and years of data collection for these two data sets are different. The MnDOT travel time runs were conducted during a different year and during a different time of year (late summer/early fall 2010) whereas the system data represents data from May 2012.

The travel time values from the deployment team data are between 27 and 45 percent lower than the MnDOT travel time runs. However, as noted in the table above, the two data sets represent timeframes that vary greatly from one another. It is possible that the travel times could have changed over this 1.5- to 2-year period of time, so little can be concluded from this comparison.

2.3 Corridor 3 – I-94 (Freeway)

The freeway segment included in the study was an 8-mile section of I-94 from TH 101/Main Street in Rogers to County Rd 109/Weaver Lake Road in Maple Grove. The corridor is shown in Figure 64 below. For analysis purposes, the deployment team divided the corridor into 16 segments.

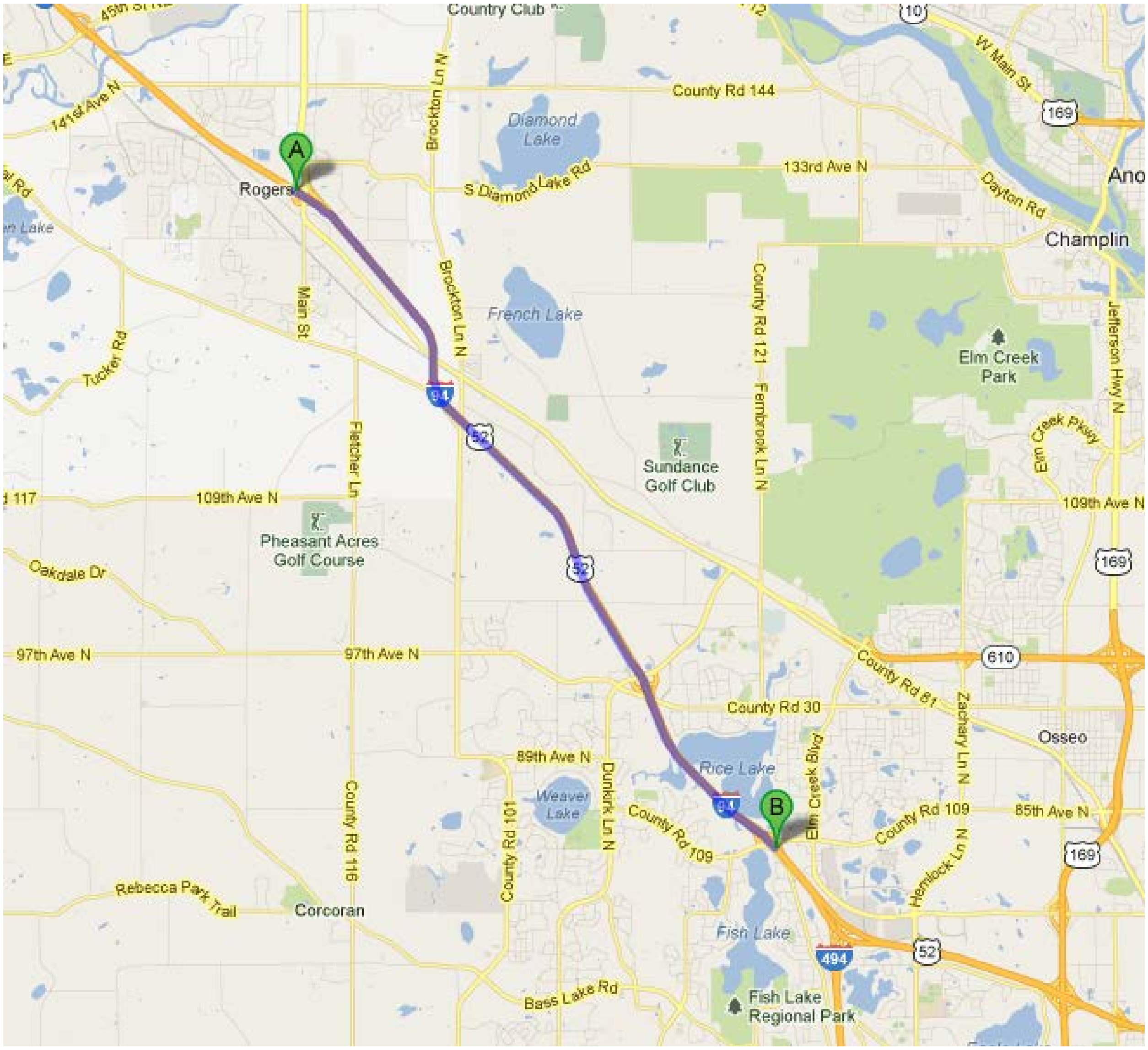


Figure 64. Location of Corridor 3 (8-mile segment of I-94).

Source: Google Maps

For the I-94 corridor, the deployment contractor focused analysis on the time period with the highest concentration of participants traveling the corridor. The highest-traveled month of the study was May 2012. Consequently, the deployment team focused on this month of travel data, analyzing data for a total of 15 days representing all mid-week weekdays (Tuesdays-Thursdays) in May 2012. The team looked at travel times in each direction of travel separately, but combined all trips occurring across the AM peak hours (a total of 30 hours) and all trips occurring across the PM peak hours (a total of 45 hours).

MnDOT derives historic travel times from the freeway sensor data and reports these values in 5-minute intervals. These historic travel times from the month of June were made available to the study team. The study team averaged these values across each peak period and compared these travel times to those of the deployment team. The dates/times and directions of travel analyzed, as well as the comparison of travel times, are presented in Table 67 below.

Table 67. Summary of Deployment Team Data for Corridor 3.

Day/Date	Time Period	Direction	Average Travel Time from Deployment Team (sum of reported segment averages)	Average Travel Time reported from MnDOT Freeway Count Stations
Tues-Thurs in May 2012 for deployment team data (15 days in total) **Tue-Thurs in June 2012 for MnDOT data (12 days in total)**	AM Peak Period (6:30am-8:30am)	Eastbound	10 min 25 sec *(n varies by segment between 103 and 197)*	8 min 3 sec
		Westbound	6 min 52 sec *(n varies by segment between 4 and 46)*	6 min 29sec
	PM Peak Period (3:00pm-6:00pm)	Eastbound	7 min 21 sec *(n varies by segment between 28 and 46)*	5 min 42 sec
		Westbound	8 min 8 sec *(n varies by segment between 254 and 312)*	6 min 57 sec

The travel time values from the deployment team data are between 6 and 29 percent higher than the travel times generated from the MnDOT count stations. However, as noted in the table above, the two data sets do represent slightly different timeframes (i.e., May versus June 2012), and this could certainly explanation the mild difference in values.

3 Discussion

The analysis of the accuracy of the travel time information derived from the MRFT data by the deployment team is inconclusive due to the fact that there was very limited real world data available to validate the travel time values. The findings are described below, but it should be noted that the inaccurate travel times discussed are not necessarily reflective of the ability of the device itself to serve as a method of collecting second-by-second data to inform travel times, but more reflective of the techniques used to formulate travel times from the data.

In the case of Corridor 1, the deployment team data did not result in plausible travel times for the AM peak hours, and the reason for this is not entirely known. In the case of Corridor 2, the deployment team's calculated travel times were between 27 and 45 percent lower than MnDOT travel times, although the time period of these two data sets differed, which could account for the difference. The freeway data presents a better opportunity for comparison, although again the timeframes differ slightly (May versus June 2012). In the case of the freeway, the travel time values from the deployment team data are between 6 and 29 percent higher than the travel times generated from the MnDOT count stations. The slightly varying timeframes between the two data sets is a possible explanation for the difference.

Figure 65, Figure 66, and Figure 67 below illustrate examples of outlier trips that were included in the deployment team's determination of travel time. The trips shown in orange are those with travel times that differ from "surrounding trips" (i.e., those trips occurring within +/- 10 minutes of this trip) by 30 seconds or more, while those shown in red have travel times that differ from surrounding trips by 60 seconds or more.

As shown in the first example (Figure 65), a vehicle appears to have traveled near the south end of the corridor segment (highlighted in blue), then away from the segment, then later returned to a location close to the north end of the segment. In the second example (Figure 66), a freeway entrance ramp caused trips to be inadvertently included in the travel time estimate sooner than they should have. These vehicles appear to have been on an arterial preparing to enter the freeway and were captured at the south end of the corridor segment prior to entering the freeway. As a result, any delay they experienced on the arterial while waiting to make a left turn and then while merging onto the freeway would have been captured as part of their travel time. In the final example (Figure 67), vehicles appear to have been captured on the corridor when they were in fact traveling on nearby arterial streets. All of these examples make the case for a more robust use of this kind of second-by-second data in developing travel times.

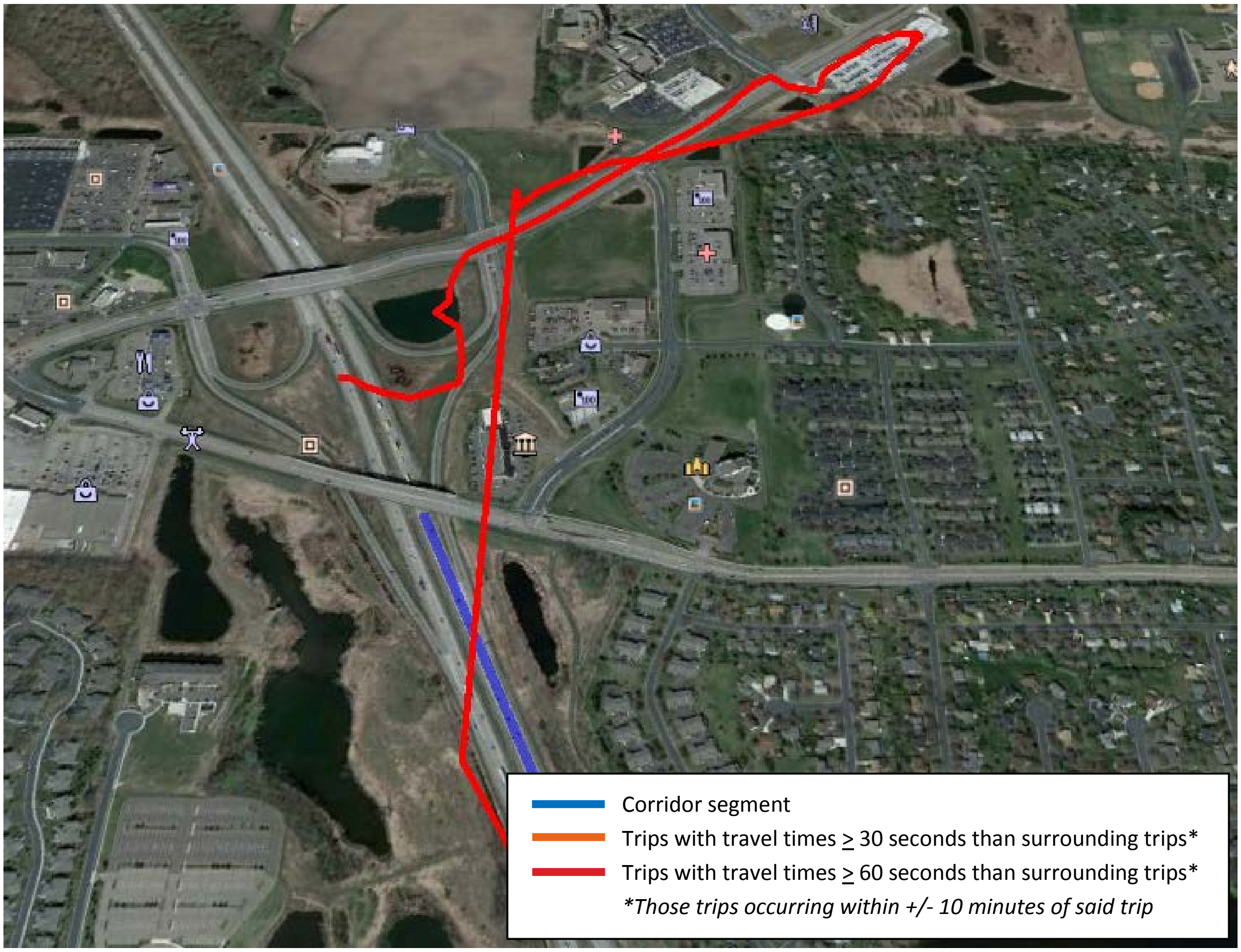


Figure 65. Example of Outliers in Travel Time Data - I-94 Segment 13, Westbound Direction.

Source: Google Earth

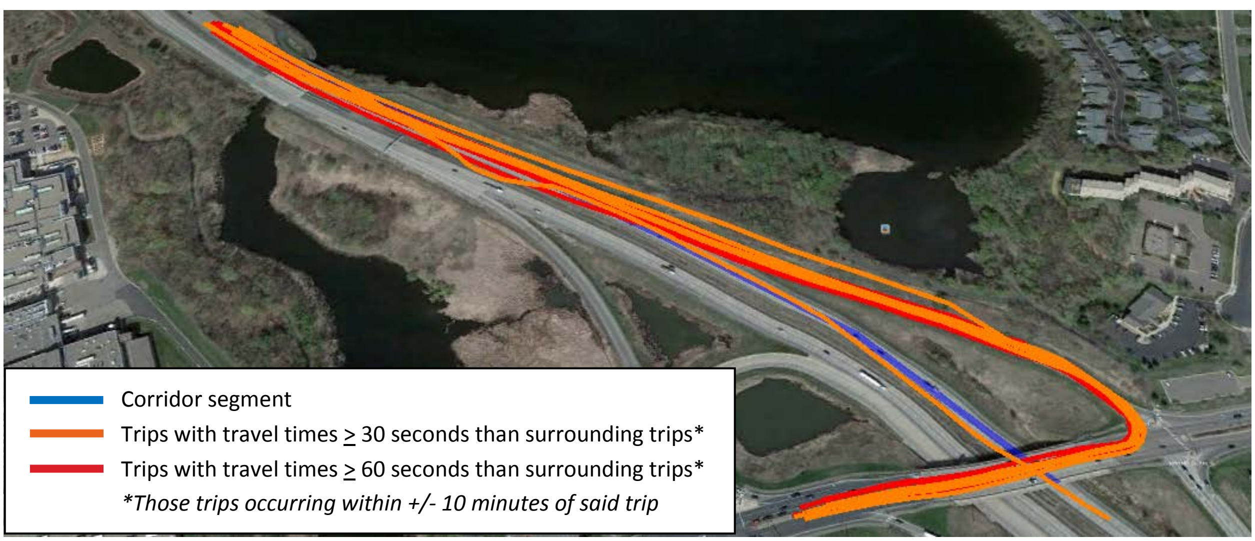


Figure 66. Example of Outliers in Travel Time Data - I-94 Segment 16, Westbound Direction.

Source: Google Earth

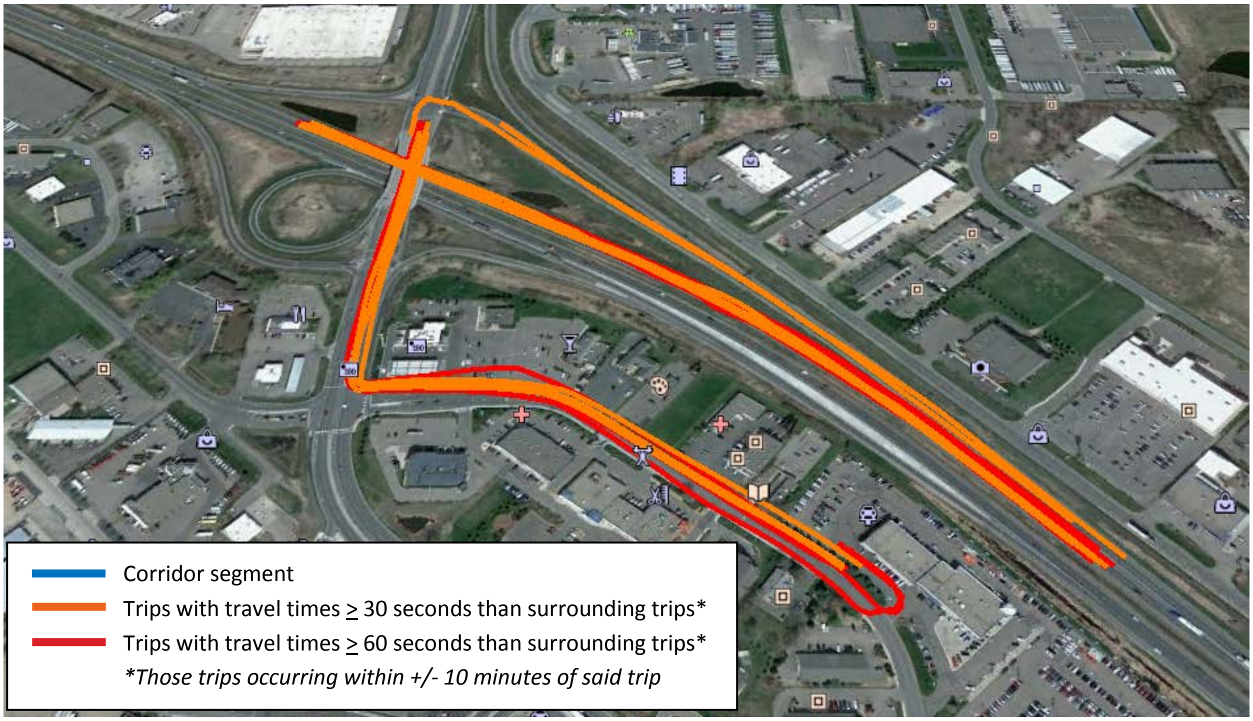


Figure 67. Example of Outliers in Travel Time Data - I-94 Segment 1, Westbound Direction.

