Travel Time on Arterials and Rural Highways:
State-of-the-Practice Synthesis on
Rural Data Collection Technology

Rural Data Collection Technology

April 2013

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16. Abstract

Travel time to a destination is a key piece of information that motorists want and need, and is vital for good decision-making by travelers. Technology now makes it feasible to provide drivers with real-time information about how long it takes to reach a given destination. The collection of travel time data is a challenging problem that deserves a systematic review. The purpose of this project was to identify, review, and synthesize information on current and potential future efforts in real-time travel time on rural highways. The current report focuses on rural highway travel time data technology considerations and is not a primer for general travel time best practices. Also, a companion report on arterial travel time data collection technology can be found in Singer, Robinson, Krueger, Atkinson, & Myers (2013). The core of the report discusses available and emerging rural travel time (RTT) data sources as well as implementation considerations, advantages, and limitations of each. These technologies researched include Bluetooth detectors, toll tag readers, in-pavement magnetic detectors, automatic license plate readers (ALPR), machine vision, connected vehicle, radar/microwave/LIDAR, inductive loops, crowdsourcing, and cell phone signal monitoring. Several implementations of RTT data collection are also discussed. In addition, two case studies are reviewed in detail (in Minnesota and Maine). The report then emphasizes key lessons learned based on questions for a practitioner to consider at each step of the planning, implementation, and management process. Although RTT data collection is a relatively new and rapidly evolving area, RTT can be successfully implemented when a project is properly planned and executed. Successful implementers have carefully considered project objectives and have provided detailed implementation plans. Regardless of the latest specific data collection technology, asking the right questions is paramount, beginning with planning, continuing to selection, and culminating with execution and evaluation. Practitioners who focus on asking the right questions and heed lessons learned by colleagues will greatly increase the chances of a successful implementation.

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List of Acronyms

ALPR	Automatic License Plate Reader
AVI	Automatic Vehicle Identification
CCTV	Closed-Circuit Television
DMS	Dynamic Message Signs
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
FHWA	Federal Highway Administration
GPS	Global Positioning System
IRIS	Intelligent Roadway Information System
ITS	Intelligent Transportation System
LIDAR	Light Detection and Ranging
MAC	Media Access Control
MaineDOT	Maine Department of Transportation
MnDOT	Minnesota Department of Transportation
ODOT	Oregon Department of Transportation
OOCEA	Orlando-Orange County Expressway Authority
RTI	Renaissance Technologies, Inc.
RFID	Radio Frequency Identification
RFI	Request for Information
RFP	Request for Proposal
RML	Radar, Microwave, and LIDAR
RTT	Rural Travel Time
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
TMC	Transportation Management Center
TAC	Technical Advisory Committee
TOIP	Traffic Operations Implementation Plan
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VSL	Variable Speed Limit
WisDOT	Wisconsin Department of Transportation
WSDOT	Washington State Department of Transportation

Executive Summary

Travel time to a destination is a key piece of information that motorists want and need. It is vital for travelers to make good decisions about which route to take and whether to divert from their planned path. Technology now makes it feasible to provide drivers with real-time information about how long it will take to reach a given destination. While travel time information has traditionally been provided by transportation agencies only on major urban freeways, there is interest in travel time messages now being communicated on rural highways.

The collection of travel time data and proper dissemination is a challenging problem that deserves a systematic review. The purpose of this project was to identify, review, and synthesize information on current and potential future efforts in real-time travel time on rural highways.

There were four main objectives:

- Identifying, reviewing, and synthesizing available and emerging technology (both nationally and internationally) for obtaining data necessary for calculating travel times on rural highways,
- Collecting and summarizing agencies' experiences with using such technology,
- Providing guidance to agencies for making the best use of available and emerging technologies to meet future needs,
- Determining the feasibility of deploying such technologies.

It should be noted that the current report focuses on rural highway travel time (RTT) data technology considerations. It is not a primer for general travel time best practices. A good source of general travel time guidelines can be found in Turner, Eisele, Benz, & Douglas, 1998. Also, a separate report on arterial travel time data collection technology can be found in Singer, Robinson, Krueger, Atkinson, & Myers (2013).

A more recent set of guidelines has been developed based on the experiences of the I-95 Corridor Coalition Vehicle Probe Project (University of Maryland Center for Advanced Transportation Technology, 2011).

The Transportation Management Center (TMC) Pooled Fund Study recognized the need to collect travel time data on rural roads, knowing that it must first be determined if technologies are being developed to obtain data necessary for calculating travel times that address specific challenges. Due to the challenges inherent in this environment and a limited history of implementations, there was a need to provide transportation agencies with information that will help them to implement such systems in a practical and cost-effective way. There are many challenges and benefits in collecting and distributing travel times on rural highways.

For example:

- Travel times are not collected in isolation and often their use is determined by the local goals and communication needs—and these can be quite different for and between rural roads.
- Rural roadways can vary greatly in their location and use: some may be remote and carry low traffic volumes, while others may be major interurban thoroughfares.
- Low traffic volumes may create challenges in acquiring sufficient data to be able to generate accurate and timely travel time estimates.
- The focus is not only identifying and dealing with congestion, but also tracking the occurrence of major incidents and providing alternate route information in the event of road closure.
- They can be hilly, rocky, curvy and mostly unsuitable for deployment of reliable intelligent transportation system (ITS) equipment or even cell phone reception in some cases.
- Some do not have parallel alternate routes, so it may be necessary to communicate issues to drivers 60 miles or more away.
- There are numerous approaches being developed, implemented, or experimented with nationally and internationally to deal with some of these issues. The table on the next page briefly summarizes candidate technologies.

Table 1 Candidate RTT Technologies

Technology	Spot Speed	Segment Travel Time	Real-time Tracking	Sensor Location	Coverage Per Sensor	% Vehicles Detected/ Matched†	Implementation Cost†	Non-traffic-info Functions†	Traffic Volumes	Vehicle Class
Bluetooth detection		X		Roadside/ above road	All lanes	Low	Low	Low		
Toll tag reader		X		Roadside/ above road	One or more lanes**	Low	Med	Med		
In-pavement magnetic detectors		X		In pavement	One lane	High	Med	Low	X	X
Automatic license plate reader (ALPR)		X		Roadside/ above road	One or more lanes**	Med	Med	Med	X	X
Machine vision	X	X*		Roadside/ above road	One or more lanes**	High	Med	High	X	X
Connected vehicle	X	X*		Roadside/ above road & in vehicle	All lanes	???	Low	High		
Radar, microwave, LIDAR	X			Roadside/ above road	One or more lanes**	High	Med	Med	X	
Inductive loops	X	X*		In pavement	One lane	High	Low	Low	X	X*
Crowdsourcing			X	None	All lanes	???	Low	Low		
Cell phone signal monitoring		X		None	All lanes	???	Low	Low		

* Possible depending upon capabilities of technology
** Multiple lanes possible depending upon capabilities of technology and sensor placement
† Can vary substantially depending on a variety of factors; estimates are approximate based on user experience
‡ Other functions can include tolling, traffic law enforcement, unregistered vehicle detection, cooperative safety, etc.
??? Unknown/no basis for assessment

To further hone the opportunity of providing useful and accurate travel time information in rural locations, it is important to ask the following questions:

1. What insights and experiences have agencies developed with these technologies, and what are the best uses of these technologies?
2. Given challenges faced in calculating and providing travel time information on rural highways, how feasible is deploying such technology?

The core of the report discusses available and emerging RTT data sources as well as implementation considerations, advantages, and limitations of each.

The key highlights of each follow:

Bluetooth Detection
Wireless technology that allows electronic devices to communicate directly with one another; recently emerged as viable RTT collection tech; open standard, allows for off-the-shelf equipment; detection range limited to about 328 feet (100 meters); less expensive than many other options; flexible; some potential privacy concerns; detection technology relies on drivers' use of Bluetooth enabled devices.

Toll Tag Reader
Detect radio frequency ID of automated toll tags, mature technology, inconspicuous, detection accuracy can decrease with distance, limited to areas with adequate toll tag fleet penetration, some potential privacy concerns, electronic tolling becoming increasingly common.

In-pavement Magnetic Detectors
Arrays of magnetometers installed in pavement, can identify and match vehicles based on each vehicle's unique magnetic signature, quick installation and self-calibrating, wireless sensors require access points and possibly repeaters, high vehicle detection rate, device life span of about 10 years, no privacy concerns.

Automatic License Plate Readers
Optical cameras capture images of license plates and software "reads" the information; mature technology (over 30 years); installed above the roadway and requires direct line-of-sight; particularly sensitive to factors that reduce visibility; privacy issues are a concern.

Machine Vision
Use of video cameras to monitor flow; installed above the roadway or on poles on the roadside; data bandwidth is a consideration; highly customizable set of features; privacy can be a concern for high-resolution systems; potential uses are likely to expand with advances in technology, processing power, and data transmission capabilities.

Connected Vehicle
Short range radio communications between vehicles and vehicles to infrastructure, technology is in very early stages of development, radio transceiver installed in host device within a vehicle, privacy protocols are being established, very inexpensive cost on a per unit basis, usefulness for travel time calculations uncertain, depends on implementation factors, potential for widespread use if initiative continues to develops.

Radar, Microwave, and LIDAR
A sensor emits radio waves (radar), microwaves, or a laser beam (LIDAR), which reflects off of vehicles, mature and widely used technology, many products available with a variety of different implementation approaches, complete privacy to drivers.

Inductive Loops
Magnetic loops in pavement detect vehicle presence, and multiple loops can be used to calculate travel times; mature and widely used technology; high detection rate; very inexpensive, but invasive installation and maintenance can increase costs; complete privacy to drivers.

Crowdsourcing
Drivers' vehicles or mobile devices provide information to a public or private entity, and that information is used to generate traffic/travel time, early stage technology, critical mass of users are necessary for success, vehicle/motorist must have device capable of transmitting information, no roadway infrastructure needed, privacy issues are minimal or non-existent when data transmitted to agencies who purchase data, use likely to increase.

Cell Phone Signal Monitoring
Cell phone location information is automatically and anonymously downloaded from cellular network switching centers in real-time; relatively mature technology and cell phone use is almost ubiquitous; data provided by vendors, and data are anonymous when provided to agencies; shows adequately precise measurements of travel time.

Several implementations of RTT data collection are also discussed:

Various State routes in Wisconsin

- I-45 from Houston to Dallas, TX
- Various routes in Oregon as part of the Frontier Travel Time project
- State Route 520 in Orange County, FL
- I-90 Snoqualmie Pass in Washington.
- In addition, two case studies are reviewed in detail: Minnesota DOT's I-35 temporary travel time system and Maine DOT's use of variable speed limit signs to provide real-time traveler information.

In addition, two case studies are reviewed in detail and lessons learned from the implementations are summarized:

Minnesota

- Define terms and requirements
- Use current rather than historical data for estimations
- Consider alternative methods for comparing travel time
- Drivers appreciated information, especially about alternative routes
- Costs less and more affordable than permanent system

Maine

- Costs much less than a traditional system of dynamic message signs (DMS)
- Posted variable speed information may imply the need for alternative routes
- Considering mobile phone applications

The report synthesizes the prior information and brings together the state-of-the-art in RTT data collection technologies and the state-of-the-practice in RTT implementations to develop a set of best practices that are based on systematic evaluation (where possible) and real-world experiences. The best practices relate to the data collection technology only; a complete set of best practices for RTT programs is beyond the scope of this effort. Best practices were developed with the understanding that every implementation of RTT involves a unique set of objectives, challenges, constraints, and environments. Therefore, rather than providing prescriptive guidance, this chapter emphasizes the key considerations at each step of the planning, implementation, and management process.

One of the most important lessons learned by RTT program implementers is the importance of asking the right questions during the planning and implementation stages. Therefore, each key consideration is phrased as a question and is followed by discussion of related issues.

These questions are focused on the following general areas (including sample questions for each):

Needs Assessment, Planning, and Specifications Development

- What are the ultimate outcomes desired?
- What are the funding and scheduling constraints?
- What is the desired RTT coverage area?
- What are the needs for scalability and mobility?
- Are real-time data required?
- What secondary benefits can be achieved?
- What are the requirements for data accuracy and timeliness?
- What partnerships are beneficial and necessary?
- What are the infrastructure requirements?
- Are data needed during low volume times?

Selecting and Acquiring Data Collection Technology

- What software, hardware, and other architectural requirements exist?
- What are the initial and ongoing costs of each technology?
- Should the technology be purchased or rented?
- How long is the data path?
- What system features can be automated?
- How will data security and privacy be protected?
- How can preliminary data collection technology be conducted?
- How should a vendor be solicited?
- How much ongoing support is offered by the vendor?
- What is the division of responsibilities and rights?
- Who owns the data?

Implementation, Management, and Evaluation

- How can sensor locations be selected?
- What technology documentation is available?
- How should the program operate when missing data?
- How should field equipment be monitored and maintained?
- How can data quality be verified?
- How should public and media relations be handled?
- How can the effectiveness of the program be evaluated?

Although RTT data collection is a relatively new and rapidly evolving area, RTT can be successfully implemented when a project is properly planned and executed. The importance of proper planning cannot be overstated. Successful implementers have carefully considered project objectives and have provided detailed implementation plans. Regardless of the latest specific data collection technology released, asking the right questions is paramount, beginning with planning, continuing to the selection stage, and culminating with execution and evaluation.

Practitioners who focus on asking the right questions and heed the lessons learned by colleagues will greatly increase the chances of a successful implementation.

1 Introduction

1.1 Background and Objectives

Travel time to a destination is a key piece of information that motorists want and need. It is vital in travelers making good decisions about which route to take and whether to divert from their planned path. If motorists were to be provided travel time information on rural highways, they may plan their trips accordingly with this new information, decreasing delays and the potential for congestion downstream. They may also be warned in advance of an incident, allowing sufficient time to choose an alternate route around congestion and delays.

Technology now makes it feasible to provide drivers with real-time information about how long it will take to reach a given destination. Many jurisdictions within the United States collect information on freeways and that information is generally provided to travelers via DMS along freeways. In contrast, cases where the information is collected and displayed on non-freeway roads such as rural highways are relatively rare. Figure 1 shows examples of typical practice.

Travel time is also a key piece of information for transportation agencies. Real-time travel time information can allow agencies to monitor roadway performance, identify problems, develop forecasts, plan future projects, and evaluate the effects of new projects. Travel time data can also help to meet goals for integrated corridor management or meet Federal information provision mandates such as the Real-Time System Management Information Program, which was included in Section 1201 of the *Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)*.

Current use of travel times for rural highways is still limited. However, interest is high and examples of successful implementations are becoming increasingly common. Researchers are investigating a variety of data collection methods that can be applied to rural highway settings, such as the use of Bluetooth technology (e.g., Click and Lloyd, 2012; Puckett & Vickich, 2010), toll tag readers

Figure 1

RTT Signs in Washington State and Minnesota

Source: wsdotblog.blogspot.com

Source: Jackels, 2012

(e.g., Wright and Dahlgren, 2001), automatic license plate readers (e.g., Eberline, 2008), in-pavement magnetic detection (e.g., Klein, Mills, & Gibson, 2006), machine vision, radar/microwave/LIDAR, crowdsourcing (e.g., INRIX, 2012), connected vehicle, cell phone signal monitoring (e.g., Avni, 2007), and inductive loop detectors (e.g., Jeng, 2010). As this list demonstrates, there is a litany of data collection technologies which have been used for rural highway travel times, but each has its own advantages and disadvantages. At this point there is no comprehensive guidance on data collection technologies and procedures.

There are numerous reviews and syntheses of travel time data collection in general. But, travel time data collection and dissemination for rural highways has unique challenges for the practitioner.

For example:

- Travel times are not collected in isolation, and often their uses are determined by the goals and communication needs at a location; these goals and communication needs can be quite different for rural versus urban roadways, and often vary among individual rural roads.
- Rural roadways can vary greatly in their location and use: some may be remote and carry low traffic volumes, while others may be major interurban thoroughfares.
- Low traffice volumes may create challenges in acquiring sufficient data to be able to generate accurate and timely travel time estimates.
- The focus is on not only identifying and dealing with congestion, but also tracking the occurrence of major incidents and the need to provide alternate route information in the event of road closure.
- Rural highways can be hilly, rocky, curvy and mostly unsuitable for deployment of reliable ITS equipment or even cell phone reception in some cases.
- There can be a lack of necessary technological backbone to support data collection and information sharing. In Missouri, for example, a fiber backbone doesn't exist in many of the rural localities, which forces transportation engineers to resort to less reliable means of data transfer.
- Some rural roads do have parallel alternate routes, so it may be necessary to communicate issues to drivers 60 miles or more away.
- The TMC Pooled Fund Study has recognized the need to determine if technologies are being developed to obtain data necessary for calculating travel times that address specific challenges. State and local agencies face the challenge of providing real-time travel time to motorists—which entails obtaining information on arterials—in a manner that allows drivers to take full advantage of it.

To further hone the opportunity of providing useful and accurate travel time information in rural highway locations, it is important to ask the following questions:

1. What insights and experiences have agencies developed with these technologies, and what are the best uses of these technologies?
2. Given challenges faced in calculating and providing travel time information on rural highways, how feasible is deploying such technology?

The purpose of this project and the resulting report was to identify, review, and synthesize information on current and potential future efforts in real-time travel time on rural highways. There were four main objectives: a) identifying, reviewing, and synthesizing available and emerging technology (both nationally and internationally) for obtaining data necessary for calculating travel times on rural highways, b) collecting and summarizing agencies' experiences with using such technology, c) providing guidance to agencies for making the best use of available and emerging technologies to meet future needs, and d) determining the feasibility of deploying such technologies.

The first objective (reviewing) is dealt with while being mindful of the ever-changing nature of recent technological advances. Unlike synthesis reports in non-technological domains that focus on research publications, many of the sources for this report were from vendors, State agencies, and practitioners who are the most up-to-date on the rapidly changing technological developments and implementation approaches.

The second objective (experiences) is addressed by incorporating lessons learned and advice (including from unsuccessful projects) from agencies' experiences using a given technological approach.

These lessons give extremely helpful insights that can be provided to the practitioner and allow the current synthesis to go beyond a simple summary of documents.

The third objective (guidance) is based on a synthesis of the first two, taking information gained from reviewing technologies and merging it with real-world experiences of practitioners. This led to the development of lists of considerations in the form of questions (and high level guidance in response) that a practitioner should use when going through the phases of assessing, planning, selecting, acquiring, implementing, managing, and evaluating a rural highway travel time system.

The final objective (feasibility assessment) was not a formal financial feasibility analysis. Instead, feasibility is taken in a broader context and refers to environmental constraints that a practitioner should take into consideration when weighing what type of system to implement. Financial information is given where available, but only in the context of background information to use when evaluating the entire practicality of an implementation approach.

The primary audience for this report is transportation agencies who are either interested in implementing a rural highway travel time data collection system, or considering making changes to an existing system. It is important to obtain, synthesize, and distribute information now so that objectively based recommendations can be provided to practitioners as they design and implement such systems.

It should be noted that the current report focuses on rural highway travel time data technology considerations and is not a primer for general travel time best practices. A good source of general travel time guidelines can be found in Turner, Eisele, Benz, & Douglas (1998). This report also focuses on travel time data collection methods that use vehicle speeds or link travel times as data sources. Efforts to estimate travel times using other data sources (e.g., traffic volumes) such as the Minnesota Arterial Travel Time Project (Athey Creek Consultants, 2009) are not addressed. In addition, there is a separate report from this project that focuses on travel time data collection technology used for arterial highways (Singer, Robinson, Krueger, Atkinson, & Myers, 2013).

1.2 Methodology

The information search for this project involved two main components: the review of data collection technology and the review of practice. The search effort began with an organized set of keyword searches. Five search categories were created to encompass the key project dimensions. Using these categories, a list of search terms was compiled within each category (see Table 2). As an example, the search terms "Bluetooth" and "GPS" were both placed in the Specific Technologies category. The table below shows the initial set of search terms used within each category. Additional search terms were added for follow-up searches. Note that an asterisk represents a "wildcard" character.

The keyword search effort revealed relatively little information on RTT implementations and evaluations. The search effort then expanded to include targeted searches to explore the state of the art technologies and practices used for RTT. This search revealed a rapidly expanding world of data collection technologies and practices.

Finally, contacts with experts and implementers were made to gain a clearer understanding of current and emerging practice and acquire additional details and direct experience reports. Two general approaches were used: 1) contacts with heads of committees and professional organizations, and 2) contacts made directly with travel time system implementers to learn about relevant implementation details. Individuals and organizations were selected for contact based on knowledge gaps that they were expected to be able to fill and their involvement in travel time programs of interest. Contacts with implementers provided a basis for implementation summaries and case studies with emphasis on explaining project logistics, decision making processes, and lessons learned. Organizational contacts provided little new information about current practice; many implementations of RTT have not been widely publicized and do not appear to be widely known among transportation engineers.

Table 2 Table of Search Terms and Categories

Core Concept	Data and Technology	Location	Specific Technologies	Supplementary
Travel time	data/data collection	en-route	RFID	network
Journey time	monitor*	rural highway	Connected Vehicle	guidelines
Traveler information	real-time	remote	Video/camera	best practices
	calculat*	stand-alone	satellite	operations
	estimat*	intercity	license plate reader	implement(ation)
	technology		Bluetooth	traffic
	infrastructure		GPS	integrated corridor management
	communicat*		cellular/cell phone	accuracy
	instrument(ation)		in-pavement/loop detect*	cost
	hardware		radar	
	intelligent transportation system (its)		LIDAR	
	software		anonymous wireless address matching/ AWAM	
	install			
	collect			
	wireless			

* Indicates wildcard character

1.3 Organization of Synthesis Report

The following chapters of this report are organized around three main topics of interest to practitioners:

Chapter 2 discusses available and emerging RTT data sources as well as implementation considerations, advantages, and limitations of each.

Chapter 3 provides two detailed case studies and additional brief summaries of select practice in RTT data collection. These summaries reflect a broad range of implementation objectives, strategies, technologies, and constraints.

Chapter 4 brings together what we know about data sources, technologies, and current implementations to develop a set of best practices that are based on scientific evaluation (where available) and real-world experiences. Rather than prescriptive guidance, this chapter emphasizes identifying options and practices that can be adapted to the needs of a particular situation. It is framed around questions that a practitioner can ask as he or she goes through the stages of developing and implementing an RTT data collection system.

2 Data Source Summaries

A variety of technologies and data sources can be used as the basis for travel time calculations.

These include:

- Bluetooth detection
- Toll tag reader
- In-pavement magnetic detectors
- Automatic license plate reader (ALPR)
- Machine vision
- Connected vehicle
- Loop detectors
- Radar, microwave, LIDAR (RML)
- Crowdsourcing
- Cell phone signal monitoring

Some of these technologies are mature and widely used, while others have emerged recently or are still in the early stages of development. While the set of technology options is largely the same for urban freeways, arterials, and rural roads, not all technologies are equally suited to all road types, environments, and topographies. This review of technologies is focused on the implementation considerations for rural highways. In addition to documenting information about the technologies themselves, the review effort addresses the integration of these technologies with existing systems and infrastructure.

This chapter summarizes technologies that can be used to capture RTT data. The summaries emphasize the tangible aspects of the data sources (e.g., hardware and installation requirements, implementation considerations, costs), but also address capabilities and disadvantages of each technology, potential privacy concerns, and other less tangible issues. Table 3 briefly summarizes candidate technologies, and then each technology is discussed further in its own subsection.

Data transmission and processing are important aspects of RTT implementations, but are not addressed in detail in this section because they are largely independent of data source. Similarly, although data sources are described individually in this section, an important trend in travel time monitoring is data integration, or "data fusion," which allows agencies to harness data from multiple sources to improve the quality, reliability, and comprehensiveness of information. Data transmission, processing, and use are discussed further in Chapter 4.

2.1 Bluetooth Detection

At a Glance

- Wireless technology that allows electronic devices to communicate directly with one another
- Recently emerged as viable travel time collection technology
- Open standard, allows for off-the-shelf equipment
- Detection range limited to about 328 feet (100 meters)
- Less expensive than many other options
- Flexible installation
- Some potential privacy concerns
- Detection technology relies on drivers' use of Bluetooth-enabled devices

How It Works

Bluetooth is a non-proprietary wireless technology standard that allows electronic devices to communicate directly with one another over relatively short distances using radio frequency communication. Since its development in the 1990s, Bluetooth has become a ubiquitous feature on a variety of electronic devices, including mobile phones, computers, hands-free headsets, and even vehicles themselves. Bluetooth detection systems work by actively searching for in-range Bluetooth devices and capturing the unique media access control (MAC) address of each device. For a Bluetooth detection system to read the MAC address of a device, the device must be turned on and be in "discoverable" mode (i.e., broadcasting its MAC address). Because each device has a unique and permanent MAC address, Bluetooth detection systems can determine vehicle travel times and speeds by calculating the time it takes for vehicles containing Bluetooth devices

Table 3 Candidate RTT Technologies

Technology	Spot Speed	Segment Travel Time	Real-time Tracking	Sensor Location	Coverage Per Sensor	% Vehicles Detected/ Matched†	Implementation Cost†	Non-traffic-info Functions†	Traffic Volumes	Vehicle Class
Bluetooth detection		X		Roadside/ above road	All lanes	Low	Low	Low		
Toll tag reader		X		Roadside/ above road	One or more lanes**	Low	Med	Med		
In-pavement magnetic detectors		X		In pavement	One lane	High	Med	Low	X	X
Automatic license plate reader (ALPR)		X		Roadside/ above road	One or more lanes**	Med	Med	Med	X	X
Machine vision	X	X*		Roadside/ above road	One or more lanes**	High	Med	High	X	X
Connected vehicle	X	X*		Roadside/ above road & in vehicle	All lanes	???	Low	High		
Radar, microwave, LIDAR	X			Roadside/ above road	One or more lanes**	High	Med	Med	X	
Inductive loops	X	X*		In pavement	One lane	High	Low	Low	X	X*
Crowdsourcing			X	None	All lanes	???	Low	Low		
Cell phone signal monitoring		X		None	All lanes	???	Low	Low		

* Possible depending upon capabilities of technology
** Multiple lanes possible depending upon capabilities of technology and sensor placement
† Can vary substantially depending on a variety of factors; estimates are approximate based on user experience
‡ Other functions can include tolling, traffic law enforcement, unregistered vehicle detection, cooperative safety, etc.
??? Unknown/no basis for assessment

to travel between two or more Bluetooth sensors that are a known distance apart.