Source: Google Earth

The study team analysis of the use of the second-by-second data to generate travel times demonstrates how the presence of more data does not necessarily allow for better reporting. The presence of millions of smartphone data points does indeed create an opportunity for more reliable travel time reporting and prediction. However, the specific processes used to measure and validate travel times can have a considerable influence on the quality of information pushed out to drivers.

Access to second-by-second data in real-time allows for extremely robust travel time prediction. For example, a travel time algorithm that uses the full richness of second-by-second data can:

- Rely on path tracing to eliminate outliers more effectively than an algorithm that is based on travel time statistics alone. As an example, a driver could cross the start point of a corridor, travel on a different nearby roadway, and later cross the end point of that same corridor. In this case a driver who is not even on the corridor of interest would be included in the analysis. Another example might be a driver on the corridor who diverts from it for a brief period of time, perhaps to drop their children off at school or to stop for a coffee. By looking only at the start and end point of the corridor, these outliers would be erroneously included in the travel time calculation, increasing the reported average travel time. Path tracing would eliminate these outliers from the travel time calculation, providing more accurate travel time predictions.

- <u>Factor in travel times for vehicles are currently on the corridor</u>. This is in contrast to circumstances where vehicle locations are only known at select locations, as is the case with toll tag readers, where only vehicles that have completed the length of the corridor will contribute a travel time. Being able to factor in travel times for vehicles currently on the corridor is of particular benefit on longer corridors, where it may take some time for a vehicle to travel the entire length of the corridor to report back a travel time. It is also of benefit on roadway segments with numerous access points, such as arterials, or segments of freeways with multiple interchanges. In these cases, having the ability to determine travel times for “partial trips” can greatly increase the sample size and thereby improve the accuracy of the data. Another case in which partial trips can be helpful is when traffic conditions are breaking down due to an incident, or conversely, when they are returning to free flow conditions following an incident. Having data from the vehicles immediately experiencing these changing conditions can again improve the accuracy of travel time predictions.

4 Conclusions

The goal of this part of the evaluation was to investigate the feasibility of using second-by-second data from participant smartphones to develop travel times that, in a real-world MBUF scenario, could be provided to drivers on their MBUF device as a value-add proposition. Although the travel time analysis was inconclusive, access to this kind of second-by-second data could certainly prove useful, both to state and municipal traffic engineers, as well as to the traveling public. The preceding discussion highlights the need for development of a robust, path-based, travel time algorithm, requiring detailed planning and analysis on the part of any DOT looking to leverage this rich source of data.

Volume VIII: Administrative and Operational Considerations in Establishing a Road User Fee Program

1 Implementing MBUF as an Alternative to the Fuel Tax

As a source of revenue, the Minnesota motor fuel tax has traditionally been an efficient way to finance transportation funding, but as discussed in Volume I, this volumetric tax has become increasingly vulnerable as a steady and reliable source of revenue. This is the result of several factors, including inflation, consumer response to rising fuel prices, and increasing vehicle fuel efficiencies. In addition, even more stringent fuel efficiency standards are planned for the near future and may further reduce the relative amount of dollars collected per vehicle mile traveled. The goal of the present volume is to discuss the paths forward for establishing new transportation funding sources like MBUF.

The study team observed the procedures and processes required to manage the MRFT deployment and interact with participants. This volume begins with a discussion of the requirements to administer and operate an MBUF program as it occurred in the field test. Then, later sections address how these requirements might change in a real world deployment and as a result of different implementation approaches. Further, this volume contains a discussion of outstanding implementation questions and the roles of various organizations and groups moving forward.

It is important to understand that the MRFT was the result of a relatively small partnership among private research and development firms and MnDOT. In an actual deployment of a road user fee program in Minnesota, there would be many more partners shaping the legislative policies, business model, public messaging, and performance criteria. Information on potential participant organizations and their roles was gathered as the result of observations during MRFT project development and system deployment, conversations with test participants, and focused interviews with project partners and stakeholders.

The revenue problem facing MnDOT and other departments of transportation can be solved through a variety of techniques, including by continuing to increase the fuel tax or by creating new road user fees. Minnesota's approach in the MRFT was to test a multi-faceted technological solution to assess a road user fee based on mileage using a technology-discount model. A key challenge for readers in interpreting the information contained in this volume is to remain aware that there are variations on the road user fee program format which might be desirable to Minnesotans (besides the one tested in the MRFT). Additionally, the desirability of any particular approach might be different to different states.

MnDOT tested the feasibility of one particular technology solution in the MRFT, and this solution offers points of discussion and insights related to that particular approach. However, there are a variety of potential road fee solutions encompassing a range of "high tech" and "low tech" approaches, various pricing schemes, and differing degrees of participant interaction with the program. Below, examples of alternative approaches are presented in Table 1. These are presented for discussion purposes only, as there are likely many variants of these approaches.

Table 68. Examples of Alternative Road User Fee Programs.

Road User Fee Approach	Description	Degree of Technology Involved	Degree of Participant Interaction	Availability of Driving Data to Adjust Fees* or Offer Services**
In-Person Odometer Readings	Drivers adhere to some schedule of manual odometer readings at a facility, such as yearly odometer readings associated with vehicle registration renewal or inspection and emissions testing.†	Low	Moderate	Low
Fuel Station Fee Assessment	Similar to the model tested in Oregon,‡ drivers would be assessed road user fees whenever they purchased fuel. Such a system would likely involve some technology-based reporting of mileage.	Moderate	Low	Low
On-Board Mileage Recorder	Simple recording device may or may not be GPS-based and transmits mileage at regular intervals to some central location.	Moderate	Moderate	Moderate
On-Board Mileage Interface	An application such as that used in the MFRT that uses a variety of GPS-based data and presents information to drivers.	High	High	High

*In the MRFT, fees could vary by a range of variables including time of data and location in or out of a metro zone.
**In the MRFT, safety signage alerts were one driver service provided based on the GPS-capabilities of the smartphone used.
† Several states, including Minnesota, states do not require vehicle inspection or emissions testing.
‡ Whitty, J.M. "Oregon's Mileage Fee Concept and Road User Fee Pilot Program." Salem Oregon Department of Transportation, (2007).

Preceding volumes of this report have focused largely on results specific to the MRFT. The present volume identifies lessons learned from the MRFT that would be applicable should the Minnesota methodology gain acceptance as a feasible road user fee approach. However, this volume also identifies broader lessons and knowledge gaps that would apply to various road user fee solutions. Chapter 2 describes the resources used to conduct the MRFT and lessons learned from this experience. Chapter 3 discusses the groups that will be involved in any solution to the transportation funding problem and the elements related to implementing any new approach.

2 Administration Processes and Resources Associated with a Mileage-Based User Fee (MBUF) Program

This chapter describes the processes and resources that the MRFT project team used to manage the field deployment. As described in Volume I, there were several roles inherent in running the day-to-day operations of the MRFT. Figure 68 depicts the project team.

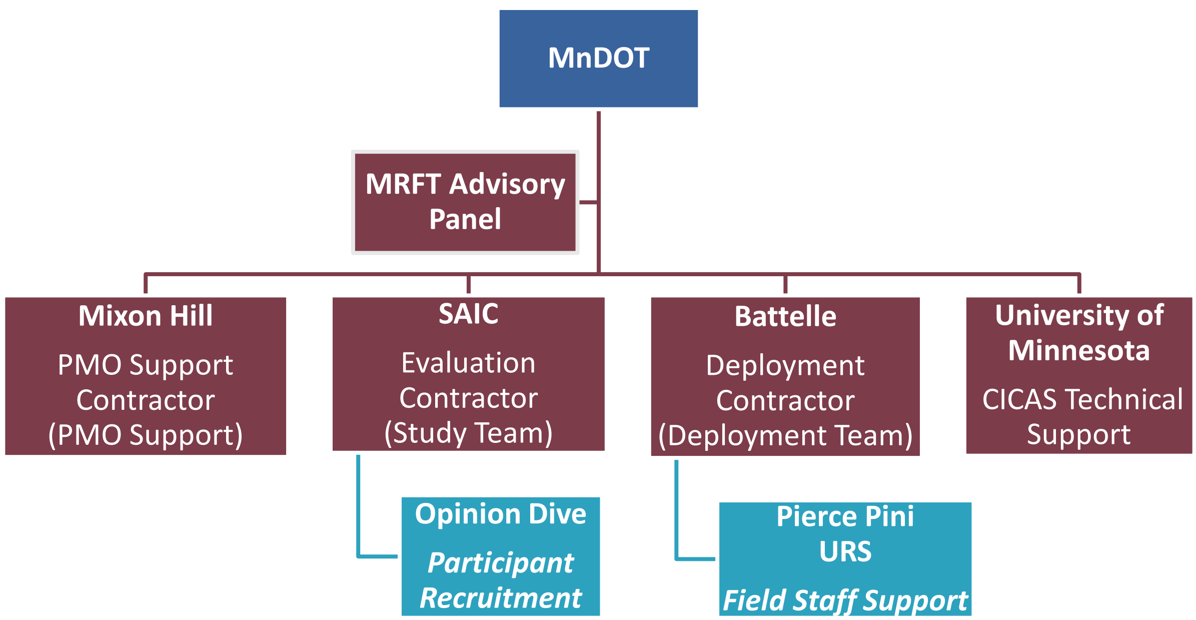


Figure 68. MRFT Project Team.

Many of the tasks required to run the MRFT were specific to the research process itself. For example, the SAIC study team recruited drivers and conducted surveys, interviews, focus group meetings, and other data collection activities. The study team tracked "points" as participants completed different activities and posted these to a study website. The study team also issued stipends at the conclusion of participation. These are all tasks which would not occur in a real-world deployment of an MBUF program. Additionally, the deployment team issued "start-up funds" to prevent participants from having to pay out of pocket for invoice expenses. This too would not occur in a real-world deployment.

However, many other MRFT activities were analogous to a real-world deployment involving a larger number of Minnesotans across the state. The deployment team had to schedule and conduct odometer readings, support device installation, provide some training, manage an invoice and payment process, and respond to driver inquiries and service issues. The processes and resources required to complete these activities are described using the following information:

- *Time Requirements* are the number of labor hours required to complete a task.
- *Staff Requirements* are the number and skill level of staff required to complete a task. Junior staff are considered staff who require only minimal training to complete the task. Mid-level staff are those who require some experience or in-depth training in completing similar tasks. Senior-level staff are those that require some advanced education or unique skill set to complete the task.
- *Facilities and Equipment* are the investment required in providing facilities (e.g., office space) or equipment (e.g., phone lines) in order to complete tasks.

Over the course of the MRFT, the deployment team identified several ways in which they could become more efficient with their resources and time management. As a result, there were operational changes made between Wave A and Wave C. For the purposes of discussion, the most efficient times are listed here and the changes to procedures are described.

2.1 Scheduling Appointments with Participants

Participating drivers were required to attend three odometer reading appointments during the MRFT.

<u>Odometer Reading 1 (OR1)</u> occurred so that the deployment team could obtain initial mileage from each vehicle and could install the smartphone system in the vehicle. It also served as an opportunity to welcome drivers into the field test and answer any questions.

<u>Odometer Reading 2 (OR2)</u> occurred so that the deployment team could obtain a second mileage reading, which was used to calculate baseline period mileage. The deployment team also turned on features specific to the test period (i.e., MBUF, safety signage). OR2 also served as an opportunity to introduce these new features to drivers through instructional materials and to answer any questions.

<u>Odometer Reading 3 (OR3)</u> occurred so that the deployment team could obtain a final mileage reading, which was used to assess test period mileage, and to allow the deployment team to collect final invoice payment and retrieve the test equipment.

In a real-world deployment, there would be no baseline period. However, drivers would need to have regular odometer readings to assess actual miles driven. Because the business model for the test was a technology discount system, any miles not recorded on the smartphone were assessed at the highest fee level. Thus, elements of OR1 and OR2 would be present as drivers first obtained and were trained about their MBUF device and had a preliminary odometer reading. Several elements of OR3 would persist in a real-world deployment as drivers would need to return equipment if they left the program and would occasionally need odometer readings to assess non-device mileage (miles not recorded on the smartphone, which would be charged the non-discounted rate).

The first task related to odometer readings was scheduling appointments with participants.

Table 69. Scheduling Odometer Reading Appointments.

Activity	Time Requirements (minutes per driver)	Percentage of Drivers Affected	Staff Skill Level	Facilities and Equipment
Receive call from driver	10	50%	1 Junior (Reception)	- Phone and dedicated phone line - Computer with internet connection - Scheduling tool
Call driver	15	50%	1 Junior (Reception)	- Phone - Computer with internet connection - Scheduling tool
Reschedule	10	10%	1 Junior (Reception)	- Phone - Computer with internet connection - Scheduling tool

Approximately half the time, test participants called the deployment team to schedule their odometer reading appointments. Each call lasted approximately 10 minutes and was handled by a junior staff member. This time included talking with the participant, inputting information on the computer, and sending a confirmation e-mail. The other half of the time, these staff members needed to reach out to participants and often leave a voicemail in order to schedule an appointment. This processes of identifying participants, attempting to reach the correct person, and eventually scheduling an appointment took approximately 15 minutes in total. About 1 in 10 participants ended up being rescheduled, which required approximately 10 minutes of a junior staff member's time. It is important to note that in a real-world deployment of a similar MBUF program, drivers might be required to attend appointments or face penalties. However, it is possible that the appointments would occur on a walk-in basis (like going to the DMV) and thus, scheduling as it occurred in the MRFT might not be necessary. Instead, an investment in developing operations strategies to support walk-in drivers might be required.

Although scheduling may or may not be a large part of a real-world deployment, a number of lessons were learned by the deployment team, including:

- A wide range of appointment times can be helpful to accommodate various schedules. Specifically, drivers frequently prefer evening appointments to accommodate job requirements.
- On-line scheduling might benefit drivers, making appointment slot availability more transparent and freeing up staff to handle phone calls on non-schedule-related issues. Further, on-line capabilities would allow drivers to perform the scheduling activity outside of normal business hours.
- Sufficient dedicated scheduling staff is important to maintain efficient scheduling and responsiveness to drivers.
- A single phone line was used for all participant interactions with the deployment team. A dedicated appointment phone line (or on-line access), distinct from the phone line for service requests, would speed processing of interactions with participants. Further, access from the smartphone itself would be more efficient and streamlined.

2.2 Preparing Equipment

Prior to participants receiving the MRFT smartphone at the first odometer reading, the deployment team prepared the equipment kits, which contained all the materials needed to install the device at OR1. Each participant's phone required a data plan to be purchased in order to enable the phone to communicate its data to the deployment team. Data plan costs ranged between $41 and $46 per phone depending on when the plan began (Wave A, B, or C). In a real-world situation, it is probable that the cost per phone would be exponentially smaller as the number of users would be dramatically larger in a real deployment. Further, a real deployment of this sort could involve a downloadable smartphone application that would function using a driver's existing data plan on a personal smartphone.

Figure 69. Participant Smartphone Kit.

Because of the scope of a real-world deployment, the equipment preparation process would likely be outsourced to an organization that specialized in such activities. As a result, it is likely that the cost per driver would substantially decline as volume of devices increased. Further, the complexity of the equipment selected, if any, would affect these costs as well.

2.3 Face-to-Face Meetings with Participants

The process for actually conducing odometer readings after an appointment had been scheduled varied considerably across the three test waves (A, B, C) as the deployment team discovered and implemented new, more efficient processes. Table 70 presents a typical odometer reading appointment for a wave C participant.

Table 70. Conducting Odometer Readings Appointments.

Activity	Time Requirements (minutes per driver)	Percentage of Drivers Affected	Staff Skill Level	Facilities and Equipment
OR1	30-35	100%	1 Junior (Technician)	Smartphone Kit, Demonstration Device, Television and Tutorial Video, Camera, Participant Agreements, Waiting Room, Storage Space, Vehicle Facility
OR2	20-25	100%	1 Junior (Technician) 1 Mid-Level or Senior (Programmer)*	Smartphone Kit, Demonstration Device, Television and Tutorial Video, Camera, Participant Agreements, Waiting Room, Storage Space, Vehicle Facility
OR3	15-20	100%	1 Junior (Technician) 1 Mid-Level or Senior (Manager)**	Smartphone Kit, Demonstration Device, Television and Tutorial Video, Camera, Participant Agreements, Waiting Room, Storage Space, Vehicle Facility, Computer with Internet Connection, Credit Card Reader, Cash Box, Receipt Book

*A programmer was onsite to perform required software upgrades.
**A Manager was present to process payments.

Table 70 presents average time requirements for OR1, OR2, and OR3. However, each of these appointments was really composed of a variety of subtasks, including:

- **Capture Vehicle Mileage**. Each appointment (OR1, OR2, OR3) included an odometer reading in which the deployment team captured the mileage of a vehicle by taking a picture of the odometer. This activity would persist for any road user fee program which required drivers to have their mileage read by a representative of the State.
- **Process User Agreements**. OR1 involved some purely administrative effort, which is analogous to a registration process in which participants officially joined the MRFT. Participants read and acknowledged terms related to the pilot test and the equipment being used. The deployment team eventually scanned these forms electronically, but this activity is not included in the time shown in Table 70. While this activity was unique in its breadth (i.e., there were several documents of varying length due to the nature of working with "human subjects" in a test setting), there would likely be some type of

information dissemination process in a real-world setting as drivers are educated about their rights and responsibilities.