State of the Technology

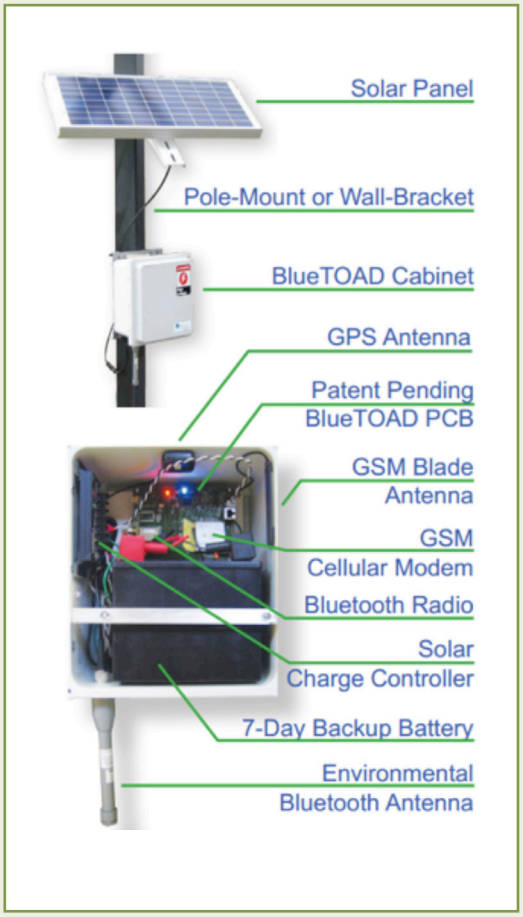
Although the Bluetooth standard is nearly 20 years old, Bluetooth detection for travel time data collection has only emerged as a viable option in recent years, largely due to the rapid growth in the adoption of Bluetooth-enabled devices. Despite its relatively recent emergence, Bluetooth detection is a commonly used technology for calculating travel times.

Hardware and Installation

Bluetooth detection offers a wide range of hardware and installation options. Because Bluetooth is an open standard, it is possible to assemble detector systems using off-the-shelf components, though complete systems can also be purchased or leased from vendors. An example of a solar-powered, pole-mounted detector is shown in Figure 2. Detector units can be placed in any location near the roadway as long as there are no major line-of-sight obstructions. Reliable detection distance can reach up to 328 feet (100 meters), allowing for flexibility in placement that may be particularly beneficial on rural roads with challenging topographies. An evaluation by Click and Lloyd (2012) found that Bluetooth detectors placed in the center of a wide rural median do not detect vehicles as effectively as when they are placed on the roadside, so for wide rural roads, two roadside detectors may be more effective than one median detector. Units can be pole-mounted, fastened to existing infrastructure, installed in a signal cabinet, or, if powered by battery, briefcase-size units can be placed in any desired location (preferably chained to a fixed object for security). However, detection rates are likely to be higher when sensors are elevated rather than placed on the ground (Puckett & Vickich, 2010). Fixed units can be powered by existing power infrastructure or solar panels, and battery-powered units can typically operate between two to three weeks on a single charge. The relatively low power consumption of Bluetooth detectors is a particular benefit when infrastructure power is unavailable. Units can work with existing communications infrastructure or record to local hard drives. When given protection from precipitation and extreme temperatures, device maintenance requirements and failure rates can be very low.

Figure 2

TrafficCast's BlueTOAD Pole-mounted, Solar-powered Bluetooth Detector and Cabinet Interior



Source: trafficcast.com

Implementation Considerations

The flexibility of Bluetooth detection makes it a viable option for a variety of implementation types, including fixed, temporary, and portable (e.g., work zone, see Haseman, Wasson, & Bullock (2010). Bluetooth detection sensors detect any "discoverable" Bluetooth-enabled devices within a radius of about 100 meters, if using a high-powered antenna. Measuring the travel time of an individual vehicle along a road segment is as simple as comparing the

time when the vehicle is detected at the beginning of the segment to the time when the vehicle is detected at the end of the segment. Dividing the length of the segment by the vehicle's travel time yields an average speed for the segment. Additional data can be acquired by observing the duration that a vehicle is within the detection zone of a single Bluetooth sensor (e.g., a long dwell duration on a rural road could indicate stopped or very slow moving traffic) (Tsubota, Bhaskar, Chung, & Billot, 2011). Some Bluetooth detection devices include global positioning systems (GPS), which allow each device to be precisely located and provides an automatic time synchronization between devices, ensuring accurate travel time calculations.

As with other travel time data collection technologies, accurate travel time estimates depend not only on accurate data collection, but also on sufficient detection rates over time as well as the use of algorithms capable of discarding outlier data. These issues are addressed in detail in Section 4.2.

Another potential limitation of some versions of Bluetooth detection is the system's "inquiry time." The system initially deployed in Houston, TX, only reported detected vehicles within a 10-second inquiry window, and therefore all vehicles detected within this window will report the same detection time. This inaccuracy could lead to travel time inaccuracies, especially over short segment lengths. Furthermore, only a maximum of eight detections could be reported within each inquiry window. This has implications for the potential to match vehicles at multiple detector locations during heavy traffic periods (Puckett & Vickich, 2010), though this might not be an issue on many lower-volume rural roads. Newer generations of Bluetooth detection systems, however, are capable of asynchronous input/output, which allows data to be output as soon as it is read.

While proper placement should ensure the detection of discoverable devices on the intended roadways, it is possible that the non-directional sensors will also detect devices on nearby roadways, parking lots, and other surrounding areas. While data processing algorithms can identify and remove many of the "noise" detections from the dataset, it is best to place Bluetooth detectors where unintended detections will be minimized. Unintended detections can also be reduced by using a lower powered antenna, but care must be taken to ensure that intended detections are not reduced as well.

Costs

Bluetooth detection systems are significantly less expensive than most alternative sensor-based travel time detection technologies. Bluetooth detectors themselves are inexpensive and the complementary hardware (e.g., modem) is also inexpensive. Prices per location vary depending upon the type of installation. For instance, installation in an existing traffic signal cabinet is likely to be substantially cheaper than a solar-powered stand-alone implementation. Depending upon the hardware and installation requirements, Bluetooth detection systems may cost as little as $1,000 to $8,000 per location when purchased from a vendor. Given the relative newness of Bluetooth technology for traffic detection, limited information exists on life span and maintenance costs, though experience in Chandler, AZ suggests that the devices can function for a period of years without maintenance or adjustment.

Privacy Issues

Bluetooth detection systems work by reading the MAC addresses of in-range Bluetooth-enabled devices. A MAC address is a unique and permanent identifier linked to a single device. MAC addresses are not linked to device sales records, so there is no direct way to match a MAC address with an individual owner or user. This affords device users a layer of privacy. However, there are indirect methods that could hypothetically be used to match MAC addresses to individuals. For instance, if an electronic device were seized by police as evidence, the MAC address could be determined and matched against Bluetooth detection records.

Similarly, users who download and use certain mobile device apps may make personal information, including their MAC addresses, known to the apps' publishers, who could then potentially mine, share, or sell this information. While these cases are hypothetical, implementers should consider the issues they raise, and the additional steps that can be taken to further safeguard the public's privacy. These measures include truncating the MAC address so that only a portion of the address is used to make the match (e.g., using only four of the address' twelve digits), randomly reassigning a different unique identifier, and/or deleting or randomizing MAC addresses after their immediate use is complete. Strong data encryption should also be used as an added layer of security against unauthorized access.

Future Considerations

The future viability of Bluetooth detection systems is dependent upon the continued prevalence of Bluetooth-enabled devices. Although there are currently no technologies on the horizon that appear to be in a position to replace Bluetooth, the generational life span of mobile technologies is often short, and if a new technology does emerge to replace or obviate Bluetooth detection, the market penetration of Bluetooth may decline very quickly. If this does occur, existing Bluetooth detection systems will either need to be replaced or retrofitted for compatibility with the new technology, if compatible. For example, WiFi could eventually become a dominant in-vehicle technology and Bluetooth detectors could be replaced or retrofitted to detect WiFi devices rather than, or in addition to, Bluetooth devices. Nonetheless, Bluetooth appears poised to remain dominant for the foreseeable future. Furthermore, an increasing number of vehicle models are manufactured with built-in Bluetooth devices. The average life span of a vehicle is significantly longer than the average life span of a portable electronic device, so it is possible that the existence of a fleet of Bluetooth-enabled vehicles will extend the viability of Bluetooth detection even longer into the future.

2.2 Toll Tag Reader

At a Glance

- Detects radio frequency ID of automated toll tags
- Mature technology
- Accuracy can decrease with distance, but also has directional advantage
- Limited to areas with adequate toll tag fleet penetration
- Some privacy issues, so extra measures are warranted
- Electronic tolling is becoming more common

How It Works

Toll tag readers, also known as automatic vehicle identification (AVI) systems, detect the unique radio frequency IDs (RFID) of motorists' automated toll tags (e.g., E-ZPass) at multiple locations and calculate travel times based on the arrival time at each location. A vehicle must have a toll tag to be counted, so the technology is only feasible where a sufficient percentage of vehicles have toll tags. Alternative RFID device could also be used as an identifier, but no viable plan exists to use such a system.

Figure 3

Toll Tag Reader (AVI) in Houston, TX

Source: ops.fhwa.dot.gov/publications/travel_time_study/houston/houston_ttm.htm

State of the Technology

Toll tag readers are a mature technology. They have been used at toll facilities for more than 25 years and have been used to provide real-time travel time data by Florida Department of Transportation (DOT) and Houston TranStar.

Hardware and Installation

Toll tag readers can be inconspicuously placed directly above the roadway or on the roadside. Figure 3 shows an example of a toll tag reader fastened to a cantilever. Readers are most accurate when located close to passing vehicles and when aimed directly at a single travel lane. Detection accuracy can decrease when placed farther from the road, when aimed at multiple travel lanes, and when there are physical obstructions between the sensor and the vehicle (Haas et al., 2009).

Implementation Considerations

Toll tag readers are only feasible for collecting travel time data on routes where a sufficient percentage of vehicles have toll tags. This may be a particular concern in rural areas where few tolling facilities exist. As noted above, toll tag readers must be appropriately positioned to achieve high detection rates. To achieve the highest detection rates, multiple readers may be required to cover all lanes of a multi-lane road. However, a single reader may be sufficient at each location if traffic volumes of detectable vehicles and match rates are high enough to generate accurate travel times. Another implementation consideration for toll tag readers is the potential for reader failure. A major toll tag reader deployment undertaken in the iFlorida Model Deployment experienced a device failure rate of about 50 percent during the course of the evaluation. At any given time, about 10 to 20 percent of toll tag readers were not functioning properly (Haas et al., 2009). Although device failure is highly dependent upon many implementation factors, the potential for failure should be considered. Best practices for minimizing and responding to device failure are presented in Section 4.3.

Costs

Costs of toll tag reader implementations can vary significantly depending upon implementation factors such as number of readers per location, distance between reader sites, and mounting location.

According to Cambridge Systematics (2012), the cost per installed reader is about $15,000. According to Hardigree (2011), a multi-lane implementation of toll tag readers can cost $75,000 or more per location. Voigt (2011) estimates that toll tag readers can cost $75,000 to $125,000 per arterial site, excluding the cost of communications. According to Wright and Dahlgren (2000), "Capital costs per reader site where such systems have been implemented range from $18,000 -$38,000 [for a six-lane roadway] and for the operations center from $37,000 to $86,000. Annual operating costs range from $4,000 to $6,000 per detector site and $48,000 to $96,000 for the operations center."

Privacy Issues

Toll tag readers read the unique IDs of each toll tag. Although toll tag IDs do not directly identify individuals, the ID can easily be used to identify the tag owner by matching the ID against the tolling authority's database of owners. As with Bluetooth detection, motorist privacy can be enhanced by truncating or transforming the toll tag IDs before the data are transmitted to the transportation agency.

Future Considerations

Toll tag reading is a mature technology that is likely to remain viable for the foreseeable future. Electronic tolling is increasingly common, though vehicle fleet penetration may not be sufficient in many rural areas. Although the emerging connected vehicle technology (see Section 2.6) uses a very similar detection technology, its privacy restrictions may make connected vehicle technology an unsuitable replacement for segment travel time data collection.

2.3 In-Pavement Magnetic Detectors

At a Glance

- Arrays of magnetometers are installed in pavement at detection locations
- Can identify and match vehicles based on each vehicle's unique magnetic signature
- Quick installation involves drilling; devices self-calibrate

- Wireless sensors require access points and repeaters
- Close to 100 percent detection rate
- Relatively high initial cost, but typically low ongoing costs
- High degree of motorist privacy

How It Works

Arrays of magnetometers are installed in pavement at detection locations. The magnetometers can identify and match vehicles at multiple locations based on each vehicle's unique magnetic signature as it interacts with Earth's magnetic field. Additional information on magnetometers can be found in the Federal Highway Administration (FHWA) *Traffic Detector Handbook* (Klein, Mills, & Gibson, 2006; also see Cheung, Coleri, Dundar, Ganesh, Tan, & Varaiya, 2005).

State of the Technology

In-pavement magnetic detection has existed for decades, and has been used to collect travel time data via vehicle re-identification for about 10 years. It has been used in various locations for vehicle counts and classifications, traffic signal actuation, and travel time calculation. Agencies using magnetic detectors to provide real-time travel time data include Missouri DOT and Utah DOT. The only commercially available magnetic detector capable of real-time data transmission identified in this review is marketed by Sensys Networks, so this technology review focuses on the capabilities of the Sensys sensor.

Hardware and Installation

Each magnetic detector is slightly larger than a hockey puck (see Figure 4). Detectors are installed in pavement by drilling a core, inserting the detector in the proper orientation, and filling the hole with epoxy. Each detector can be installed in 15 minutes and requires no calibration. To be capable of matching vehicles at multiple locations to generate travel time data, an array of five sensors is needed in each monitored lane (Greg Owens, personal communication, October, 2012). Unlike traditional loop detectors, magnetic detectors can function wirelessly and can have a battery life of up to 10 years. Relative to wired inductive loops, magnetic detectors are easier to install and less prone to failure. Detectors require an access point to be installed within about 150 feet to establish a communication link. Additional repeaters may be used to extend wireless connection range. Figure 5 shows a typical installation configuration.

Figure 4

Sensys Sensor

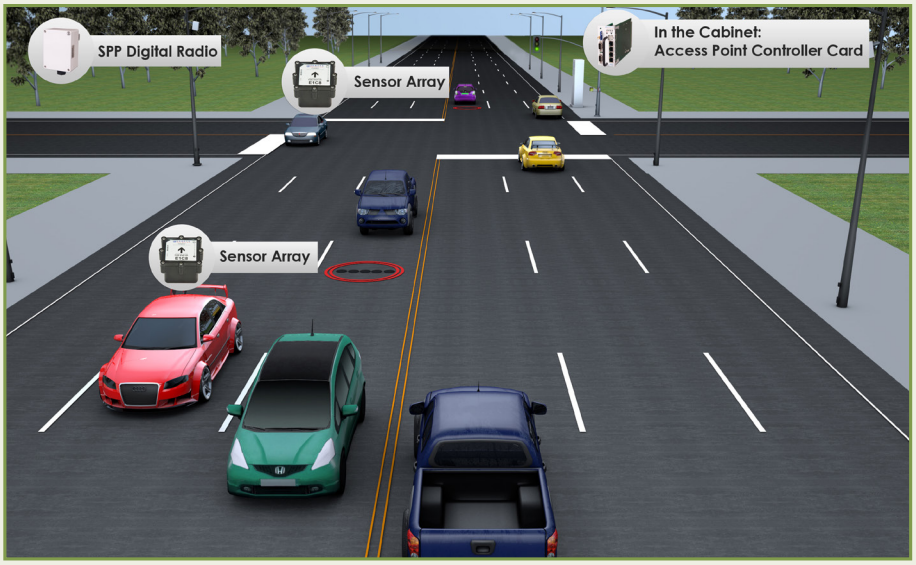
Source: www.sensysnetworks.com

Implementation Considerations

An advantage of magnetic detectors over some other probe vehicle technologies is that the detection rate for vehicles passing over the monitored lane approaches 100 percent (though missed detections and double-detections are possible), providing transportation agencies with data that can be used for various purposes. The high detection rate may be especially valuable for maintaining the ability to generate accurate travel time estimates on rural roads with relatively low traffic volumes. A comparison to ground truth video data conducted by Sensys showed that in-pavement magnetometers achieved a 70 percent match rate (Volling, n.d.). The high detection and match rates may be particularly advantageous on low volume roads. If traffic volumes are sufficient, cost savings can be achieved by only installing sensors in one travel lane. Sensys generally recommends installing sensors in only the left through lane of a road because this lane carries the most through traffic and is least affected by vehicles entering and exiting the roadway. Due to the invasive nature of the installation, in-pavement

Figure 5

Typical Sensys implementation showing sensor array, repeater, and access point



Source: www.sensysnetworks.com

magnetometers are not likely to be practical for short-term deployments.

Additional data such as vehicle class data can also be derived from this technology, though additional sensors may be required in an array. Research by Medina, Hajbabaie, and Benekohal (2010) cautions that magnetic detectors may overcount vehicles at or near signalized intersections by 16 to 22 percent, largely due to detections of vehicles in adjacent lanes or vehicles positioned between lanes. Day, Premachandra, Brennan, Sturdevant, and Bullock (2009) also found that magnetic detectors may miss detections of motorcycles if the motorcycle does not pass directly over the detector. Although installed in pavement, Sensys sensors can perform diagnostic checks and software upgrades remotely. Devices can be removed from pavement and reused.

Costs

Costs for in-pavement magnetic detectors depend upon a number of factors, including number of sensors per array and the number of arrays per location (i.e., number of lanes monitored). Costs may also vary depending upon other services provided by the technology vendor. Although in-pavement magnetic detection is likely to cost significantly more than Bluetooth detection, the devices are expected to require little to no maintenance during their reported 10 year battery life. However, road work may require the devices to be removed before the end of their battery life.

Privacy Issues

Because magnetic detectors rely on a vehicle's magnetic signature, which can change depending upon vehicle occupancy and other factors, they offer a very high degree of inherent motorist privacy. An anonymous identifier is assigned to a vehicle that allows it to be re-identified at a downstream location.

Future Considerations

There are no emerging trends that are expected to influence the use of in-pavement magnetic detection. It is a viable solution for RTT data collection, as long as communications are available, and is expected to remain so.

2.4 Automatic License Plate Readers (ALPR)

At a Glance

- Optical cameras capture images of license plates and software "reads" the information
- Mature technology (over 30 years)
- Installed above the roadway and require direct line-of-sight
- Particularly sensitive to factors that reduce visibility
- Potential privacy issues are a concern

How It Works

Optical cameras capture images of license plates of oncoming or receding traffic and use video image processing to "read" the license plates. License plate numbers can then be matched at sensor locations downstream to generate travel times. Camera images can be stored, though this is not required for travel time data generation. While ALPR is often implemented as a stand-alone function, it can also be considered as one potential function of a machine vision system (see Section 2.5). One advantage of ALPR is that nearly all vehicles have a license plate that can potentially be observed.

State of the Technology

ALPR is a relatively mature technology that has been used for more than 30 years, though technology has improved and become substantially less expensive since the earliest implementations. ALPR has been used for tolling, law enforcement (e.g., detection of unregistered/stolen/warranted vehicles, automated speed enforcement), and real-time travel time.

Hardware and Installation

ALPR uses cameras that operate in the visible light spectrum. Cameras require direct line of sight to license plates, so they must be installed above the roadway or on the roadside in locations that minimize visual obstructions (e.g., from surrounding traffic) and avoid off-axis angles that could reduce recognition accuracy. To trigger image capture, cameras can use video image processing to detect vehicle presence in the frame, or a separate presence-detection technology can be used (e.g., inductive loop). At night, cameras may need additional visible or infrared illumination for adequate license plate recognition. Figure 6 shows an ALPR camera and illuminator used in Arizona. Current systems most often use one camera per lane for license plate recognition.

Implementation Considerations

ALPR can be used for a variety of purposes individually or simultaneously. For instance, it can theoretically be used to detect unregistered vehicles (i.e., cross-reference license plate readings against vehicle registration database), conduct average speed enforcement (i.e., detect an individual vehicle's excessive speed over a road segment), serve as a closed-circuit television (CCTV) feed, and serve as a travel time data source all at the same time. Because it relies on a clear view of license plates, however, ALPR is particularly sensitive to any factors that reduce visibility, such as precipitation, lens fog, line-of-sight obstructions, low ambient light, off-axis viewing, and license plates that are dirty, obstructed, missing, or have low character contrast. In a work zone implementation on a two-lane rural highway in Arizona, ALPR achieved a 60 percent recognition rate and a segment license plate matching rate of 11 percent, which was considered sufficient for this implementation (FHWA, 2004). Not all States require vehicles to have a front license plate, so ALPR may have the highest recognition rates using rear plates. Depending on how the system is implemented, data bandwidth may be especially high for ALPR (e.g., if video or camera images are transmitted).

Costs

The FHWA Knowledge Resources database provides some cost examples for ALPR. Eberline (2008) provides cost estimates for an ALPR system used on freeways in Arizona to detect unregistered and uninsured vehicles. He estimates that the cameras cost $20,000 each with an approximate installation and supporting hardware cost of $4,000 per camera. Given that one camera is required for each monitored lane of traffic, actual costs will be higher if multi-lane coverage is needed. The Texas Transportation Institute estimated that ALPR would cost $25,000 for a four-lane installation, where each lane has its own sensor (ITS International, 2010).

Figure 6

ALPR Illumination Foreground) and Camera (Background) Used in a Work Zone on Arizona State Route 68

Source: FHWA, 2004

Privacy Issues

ALPR records license plate numbers, and potentially camera images or video of vehicles, which can be used to identify vehicle owners by cross-referencing motor vehicle records. Depending on the implementation, drivers may be identified by video or camera images. The American Civil Liberties Union has expressed concerns over the potential for ALPR to be used to track individuals without a warrant and has sued Federal agencies for access to their records on license plate tracking (Crockford, 2012). Agencies can minimize privacy concerns by limiting their access to personally identifiable information and adhering to clearly stated policies for what can and cannot be done with ALPR data. For instance, ALPR systems can be designed to prevent operator access to license plate numbers or images by deleting records immediately after use and providing only randomly reassigned identifiers to agencies for record keeping purposes.

Future Considerations

ALPR is a relatively mature technology with a broad set of potential uses. Improvements in digital camera and image processing technology are likely to lead to continued enhancements of these systems as well as reduced costs. Perhaps the greatest potential limitation of ALPR in the future relates to privacy issues, as discussed above.

2.5 Machine Vision

At a Glance

- Use of video cameras to monitor flow
- Installed above the roadway or on poles on the roadside
- Data bandwidth is a consideration
- Highly customizable set of features
- Privacy can potentially be a concern for high-resolution systems
- Potential uses are likely to expand with advances in technology, processing power, and data transmission capabilities; costs are also likely to decrease with expanded usage

How It Works

In machine vision, also known as video image processing, video cameras monitor traffic flow in the visible light spectrum. Software is used to set up detection zones within the video field that can identify vehicle presence, lane occupancy, speed, and vehicle class. Speeds can be measured using "virtual loops" that may be up to several hundred feet in length, depending upon camera location. The length of virtual loops may provide a more useful speed measure than instantaneous spot speed, especially if the site is prone to congestion or intersection control fluctuations in traffic speed. More advanced machine vision systems have the potential to provide segment travel times by matching vehicles at multiple roadway locations (e.g., using ALPR). Additional information on machine vision can be found in the FHWA *Traffic Detector Handbook* (Klein, Mills, & Gibson, 2006).

State of the Technology

Machine vision has been in use for many years for a wide variety of traffic management purposes. Advances in hardware and software capabilities have improved the functionality and reliability of systems.

Hardware and Installation

Video cameras can be installed above the roadway or pole-mounted on the roadside. Depending upon site configuration and camera location, a single camera may be sufficient to monitor traffic in both directions or in several lanes of a multi-lane road. A variety of camera configurations are possible, however, including multiple relatively low-resolution cameras in place of a single, high-resolution camera. Another consideration for machine vision systems is data bandwidth: sufficient bandwidth is required to transmit images. Bandwidth requirements can be influenced by whether the processing is done within the camera, at an on-site processor (e.g., in a traffic signal cabinet), or remotely (e.g., at a TMC). Cameras should be placed to avoid any direct exposure to sun glare. The accuracy of machine vision systems can also be affected by shadows and lighting variations. Exterior visible or infrared lighting may be required for nighttime functionality. Setup requires users to establish virtual loops or other image-based triggers within the video image that are activated when a vehicle passes through them. A variety of activation zones can be setup and customized to the particular implementation.