- **Install Equipment**. OR1 involved the "installation" process in which drivers received the smartphone and associated equipment. There are a variety of real-world scenarios in which drivers would be required to carry or install equipment with them when they drive in order to assess road user fees. The complexity of these tools would affect the complexity of any installation process and would affect whether drivers required assistance or completed a "self-install" procedure.
- **Train Drivers.** At OR1, participants were provided with modest instructions for turning on the smartphone for their driving trips in order to facilitate the collection of baseline data. At OR2, the MBUF and signage functionality of the MRFT application were enabled, and participants were given a written pamphlet describing how the system functioned. They were also given brief instructions about the new functionality and were given a demonstration of how use of the device to discount their MBUF fees. In the real world, it is likely that comprehensive in-person training could be cost-prohibitive. Therefore, the majority of training might occur in written or video-based material.
- **Uninstall Equipment.** At OR3, the deployment team retrieved the smartphone and associated equipment from the vehicle. Participants who paid their final invoice would get to keep the smartphone (with original factory settings) or in some cases choose to receive a $100 honorarium in lieu of the equipment. In the real-world situation requiring drivers to use some form of equipment, there would be multiple scenarios in which devices would need to be removed such as for downloading data, repair or replacement, and exiting from the program.
- **Process On-Site Payment.** Because the final invoice was calculated at the OR3 when odometer mileage was read, participants were required to make payment at this time. This payment was collected by the deployment team. In-person payment would likely be an option in a real-world scenario both for regular invoicing and for making a final payment when exiting the program.

Table 71 shows these various subtasks which occurred at different appointments and indicated the amount of time (in minutes) each took. These times sum to the estimated totals presented in Table 70. Processing user agreements was a task that varied greatly in the time required to complete it (5-25 minutes), likely because of individual participants' different level of engagement and reading speed. Similarly, the time for training drivers varied as different participants had different levels of comprehension and different types of questions (5-15 minutes). Finally, processing a payment also varied in the time it took to complete (5-15 minutes) as participants used different mechanisms to pay (cash, check, credit card, PayPal®).

Table 71. Subtasks Occurring During Each Appointment.

Activity	Time Required (minutes)	OR1	OR2	OR3
Capture Vehicle Mileage	3	♦	♦	♦
Process User Agreements	5-25	♦		
Install Equipment	4	♦	♦	
Train Drivers	5-15	♦	♦	
Uninstall Equipment	3			♦
Process On-Site Payment	5-15			♦

The times presented in Table 71 reflect changes by the deployment team made over the three data collection waves in order to be as efficient as possible, including:

- A video that was displayed in the waiting area prepared participants for their first odometer reading. The deployment team found that this video facilitated processing participants more quickly because while they were waiting they were learning about the device. Prior to Wave B, a staff member was required to cover all of the material contained in the video in-person with each participant.
- In order to condense the schedule, staff members also limited the amount of training material covered during each odometer reading and instead provided participants with troubleshooting materials and device operation instructions.
- During the MRFT, all forms were paper and scanning the forms into an electronic format was required following each appointment. This took approximately 5-10 minutes per participant due to scanning and upload time. Pre-populating odometer reading forms electronically and printing them prior to the appointments also increased efficiency during appointments as less written information was recorded. Electronic tools such as tablet computers could be used on-site to facilitate data entry.
- Access to any end-user agreements online from home or on tablet devices onsite would facilitate drivers' understanding of those agreements and make the process more efficient. Additionally, making available an outline of the end-user agreements can minimize questions as participants prepare to sign the forms.
- During Wave A, participants were first asked if they would like to install the device themselves with guidance from field staff. The occurrence of participants requesting support was greater in Wave A than in later waves.
- It is possible for odometer readings to be done manually by drivers. In order to be efficient, there were a few occasions on which the deployment team allowed

participants to take a picture of their odometers to record mileage and email it. Some sort of self-report method might be feasible in a real-world scenario if measures were in place to enforce accurate reporting.

2.4 Service Requests and Maintenance

Support for participants was made available by the deployment team during the entire course of the MRFT. Participants' primary method of asking for support was through telephone or email service requests to the deployment team. These requests ranged from issues related to logging into the website (e.g., forgotten passwords) to questions and complaints regarding the performance of the smartphone or MRFT application. The deployment team responded to these requests and provided a file containing all interactions with participants for analysis by the study team. This analysis is discussed in Volume III.

The study team also gathered information from the deployment team related to approximate times required to manage different types of service requests. These were categorized as either a responses to *known* technical issues or *new* technical issues. New issues were those that required more elaborate conversation and investigation by the deployment team. Associated with the issues were the need to document the service request, escalate the issue to a specialist (e.g., to the development team), and occasional follow-up with participants subsequent to this escalation. These and associated tasks are summarized in Table 72.

Table 72. Service Requests and Maintenance Activities.

Activity	Time Requirements (minutes per driver)	Percentage of Drivers Affected	Staff Skill Level	Facilities and Equipment
Receive and Document a Phone Service Request	< 10	xx%	1 Junior (Reception)	
Provide Guidance for a Known Technical Issue	10-15	67%	1 Junior (Reception)	
Provide Guidance for a New Technical Issue	< 60	33%	1 Junior (Reception)	
Escalate Issue to Specialist	NA*	33%	Mid-Level or Senior (Technical Staff)	

* The deployment team could not provide an estimate on the number of hours spent researching and developing solutions for the complex service requests.

Participants generally interacted with junior staff members to report service requests, and frequently these interactions took 10 minutes or less. However, if an issue was new, deployment team members would frequently have to expend significantly more time to understand the problem and attempt to solve it (as much as an hour). This was frequently an issue of "translation" from what participants reported to what the technical staff understood of how the smartphone and MRFT application worked. If they were unable to solve the issue, these "first line" staff members escalated the issue to specialists on the deployment team who would investigate the issue over a period of hours or days before it was resolved.

The deployment team identified several ways in which the service process might change or become more efficient.

- As shown in Table 72, 33 percent of all service requests were new issues, but these accounted for at least 50 percent of the time spent responding to service requests during the MRFT. In a real-world deployment new issues would be less frequent due to the rigor of the development process for a non-research device.
- A robust ticketing system with dedicated service staff would be required during a real-world scenario. During the MRFT, service requests were recorded in a simple file format specifying the participant, the date(s) of service, and the content of each interaction. The deployment team observed that standardizing data entry for service requests was beneficial to the service request process. In a real-world setting, it is likely that a full service "help desk" provider would be put in place and dedicated to providing customer service. They would likely employ a software product specifically designed to support efficient ticketing of driver inquiries.

2.5 Invoicing and Payment Management

The deployment team managed the process of sending invoices to participants and receiving payments. These activities are presented in Table 73. All participants received an invoice electronically (if they provided an e-mail address) and these were generated automatically. The deployment team also sent paper invoices to all participants, and these took approximately 3 minutes per participant to generate and mail. The deployment team received and processed payments in several ways including check by mail; online via PayPal through the participant portal; or in-person by check or PayPal at the MRFT office where odometer readings took place. The methods by which participants chose to pay were described in Volume II.

Table 73. Activities Related to the Invoicing Process.

Activity	Time Requirements (minutes per driver)	Percentage of Drivers Affected	Staff Skill Level	Facilities and Equipment
Generate and Mail Paper Invoices	2-4	100%	1 Junior (Administrative)	Computer Printer Envelopes Stamps
Process Payments Received	5-10	100%	1 Junior (Administrative)	Scanner Computer
Manage Late Payments ("Unlock")	5	<10%	1 Junior (Technician)	Computer

Approximately 6 percent of participants were "locked out" of their smartphone at some point due to a failure to pay an invoice on time (this procedure is described in Volumes 1 and 2), and five of these participants were locked out more than once. As a result, the deployment team spent some time reaching out to participants to remind them to pay and then unlock the smartphone. Often, this would require an in-person visit between a member of the deployment team and the participant, resulting in travel which would require as much as 90 minutes of time. However, if the locking procedure was used in a real-world scenario, there would likely be a central office with stable office hours during which drivers could visit. As a result, the 5 minutes to actually "unlock" the device is presented here.

The deployment team identified several lessons learned from the MRFT that relate to the invoicing process:

- The deployment team developed more streamlined techniques to print and prepare paper invoices (i.e., establishing a clearer "assembly line" procedure). This highlights the nuances of interacting with participants and the effect that these decisions have on resource allocation and time requirements. In a real-world scenario there would likely be a dedicated staff that specializes in efficient billing systems to produce paper invoices.

- There were some idiosyncrasies in the payment process (e.g., a participant overpaying his or her invoice). These are the sorts of instances that would cause additional time and resources to be expended. For instance, the office staff that dealt with payments did not have any way to credit an account, so any overpayments would trigger a complex series of events in which the participant would need to re-pay, occasionally resulting in a late payment and a locked smartphone. In a real-world setting, there would be streamlined procedures for managing these sorts of situations, reducing the expenditure of extraneous resources.
- The deployment team originally hoped to utilize PayPal® in order to facilitate a consistent payment system that would minimize interactions with personal account data. While participants could easily choose to use PayPal® from home, it was difficult to use access multiple PayPal® accounts from a single office computer (since users needed to answer security questions when using a new device to log in). This led the deployment team to introduce different ways to receive in-person payments. However, this is more consistent with a real-world setting in which drivers would want multiple payment options available to them.

2.6 Other Activities

There were many other activities performed in support of the MRFT. They are mentioned here in order to identify the range of tasks required to administer and operate a road user fee program. However, they would vary dramatically in scope and level of effort to complete them in the real world due to the increased number of drivers served while centralizing the processing of many tasks to designated staffing resources.

Application Development and Testing. The deployment team selected the platform for and developed the MRFT application based on requirements defined in collaboration with MnDOT and in support of the study team's analysis goals. This process would be required for many of the potential real-world solutions for a new revenue collection approach. The complexity of the technological elements would determine the length of time and level of resources involved in development and testing. As demonstrated by the findings in Volumes II and III, user interface design and usability testing should be a crucial aspect of this activity.

The MRFT deployed a very specific technology solution on a single commercial-off-the-shelf (COTS) platform. One alternative to this in a real-world deployment might revolve around developing applications (i.e., "apps") that would perform on a wide variety of platforms and operating systems. This would require a different management procedure as software testing across devices would be required. Another alternative to the COTS model tested in the MRFT is for a developer to design a custom hardware and software.

Operational Procedure Development. The development team constructed all of the procedures used during the MRFT regarding interactions with participants. This would need to occur in any real-world deployment, even if the approach selected was not technologically complex. These procedures would include activities like establishing a payment schedule, consequences for late payments and device misuse, and processes for escalating service requests.

Establishing Fees. The study team advised MnDOT on a wide range of pricing factors that might be used to determine fees, and, as described in detail in Volume I, MnDOT selected a very simple fee structure that varied by location and time of day. In the real-world, this process would likely be iterative as fees that are initially set are continually reevaluated for sufficiency and equity to road users.

Data Management. The deployment team managed all the data collected by the smartphone application and data related to interactions with participants. They used cloud-based data processing and analysis, which they reported to be stable, expandable, flexible, and inexpensive (approximately $250 per month for more than one terabyte of storage). Clearly these costs would vary in the real world based on the complexity of the data collected and the hosting solution selected.

Another aspect of data management revolves around data integrity. This includes both maintaining data security (and thus the privacy of drivers) and ensuring data quality (i.e., that the data collected is accurate and complete). This requires specialized skills and careful planning in development and testing.

Hardware and Software Management. The deployment team was responsible for obtaining and maintaining an inventory of smartphone devices and related equipment. The MRFT used a single device and operating system. However, in a real-world scenario, versions of a particular device or operating system change with frequency. Phone vendors may make minor changes to the internals of a phone within a production run, and radical changes may occur when a new phone is released (e.g., new GPS chipsets, changes in resolution of the display). Hardware can become outdated very quickly, and proactive software development and hardware inventory management procedures need to be created to facilitate a quick response. Thus, regardless of whether a single device is chosen for deployment or an application is created to work on multiple devices, it would be important to be responsive to changes in vendor hardware and software.

Development of Messages. The study team collaborated with MnDOT to develop a communication strategy for educating participants about MBUF and the MRFT. In the real world, strategies would become more complicated as the State tries to reach a wider audience to whom they have less access.

Development of Training Materials. The deployment team developed written instructions, guides, and videos for participants to use during the MRFT. This development process must happen in coordination with platform selection and application development so as to consider the knowledge, skills, and expectations of the drivers. Materials must effectively instruct different audiences based on experience with technology or language differences. Further, these materials will need frequent updating to respond to new fee structures or hardware and software changes.

Development and Maintenance of a Participant Portal. A website will likely be used to communicate with drivers regardless of the complexity of the revenue approach selected. In the case of the MRFT, the participant portal was a centralized source of training material, payment records, and individual trip data. Such a website needs to reflect the messages and training described above. There will also be a need to update continually the information contained within. Finally, the website itself will require extensive consideration with respect to usability (e.g., ease of navigation) or else it will not be an effective tool in responding to drivers' inquiries.

Cross-Organizational Coordination. During the MRFT, there were multiple organizations with different roles and responsibilities that coordinated to plan and complete the test (see Figure 1). This level of coordination would grow with the larger scope of a real-world deployment, which would have its own requirements to share information.

2.7 Summary of Known Resources

One of the chief unknowns related to establishing a new transportation revenue source is the administrative and operational resources for doing so. These are important to understand for a couple of reasons. First, the amount of fee for which each citizen is responsible will include a portion of these administrative and operational costs. Second, the proportion of the fee that these costs represent will have a major impact on citizens' perceptions of the fee. Minimizing administrative and operational expenditures will be key to obtaining buy-in from stakeholders and project partners. This is a concern from the perspective of how to communicate the reasonableness of the revenue mechanism to its end users, the citizens of the state.

The MRFT provides insight into the types of planning, management, and customer interactions that would be involved in many of the road user fee approaches that a state might adopt. However, it is important to note that much of the cost associated with these activities occur upfront during development and testing. Making an investment early on to thoroughly understand the end users, craft and test procedures, and train staff will enable long-term stability in deploying a system. Further, the MRFT supported only 500 drivers, so supporting activities were carried out by a small research team. In the real world, many activities would be outsourced to state organizations or private firms that are specialized, such as call centers to process service requests or mail facilities to process paper invoices.

3 Collaboration to Establishing Alternative Transportation Funding Approaches

MnDOT was empowered by the Minnesota Legislature to conduct a technology demonstration of MBUF. The technological approach undertaken in the MRFT is but one solution to collecting these road user fees. The findings from the MRFT provide a great deal of insight into what would be required in a real-world deployment to make the tested solution a reality. Further, the findings provide insight into general policy issues and specific practical concerns that need to be addressed before moving forward with any alternative transportation funding approach. In addition to evaluating the data described in preceding volumes, the study team interviewed various members of the project team in this effort and integrated this information with observations of driver behavior and attitudes. The present chapter identifies the key collaborators in selecting if and how to move forward in selecting alternative transportation funding mechanisms, including stakeholders in the process, champions of the effort, and those who may ultimately be called on to put into practice a particular revenue solution.

3.1 Stakeholders

There will be stakeholders of whatever funding approach is selected. Identifying these stakeholders is important for speaking knowledgably about the policy issues that matter and for identifying partners in moving forward in selecting and implementing an approach. MnDOT led the research conducted as part of the MRFT and is a key stakeholder of any transportation revenue solution. Further, the research findings contained in this report demonstrate how a technology-based approach to revenue can also provide a rich source of transportation operational and safety data (see Volumes IV and V). MnDOT has the subject matter expertise of knowing “ground truth” in terms of what the road users in Minnesota need with respect to transportation services and in terms of how to best provide these services. Thus, MnDOT should advocate for the needs of their customers for improving road operations and safety.

Ultimately, it is these customers, the road users of Minnesota, who will benefit from maintaining sufficient revenue for the roads. At present time, few drivers give much thought to how roads are built or maintained. Only when there is a problem (such as the well publicized 2007 I-35W bridge collapse in Minnesota[1]) do citizens question issues such as transportation funding and utilization of taxes. However, the customers of transportation services are not only stereotypical passenger car or light truck drivers. The users of Minnesota's road system include commercial vehicle operators, bicyclists, taxi cab service providers, transit service operators, and others. All of these will benefit from sustainable roads. However, each will have varied concerns about the precise mechanism for collecting revenue. It often falls on these citizens' representatives in the executive and legislative branches of government to work on their constituents' behalf to identify solutions to make sure these services are delivered fully and seamlessly.

3.2 Selecting an Approach

MnDOT's expertise lays in delivering services to drivers and other road users in Minnesota but not necessarily in determining in the most effective way for raising the funds to do so. Citizens have the most interest in ensuring their state's roads are sufficiently funded but most have little experience with the relevant issues. In Minnesota, the potential problem of insufficient transportation funding will likely be taken up at the legislative and executive level of government. They will consider questions such the state of the current fuel tax system, possible replacement or supplemental revenue alternatives, and their effects on different segments of the driving population.

3.2.1 The Current Fuel Tax.

Is the current fuel tax truly "broken"? If it is not currently failing, will it in the near future? To answer this issue requires insight into the inner workings of current financial policy and governmental budgeting, which is constantly evolving and subject to subjective interpretation and political contextualization. However, there will be objective, measurable changes to vehicle fuel efficiency that are likely to affect the current fuel tax system in some way, and these must be considered.

In response to projected decreases in the volume of motor fuel purchases, Minnesota has increased the per-gallon tax rate on motor fuel. Between 2005 and 2012, the tax rate per gallon increased from $0.200 to $0.285. While historically tax increases on motor fuels purchased have helped to maintain revenues by making up for the reduced volume of fuel being purchased, macro-factors are at work which may accelerate the need for change. With the new

[1]Minnesota Department of Transportation. *Interstate 35W Bridge in Minneapolis*, http://www.dot.state.mn.us/i35wbridge (accessed 12/1/2012).

fuel efficiency standards,[2] a 44 percent increase in fuel efficiency is planned over the next 4 years, and a 120 percent increase is planned over the next 13 years, making it difficult for the fuel tax to keep pace without some modification. Without modification to the existing tax structure, an alternative approach will be needed to make up the revenue shortfall.