Implementation Considerations

Video image detection offers a highly customizable set of features that can be used for a variety of traffic management purposes, including direct video monitoring. Hardware and software should be selected carefully to ensure that needed capabilities are present.

Costs

Costs reported in the FHWA Knowledge Resources database vary, but unit prices were most often reported to be between $16,000 and $18,000, and life span was expected to be about 8-10 years. Systems are likely to become cheaper and/or more powerful as the technology improves.

Privacy Issues

Machine vision systems can be used for many purposes. At the most basic level, they observe traffic similarly to CCTV cameras and capture no personally identifiable information, so there are no notable privacy issues. However, it is possible that high-resolution systems could be used to capture personally identifiable information (e.g., automated enforcement and license plate recognition), and these uses could raise privacy concerns, especially as the increasing capabilities of machine vision systems make such uses more feasible.

Future Considerations

As cameras, software, data transmission, and processors grow more capable and inexpensive, the potential uses of machine vision systems are likely to

expand. For instance, increased image resolution can make machine vision systems operate more precisely and make feasible other uses including enforcement of a variety of traffic laws, ALPR, and security (e.g., trespass detection). While current systems generally process data at the camera, recent developments in cloud computing and WiFi data transmission could offer increased image processing power with less investment in onsite systems.

2.6 Connected Vehicle

At a Glance

- Short range radio communications vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I)
- Technology in very early stages of development
- Radio transceiver installed in host device within a vehicle
- Privacy protocols being established
- Very inexpensive cost on per-unit basis
- Usefulness for travel time calculations uncertain; depends on implementation factors
- Potential for widespread use if initiative continues to develops

How It Works

The U.S. DOT's connected vehicles initiative is designed to provide communications between vehicles, and between vehicles and infrastructure, using dedicated short range communications (DSRC). DSRC is a communication standard allowing reliable, low-latency radio-frequency communications. Within the connected vehicle program, DSRC may be capable of data transmission over distances up to about 3280 feet (1 kilometer). DSRC is capable of two-way communication, allowing devices to both send and receive data. DSRC transceivers may be built into vehicles or portable devices such as smartphones.

In the United States, a section of DSRC bandwidth is reserved for use by ITS, including V2V and V2I applications applications. DSRC technologies and applications are currently in development. The U.S. DOT is pursuing a program of research and development that is focused on providing applications that enhance highway safety and mobility and reduce pollution, within a secure and reliable architecture.

In V2V communications, vehicles anonymously exchange information about their position, speed, and heading, allowing each vehicle to be "aware" of surrounding vehicles and potential threats. Currently envisioned V2V applications primarily involve cooperative safety features designed to warn drivers of potential collisions and conflicts. In V2I communications, vehicles and infrastructure (instrumented with DSRC transceivers) can communicate with one another. Infrastructure can communicate location-specific or general messages to vehicles, such as curve speed warning, road condition warning, weather information, incident/detour information, and so forth. Vehicles can indicate their presence to infrastructure, enabling features such as traffic signal actuation, automatic toll payment, and incident detection, as well as providing more general information such as traffic volumes and travel times.

State of the Technology

The U.S. DOT and a wide range of research partners are currently testing DSRC technologies and developing protocols. While the capabilities of the technology are relatively well understood, numerous key implementation decisions have not been made yet, so the ultimate capabilities of DSRC are not yet known. According to current estimates, some DSRC features are expected to become available to the public in or around 2017.

Hardware and Installation

At a minimum, DSRC requires a small radio frequency transceiver to be present in a host device (e.g., vehicle, smartphone, signal cabinet). For basic travel time data collection purposes, the vehicle-based transceiver only needs to send its current speed to an infrastructure transceiver.

Implementation Considerations

To protect driver privacy, current plans call for DSRC transceiver IDs to be randomly reassigned every 5 minutes (Ben McKeever, personal communication, January, 2013). Although this plan could be revised before rollout, this randomization scheme means that the ability to track individuals between multiple locations would be severely limited. To achieve a match using this method, a vehicle would have to pass two or more infrastructure transceivers during the 5-minute span in which a single random ID is active. Match rates would likely be very low unless

infrastructure transceivers are closely spaced. For example, if the average travel time between transceivers is 3 minutes, a match rate of about 40 percent could be expected, because about 60 percent of DSRC IDs would have expired in that span of time; this match rate is before accounting for other potential sources of data loss. If congestion increases average travel times, the match rate between stations could drop to zero. However, DSRC could theoretically provide a near-100 percent detection rate of instrumented vehicles if the system is designed to base calculations on vehicles' spot speed measurements instead of segment travel times. While travel time estimates using spot speed can be difficult to make, especially on roads prone to high speed variability, the relatively low cost and variety of other uses and benefits of DSRC might make this technology viable for RTT estimation, either alone or as a complement to other technologies.

Costs

Although commercial products containing DSRC are not yet available, the enabling technology is expected to be very inexpensive on a per-unit basis. Supplementary technologies such as GPS could add to unit costs, though in many products (e.g., smartphones and vehicles), GPS may already be built in.

Privacy Issues

Given the broad range of ITS features expected to make use of DSRC, security of DSRC communications is of critical importance. A substantial piece of the DSRC development effort has been dedicated to ensuring data security and privacy. Current implementation plans provide for driver anonymity by automatically randomizing the ID of DSRC transceivers every 5 minutes, though this approach has not been finalized (Ben McKeever, personal communication, January, 2013). In addition to providing anonymity, it would also prevent the tracking of vehicles/devices over time and space, which has implications for using these data for travel time calculations.

Future Considerations

Although there are many uncertainties regarding the details of implementation, DSRC has the potential to be used for travel time calculations. The feasibility of use, however, depends on a number of unknown implementation considerations.

2.7 Radar, Microwave, LIDAR (RML)

At a Glance

- An active sensor emits radio waves (radar), microwaves, or a laser beam (LIDAR), which reflects off of vehicles
- Mature and widely used technology
- Many products available with different features and implementation methods
- Use limited to spot speed measurement
- Complete privacy to drivers

How It Works

Radar, microwave, and LIDAR are unique technologies operate on the same principle: An active sensor emits radio waves (radar), microwaves, or a laser beam (LIDAR), which reflects off of vehicles. The frequency shift observed in the reflected energy or the return time of the reflection can be used to determine vehicle speed. Some products can also measure vehicle speeds when aimed perpendicular to the flow of traffic. Additional information on these technologies can be found in the FHWA *Traffic Detector Handbook* (Klein, Mills, & Gibson, 2006).

State of the Technology

RML are mature technologies that have been used to calculate vehicle speed for decades. Use of these technologies is most prevalent on limited access roads where speed variance along a road tends to be minimal.

Hardware and Installation

There are numerous RML products available, each with its own capabilities and requirements. Interested agencies can seek products that are best suited to their needs. To ensure accurate speed measurement, sensors must face oncoming or receding traffic, though in some cases, sensors can be aimed perpendicular to the travel flow). This can be achieved with overhead or sidefire sensors. Functionally, one of the primary differences between radar and LIDAR is their directionality. Radar emits energy in a wide cone that can monitor a broad roadway while LIDAR emits a narrow beam that can target a specific lane at long range.

Implementation Considerations

RML cannot be used to match vehicles at multiple locations, so their use is limited to spot speed

measurement, which can be relatively difficult to use on roads with varying speeds due to traffic control devices, speed limit changes, and topographical features. Measurement locations must be selected carefully to ensure applicability. The functional range of these technologies can be reduced during heavy precipitation.

Costs

Installation costs per radar site are estimated at $8,000 according to Cambridge Systematics (2012), but costs may vary depending upon type of installation. North Carolina DOT reports that microwave sensors cost approximately $48,600 per mile of roadway on a major freeway, based on the typical sensor spacing used.

Privacy Issues

RML measure spot speed without capturing any identifying information about a vehicle or driver. Therefore, these technologies provide complete privacy to drivers.

Future Considerations

While RML can be used to measure spot speeds for travel time calculations and may be effective on roads where travel speed variability is minimal, their use is likely to diminish as probe technologies that provide direct travel time estimates continue to become increasingly viable and affordable.

2.8 Inductive Loops

At a Glance

- Magnetic loops in pavement detect vehicle presence
- Mature and widely used technology, though often not ideally suited to travel time data collection
- Paired loops can measure spot speed; special processors can match vehicle signatures at multiple locations using single loops
- High detection rate
- Inexpensive, but invasive installation and maintenance can increase costs
- Complete privacy to drivers

How It Works

Inductive loops detect the magnetic presence of a vehicle. Loop detectors can be used to measure spot speed when installed in pairs a known distance apart. The time differential between presence detection at each loop can be used to calculate spot speed. With suitable processing hardware, single loop detectors can also be used to measure vehicle signatures for re-identification at a downstream location (e.g., Jeng, 2010; Ritchie, Park, Oh, Jeng, & Tok, 2005; Coifman & Cassidy, 2002; Zhang, Kwon, Wu, Sommers, & Habib, 1997). Additional information on inductive loops can be found in the FHWA *Traffic Detector Handbook* (Klein, Mills, & Gibson, 2006).

State of the Technology

Inductive loop detection is a mature technology that is ubiquitous on highways for a variety of detection purposes. Dual loops are commonly used to measure spot speeds. The use of single loops for vehicle signature detection is a relatively recent development that has been proven feasible by researchers, but has not been widely deployed. One processor card capable of vehicle re-identification (IST-222 from Inductive Signature Technologies, Inc.) no longer appears to be in production.

Hardware and Installation

Electrically conductive wire is installed in the roadway along with a lead-in cable to connect the loop to a processor. Typical processors measure vehicle presence and can be used to derive other variables such as vehicle speed and class. Special processors are required for vehicle signature detection and re-identification.

Implementation Considerations

Transportation agencies are generally quite familiar with the implementation considerations of inductive loop technology. To add vehicle re-identification capability may require an upgraded processor card, though current inductive loops are likely to be compatible with the new card. In fact, research by Blokpoel (2009) suggests that re-identification can be achieved at a rate of nearly 90 percent even when upstream and downstream loop detectors are different sizes.

Costs

The materials cost for loop detection is significantly lower than for most other travel time monitoring sensors, but the cost and inconvenience of invasive pavement installation can add significantly to lifecycle costs. To add vehicle re-identification capabilities to existing loops may require only an upgraded processor card, which is likely to be a relatively inexpensive way to add segment travel time capability to an existing loop detector deployment.

Privacy Issues

Loop detectors do not capture personally identifiable information, and therefore there are no privacy issues.

Future Considerations

Loop detectors have been ubiquitous as traffic detectors for decades due to their simplicity and low cost. They can be used in pairs to collect spot speed data. While there have been developmental efforts to use loop detectors to measure segment travel times, this review did not identify any current commercialized products or accounts of agency use. However, this remains an area of active research among companies including Berkeley Transportation Systems, Inc. and CLR Analytics, Inc., and it is possible that new systems will be introduced in the future.

2.9 Crowdsourcing

At a Glance

- Drivers' vehicles or mobile devices provide information to a public or private entity, and that information is used to generate traffic/travel time
- Early stage technology
- Critical mass of users are necessary for success
- Vehicle/motorist must have device capable of transmitting information; no roadway infrastructure needed
- Private sector currently dominates this market
- Privacy Issues largely within purview of private sector entities
- Use likely to increase as trackable devices and applications proliferate

How It Works

Drivers' vehicles or mobile devices provide information on their location, speed, and possibly additional information to a public or private entity, and that information is used to generate traffic/travel time information. The typical model for crowdsourced data involves location-aware (GPS or cellular network-based) devices running an application that automatically sends information to a central server using cellular transmission. One particular advantage of location-based crowdsourcing is that vehicles can be individually tracked in near real-time, allowing more precise and timely speed and travel time estimates than can be achieved by other data collection technologies.

State of the Technology

For travel time crowdsourcing to work, a "critical mass" of active data-providing devices is required to achieve sufficient roadway coverage to generate accurate travel time estimates. GPS crowdsourcing has only recently become a viable travel time data source because of the rapid growth of smartphones and similar devices that allow transmission of data on vehicle speed and position to servers where data can be analyzed, compiled, and used to provide travel time data. Currently, the only known examples of crowdsourcing that produce enough data to generate accurate travel time data for non-freeway routes come from private sector vendors. Crowdsourcing data providers include INRIX, Navteq, Google, TomTom, and Waze. As of October 2012, INRIX claims to have about 100 million data-providing devices in its network (INRIX, 2012). Some of these vendors merge crowdsourced data with data from other sources to generate travel times. ENTERPRISE provides a detailed report on the use of third-party travel data and information (ENTERPRISE, 2012).

Hardware and Installation

In the current implementation model of travel time crowdsourcing, transportation agencies simply purchase travel time data from a private sector provider. No sensors or other hardware are required, which may be particularly advantageous for rural areas where sensor instrumentations are deemed infeasible. While it is theoretically possible for a transportation agency to pursue its own crowdsourced data (e.g., by providing a downloadable data logging app to drivers), no examples of this approach were identified in this review. If this

approach were to be used by a transportation agency, crowdsourced data would likely need to be initially used in combination with other data sources.

Implementation Considerations

For crowdsourcing systems to function, at a minimum, vehicles must have a device capable of transmitting their position and speed to central servers in near real-time. Some mobile devices or GPS monitoring systems may inherently be capable of doing this, while others require users to install a specific app on their devices. Such apps are typically free or inexpensive, and may provide users with mapping, navigation, and real-time traffic information in return. Transportation agencies that wish to purchase travel time data from a provider must make arrangements with the company to determine what information will be provided and under what specifications (e.g., network coverage, timeliness, accuracy). Some providers may also offer features such as incident information, predictive travel time algorithms, and fusion of data from other sources (e.g., roadway sensors). One challenge of using vendor-provided data may be combining third-party data with data collected directly by the agency (e.g., using roadway sensors). This issue is addressed in Section 4.2.

Costs

Costs can vary substantially depending upon the particular billing arrangements with data providers. According to the FHWA Knowledge Resources database, travel time data received from a private sector provider in the I-95 Corridor Coalition Vehicle Probe Project cost about 75 percent less per mile than data from microwave or radar sensors.

Privacy Issues

Travel time data from private sector providers are provided to transportation agencies anonymously, so no privacy issues should exist for transportation agencies. However, agencies should verify that the vendor's privacy procedures are deemed acceptable.

Future Considerations

Crowdsourcing is likely to become increasingly viable and precise as the number of users with compatible devices and applications continues to grow. As data providers increase the size of their networks of data-providing devices, travel time coverage becomes increasingly available on lower volume roads.

2.10 Cell Phone Signal Monitoring

At a Glance

- Cell phone location information is automatically and anonymously downloaded from cellular network switching centers in real-time
- Relatively mature technology and cell phone use is ubiquitous
- Data provided by vendors; data are anonymous when provided to agencies
- Shows adequately precise measurements of travel time

How It Works

Cell phone location information is automatically and anonymously downloaded from cellular network switching centers in real-time. A variety of statistical methods can be used to determine the location of a cell phone based on cell phone network handoff or signal tower triangulation. Different methods can operate with varying degrees of accuracy. One system updates location information about every 750 feet (230 meters) and then matches with a map database to determine devices' locations on roadways, and changes in location over time can be used to calculate speed. This method of cell phone signal monitoring provides reported location accuracy within 90 to 120 feet (27 to 37 meters). Other cell phone signal monitoring methods may be accurate only within 1,500 feet (460 meters) or more (Avni, 2007).

State of the Technology

Cell phone use in the United States is ubiquitous, though cell phone coverage on rural roads may be sporadic or nonexistent in some areas, depending upon service carrier. In addition to improved rural coverage, there may still be some room for technology providers to enhance the location accuracy of cell phone signal monitoring using improved statistical methods and algorithms.

Hardware and Installation

No hardware is required of transportation agencies. Data are provided directly by the vendor.

Implementation Considerations

Cellint's TrafficSense is a traffic information system that continuously monitors traffic speeds, travel times, and incidents in real-time. Cellint describes its implementation process for 100 miles of roadway as hours of installation at the cellular network, days of offline mapping and signature preparation, and weeks of calibration and tuning before the system goes operational (Cellint, 2007).

Cellint reports that it uses anonymous cell phone location data, but it is not clear what percentage of cell phones can be located. Cell phone signal monitoring can differentiate between two nearby roads down to 150 feet (46 meters), which should result in accurate location data on most rural roads, but errors could occur with two nearby parallel roads. Cellint reports that, overall, about 5 percent of data cannot be reliably correlated to a road. Evaluation of a different vendor's cell phone signal monitoring technology against ground truth data found that 95 percent of monitored limited access roads had an absolute speed error within 10 miles per hour and 80 percent had a speed error bias within 5 miles per hour. On rural arterials, only 75 percent of monitored limited access roads had an absolute speed error within 10 miles per hour and only 50 percent had a speed error bias within 5 miles per hour. Accuracy was even lower on urban arterials (Lattimer, 2010). Although the generalizability of these results is not clear, it suggests that the feasibility of cell phone signal monitoring data collection should be evaluated before committing to an implementation, especially on arterials.

Costs

Costs may vary significantly depending upon the data required and must be determined on a case-by-case basis. However, Cellint claims that costs are significantly lower for cell phone signal data than for comparable roadway sensor data.

Privacy Issues

Location and speed data are provided to the transportation agency anonymously, and technology vendors also claim that they receive anonymous data. Therefore, there are no direct privacy issues. However, cell phone tracking has received recent media attention because it has become a popular tool for law enforcement and can often be conducted without a warrant. As a result, there may be public sensitivity to the concept that should be addressed through clear public relations statements indicating how individual privacy is protected.

Future Considerations

Cell phone signal monitoring has been shown to provide adequately precise travel time estimates for rural roads, depending on the data processing method, but has only emerged as a viable option relatively recently. Cell phone signal monitoring may be considered as a competitive (or possibly complementary) technology to GPS device tracking. While cell phone signal monitoring currently has the advantage of high vehicle fleet penetration rates, the presence of GPS in vehicles is increasing, and GPS offers benefits in terms of location accuracy. Interested agencies may explore vendor options for both data types.

3 Implementations of Rural Travel Time Data Collection

This section provides summaries of RTT data collection implementations. The implementations described were selected to represent a broad range of implementation objectives, methods, and technologies. Emphasis is placed on implementations that collect travel time data that can be leveraged in real-time. Note that the first two RTT implementations addressed in this section (I-35 Minnesota, Duluth to Hinckley; and I-95 Maine, Portland to Houlton) are described as detailed case studies, whereas the following implementations are described more briefly.

3.1 Minnesota DOT's I-35 Temporary Travel Times System

3.1.1 Background and Planning

Background

In 2012, Minnesota Department of Transportation (MnDOT) initiated three separate roadway improvement projects along I-35 from Hinckley to Duluth that covered approximately 70 miles of rural highway. The roadway is not a typical weekday commuter route; I-35 is primarily a recreational route with high traffic volumes over holidays and weekends. The peak traffic times occur mostly on weekends when motorists are traveling to and from resort areas, and traffic would be most impacted by construction from May 2012 to October 2012. A detailed account of the project and its results is provided in the final report by Athey Creek Consultants (2013).

Defined Need

MnDOT recognized the need to provide accurate travel times and congestion information to motorists along the freeway during construction with minimal latency issues. The system was to be designed and deployed to aid travelers in making decisions on whether to travel I-35 or Minnesota State Route 23, an approved alternate route during construction, as shown in Figure 7. "The purpose of this project is to inform the traveling public of the travel times through three major reconstruction projects on I-35 this summer," said Dave Mavec, project engineer. "The intent is to reduce driver frustration by displaying the actual driving time it takes to drive through the corridor. State Route 23 travel times are displayed to encourage State Route as an alternate route." It was also important to MnDOT that the public be involved in providing feedback on the travel time project.

Objectives

In addition to several internal criteria, MnDOT defined the project's intent and purpose as the following:

- Inform travelers of travel times on both I-35 and the parallel State Route 23 using roadside static signs with inserted changeable modules which display real-time travel time information.
- Reduce driver frustration, enhance safety, and increase traffic efficiency by sufficiently informing the public about travel times on the alternate route, thereby encouraging use of State Route 23 during peak traffic volume periods.

Figure 7

Project Location and Minnesota State Route 23

Source: Athey Creek Consultants, 2013

- Inform the traveling public, via a website link to the MnDOT 511 website, about real-time travel time information as displayed on the signs.
- Adhere to specific accuracy requirements for each travel time display.

Specifications

The travel time system was to be automated and used temporarily during the I-35 construction projects MnDOT created a performance specification allowing the contractors to pursue the travel time system that met the project objectives so long as maintenance and upkeep of the system were minimal. Among other criteria, the specifications included the following:

- The system shall have sufficient traffic detection devices to detect traffic speeds and by the use of an algorithm compute and communicate estimated travel time to the signs at the locations in the plan.
- All traffic sensors for this project shall be non-intrusive to the pavement except as permitted by the Engineer.
- The system message shall update at least every 5 minutes. The system shall self-test for communication or sensor failures. All sensors shall be of a type whose accuracy and latency are not degraded by inclement weather or degraded visibility conditions including precipitation, fog, darkness, excessive dust, and road debris and have sufficient power capability to run 24 hours per day/7days per week for the duration of the project.
- The contractor shall create a website which is accessible from a link on the MnDOT 511 website which displays a map-based representation of the project showing the sign locations and the near real-time travel times as shown on the actual signs (deployed in the field).

3.1.2 Implementation and Management Contract Requirements

MnDOT hired a contractor through its Design-Build process to implement a temporary standalone travel time project throughout the I-35 work zones and on an arterial highway, State Route 23. The system included deployment of seven roadside static signs along I-35 with inserted changeable modules that displayed travel times to the motorists in real-time, as shown in Figure 8.

The system was required to have sufficient traffic detection devices (sensors) to detect traffic speeds and, by the use of an algorithm, compute and communicate estimated travel times. The quantity and location of sensors were not specified in the plans and were to be tailored to the site by the contractor. Sensors were required to be relocated when construction stages changed. The contractor, Renaissance Technologies, Inc. (RTI), deployed 12 radar sensors to collect travel time information. The traffic data collected was archived in an .zxml format and ultimately transferred to MnDOT ownership (Athey Creek Consultants, 2013). Updates to travel time information were required to occur at least every 5 minutes. The accuracy and latency values were determined by reviewing values used by MnDOT for travel time displays in the Metro area, calculations based on a percentage of travel times between signs at normal speeds, and a maximum deviation thought to be acceptable to the public. After this analysis, MnDOT estimated that the public would not likely accept more than a 15 minute deviation at any one sign. The final accuracy and latency deviation from the displayed travel time values were determined using engineering judgment for each sign location.

Figure 8

Travel Time Sign Located Near 40th Avenue on I-35 in Duluth

Source: Athey Creek Consultants, 2013

Dissemination

RTI's flagship software, TrafAlert™, was used to communicate travel time information to the public via eight DMS, seven roadside static signs, and an online travel time map. Messages displayed on the seven roadside static signs are depicted in Figure 9. The TrafAlert™ software enabled total control of roadside signs and sensors from a central location. Because this work zone was outside of the installed communications devices of the MnDOT TMC's central dispatch, the I-35 system operated independently of the TMC and was not integrated into any other MnDOT system.

Evaluation

Travel time accuracy was assessed by MnDOT using floating car runs to compare travel time estimates to actual drive times. The assessment found that 95 percent of travel times were within the allowable accuracy range and that, among the 5 percent that were out of range more than 85 percent of these instances occurred during or shortly after periods of congestion began. MnDOT also conducted online surveys to assess travelers' reactions to the travel time system. The surveys found that nearly all respondents who traveled the designated route noticed the travel time information. Respondents felt that the information helped them make route and other planning decisions, set expectations, and reduce stress.

3.1.3 Lessons Learned

Overall, MnDOT deems the project as a success which benefited travelers throughout the summer travel season. Feedback obtained through a public survey was generally positive, and respondents appreciated having information that prepared them for congestion in the work zone and assisted them in making decisions about taking alternate routes.

Through comments provided by MnDOT staff and the contractor, MnDOT has indicated they may provide additional system specifications to contractors in the future in order to enhance travel time data output accuracy and minimize latency. MnDOT indicated that project costs were much more affordable compared to implementing a permenant system.