3.2.2 Alternative Approaches

There are a variety of approaches that can be taken in response to concerns that merely raising the current fuel tax will be insufficient in the future. Many of these involve applying some sort of fee to driving. Some considerations relevant to a fee system include:

- *Who should pay the fee?* Fees could be applied to all drivers or to a subset of drivers. For instance, some states (e.g., Oregon) are considering applying fees to extremely high-efficiency vehicles such as electric vehicles (so that these drivers are paying into the transportation system at a rate more consistent with other drivers). Additional decisions need to be made in relation to how to assess fees for unique groups of road users, such as transit bus agencies, taxi cab providers, and commercial vehicles.
- *What factors should influence fees?* At its most simplistic, a new approach would be to assess a flat fee for all drivers. Further, fees could vary based on driving behavior, such as the time of day and day of week or type of road driven. In the MRFT, MnDOT was testing an opt-in discount technology option. This sort of model would mean that some drivers might accept a more complex fee system in exchange for more specific pricing options.
- *Will the fee replace or supplement the fuel tax?* The fuel tax is a known entity. To essentially eliminate the fuel tax could require a shift in the world view of drivers. Depending on how a fee is collected, it will affect, at a very practical level, how drivers budget on a weekly or monthly basis. However, a supplemental fee approach could appear to be a more complex approach to explain to citizens and there could be negative perceptions of being "double charged."

Answers to these questions will determine how the ultimate approach is carried out in practice. However, each element of an approach will affect its ultimate complexity. For instance, to assess fees relative to driving behavior would require more complexity in determining the amount of fees and the ability to charge a fee based on driving location, as in the MRFT. This requires the design of an effective and secure technological solution. So, while there are high-level decisions to be made regarding how to set up a road user fee structure, these decisions

[2] Office of the White House Press Secretary, "Obama Administration Finalizes Historic 54.5 MPG Fuel Efficiency Standards," *White House Press Release* (August 28, 2012). Available at: http://www.whitehouse.gov/the-press-office/2012/08/28/obama-administration-finalizes-historic-545-mpg-fuel-efficiency-standard

drive many layers of implementation and practical considerations (to be discussed further in Chapter 4).

3.2.3 Real Effects on Drivers

It is easy to think in the abstract about issues of fairness and equity in terms of ensuring all drivers pay into the transportation system. However, each potential funding approach will have "winners and losers." That is, there are real individual drivers who will experience a very personal change in how much they pay for roads. A driver who has a relatively low fuel-efficiency vehicle may benefit from a road user fee if it is a flat per mile fee. These sorts of situations will be most noticeable during a transition period, but are a real political issue in that subsets of drivers will feel more or less affected by a change. However, there are also larger, long-range effects possible (e.g., environmental) if there is no longer an incentive for drivers to buy more fuel efficient vehicles. Minnesota, the Nation, and the world may be at a crossroads in this area as more improved fuel efficiency options (and alternative energy solutions) have momentum, but are ironically affecting the funding that has so long been related to incentivizing their use.

3.3 Implementing an Approach

Once an overall road user fee approach (mileage-based or otherwise) is selected, it will need to be implemented. The current section discusses the various practical considerations that would be dealt with in order to implement a new revenue approach. This is based off what was observed during the MRFT and conversations with project partners and test participants.

The Federal government has been restrained in its response to the concept of an MBUF, and enabling states to investigate the nuances of their particular situations (i.e., funding needs, driver characteristics, political tone). However, there is little doubt that, at some point, Federal leadership will be required to enable more research to support large scale pilot testing and, ultimately, real-world implementation of new approaches to transportation funding. While the issues related to any sort of transportation funding approaches fall at the doorstep of all Minnesotans, responding to these issues will likely require a champion (or champions) to step forward and promote the discussion between stakeholders and government representatives. At this writing, several states are looking at these issues. Minnesota, in addition to the present policy and pilot test research into MBUF in particular, recently held a meeting of the Minnesota Transportation Finance Advisory Committee[3] to investigate a broad range of ideas "to develop recommendations for the next 20 years to fund and finance the state's highways, roads, bridges

[3] Minnesota Department of Transportation. http://www.dot.state.mn.us/tfac/docs/TFACSummaryReportNov30.pdf (accessed 12/13/2012).

and public transport systems, as well as its air, rail and port facilities." Implementation issues are discussed in subsequent sections.

3.3.1 High Level Implementation Issues

One of the more complicated aspects of establishing a new way to collect revenue for transportation funding has to do with jurisdictional issues. For instance, if Minnesota chose to adopt the MBUF approach used in the MRFT, it would be important to distinguish fees collected on Minnesota roads versus roads in other states or in other countries, such as its northern neighbor Canada. The results presented in Volume II show that the technology tested in the MRFT is a feasible way to determine these boundaries and accurately distinguish fees. It could be assumed, therefore, that if other states created different fee structures, then these could be assessed accurately using the same technology.

What is more difficult is the case where two states select different collection mechanisms. For instance, if Minnesota selected to implement the MBUF system but its neighbor, Wisconsin, chose to only employ yearly manual odometer readings. Without additional steps taken, there would be no way for visiting Wisconsinites to pay their share of the Minnesota MBUF. The federal government could potentially play a role here in terms of facilitating communication between states on these topics and may even eventually have a role in establishing interstate standards.

The flip side of this multi-jurisdictional issue has to do with the dispersal of revenue after it has been collected. Currently, the revenue from the Minnesota motor fuel tax is dedicated to the Highway User Tax Distribution (HUTD) Fund, which is also funded from motor vehicle sales tax and vehicle registrations. Five percent of the HUTD goes into a "Flexible Fund," and the remainder is distributed to the State Trunk Highway Fund (62 percent) as well as to municipal (9 percent) and county (29 percent) state aid.[4] Municipalities and counties also collect their own taxes, which benefit local transportation needs. As discussed in Volume III, MRFT participants were concerned with how MBUF would be distributed fairly. Because the MBUF system tested inherently had information about how roads were used, participants felt that MBUF revenue should be distributed accordingly. This is a challenging policy topic, and deciding to change how transportation revenue is distributed would need to be addressed as well. Further complicating this issue is the role of federal funding. Currently, the federal motor fuel tax, in addition to other revenue, also supports state transportation. MRFT research addressed only the Minnesota state fuel tax. The appropriate distribution of federal fuel tax would also need to be determined.

[4] Minnesota Department of Transportation, http://www.dot.state.mn.us/planning/stateplan/pdfs/5%20Transportation%20Funding.pdf (accessed 12/3/2012).

3.3.2 Setting Fees

In Minnesota, there is no established organizational structure for setting road user fees as would be required for an MBUF solution. Currently, the legislature of Minnesota takes up the issue of adjusting the motor fuel tax. Recently, the Minnesota fuel tax has been increased by the state legislature, although there is no further increase on the books past 2012

MnDOT has only tangential experience in setting fees of any kind. In the case of MnPASS, for example, an electronic toll collection system, toll prices are set to cover the costs of operating the system. While MnDOT has a role in providing real-time traffic information, infrastructure, and enforcement, with respect to fee setting, it also develops and sets the variable pricing tables which are managed to optimize lane performance through dynamic toll price adjustments. In some other states, a toll authority exists to collect revenue. Counties in Minnesota currently have an ability to set and collect a capped "wheelage tax" associated with vehicle registrations. This too could serve as a model for a fee system.

It is likely that in order to set road user fees, a board of some kind would have to be created to develop, monitor, and incrementally change fees, analogous to how electric or water utilities set rates. There also are likely to be lessons learned from European roadways which have made an attempt to standardize tolls across country borders.

3.3.3 Customer Experience

Implementing an alternative revenue collection approach will require some level of "on the ground" resources for interacting with drivers. In the case of the MRFT test outlined in Chapter 2, participants had to go to in-person odometer readings, install a smartphone in their vehicles, and pay invoices. This required an array of resources for the MRFT, and it would require many more in a real-world deployment. Odometer readings, if in-person, would require office/garage space, staff, and computers and other equipment at locations around the State. Additionally, MBUF collection would require the ability to collect personal contact information, vehicle information, and financial information related to payments. Such an office would be the first line of contact for the Minnesota customer to register for participation in a program, request equipment, pay a bill, or question an invoice.

Minnesota Driver and Vehicle Services[5] (DVS) may be in a good position to serve as a model in this area. This division of the Department of Public Safety (DPS) serves more than 11 million customers annually providing services related to vehicle ownership, license plates and registration, driver licenses, and motor carrier registration. The Department of Revenue is responsible for fuel tax collection. Currently, DVS has 538 employees who staff the central

[5] Minnesota Department of Public Safety. https://dps.mn.gov/divisions/dvs/about/Pages/default.aspx (accessed 12/3/2012).

office in St. Paul and the 95 state-operated driver's license exam stations. DVS also appoints and oversees 126 independent driver's license agent offices and 175 independent deputy registrar offices. Approximately half of these deputy registrar offices are private and half are government jurisdictions (i.e., cities, counties). These businesses are fee-based, and they will expect payment if they are required to handle the distribution of devices or additional transactions related to collecting odometer readings.

While it is not clear that such facilities could be repurposed to also support an MBUF program (like that tested in the MRFT), it is clear that DVS has the an existing infrastructure in terms of facilities, staff, and equipment to interact with drivers on a regular basis and to collect payments. The following are some issues which exemplify the types of detail with which DVS frequently deals.

DVS sends motor vehicle registration renewal notices, which could serve as the model for invoicing a road user fee. If these were used as the "invoice" mechanism, DVS would require that the odometer reading occur approximately 3 months prior to the time that the motor vehicle registration payment was due. This would allow for the fact that DVS mails the notices 6 weeks prior to the expiration date; printing and mailing takes 2 weeks, and another month would be required for the odometer notices to be printed and mailed and for data entry of all the readings and calculations of fees due. Significant programming efforts would be required upfront to enable all of this functionality.

With respect to odometer readings, there are existing DVS mechanisms for recording mileage. However, these would require updating to meet the requirements of a new revenue collection system. The Federal Truth in Mileage Act (TIMA) only requires odometer readings on vehicles that are 10 model years old and newer. The State of Minnesota does not have separate requirements for the collection of odometer readings. A large number of motor vehicle records have NR (Not Required) flags in the odometer reading field. Consequently, there is no baseline for establishing accrued mileage. If an odometer reading is recorded in error, and subsequently corrected or lowered, DVS often adds NA (Not Actual) to the odometer field. Some imported vehicles record kilometers. DVS converts these readings to miles, but the actual odometer may display kilometers. Further, there is no mechanism to deal with vehicles that leave the state in order to determine miles not driven within Minnesota.

There also would need to be consideration of the complex ownership relationships that might exist. Vehicles often have two or more owners (e.g., spouses, grandparents/grandchildren, siblings, partners). Owners may or may not have the same address, and only the first listed owner's address is captured in the DVS database. Some more unusual ownership relationships include vehicles that are titled in the name of a company and an individual, leased vehicles, rental vehicles, and vehicles held in trusts (revocable and irrevocable) and guardianships.

New and used vehicle sales also require special consideration. New dealer vehicles pose a unique situation as these vehicles are not even recorded on the DVS database until they are sold to the first retail customer. Most of these vehicles have less than 10 miles on them; however, dealers may put as many as 20,000 miles or more on a new vehicle before selling it to a retail customer. Dealers are exempt from registration tax on vehicles that they are holding for resale, even though they may be putting a significant number of miles on the vehicle.

Fifty percent of the vehicle sales in Minnesota are through dealerships, and fifty percent are personal sales (between individuals). With respect to used vehicles, if a dealer takes a vehicle in as a trade-in, they may also put significant mileage on the car while it is "held for resale." It would not be ethical to charge either the previous owner or the new buyer for these miles. Dealers would need to be either exempted or charged for the mileage, and procedures for this would need to be established. In private sales, typically the seller does not accompany the buyer to the Deputy Registrar to record the transfer of ownership. If there has been a fraudulent mileage reported, or if the MBUF mileage has not been paid, who collects the missing fee from the seller? Frequently buyers will delay the transfer of their title until such time as the next registration is due. In order to avoid late fees, they will report a fraudulent date of sale that is later than the actual sale date.

If Minnesota elected to adopt an approach requiring a driver to use a specific tool or technology, the state would also be required to develop a production/procurement and management system for storing, inventorying, and transporting these systems statewide. Further, the State would need to establish an efficient service center approach (i.e., a call center or help desk) that would not only deal with information inquiries and payment but support questions related to technology performance). At present time, there is no current model for this in Minnesota, and research into private sector models might be useful.

3.3.4 Information Management

Data is a central factor in any alternative to the Minnesota fuel tax. The range of potential data is large and includes:

- Contact information (e.g., name, address);
- Vehicle information (e.g., VIN, registration number);
- Financial information (e.g., credit card numbers); and
- Trip information (e.g., type of roadway driven, time of day).

The State, particularly DVS, has vast experience in collecting and storing the first three types of information. However, trip information at the level of detail available from a GPS-based technological approach is unusual.

An element of establishing practices for data management is related to if and how the data could be used to improve transportation services. The MRFT was able to demonstrate that GPS-based data could be used as part of a time of day or location (zone)pricing strategy (Volume I) and to provide travel time data (Volume VI). MnDOT developed feasible strategies for using this data in a way that it was not personally identifiable. These data are rich and could be of great value both to MnDOT for traffic management, to private companies who provide travel information, and ultimately to drivers, who would benefit from better traffic management and more reliable travel times (especially on arterials).

MnDOT strove to create a unique privacy solution for this data as part of the MRFT and this was ultimately quite successful and accepted by participants in the test. However, privacy remains a major concern in all discussions of road user fees. Any real-world deployment will require the establishment of data practices that ensure first that citizens are aware of the type and scope of data being collected and second that the security of data is ensured through rigorous protocols.

As discussed in Volume III, MRFT participants indicated that there were analogous systems in which they entrusted their data, including cell phone providers, services such as OnStar™, and online data transmissions certificates (e.g., when paying with a credit card). The fact is that many entities, public and private, securely hold substantial amounts of personal data about individuals; participants in the MRFT reported that they did not believe the state would necessarily misuse the data, but wanted assurance that the data would be protected from entities who might seek to misuse it. Therefore, some agent of the state would need to take responsibility for these data practices.

3.3.5 Enforcement

In any revenue collection process, there are opportunities for evasion either in terms of failure to participate fully (e.g., failure to pay invoices) or by outright fraud (i.e., tampering with a device or odometer). In order to implement any approach it will be necessary for responsibilities to be assigned to the State and to the customer. Requirements will need to be made clear and policies for enforcement established. Depending on the approach chosen, there would be a variety of unique conditions for which enforcement would need to specialize. For instance, odometers vary considerably in their accuracy due to natural driving factors such as the size and inflation of tires a vehicle has as odometers are generally calibrated to the size of tire standard on the vehicle and any deviations to the tire size will affect the odometer's ability to accurately capture mileage information. Such factors will need to be well understood in order to develop definitions of compliance and criteria for enforcement. Alternatively, certain technologies may be more prone to tampering (i.e., "hacking"), and this may require a unique skill set for inspection to identify cases of tampering.

In FY 2011, Minnesota's motor fuels taxes raised $849.6 million. Typically, the state's 423 distributors collect and remit the motor fuels tax, but in some cases the tax is collected by special fuel dealers or bulk purchasers. There are 168 licensed special fuel dealers in the state.[6] The Minnesota Department of Revenue has expertise in the area of enforcement in relation to fuel distributers who are evading the fuel tax. Thus, the administrative costs of evasion are not negligible today, although it might be perceived so by the average driver. The main difference between the current system and a system like that tested in the MRFT would be scale of the infractions. There would be more opportunity for individuals to evade for a small amount compared to businesses to evade for a large amount.

Law enforcement would also need involvement in determining whether drivers are compliant. For instance, drivers might need to display proof of road user fee payment, such as with a window sticker or license plate tab. Law enforcement officials would need to be able to verify payment through driver/vehicle records check. Finally, penalties for evasion would need to be established.

3.4 Incorporating Services

One of the advantages of selecting a COTS approach utilizing the available GPS technology with a detailed user interface is that it enables MnDOT to consider providing enhanced driver services. First, in the MRFT, participants interacted with safety signage functionality (described in Volume V). Second, the MRFT provided a proof of concept that the wealth of available GPS data could be used to provide more accurate travel times to drivers (described in Volume VII). Third, GPS data also permits MnDOT to use a fee structure that varies by location and time of day to better manage traffic and improve travel (described in Volume IV).

MRFT participants reacted strongly to the presence of other elements beside revenue features in the test. They recognized the need to find new, more stable revenue mechanisms; however, the topics of time of day and Metro Zone pricing, safety signage alerts, and the potential for improved travel times were not engaging topics for them. Participants preferred for the revenue issue to be simply addressed and not confused by layering other capabilities on top of it. The study team observed that drivers generally did not admit that any of these services might be useful to them personally, while acknowledging other people might benefit from them.

An additional type of service that is attractive to some researching road user fees is to integrate insurance services with fee assessment. Some insurers are already using driver data to

---

[6] Minnesota Department of Revenue, "Minnesota's Motor Fuels Taxes – Overview," January 2012. Available at: http://www.revenue.state.mn.us/legislativeupdate/Documents/MN_Motor_Fuels_Tax_2012.pdf (accessed 12/3/2012).

calibrate rates (e.g., Progressive™ "Snapshot"[7]). Drivers may see value in providing driving data to insurers to obtain a reduced insurance rate. Insurers, like transportation agencies, would find value in the wealth of data a technology (i.e., GPS-based) solution might provide[8, 9].