Figure 9

Travel Time Sign Locations and Messages on I-35

Source: Athey Creek Consultants, 2013

An extensive set of lessons learned by MnDOT and the project contractor are provided in the project final report (Athey Creek Consultants, 2013) and select lessons learned are summarized below:

1. The "best-value procurement" method was effective in helping MnDOT to select a qualified contractor. MnDOT has a manual that describes the best-value procurement method (MnDOT Office of Construction and Innovative Contracting, 2012).
2. Language used in bid documents should avoid unnecessarily restrictive requirements and all terms should be unambiguous.
3. MnDOT provided specifications to the contractor that emphasized performance outcomes rather than detailed design specifications. This gave the contractor more ability to innovate and adapt to create the best possible system. This approach also transferred risk and liability to the contractor rather than to MnDOT. However, more detailed design specifications for some system aspects (e.g., sensor spacing and detection capabilities) could have potentially led to improved system performance. The project staff acknowledges that there are tradeoffs between cost and system performance.
4. Contractors should be required to provide a detailed quality control plan that outlines how they will set up and test the system and monitor and correct issues.
5. The methods and criteria that the transportation agency plans to use to verify travel time data accuracy should be specified to contractors during the bid process so that they can assess the validity of the method and the potential risks of not meeting performance criteria. The verification method should include multiple assessments at different times and days.
6. The contract initially stated that monetary deductions would be assessed against the contractor if any part of the system was not functional, but was later revised to state that deductions would only occur if the nonfunctional component adversely affected travel times. This revised language provides contractors with an incentive to design a robust system and avoid penalization for inconsequential issues.
7. A project website with a construction map was created by the contractor and was available via a link on the MnDOT 511 website. The link was difficult to find, however, and true integration of the site within the MnDOT website could have been more effective.
8. It would have been useful to provide ITS system training to work zone supervisors prior to developing bid documents so that they could become more familiar with the candidate technologies.
9. Public feedback about the travel time project was generally positive, although northbound travelers would have liked to receive the travel time information before passing an exit to a viable alternate route. This emphasizes the need to provide motorists with travel time information prior to decision points to allow them to make effective routing choices.

3.2 Maine DOT's Use of Variable Speed Limit (VSL) Signs to Provide Real-Time Traveler Information

3.2.1 Background and Planning

Background

During 2008 and 2009, the State of Maine updated its VSL signs system (see Figure 10) on Interstate 95, Interstate 295, and surrounding arterial routes. The State's intention was not just to capture data related to user delay and vary speed limits to make them appropriate for conditions, but ultimately to provide travel time information to motorists. The Maine Department of Transportation (MaineDOT) currently displays variable speed limits across the I-95 corridor and provides situational alerts through the 511 system. The system measures and displays speeds to enhance real-time information relayed to motorists.

Figure 10

State of Maine
Variable Speed Sign

Source: Maine DOT, 2013

Objectives

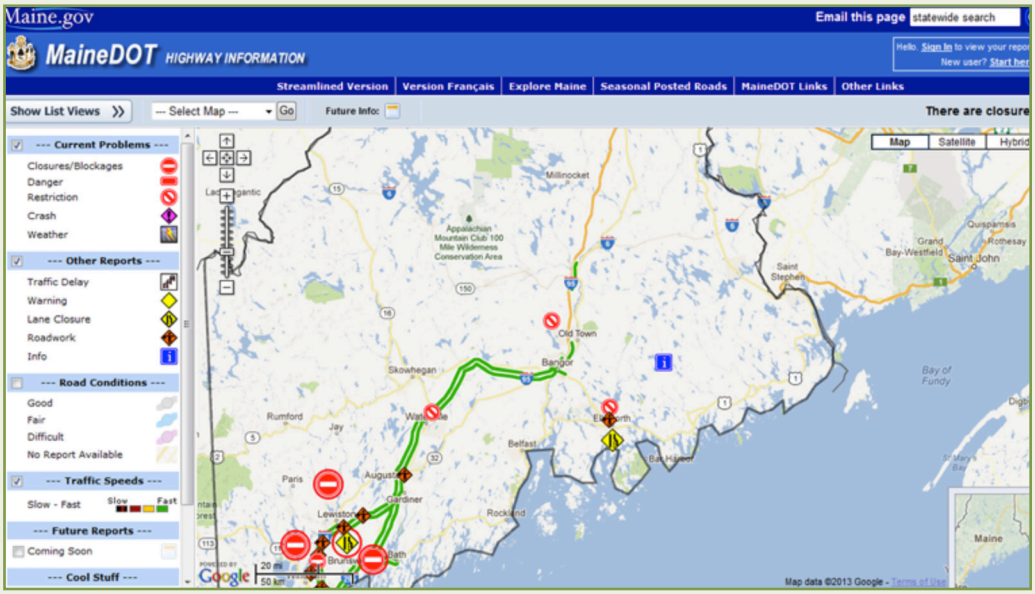
Initially, the State's goal was to improve incident notification information for all highway incidents and weather events, control speeds, and improve the State's 511 System mapping capabilities for the public. The Maine 511 Travel Information Service is designed to help commuters and travelers access information regarding weather-related road conditions, construction zones, and congestion areas, via either the 511 website (www.511maine.gov) as shown in Figure 11 or phone, 24 hours a day and 7 days a week. The 511 website hosts a traveler information map containing information on speeds along the corridor. While motorists aren't explicitly given travel time information, in a rural setting the posted variable speed limit may help to identify areas where delays exist and implicitly advise motorists to consider other routes.

Data Collection

The addition of the radar units on the back of the VSL signs allows MaineDOT to measure average Interstate segment speeds, which can be used to detect delays

Figure 11

MaineDOT's 511 Traveler Information Map Showing the I-95 Corridor



Source: www.511maine.gov

and estimate travel times to key junction points. The agency uses this information to manage the corridor and reduce impacts to travel caused by incidents or weather, with information being updated to the traveler information map.

3.2.2 Implementation and Management

Sensor Locations

The systems are installed at the end of interchange on-ramps on both the northbound and southbound side of I-95 and I-295 and controlled via cell modem from MaineDOT's central radio room. There are 75 signs installed from Portland to Houlton covering a distance of approximate 260 miles. The distance between the interchanges ranges from 2 miles to 10 miles apart. The VSL signs allow the Department to measure average Interstate segment speeds, which can be used to detect delays and allow motorists to estimate travel durations to key junction points. MaineDOT is also using Bluetooth technology through TrafficCast to monitor real-time travel data for several other routes.

System Architecture and Processes

The VSL system is not part of an integrated system, but it uses a tiered approach that involves the radar, camera, and dispatcher information to verify incidents on the corridor and reinforce decisions for the route. Analysis of the data is automated, but it involves direct review, analysis, and decision making by MaineDOT dispatchers. MaineDOT built this into their process to give a sense of ownership to the dispatchers. The dispatchers have three main roles: 1) monitor the two-way radio communications; 2) address public inquiries; and 3) maintain the data entry of the information posted on the 511 website and traveler information map. The dispatchers oversee the communications to the signs. This is accomplished through the use of a cellular modem, which is sampled every 15 minutes. Speed and occupancy data are sent to a server and processed through an algorithm analysis. A threshold speed of 40 mph initiates an alert that is emailed to a dispatcher. The dispatcher reviews the data, which are displayed in a spreadsheet. Based on the data presented, the dispatcher will program the VSL sign(s) to reflect an appropriate speed for the current road conditions. If available, the dispatcher will use a camera feed to verify the roadway condition, and issue a situational alert for public and operations posting.

3.2.3 Future Considerations

Mobile Applications

MaineDOT is considering evaluating mobile applications used by smartphones to collect traveler information that the user agrees to send. One example of a social application is Waze, a community-based traffic and navigation application for real-time traffic and road information. The data from the Waze application may be used in the future to build value on top of data currently available to MaineDOT and can supplement information being collected by the agency. This information may eventually help to explicitly communicate travel times to motorists who are without access to mobile devices. To consider integrating mobile applications into the traffic management process, MaineDOT is working on a request for information (RFI) to solicit other application vendors to come forward and be evaluated.

Costs

Costs for this basic but informative way to share travel information are much less than deployment of DMS and associated hardware, software, and technology packages. The total MaineDOT VSL project cost was $776,849.54. The replacement cost for a VSL sign is estimated at approximately $10,000. To add a radar unit to each sign costs approximately $500 and each camera costs approximately $1,500. The combined cost for cameras and radar units was approximately $66,000. In comparison, deploying this type of system costs approximately one-tenth of traditional travel time communication devices such as DMS.

3.3 Various Statewide Routes, Wisconsin

Wisconsin DOT (WisDOT) has implemented travel time data collection systems on rural roads as part of its Traffic Operations Implementation Plan (TOIP), which guides efforts in transportation planning and improvement and allows ITS to be implemented in major roadway projects at a cost that is considered incidental to the project (i.e., less than 10 percent of project cost). The TOIP encourages ITS deployment to be considered in the construction process to mitigate construction-related congestion; it also

supports efforts to distribute ITS deployments where they are most needed.

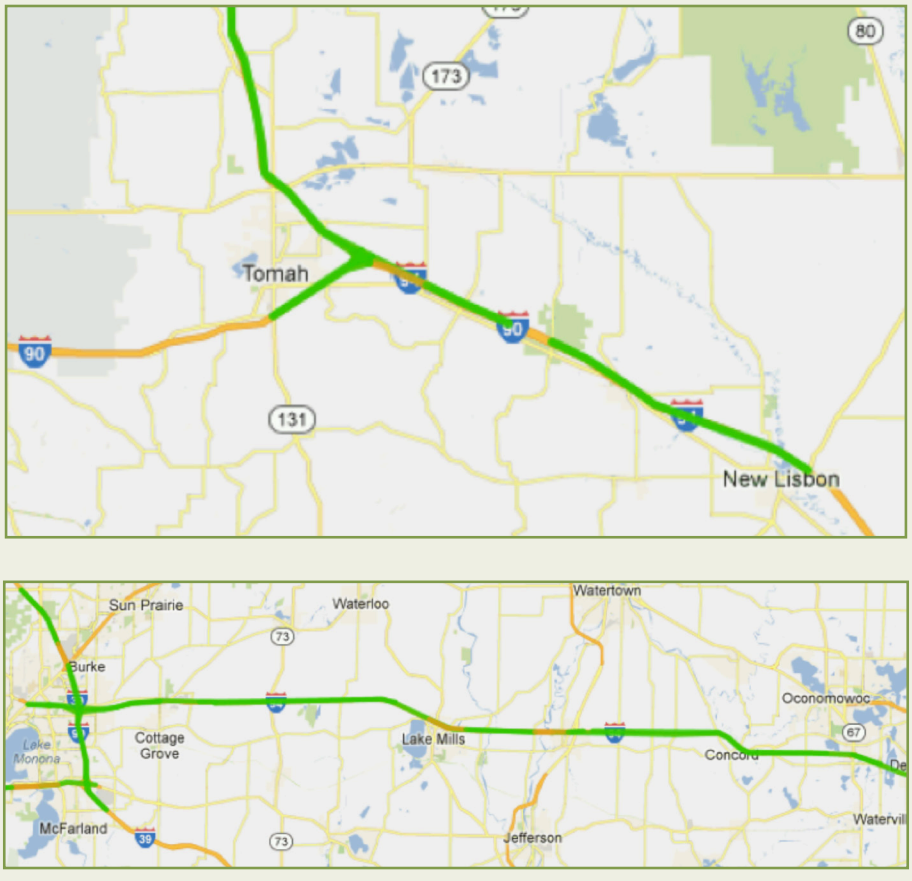
On rural freeways, WisDOT captures travel time data using sidefire microwave detectors. RTT coverage is provided in the vicinity of the I-90/I-94 split near Tomah, WI (see Figure 12) on the I-94 corridor between Milwaukee and Madison (see Figure 12), and a portion of US-41 between Milwaukee and Green Bay. WisDOT has been implementing these travel time deployments for about 7 years. Prior to sidefire radar, WisDOT used loop detectors as its primary source of travel time data, then shifted to microwave detection. Microwave detection was preferred over loop detectors and eventually became standard practice because it was easier to maintain and replace, with the particular benefit of not requiring lane closures and invasive pavement work.

WisDOT experience shows that rural travel times vary infrequently unless there is a traffic incident. The RTT system, however, is not intended specifically for use as an incident detection system and does not include any features for automatic incident detection; WisDOT generally learns of incidents first from police reports.

WisDOT provides DMS showing travel times on some rural routes. In a non-scientific survey, about 80 percent of drivers stated a preference for messages that show both travel time and

Figure 12

Examples of Rural Freeway Travel Time Coverage in Wisconsin



Source: 511wi.com

distances to destinations. In rural areas, travel time sign destinations may be relatively far away and destination names might not be meaningful in and of themselves to drivers, so providing distance allows drivers who are unfamiliar with the area to calculate travel times for themselves.

In the future, WisDOT anticipates that travel time data collection technologies may transition to Bluetooth probe technologies due to the lower cost of installation and maintenance, or the agency may opt to purchase third-party travel time data. WisDOT is also interested in the possibilities of connected vehicle for travel time data. It is possible that the future role of WisDOT and other DOTs will not be in collecting travel time data themselves, but validating data from third-party sources.

3.4 I-45 from Houston to Dallas, Texas

The I-45 corridor is a rural Interstate of approximately 230 miles that connects Houston and Dallas and serves as a hurricane evacuation route. In recent years, major hurricanes threatened the Gulf Coast and have brought attention to the need for effective hurricane evacuation management. Transportation officials needed the ability to monitor traffic conditions along the evacuation route and to determine whether to deploy contraflow (Texas Transportation Researcher, June 2010).