3.5 Developing Messages to Communicate with Road Users

As described above, many if not most citizens in Minnesota have little appreciation of the complexities of transportation funding in the State. This is not surprising, as the electorate has several important issues on its collective mind, education and public health and safety being two primary concerns. Transportation and its funding needs to rise to this level of awareness with more citizens. At present, drivers do not think about how the roads are funded, unless there is a crisis. If drivers were to pay a road user fee, they would start to think about transportation as a service as they often think about paying a cell phone bill or utility bill. However, there is a lot of "clutter" in the information citizens are faced with on a daily basis. It is difficult to reach through this clutter and educate drivers about the issues. Compounding the difficulty in communicating transportation funding needs to drivers is the fact that the issues addressed by concepts like MBUF are long-range issues. Fuel efficiency improvements are having only a modest effect on revenue generation currently, but their real impact will be felt in 10 years or more. It is difficult to communicate to drivers a sense of urgency to act when the consequences of inaction will not occur for a decade or more.

Complicating this issue further is that different segments of the population are focused on different issues. Some are concerned with privacy and sensitive to the use of any or some elements of their personal data. Some drivers perceive themselves to be overly burdened by taxes and are resistant to any changes to the current tax system. Some drivers are early adopters of technology and eager to use technology to solve problems, be it to perform revenue collection or to provide more accurate travel time information. Other drivers are wary of technological impacts on their lives or may be unfamiliar with advanced technologies and require a higher level of education and experience than the early adopter driver. As a result

[7] Progressive Insurance. "Linking Driving Behavior ro Automobile Accidents and Incurance Rates: An Analysis of Five illion Miles Driven." http://www.progressive.com/newsroom/images/snapshot_report_final_070812.pdf (accessed 12/12/2012).

[8] Proceedings of the 2010 Symposium on Mileage-Based User Fees: Moving Forward, "Workshop on Integrating PAYD Insurance and Mileage-Based Road User Fees," Humphrey Institute of Public Affairs, University of Minnesota, April 19, 2010. Available at: http://utcm.tamu.edu/mbuf/2010/proceedings/documents/PAYD_Insurance_Workshop_Summary.pdf (accessed 12/12/2012).

[9] Proceedings of the 2011 Symposium on Mileage-Based User Fees. "Summary of Workshop on Integrating PAYD Insurance and Mileage-Based Road User Fees," Breckenridge, CO, June 15, 2011. Available at: http://utcm.tamu.edu/mbuf/2011/summary/documents/2011_PAYD_Insurance_Workshop_Summary.pdf (accessed 12/12/2012).

communication strategies need not only to communicate funding needs to drivers, but also to distill messages regarding privacy, security, evasion, and costs to citizens with a wide variety of interests and concerns.

Volume IX: Discussion of Findings

1 Overview of the Minnesota Road Fee Test

States have expressed growing interest in exploring options for replacing or supplementing the motor fuel tax, including the possibility of implementing road user fees—specifically, mileage-based user fees (MBUF). In Minnesota, the Legislature appropriated funds for a technology research project exploring mileage-based user fees that was carried out by the Minnesota Department of Transportation (MnDOT) between 2007 and 2012. In addition to this investigation of MBUF, MnDOT elected to investigate technology that could enable other safety and mobility functions in support of the USDOT's connected vehicle and CICAS initiatives.

The objective of the Minnesota Road Fee Test (MRFT) was to inform future public policy decisions regarding mileage-based user fees and connected vehicle applications. The three primary goals of the MRFT can be summarized as follows:

1) Assess mileage-based user fees;
2) Convey safety alerts to drivers through in-vehicle signing; and
3) Provide a means for vehicles to provide data for the purpose of generating travel times on major corridors.

This volume will present an overview of the key issues related to instituting a new transportation revenue mechanism and enumerate the various questions that the study team addressed in evaluating the performance of the system, the operational aspects of the test, participant drivers' opinions, and the perspectives of potential stakeholders and project partners. Chapter 2 presents the key findings of the test. Chapter 3 will discuss some of the important questions related to new approaches to funding the Nation's roads and what was learned relative to this from the MRFT. Chapter 4 explores next steps for moving forward, including opportunities for future research and testing.

2 Key Findings from the Test

MnDOT deployed and tested an MBUF system with 500 Minnesota citizens. Some of the key features of Minnesota's approach were to use one commercial off the shelf (COTS) device with GPS capabilities to enable the collection of mileage-based user fees (MBUF) integrated with safety alerts and the generation of travel time data. The system designed for the test did accomplish all three of these functions as described in this report. However, this field study was not merely a test of a particular technological solution. It was also intended to test approaches to a variety of practical issues associated with an MBUF deployment, such as driver acceptance of technology features and concerns over privacy, the process of paying and remediating MBUF invoices, and other administrative and operational issues including fee setting, invoicing, and repudiation; communication and outreach to the public; and customer service.

Several key findings can be identified from the field test:

- MnDOT developed a better understanding of the “opt-in” discount system approach to MBUF.
- Participants were accepting of modest monthly MBUF invoices.
- Privacy was not of paramount concern to participants.
- MnDOT developed a better understanding of customer requirements for an MBUF program.
- The basic messaging used in the MRFT was effective at conveying the need for a funding alternative to drivers.
- The test provided insight into the types of planning, management, and customer interactions that would be required of an MBUF program.
- Regardless of their perceptions, drivers showed some compliance to in-vehicle safety signage.
- Drivers value simplicity in the design of any alternative transportation funding program.

Each of these findings is described in more detail in the following sections.

2.1 MnDOT developed a better understanding of the “opt-in” discount system approach to MBUF

MnDOT met its goal of deploying the conceptualized system in a realistic and thorough manner. The MFRT offers the unique perspective of having 500 drivers who became experts with this particular implementation over a half-year period. These drivers have been the closest of anyone in Minnesota, and perhaps the nation, to having such a robust real-life experience with an MBUF concept and a specific COTS technology implementation.

Almost 500,000 individual trips were recorded in the 4-month test period (following a 2-month baseline period) and 83 percent of these trips were voluntarily linked to participant drivers for the purposes of the study team’s data analysis and evaluation. The half-million trips represented almost 4,000,000 miles of travel recorded on the technology device and at odometer readings. These combined miles resulted in a total of nearly $38,000 in field test “revenue.”

A unique component of the MRFT was that MnDOT created an MBUF program to which drivers could “opt-in.” The purpose of this approach was to enable drivers to determine when and where they wanted to share personal data. The MBUF system was essentially a fixed fee system at $0.03 per mile. However, a discounted rate ($0.01 per mile) was available for drivers who were willing to share anonymized trip information with MnDOT. This tested approach served as a model for how an MBUF system might gain entry to the customer market place.

The results of the field test show that 77 percent of all the miles driven during the test were recorded on the device making it appear that drivers used the device approximately three-quarters of the time. However, participants’ ability to obtain this discounted rate was not optimal. Because of software and hardware challenges, the device occasionally captured more or less miles than the participant actually drove. Reasons for this are varied and are explained in detail in Volume II.

2.2 Participants were accepting of modest monthly MBUF invoices

While this field test generated almost $40,000 in simulated revenue, the amount paid by each individual participant was modest, averaging $20 per month, which equates to less than a dollar a day for most drivers. This was designed to be a reasonable approximation to the current Minnesota fuel tax (as described in Volume IV), and is a relatively modest invoice amount compared to many utility bills. In considering initial reactions to the MBUF rates, only 17 percent of participants reported that the rates were higher than they expected and the rest reported they were the same (53 percent) or lower (30 percent) than expected. The majority of the participants also agreed that it was reasonable to vary a fee by time of day (i.e., peak/off-peak hours) and location (i.e., inside or outside the “Metro Area”).

Non-payment and enforcement of payment was a minimal concern in the field test. Of course, there is some level of “self-selection” present in this type of research meaning that participants who volunteer and receive stipends have some motivation for complying. However, this is still an important finding since the assessment and invoicing process were not so tedious or difficult that bills were not paid. It was in fact a successful process, although participants did offer suggestions for improving the content and presentation of the material.

They were also asked, based on their 6 months of experience in the test, if they would prefer to pay mileage-based fees as a replacement for the fuel tax. While participants were quite divided on this question, with 37 percent indicating that they would prefer to pay a mileage-based fee as a replacement, 48 percent indicating they would prefer just to continue to pay the fuel tax, and 15 percent responding that they did not have an opinion or that they were not sure of their preference. Participants indicated numerous reasons for preferring a mileage-based fee, including that a mileage fee ensured that everyone paid their “fair share.” Of the participants who indicated that they would prefer to continue to pay the fuel tax, common reasons were that a mileage fee highlighted the amount of money being paid each month in taxes while the fuel tax “hid” the cost in the price of a gallon of gas, and paying a monthly invoice was “just one more bill.” The undecided participants indicated that they had not determined if a mileage fee would save them money or that it would depend on how a state would implement a mileage-based user fee system.

The fact that nearly 40 percent of respondents preferred a mileage-based user fee over the fuel tax at the end of the test is quite positive given that the majority of these participants were unaware of the idea of a mileage-based user fee prior to the start of this test and that this concept was completely new to them.

2.3 Privacy was not of paramount concern to participants

The privacy of individual drivers’ data was of utmost concern during the conduct of this field test, and it was assumed that it would be a major concern of participants as well. Therefore, the MnDOT project team took multiple steps to ensure driver privacy through establishing an opt-in model and anonymizing the data collected by the deployment team. Because an MBUF system inherently relies on user information to assess fees, some amount of personal information is required (e.g., who the consumer is, how many miles have been driven). The amount and sensitivity of the information may vary based on the approach to collection. Systems that rely on higher levels of technology (e.g., GPS) require that more detailed and perhaps more “personal” information be collected. The MRFT application was designed to demonstrate that participants’ data can be kept private; drivers had to expressly allow the study team access to their data for use in this research project.

All this had been explained to participants, but participants did not express much interest in knowing the details of the process. In fact, the MRFT study team found that drivers did not express fear about a lack of privacy per se, believing that they give up their privacy regularly (e.g., to mobile phone service providers). Instead, participants worried that their data would be vulnerable to access by wrongdoers (e.g., “hackers”) who would seek to misuse the information. They wanted reassurance that their data could be safely held by the State, such as in the form of a security certificate program.

2.4 MnDOT developed a better understanding of customer requirements for an MBUF program

Volume VIII lays out the broad range of activities completed by the project team as part of the MRFT. Some of these were specific to the field test (e.g., issuing stipends related to participation) while others were activities which would need to occur in any real-world deployment similar to the field test. At present time, MnDOT does not regularly provide services on an individual basis to its customers. Whatever organizations participate in deploying a real world MBUF system will be required to become more responsive to individual concerns. Some of the activities expected to be present in a real world deployment are:

- Scheduling appointments.
- Capturing vehicle mileage.
- Process user agreements.
- Installing equipment.
- Training drivers.
- Preparing equipment kits.
- Uninstalling equipment.
- Processing on-site payment.
- Receiving and documenting a service request.
- Providing guidance for a known technical issue.
- Providing guidance for a new technical issue.
- Escalating issue to a specialist.
- Generating and mailing paper invoices.
- Processing payments received.
- Managing late payments.
- Developing and testing the application.
- Developing operational procedures.
- Establishing fees.
- Managing data.
- Managing hardware and software.
- Developing messages to drivers.
- Developing training materials.
- Developing and maintaining a participant portal.
- Coordinating across organizations.

Participants reported a generally high level of satisfaction with the service they received during the MRFT. Nearly all participants agreed that scheduling the odometer reading appointment was easy, the staff clearly explained all materials, and the staff successfully and fully answered all questions. Further, many participants wrote in additional comments recognizing the odometer reading staff for their understanding of the program as well as their ability to relay that information to the participants and answer any questions they had. The design and operation of these odometer readings operated well and the basis could be adopted and expanded to a larger scale deployment.

However, it is important to note that much of the cost associated with these activities occurs upfront during development and testing. Making an investment early on to understand the end users thoroughly, to craft and test procedures, and to train staff will enable long-term stability in deploying a system. Further, the MRFT supported only 500 drivers, so supporting activities were carried out by a small research team. In the real world, many activities would be outsourced to state organizations or specialized private firms (such as call centers or mail facilities) to process service requests or process paper invoices, resulting in efficiencies.

2.5 The basic messaging used in the MRFT was effective at conveying the need for a funding alternative to drivers

Participants in the study received very little education or training about the transportation funding issues driving the MRFT. Yet, by the conclusion of the study they easily understood the basic needs and saw the needs as reasonable and trustworthy. That implies that the messages used in the MRFT were very effective.

A solution is needed to bridge the transportation funding shortfall, and whether or not MBUF is determined to be the solution, developing communication strategies for effectively communicating with the public on the topic of transportation funding is critical. Communicating the problem is the first step. Future public outreach efforts are needed to make the larger community of road users knowledgeable about, and invested in, the transportation funding issues that face the state. MnDOT representatives report that the current situation is not that drivers do not care about this issue, but that it has not been raised to such a visible level as issues like education or health care. The revenue issue must become more tangible to drivers. Even encouraging a basic understanding of how much drivers currently pay in motor fuel tax today might benefit the discussion. One idea raised during the study was to publish the cost of the fuel tax at the pump. Further work might involve promoting the spending of dollars to build and maintain roads in terms of “your motor fuel taxes built this road.”

Key to communicating to drivers is to understand the segments of the population to be contacted. Most drivers in the field study were sensitive to ways in which the fuel tax is not equitable, but they also were concerned with how a mileage fee might penalize some drivers. Paying mileage-based user fees will have a very personal and practical effect on drivers. While on the whole it might be a fair solution, there will always be individual winners and losers during the transition to a new system (as demonstrated in Volume 4).

2.6 The test provided insight into the types of planning, management, and customer interactions that would be required of an MBUF program

The MRFT demonstrated that multiple organizations with different roles and responsibilities were required to complete a test with 500 participants. While a real-world deployment would be able to draw from the design and lessons learned during the MRFT, a real-world deployment would require coordination with many more individuals and organizations (e.g., customer service, data management, etc.) that interact virtually and in different geographic locations. Also, in order to implement an MBUF program on a regional or national level successfully, the involvement of multi-state groups must be considered, as challenges exist with the ability to collect fees from out-of-state drivers. Research is needed to understand how these groups could be formed and how they would function seamlessly from the perspective of drivers and in a way that maximizes the efficient use of resources.

One of the foremost unknowns relative to establishing a new transportation revenue source is the administrative and operational resources for doing so. These are important to understand for a couple of reasons. First, the amount of fee for which each citizen is responsible will include a portion of these administrative and operational costs. Second, the proportion of the fee that these costs represent will have a major impact on citizens' perceptions of the fee. Minimizing administrative and operational expenditures will be critical to obtaining buy-in from stakeholders and project partners. The MRFT provides insight into the types of planning, management, and customer interactions that would be involved in many of the road user fee approaches that a state might adopt. It is important to note that much of the cost associated with activities in an MBUF program occur upfront during development and testing. Making an investment early on to thoroughly understand the end users, craft and test procedures, and train staff, will enable long-term stability in deploying a system.

2.7 Regardless of their perceptions, drivers showed some compliance to in-vehicle safety signage

MnDOT leveraged the capabilities of the COTS GPS-featured technology to integrate connected vehicle features, and demonstrated that safety alerts can be provided without roadside infrastructure investments. The speed-related safety alerts were found to be effective at reducing speeds. Both visual and audible alerts appear to have improved speed limit compliance and reduced driver speeds, while drivers showed a greater reduction in speed when presented with audible alerts. The largest benefit was seen with the 7 percent of drivers who previously increased their speed upon entering the zone, but who slowed down upon entry when alerts were present. Overall there was an average reduction in speed of 9.0 mph among these drivers.

It may be wise to phase these elements in later, so as to not complicate the public acceptance issue of MBUF. Generally speaking, drivers saw the potential value in these services to drivers, but did not necessarily think they should be part of a revenue-oriented program. In fact, they reacted strongly to the presence of other features besides revenue features being present in the test. They recognized the need to find new, more stable revenue mechanisms. However, the topics of time of day and metro zone pricing, safety signage alerts, and the potential for improved travel times were not engaging topics for them. Participants preferred for the revenue issue to be handled in a way that is simple and not confused by layering other capabilities on top of it. It may make sense for a state to consider adding (or offering) these kinds of features in the future once the public has accepted a base program of MBUF.

Providing participants flexibility to customize safety alerts (e.g., location, volume, tone, etc.) would likely enhance participant acceptance. While the majority of the participants felt that the visual and audible alerts were useful tools for drivers, about half of respondents indicated that they would prefer to disable both the visual and audible safety alerts, implying that the signage features are useful for "other drivers." Telephone interviews with participants found that participants often drove through the same signage zone numerous times each week, or even each day, throughout the test. This repetition of safety warnings likely caused an increase in those responding that would like to disable the signage. The limited set of seven drivers who participated in the CICAS safety test spoke favorably about the intersection gap acceptance alerts, but it should be noted that this limited set of drivers was separate from the 500 MBUF participants and therefore they did not experience this safety signage as an added "feature" to the MBUF application.

The MRFT demonstrated that safety alerts can be delivered to drivers via a smartphone application. By cataloging sign locations using GPS coordinates, the field test produced a sample roadside sign database which was referenced by the MRFT application to determine if a participant was driving through a signage zone or not. As states improve processes for maintaining roadway infrastructure, many are using GIS to inventory certain roadway features such as sign locations. With the availability of this data and as GPS technology on smartphones continues as the norm, similar applications could be developed and made available for download to the general public without requiring any infrastructure investment.

2.8 Drivers value simplicity in the design of any alternative transportation funding program

Many of the participants in the MRFT who preferred the fuel tax over an MBUF program noted that one of the significant reasons they preferred the fuel tax was its simplicity. The current fuel tax requires very little thought at present time and requires no work on the part of the driver. Anything else, and in particular, a personal technology device like a smart phone, will require more involvement on the part of the driver.

This desire for simplicity was echoed in participants' perceptions regarding device usability and overall opinions of this particular MBUF technology solution. Again and again, participants in the MRFT expressed a desire for the technology to be integrated into the vehicle so that it would require little (if any) interaction on their part. To accomplish this would require a delicate balance of making fees and invoicing transparent to drivers while minimizing their interactions with technology. Further research is needed to fully understand the advantages and disadvantages of this approach. While a device permanently installed into a vehicle dedicated to collecting and transmitting MBUF information may provide the highest level of service to the user, these devices are not currently available and would require research, design, development, and production prior to becoming a reality.

As demonstrated in the MRFT, the use of COTS devices can add its own set of challenges. In some cases during the test, hardware or software issues hindered the system's ability to reliably capture trips. Location data is a critical component in properly assessing user fees, but in the MRFT, it appears that GPS availability was a significant system issue. Smartphones are quickly changing and improving, and the quality of GPS chips in smartphones in the near future may very well be better-suited for this kind of application, but it may be too early at this time to rely on smartphone technology to achieve the level of accuracy expected/desired for an MBUF program.

Developing a standard application for a COTS device, such as a smartphone, would allow the public to enroll without the purchase (or provision) of additional equipment. However, the challenge with allowing the use of participant-owned personal devices is that while the use of these devices can more quickly increase adoption by drawing upon the thousands of devices already in the hands of the public, it would also increase the number of both manufacturers and device models being used in the program, all requiring technical support by the administering agency.

3 A Policy Viewpoint on the Minnesota Road Fee Test

As discussed throughout this report, there are various approaches available to solve this potential problem to funding transportation. Increasing the fuel tax is one possible solution, as is developing a new road user fee (including MBUF). Every possible approach has consequences in terms of its effectiveness over the long term; its cost to implement; and its acceptance by various segments of the public. For instance, increasing the fuel tax would be consistent with drivers' current understanding of paying for road services, but it also could result in an increasing gap in the amount of tax paid among certain members of the motoring public. With the rising fuel standards,[81] those who can afford newer vehicles will have the advantage of greater fuel efficiency than those who cannot afford newer vehicles, creating an expanding tax inequity among roadway users and, over the long term, taking the revenue

[81] White House, "Obama Administration Finalizes Historic 54.5 MPG Fuel Efficiency Standards," White House, Office of Press Secretary, http://www.whitehouse.gov/the-press-office/2012/08/28/obama-administration-finalizes-historic-545-mpg-fuel-efficiency-standard

model farther away from the concept of drivers paying to maintain the roads they use. Alternatively, an MBUF program might have other consequences, such as increasing operational costs, which affect its implementation.

The MRFT study team sought essentially to evaluate the feasibility of implementing a technology-based MBUF approach in the state of Minnesota. The findings suggest that it is feasible to do so and that, by doing so, it is also feasible to provide services such as safety alerts to drivers. Further, such technology could allow MnDOT access to a greater quantity of more precise traffic data, allowing the agency to provide more reliable travel times to drivers. Although all of these functionalities proved feasible and useful, several findings provide information related setting specific policies around MBUF and developing an implementation strategy.

3.1 Policy Issues

MnDOT conducted a study that focused exclusively on policy issues related to mileage-based user fees. This study was led by the Humphrey School of Public Affairs at the University of Minnesota and was completed in December 2011.[82] This study overlapped with the MRFT field deployment piece of this test, and thus, where possible, the study team sought to assess what was learned that might influence future policy decisions.

Many policy factors must be considered when weighing any alternative approach, and some of these factors can be addressed by the findings of the MRFT. Note that some of these factors were also outlined in *Report of Minnesota's Mileage-Based User Fee Policy Task Force*. This report was the result of a separate, concurrent, contractual vehicle undertaken by MnDOT to study the policy issues related to the possibility of an MBUF program in Minnesota to "engage stakeholders and a Policy Task Force, with the intent of identifying and evaluating issues for potential implementation of MBUF in Minnesota."[83]

The Policy Task Force used a series of public outreach and data collection techniques to gather input related to these policy objectives. These included five listening sessions with local government leaders, transportation officials, and trucking and business representatives; an internet panel survey of 400 Minnesota residents; attendance at the 2011 MBUF Symposium in Breckenridge, CO; and two transportation finance roundtables.[84] Through deliberation and discussion, the Policy Task Force identified several key policy topics for MBUF efforts in

[82] University of Minnesota, *Report of Minnesota's Mileage-Based User Fee Policy Task Force*, December 2011.
[83] *Report of Minnesota's Mileage-Based User Fee Policy Task Force*. MnDOT. December 2001. p 2. http://www.dot.state.mn.us/mileagebaseduserfee/pdf/mbufpolicytaskforcereport.pdf
[84] *Mileage-Based User Fee Policy Study: Supporting Technical Information*. MnDOT. April 2012.

Minnesota,[85] which are summarized below. In identifying these topics, the task force also offered an opinion of what it might take for Minnesota drivers to participate in—and for MnDOT to operate—an MBUF system on a day-to-day basis.

The two main objectives associated with an MBUF were to promote equity and to generate transportation funds. Relevant MRFT findings are described below.

3.1.1 Promote Equity

The Policy Task Force defined promoting equity as "ensur[ing] that all motorists pay for their use of the roadway transportation system, regardless of vehicle energy source."[86] This objective also includes the concept that users may pay different rates based on variables such as vehicle class, weight, time of day, type of roadway, and fuel economy. The Policy Study found a strong sense that the current fuel tax regime is inequitable, that not all users pay a fair share. However, those involved in the policy study raised several concerns about MBUF, including that MBUF could discriminate against rural drivers (based on the belief that rural populations drive longer distances in course of daily life); that MBUF will pass additional freight costs along to consumers in increased prices for goods; and that MBUF could penalize those who drive more.

Study team findings from the MRFT were generally consistent with what the Policy Task Force concluded. Drivers were sensitive to ways in which the fuel tax is not equitable and were concerned with how a mileage fee might penalize some drivers. As described in Chapter 3, paying MBUF will have a very personal and practical effect on drivers. While on the whole it might be a fair solution, there will always be individual winners and losers during the transition to a new system. A key finding of the MRFT is that messaging—**developing an effective communication system with a wide range of drivers**—is a crucial step for moving forward.

It is important to understand that **equity has different meanings to different people**. One meaning of equity is that all drivers pay into the system equally. Some drivers see the road system as a public commodity for which all citizens should pay. Other drivers see the roads as used disproportionally by different users and feel that the costs and distribution should be determined based on these specific use patterns. Further, some drivers consider social equity as a factor. For instance, some jobs will not allow drivers to adjust their commute patterns to avoid fees (i.e., in a congestion pricing model) and some perceive that rural drivers will pay for metro roads because they drive longer distances.

[85] *Mileage-Based User Fee Policy Study: Supporting Technical Information*. MnDOT. April 2012. pp 18-19.
[86] *Mileage-Based User Fee Policy Study: Supporting Technical Information*. MnDOT. April 2012. p 19.

3.1.2 Generate Transportation Funds

In this objective, the Policy Task Force looked at “generat[ing] transportation revenue by supplementing or replacing the motor fuel tax with mileage-based user fees over time.” Questions for consideration under this topic included whether or not an MBUF system would provide, or would be perceived to provide, adequate revenue, and if revenues should be used only for roads, for roads and transit, or for broad transportation applications. MBUF could provide a more stable transportation revenue stream (i.e., MBUF revenue increases with total travel, which MnDOT needs for maintenance and expansion). In addition, the state could allocate revenue by jurisdiction more accurately because it would have greater understanding of road usage trends and thus distribute funding for maintenance more accurately. Some concerns related to this were that MBUF should result in additional revenue to finance these maintenance and reconstruction activities, not be revenue neutral.

The MRFT study team observed that the tested approach was feasible in that it enabled fees to be collected in a highly flexible manner (e.g., by time of day, zone, road type), and to be more easily adjusted over time if a fee-specific “board” was put in place whose sole duty was to set and adjust rates over time. MnDOT stakeholders felt that this approach would allow revenue to change with need and not be tied to spurious factors such as consumption. MRFT participants perceived that such a system could collect sufficient revenue, although they worried that the administrative and operational costs would be greater than under the current system. They were also sensitive to the fact that since the system knew where revenue was being collected, this information could indeed be used to determine how to disperse funding proportionally to different jurisdictions.

3.1.3 Other Considerations

While equity and funding are the key goals of MBUF, there are other factors which are commonly thought to affect the potential of MBUF to be effective in implementation. These were considered by the Policy Task Force and are discussed below in relation to what was observed as part of the MRFT.

3.1.3.1 Operate Transparently

While not a stated policy objective for the MBUF Policy Task Force, this area could be considered essential since moving from the motor fuels tax to a mileage-based fee introduces a novel approach to the driving public. The idea of paying for road usage by the amount of miles traveled is relatively easy to grasp. However, ensuring that motorists understand how that concept is implemented could be complicated. In order to trust the new system, road users must be able to understand the system and view its administration as transparent.

The study team observed that MRFT participants comprehended the fee system clearly. In fact, they reacted strongly to the presence of other features besides revenue features being present in the test. They recognized the need to find new, more stable revenue mechanisms. However, the topics of time of day and metro zone pricing, safety signage alerts, and the potential for improved travel times were not engaging topics for them. Participants preferred for the revenue issue to be **handled in a way that is simple and not confused by layering other capabilities** on top of it.

3.1.3.2 Operate Efficiently.

Like operating transparently, operating efficiently is crucial to public acceptance of an MBUF system. In public policy terms, efficient organizations are those that "get things done with a minimum of waste, duplication, and expenditure of resources."[87] As applied to MBUF, bureaucracy must be minimized and the public must view any mileage-based fee as easy to implement and enforce and must see its administration as cost-effective. The Policy Task Force found a general belief that any MBUF approach would be best if implemented at the national rather than state level.

The study team observed that MRFT participants also held these concerns. However, participants did not see this as an unavoidable obstacle. Instead, they merely expressed an interest in being convinced that the state would control costs and prove itself able to perform these services with minimal overhead. Interestingly, drivers presume that the motor fuel tax is administratively "free" when in fact there are costs associated with accounting and enforcement. Therefore, it might be beneficial to **educate drivers about the costs associated with the motor fuel program** and any other program as an early step towards MBUF or alternatives.

Further, they expressed concern over the fact that all the states would need to coordinate on this topic. While they did not express any desire one way or the other to involve the federal government per se, they did express an interest in having this be nationally implemented in order to be equitable to all drivers (i.e., all drivers in Minnesota should pay regardless of whether they live there or not). Further, in talking with stakeholders, there was general consensus that the federal government would need to take a leadership role in moving forward any agenda associated with ensuring sufficient transportation funding in the future. However, the scope of that role was unclear, as states vary so much in terms of their unique needs. In the future, it will be important to **prioritize minimal costs in establishing operational procedures**.

The Policy Task Force participants also expressed concerns that inadequate technology could be used to implement an MBUF system. MRFT participants noted their concerns about the

[87] Stone, Deborah. Policy Paradox: The Art of Political Decision Making. New York: W. W. Norton & Company. 2002.

general accuracy of GPS units and indicated that any fee assessment and data collection system should be audited regularly to ensure accuracy. The MRFT study team found that the perceived accuracy of the MRFT application was a concern to participants. However, they seemed to recognize that this was a test, and they were understanding of the difficulties they encountered in terms of system issues. They did express that the accuracy they perceived during the test would not be acceptable in the "real world." Thus, it seems critical **to establish performance criteria and analyses that are reportable to drivers** to develop their trust in the approach undertaken in a real-world scenario.

3.1.3.3 Protect Privacy

Policy Task Force participants noted that questions such as who would have access to data and how it would be protected need to be addressed in any MBUF system. In addition, they indicated that the system should be audited regularly to ensure privacy. The Policy Task Force found that, the idea of "high-tech" devices in and of themselves imply a loss of privacy, whereas the use of high-tech devices with explained driver benefits tended be more acceptable in participants' minds.

Because an MBUF system inherently relies on user information to assess fees, some amount of personal information is required (e.g., who the consumer is, how many miles have been driven). The amount and sensitivity of the information may vary based on the approach to collection. Systems that rely on higher levels of technology (e.g., GPS) require that more detailed and perhaps more "personal" information be collected. The MRFT application was designed to demonstrate that participants' data can be kept private; drivers had to expressly allow the study team access to their data for use in this research project. While this had been explained to MRFT participants, they did not really express an understanding of the nuances of this process, and the MRFT study team found that drivers did not fear a lack of privacy per se, believing that they give up their privacy regularly. Instead, they worried that their data would be vulnerable to access by wrongdoers (e.g., "hackers") who would seek to misuse the information. They wanted reassurance (e.g., in the form of a security certificate program) that their data could be safely held by the state. This suggests that states should **discuss the issue of data security above the issue of data privacy**.

However, with respect to safety signage data, participants in the MRFT were sensitive to the idea that law enforcement might try to gain access to this information for the purpose of enforcing speed laws. This implies that **the state must make clear its intentions for expanding the use of data and make clear the limitations of its use**.

3.1.3.4 Protect the Environment and Improve Transportation System Performance

The Policy Task Force described ancillary objectives as “support[ing] environmental objectives by reducing vehicle emissions and fuel consumption” and “reduc[ing] the need for additional investment in roadway transportation system capacity by more efficiently managing travel demand.”[88] It concluded that incorporating additional pricing factors and policy objectives may muddy the water on MBUF costs and benefits and hinder likelihood of implementation.

As described above, MRFT participants suggested that the approach be kept as simple as possible. They understand that this is a revenue problem and were confused by discussions of safety, travel time information, or congestion pricing. That said, they did recognize that **some of these services would benefit them or other drivers**.

The study team did not directly assess the potential effect of mileage fees on drivers’ willingness to purchase more fuel-efficient vehicles such as hybrids or electric vehicles. However, some participants did express concern that a mileage fee that replaced the fuel tax could act against any incentive drivers currently feel to purchase a highly fuel efficient vehicle. However, they also expressed recognition that **the fuel tax was designed to support the transportation infrastructure and not motivate behavior or create social change**.

MnDOT stakeholders also expressed **how the kind of detailed driving data available from a technology option would be a great benefit to their ability to serve the road users of Minnesota and meet their safety and operational goals**. Being able to have more traffic management access and control will improve the driver experience and has the potential to reduce carbon emissions by reducing congestion.

Therefore, the opt-in model tested in the MRFT seems to make a lot of sense, as drivers would be able to take advantage of services that most interest them. However, the services (primarily safety signage) provided in this test were not engaging enough to drivers to make them particularly excited about them.

4 Moving Forward

The MRFT examined a very specific approach to collecting revenue to meet future transportation funding needs. Focusing on a specific approach allowed for a detailed and comprehensive understanding of operational performance and participant perceptions, but it did not allow for research and documentation of other, similar approaches. However, the MFRT offers the unique perspective of having 500 drivers who became experts with this particular implementation over a half-year period. They have come the closest to any in

[88] *Mileage-Based User Fee Policy Study: Supporting Technical Information*. MnDOT. April 2012. p 19.

Minnesota and perhaps the nation to real-life experience with such an MBUF concept and its technological implementation.

4.1 Next Steps for Minnesota

MnDOT was challenged to investigate a broad range of questions related to road user fees, particularly the MBUF; a GPS-based technology; an actual fee assessment, invoicing, and payment process; and integrated connected vehicle functionality. With this knowledge now in hand, the state of Minnesota will require a champion or champions to consider how to move forward. The timeframe surrounding diminishing transportation revenue is not immediate; Minnesota is looking at identifying a new funding approach over a period of one or more decades. However, there are many choices to be made. As described in Volume VIII, MnDOT is a subject matter expert on how to provide transportation services, but they are not organizationally structured to implement a fee collection system. Thus, MnDOT can identify its funding needs and can specify the sort of data that would benefit their safety and operational goals. However, it is likely that the state will need to leverage the existing state infrastructure to identify an implementation plan.

Before actual implementation, several questions need to be answered in order to develop a business model:

- Who will pay the fee?
- How much will the fee be?
- Will the fee vary by some factor(s)?
- How will the monies be distributed?
- Will implementation occur "all at once" or gradually, through a phased-in approach, with certain subsets of drivers?

Assuming that any one state, such as Minnesota, is ready to proceed with answers to these questions, there are still existing knowledge gaps that can be understood through further research.

4.2 Knowledge Gaps

While the MRFT did an excellent job of implementing a robust "test" deployment, there were many lessons learned that suggest further avenues of research and many additional questions that must be resolved prior to implementing a real-world MBUF program. For example, while the MRFT demonstrated that an MBUF program could be deployed using COTS equipment, research must be conducted to determine how to best communicate about such a program to engage the traveling public and other transportation stakeholders, such as transit agencies or the commercial vehicle industry. Without this, an MBUF program will be difficult to implement successfully.

Further, a key concern understood before the MRFT, and discussed frequently during the MRFT, is the ability to manage the implementation and secure the wealth of data being generated through an MBUF program. The MRFT proved successful with a fee structure that varied based on time of the day as well as location, but the Metro Zone where the fee varied was limited for simplicity of the test. If the state would like to implement a varying fee structure on a larger scale, would the public be able and willing to participate in such a program? Questions also remain as to the equipment that would be used in a real-world MBUF program: would an application be developed allowing the public to use their personal devices with the program, and, if so, how would the involvement of personal devices affect the operation for the state? Finally, the development and implementation of an MBUF program will be challenging without involvement from neighboring states, and further research is required to understand how multiple states could work together to implement such a program.

4.2.1 Messaging about Transportation Funding

Throughout this test, participants regularly noted that they were unaware of the revenue shortfall being faced due to the ever increasing fuel efficiency of modern automobiles. Even those participants who indicated they believed there was a revenue shortfall could often not provide a concrete example of the shortfall. To implement an MBUF program, more research should be conducted on developing a message for transportation funding to allow the public to understand 1) the need for a new form of funding, and 2) how issues with transportation funding affect the everyday life of the public. During the focus groups in the MRFT, participants generally understood the link between freight transportations and the economy (i.e., the state cannot simply raise taxes on the heavy commercial vehicles because these shippers would then increase the cost of service, therefore increasing the cost of goods), but did not understand a link between deteriorating transportation infrastructure and their life. In order to implement an MBUF program successfully and effortlessly, the state will need to refine the message to ensure that the public understands how transportation infrastructure affects their daily activities.

Future public outreach efforts are needed to make the larger community of road users knowledgeable about, and invested in, the transportation funding issues that face the state. MnDOT representatives report that the current situation is not that drivers do not care about this issue, but that it has not been raised to a visible level like education or health care. The revenue issue must become more tangible to drivers. Even encouraging a basic understanding of how much drivers currently pay in motor fuel tax might benefit the discussion. One idea raised during the study was to publish the cost of the fuel tax at the pump. Further work might involve promoting the spending of dollars to build and maintain roads in terms of “your motor fuel taxes built this road.”

4.2.2 Implementation Planning

Further research and development must also be conducted on implementation planning. While critical components, such as data management, are already being implemented in some form at many state and local agencies, data collected through an MBUF program could include personal driving habits of the public and thus would require heightened attention in collecting, maintaining, and using data. This would occur at three levels: the development of hardware and software with precautions to protect privacy and make drivers clearly aware of what they are sharing; the storage and protection of data that drivers permit the State to use; and developing regulations regarding the use of data regardless of where or how the data is stored.

Researchers should review the data management and collection practices of other agencies and industries to develop protocols needed for the implementation of an MBUF program. This is likely to be the result of public and private partnerships, as expertise in these areas should be leveraged. The USDOT’s connected vehicle research initiative is currently investigating many of these same questions (e.g., security, data management), and lessons learned through that effort can likely be used by any agency implementing an MBUF program.

4.2.3 Possible Fee Structures

The MRFT studied a fee structure that was based on a revenue-neutral replacement of the Minnesota fuel tax. However, this was driven by an assumption that administrative and operational costs for an MBUF program would be at least as great as those associated with the fuel tax. Additionally, the fees varied based on both time and location, demonstrating use of a fee structure that varies by location and time of day to attempt to influence driving patterns. Any state, including Minnesota, will need to identify the policies of value to their state when determining the structure of fees.

This variation in fee rate only took place in a pre-defined “Metro Zone” during peak hours. While many of the participants in this test responded that they felt it was fair to structure a fee as a function of both time and location, many of these participants did not travel in the Metro Zone area during peak hours and were not affected by the higher fee rate. If it is determined that a different or more detailed fee structure should be implemented, research will need to be conducted to determine the public’s opinions and perceptions of the proposed structure. Further, an observed theme that carried through the MRFT is that if an agency is going to implement an MBUF, transparency is required. **Participants in the MRFT indicated that they wanted access to information in order to learn how much of the generated revenue was**

going to the transportation infrastructure and, even more specifically, what types of projects the revenue was being used to fund.

In addition, if a more complex fee structure is considered for a real-world deployment of an MBUF program, research must be conducted to understand participant comprehension and acceptance of the fee structure. Many of the participants in the MRFT who preferred the fuel tax over an MBUF program noted that one of the significant reasons they preferred the fuel tax was its simplicity.

Finally, revenue projection will be an important element in determining an appropriate fee structure. It is important to "get it right" the first time as a state will not want to have to increase fees shortly after rolling out an MBUF program only because of revenue shortfalls that resulted from poor planning. If an "opt-in," "opt-out" approach is taken, with differing rates for each, much consideration has to be given to projecting how much of the time drivers will use the device. The fee structure in the MRFT was intended to be revenue neutral, and assumed a 15 percent non-device usage, a number which ended up being close to reality, although actual usage was lower than expected.

4.2.4 MBUF Equipment and Applications

If an agency were to implement an MBUF program, it would have to decide how and what equipment would be used in the program. While equipment dedicated to capturing and transmitting MBUF information may provide a higher level of service, as it would likely be less prone to malfunction since its sole function would be performing MBUF-related operations, this high level of service would come at a cost. One way to potentially reduce costs, while still having a device that is dedicated to MBUF, is to privatize the program, with one or more private firms offering their own products for how to collect the data and payments from their customers, Minnesota vehicle owners. Each company could do it differently, but all would be required to provide data and revenue to the state in a standardized, accurate, and auditable manner.

The MRFT demonstrated that it is possible to outfit a COTS device, such as a smartphone, with a custom application and to use the device to operate an MBUF program. If the agency developed an application for a COTS device, such as a smartphone, it would be able to increase the MBUF initiative's membership more quickly as potential participants would be able to enroll without the purchase of additional equipment. However, the challenge with allowing the use of participant-owned personal devices is that while the use of these devices can more quickly increase membership by drawing upon the thousands of devices already in the hands of the public, it would also increase the number of both manufacturers and device models being used in the program, all requiring varying technical support by the agency.

In addition, participants in the MRFT expressed a desire for the technology to be integrated into the vehicle and require little interaction on their parts. To accomplish this would require engagement of vehicle manufacturers as well as a delicate balance of making fees and invoicing transparent to drivers while minimizing their interactions with technology. Further research should be completed to describe the advantages and disadvantages of the different methods to collect and transmit MBUF data as well as the costs to the implementing agency, auto manufacturers, and the end user.

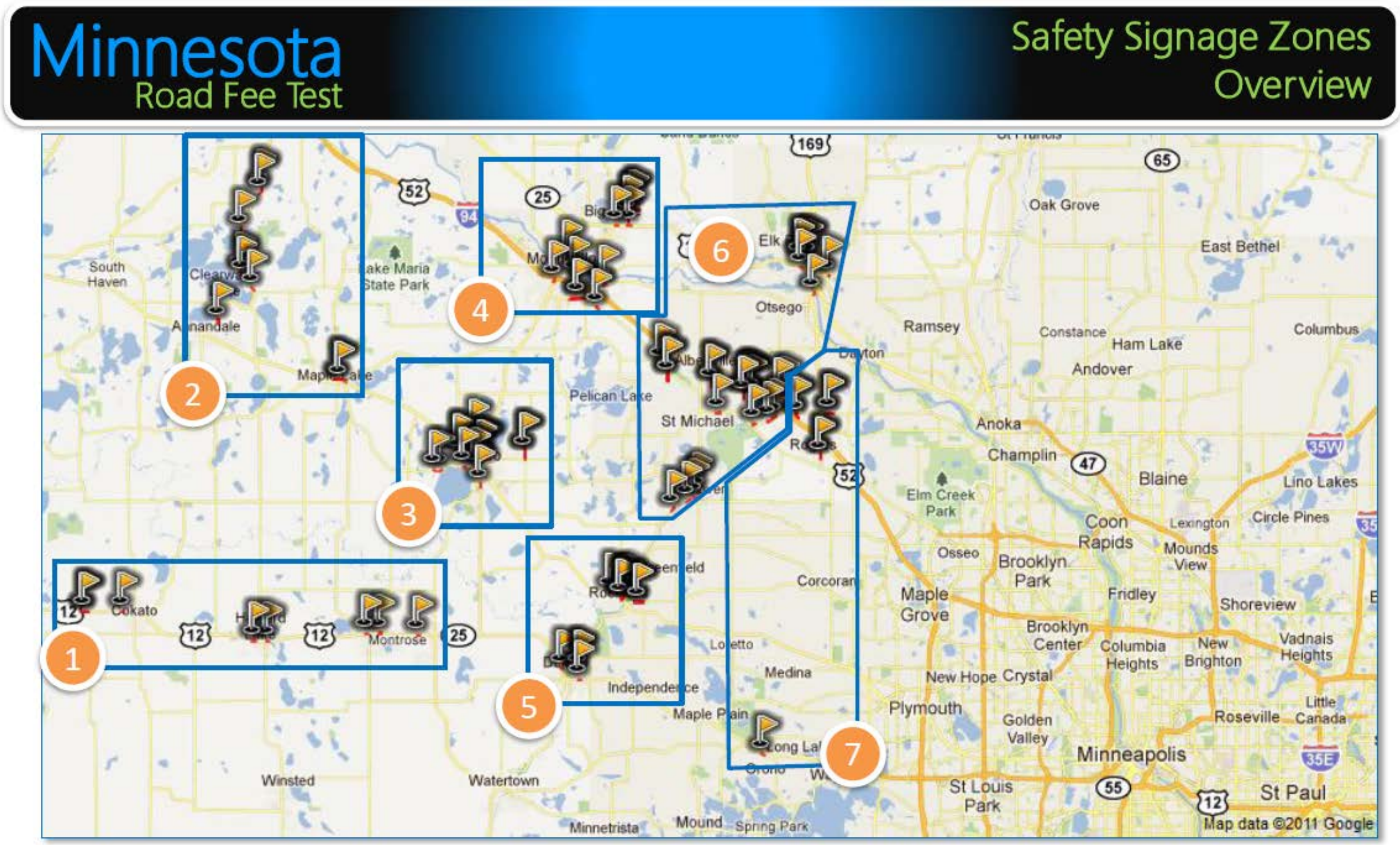
4.2.5 Cross-Organizational Coordination

Further research is needed in the area of cross-organizational coordination, including multi-state collaboration, to implement an MBUF program. The MRFT demonstrated that multiple organizations with different roles and responsibilities were required to complete a test with 500 participants. While a real-world deployment would be able to draw from the design and lessons learned during the MRFT, a real-world deployment would require coordination with many more individuals and organizations (e.g., customer service, data management, etc.) that interact virtually and in different geographic locations. Also, in order to implement an MBUF program on a regional or national level successfully, the involvement of multi-state groups must be considered, as challenges exist with the ability to collect fees from out-of-state drivers. Research is needed to understand how these groups could be formed and how they would function seamlessly from the perspective of drivers and in a way that maximizes the efficient use of resources.

Appendix A. Participant Welcome Packet

Appendix B. Participant Training Materials

Appendix C. Signage Zone Locations



1 Wright County Safety Signage, South Region (Route 12)

2 Wright County Safety Signage, North West Region

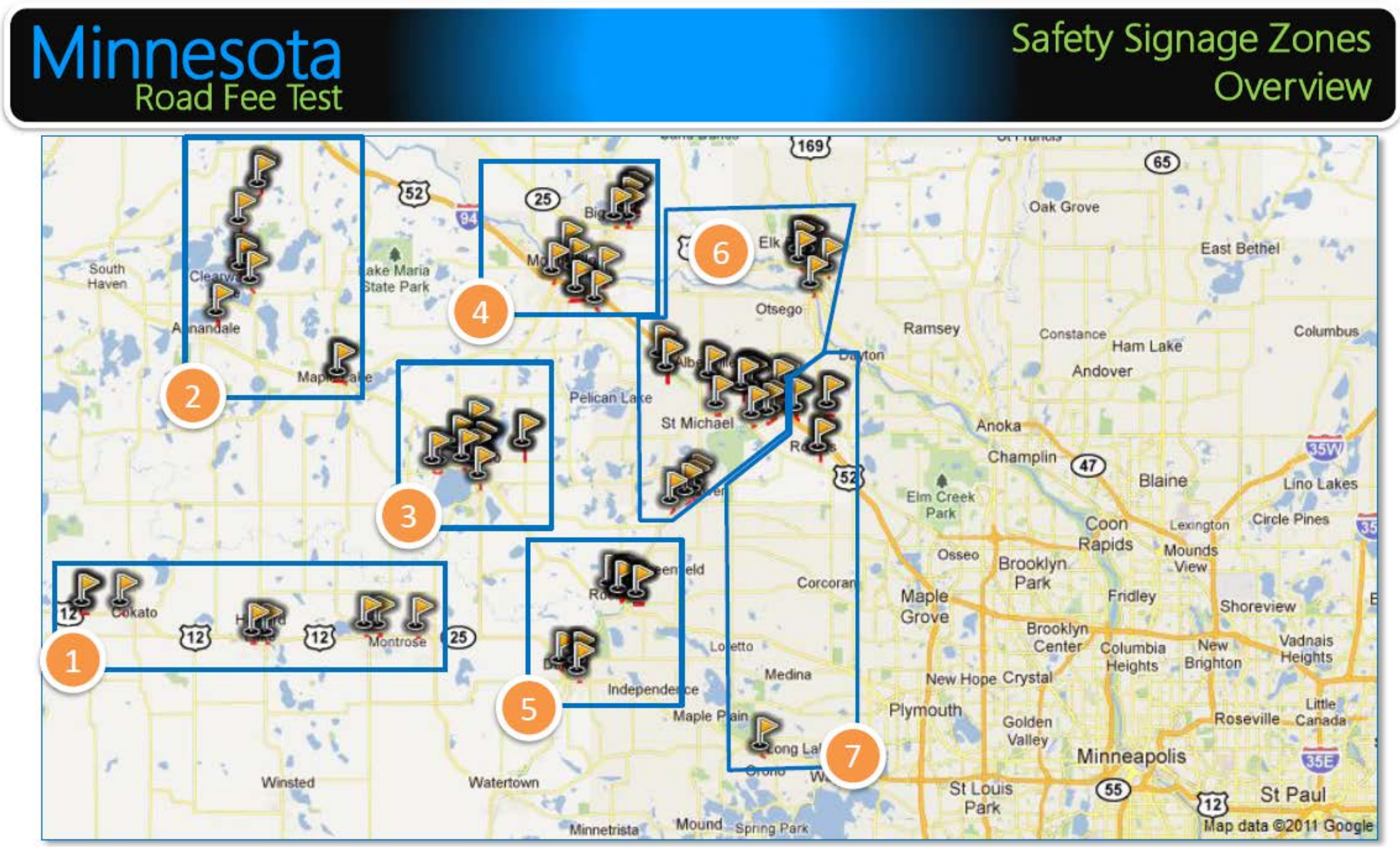
3 Wright County Safety Signage, Central Region

4 Wright County Safety Signage, North Region

5 Wright County Safety Signage, South East Region

6 Wright County Safety Signage, North East Region

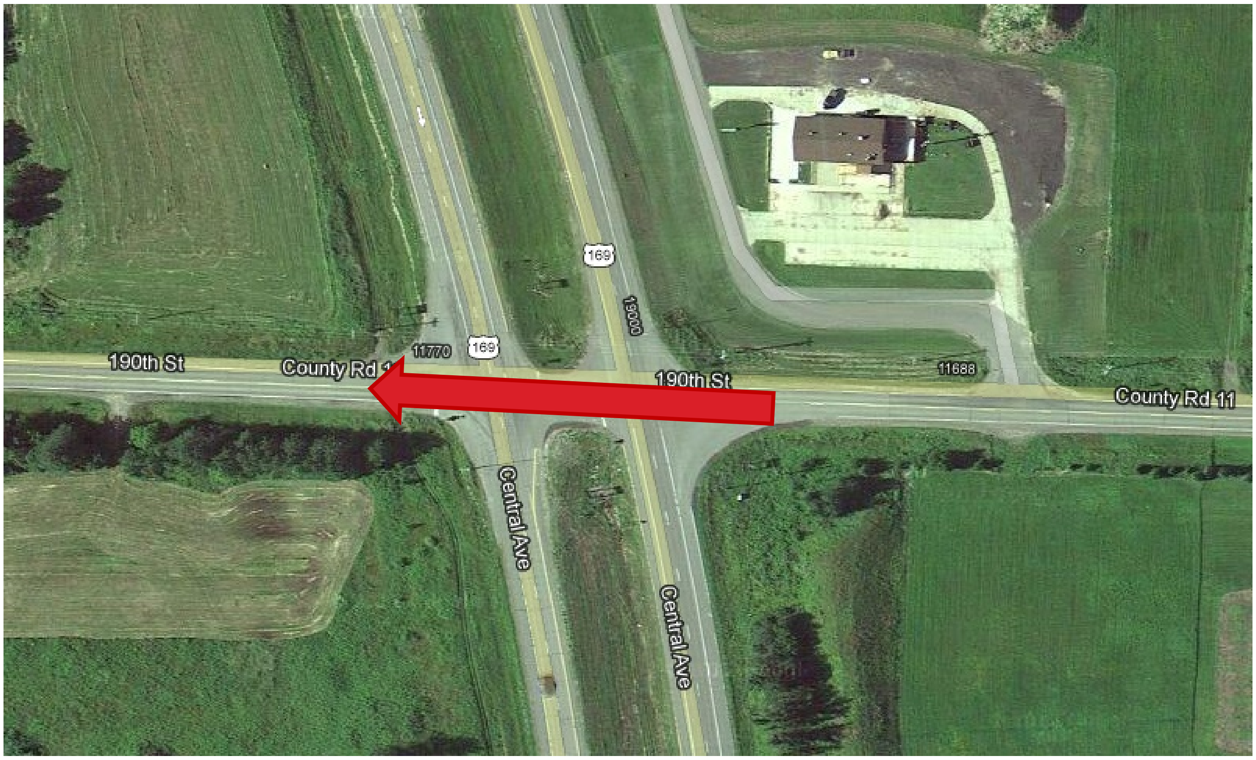
7 Hennepin County Safety Signage



1. Wright County Safety Signage, South Region (Route 12)
2. Wright County Safety Signage, North West Region
3. Wright County Safety Signage, Central Region
4. Wright County Safety Signage, North Region
5. Wright County Safety Signage, South East Region
6. Wright County Safety Signage, North East Region
7. Hennepin County Safety Signage

Appendix D. CICAS Survey Materials

4.2.5.1 Scenario #1

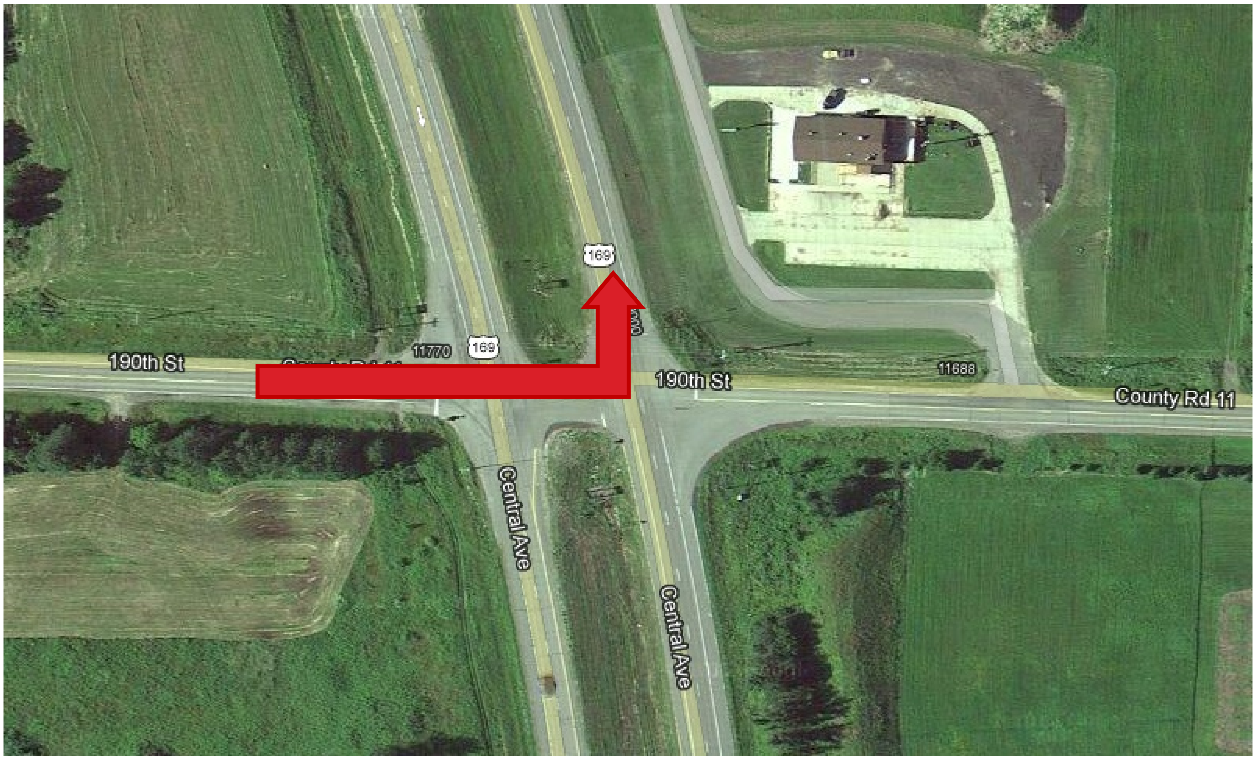


Source: Google Maps

At this approach I relied on information from:

	Not at all 0	1	2	3	4	5	6	7	8	9	Completely 10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2.5.2 Scenario #2

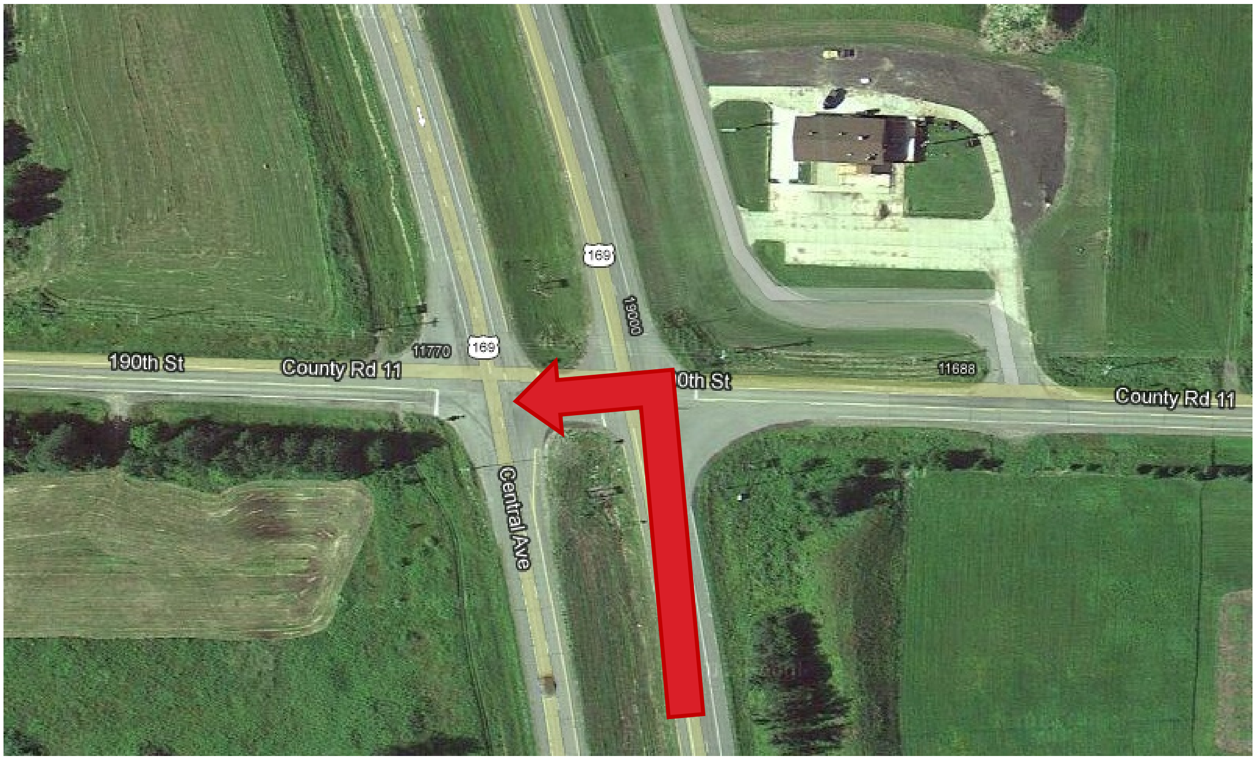


Source: Google Maps

At this approach I relied on information from:

	Not at all										Completely
	0	1	2	3	4	5	6	7	8	9	10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2.5.3 Scenario #3

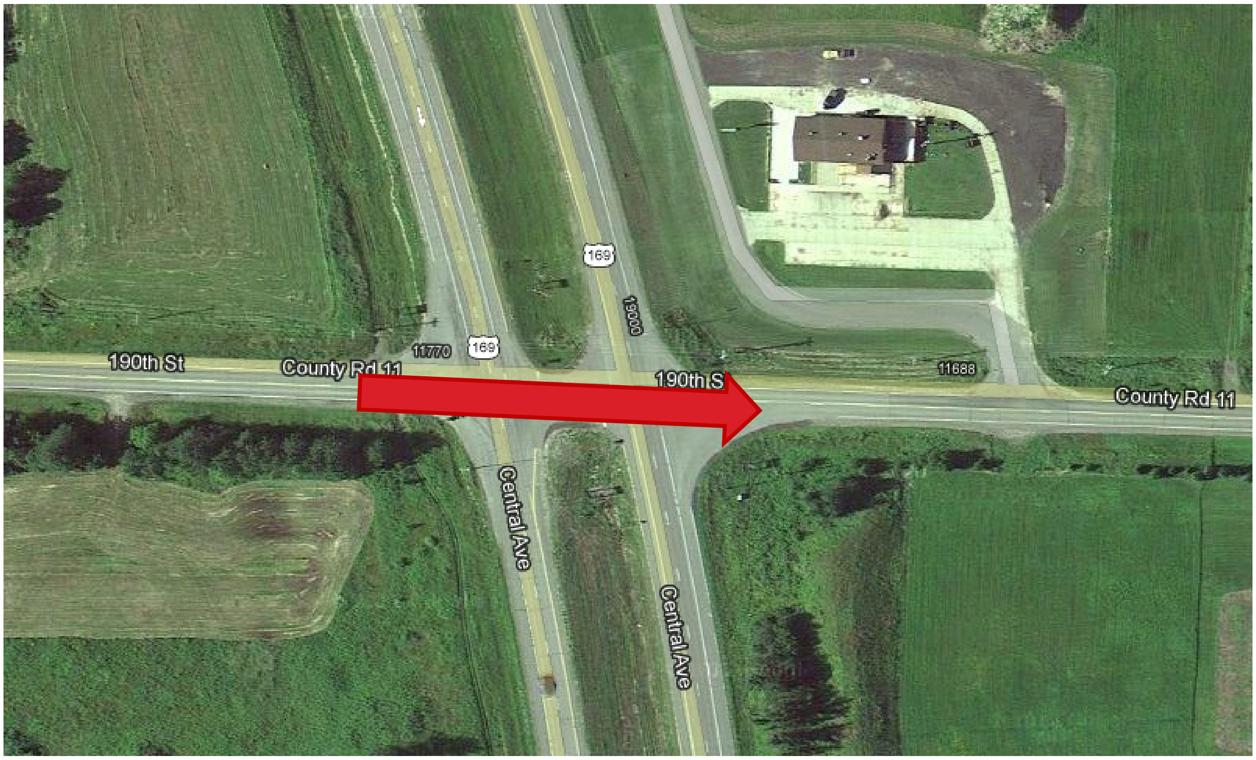


Source: Google Maps

At this approach I relied on information from:

	Not at all										Completely
	0	1	2	3	4	5	6	7	8	9	10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2.5.4 Scenario #4

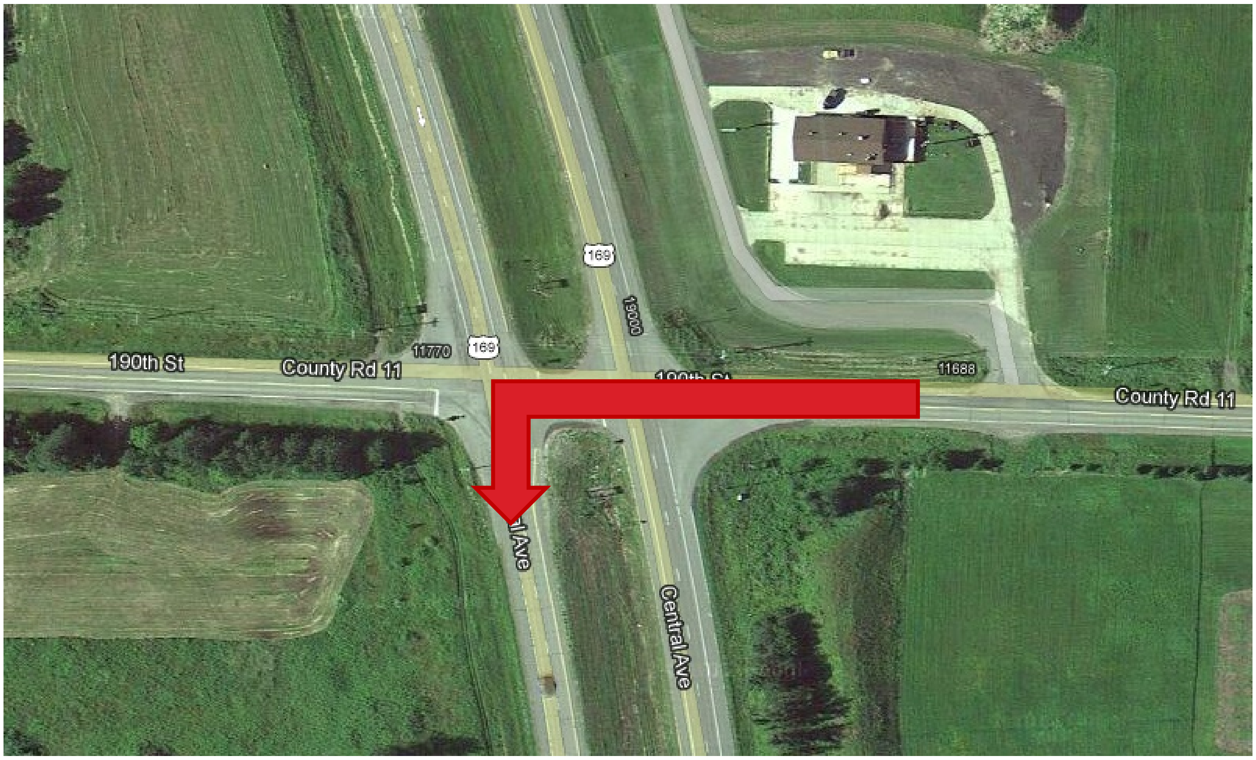


Source: Google Maps

At this approach I relied on information from:

	Not at all										Completely
	0	1	2	3	4	5	6	7	8	9	10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2.5.5 Scenario #5

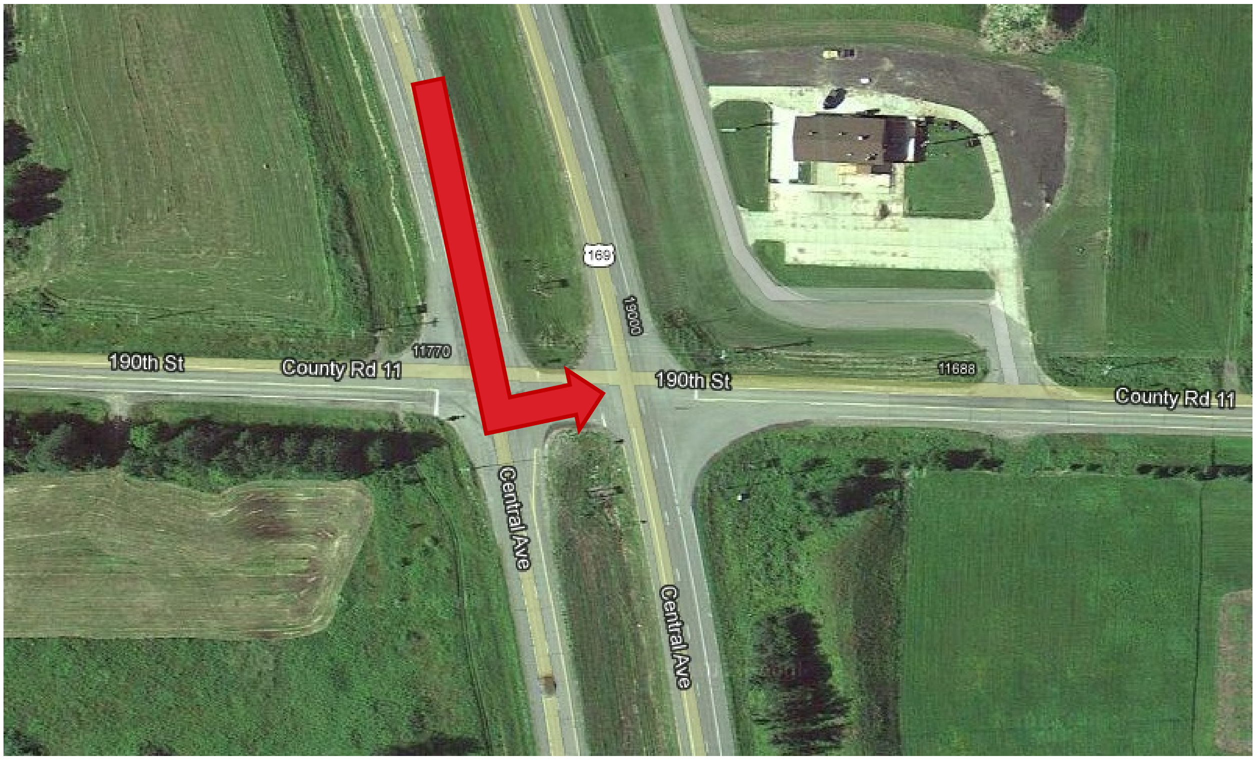


Source: Google Maps

At this approach I relied on information from:

	Not at all										Completely
	0	1	2	3	4	5	6	7	8	9	10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

4.2.5.6 Scenario #6



Source: Google Maps

At this approach I relied on information from:

	Not at all										Completely
	0	1	2	3	4	5	6	7	8	9	10
The Roadside Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
The In-Vehicle Display	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Visual Inspection of Traffic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

For the following statements, please indicate the answer that best represents your opinion:

	Roadside Display	In-Vehicle Display	Both	Neither	
Personally, I would prefer to receive safety alerts from the:	☐	☐	☐	☐	
	Disagree	**Somewhat Disagree**	**Somewhat Agree**	**Agree**	**Not Sure**
The in-vehicle safety alert was easy to understand.	☐	☐	☐	☐	☐
I found the in-vehicle safety alert distracting.	☐	☐	☐	☐	☐
I think the in-vehicle safety alert is a useful feature for drivers.	☐	☐	☐	☐	☐
I would prefer not to have the in-vehicle safety alerts.	☐	☐	☐	☐	☐
The roadside safety alert was easy to understand.	☐	☐	☐	☐	☐
I found the roadside safety alert distracting.	☐	☐	☐	☐	☐
I think the roadside safety alert is a useful feature for drivers.	☐	☐	☐	☐	☐
I would prefer not to have the roadside safety alerts.	☐	☐	☐	☐	☐
I think it is useful to have the safety alert appear on both the roadside display and the in-vehicle display.	☐	☐	☐	☐	☐

If you wish to further explain any of your responses or provide a general comment on your experience that you think may be helpful to us, please do so in the space provided below.