In 2009 Bluetooth detectors were installed along 225 miles of I-45 to collect the necessary traffic information. Two examples of pole-mounted Bluetooth units are shown in Figure 13. Detector spacing ranges from 5 miles to 20 miles, but sensors are typically between 5 and 8 miles apart. Bluetooth was selected for use primarily because it was significantly less expensive than the toll tag reader technology that has been used in earlier implementations. Before the implementation began, Houston TranStar, a partnership of government agencies responsible for providing transportation and emergency management services to the Greater Houston Region, conducted feasibility testing to ensure that Bluetooth captured sufficient data and reported accurate travel times. Testing showed that Bluetooth performed comparably to Houston's more established toll tag reader technology (Puckett, 2011)

Figure 13

Two Examples of AWAM Bluetooth Sensors

Source: tti.tamu.edu

In addition to aiding with evacuation planning, the travel time system is intended to provide useful information to motorists and TranStar staff regarding current traffic conditions. Color coded real-time travel times are displayed on a map on the Houston TranStar website (see Figure 14).

Figure 14

Houston TranStar I-45 Traffic Map

Source: traffic.houstontranstar.org/layers/layers.aspx?mapname=region_houston_dallas&inc=true&rc=true

3.5 Various Routes in Oregon, Frontier Travel Time Project

In 2000, the Frontier Project Technical Advisory Committee (TAC), which includes representatives from eight State DOTs, selected an RTT estimation system for demonstration on rural highways near the Oregon coast (Wright, Shi, & Lee, 2005). Congestion and incidents are common on this corridor, and the TAC intended for the demonstration project to be capable of providing travel times and incident information to Oregon DOT (ODOT) and to motorists.

The TAC distributed system requirements to interested vendors and vetted bids based on price, previous success with travel time deployments, and timeliness. The TAC chose an infrared ALPR technology. The system read license plates, encrypted the license plate numbers, and sent them via telephone communications to a central server, where vehicle matches were made and travel times were calculated. The entire travel time system consisted of a total of six license plate recognition cameras mounted on cantilevers above the road. Each installation consists of two cameras, one for each direction. One road segment was 3.15 miles long and the other road segment was 22.25 miles long. The TAC cooperated closely with the vendor to ensure that the system was installed as specified.

The system operated as intended for the first 2 months in 2001, but then a series of software and equipment failures ended the initial effort, and the system remained dysfunctional until 2004. The most significant problem was a faulty power supply module, which was not replaced by the vendor for almost 1 year. Once the replacement part was available, it took another year for ODOT staff to fully repair the system because there was a significant backlog of maintenance work elsewhere, and the travel time system was considered non-critical to safe operation of the roadway network.

Upon restoration of the system, the quality of the system's data was evaluated. Analyses showed that when the system was functional, it provided accurate travel times, though an insufficient amount of data were available under congested conditions to evaluate system accuracy when traffic is heavy. Segment length had a significant effect on vehicle match rates: for the long 22-mile segment, match rates were under 5 percent of traffic, whereas for the short 3-mile segment, match rates were above 15 percent. The system also could be used for incident detection, but ODOT found that cell phone calls from motorists and other communication means were generally faster and more reliable. Despite this success, the system was discontinued due to ongoing operational and maintenance issues; ODOT was not willing to rely on the data or disseminate it given that the system was prone to failure.

Lessons learned in this demonstration project include:

- Maintenance of ITS devices is particularly burdensome to rural transportation districts, which may have less staff covering a wider area than urban districts and fewer maintenance funds
- Travel time systems must be operationally reliable to be used effectively
- Sufficient staff, equipment, and funding should be available for system maintenance
- There are risks in deploying a first-of-its-kind project
- Segment length and congested conditions have an effect on data reliability

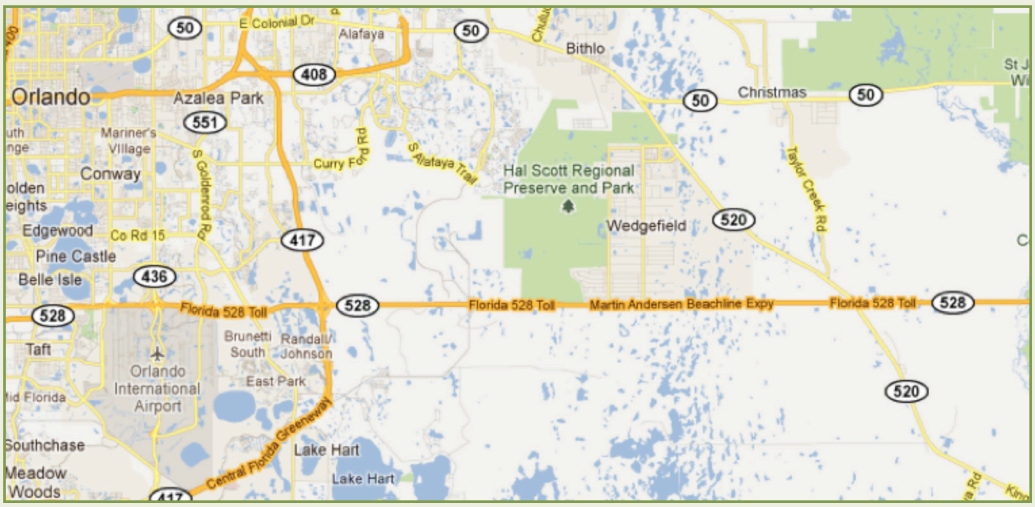
3.6 State Route 520 in Orange County, FL

The Orlando-Orange County Expressway Authority (OOCEA) manages one DMS, located in the eastern part of Orange County, between Orlando and the Atlantic coast. The sign was installed in 2008 on northbound SR-520, about 0.5 miles before reaching SR-528. This sign is in a largely undeveloped, rural area.

This DMS was originally intended to assist with coastal evacuations: in such scenarios, the SR-520 northbound to SR-528 westbound route would be heavily utilized (see Figure 15). However, at this junction drivers headed toward Orlando have the choice of either remaining on SR-520 or switching to SR-528; both routes are viable options to reach much of the Orlando area. To aid drivers, travel times for westbound SR-528 are shown on this DMS. SR-528 is a toll road that is heavily used by commuters to Orlando and travelers headed to or from Orlando International Airport. Although travel times are not shown for SR-520, drivers can use the SR-528 travel time to help determine which route would be best for them. For

Figure 15

Orange County Road Network



Source: Google Maps

example, an unusually long travel time on SR-528 might suggest that SR-520 would be a faster route. As an added incentive, there is no toll on SR-520.

Travel times are calculated from vehicles' on-board toll transponders, used for toll collection on SR-528. Travel times are calculated each minute. However, 10 vehicles matched between 2 locations are needed to develop an average. When there are fewer than 10 matches every minute, the sign displays the travel time as calculated from the most recent 10 reads.

The sign is normally formatted as displayed in Figure 16. The destinations displayed are always Orlando International Airport and SR-417. However, if the travel time to either of these destinations is a certain percentage (e.g., 50-100 percent) above the normal or expected travel time, there is instead another display. (Expected travel time is calculated from the mean travel time at that time of day, as recorded over the past 4 weeks.) The banner "TRAVEL TIME VIA SR 528 TO" is then replaced by "TRAVEL TIME ALERT." The word "ALERT" flashes, as do the destination(s) for which the travel time is elevated. The travel times also flash. In the case of a travel time alert, the DMS is two-phased and alternates with an incident-related message (i.e. CRASH AHEAD). Although travel times are not shown for the alternate route (SR-520), drivers can use the SR-528 traffic conditions as a basis for route choice. The sign operates 24 hours a day.

Figure 16

Typical Display Format of OOCEA Travel Time Sign

Source: www.fl511.com

3.7 I-90, Snoqualmie Pass in Washington

I-90 is a major freeway connecting Seattle with inland Washington State, though much of the route is situated in a rural setting. About 50 miles from Seattle, I-90 traverses Snoqualmie Pass, a mountain pass at 3,000 feet elevation. According to Washington State DOT (WSDOT), the Pass carries more than 10 million travelers per year. Due to the pass's unique climate, it receives huge amounts of precipitation, including an average of more than 400 inches of snow per year. The extreme weather conditions can make the Pass unsafe to drive, occasionally required road closures due to unsafe conditions or avalanche risk. In recent winters, crash-related closure of the Pass has averaged fewer than 20 hours per winter. Avalanche closures are more varied, ranging from fewer than 10 hours in 2009-2010 up to more than 100 hours in 2007-2008 and 2008-2009. In addition to winter weather issues, Snoqualmie Pass can experience congestion on summer weekends and holidays, and a long-term construction project is expected to add to delays (Rick Gifford, personal communication, February 2013).

Due to unpredictable mountain pass conditions, in 2011 WSDOT began providing information to drivers on its website, smartphone app, and on travel time signs on I-90. The website (www.wsdot.com/traffic/passes/snoqualmie/) provides travel times for the 74-mile stretch of mountainous terrain as well as a color coded traffic map with live traffic cameras (see Figure 17), and additional information on current weather and road conditions, forecast, and travel restrictions.

Three travel time signs (one eastbound and two westbound) provide drivers with travel times and distances to the Pass (see Figure 18). The travel times are currently calculated using data from the third-party data provider INRIX. However, WSDOT is currently installing nearly 30 radar detectors along the 74 miles surrounding the Pass that will ultimately be used to calculate travel times in place of the INRIX data.

Advantages of radar over INRIX data for WSDOT include data ownership, a more compatible costing structure (i.e., easier to obtain funding for purchases than ongoing payments), and overall

Figure 17

Snoqualmie Pass Traffic Map

www.wsdot.com/traffic/passes/snoqualmie/

Figure 18

Travel Time Sign Approaching Snoqualmie Pass

Source: wsdotblog.blogspot.com

cost savings (Rick Gifford, personal communication, February 2013). The combination of radar and probe data provides WSDOT with more precise speed data, and adds traffic volume data.

According to WSDOT, "This work was funded by $800,000 of electrical preservation funds, as well as $500,000 from the I-90 Snoqualmie Pass East corridor project. The $1.3 million project replaces a 20-year-old communications system and includes the online [traffic] flow maps, travel time signs that were activated earlier this summer, and provides real-time information to drivers and our Traffic Management Center."

4 Best Practices for Rural Travel Time Data Collection

This chapter brings together the state-of-the-art in RTT data collection technologies and the state-of-the-practice in RTT implementations to develop a set of best practices that are based on evaluation and real-world experiences. It focuses on best practices related to the data collection technology; a complete set of best practices for RTT programs is beyond the scope of this effort. The best practices were developed with the understanding that every implementation of RTT involves a unique set of objectives, challenges, constraints, and environments. Therefore, rather than providing prescriptive guidance, this chapter emphasizes the key considerations at each step of the planning, implementation, and management process.

One of the most important lessons learned by travel time program implementers is the importance of asking the right questions during the planning and implementation stages. Therefore, each key consideration is phrased as a question and is followed by discussion of related issues. While the key considerations are divided across three high-level topics, the issues addressed in this chapter should be considered across all stages of an RTT implementation.

4.1 Need Assessment, Planning, and Specifications Development

The following questions may help practitioners assess and plan their travel time needs as well as lay out the framework for specification development.

What Are the Ultimate Outcomes Desired from the RTT Program?

Agencies that have implemented their own RTT programs have done so for a variety of reasons. Some intended to enhance their own abilities to monitor regional traffic conditions. Some intended to provide traveler information to improve drivers' abilities to make efficient routing decisions during construction projects. Some intended to improve their ability to monitor and control evacuations.

Exploring high-level objectives should help to define some basic parameters of the program:

- Are data needed in real-time?
- Who will have access to the data, and how will it be disseminated?
- What geographic area requires RTT coverage?

While the primary objectives of an RTT program may be initially defined according to high-level needs, it is also useful to consider potential secondary benefits of travel time data. Depending upon the data collection technology selected and how it is implemented, RTT systems can provide data on traffic volumes, vehicle class, perform enforcement tasks, function as CCTV cameras, and more. Travel time data can also be used for a variety of purposes, including statewide planning model calibration, program/project evaluation, integrated corridor management, and so forth. Clearly defining "needs" and "wants" will aid in the development of project specifications.

Once the objectives have been defined, the next step is to determine the specifications for the RTT program. Development of specifications for an RTT program is likely to be the most critical stage in determining the success of the program. Clearly stated specifications will help to guide the technology acquisition and implementation process and ensure that the RTT program will be capable of achieving its objectives.

How Can RTT Meet Mandates?

An RTT implementation could potentially help an agency meet certain requirements for network performance or information dissemination. One important mandate is the Real-Time System Management Information Program, which was included in *Section 1201 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users* (SAFETEA-LU) (http://ops.fhwa.dot.gov/safetea.htm). According to FHWA, "The Real-Time System Management Information Program is

to provide the capability to monitor in real-time the traffic and travel conditions of the major highways across the United States and provide a means of sharing these data with state and local governments and with the traveling public. [...] The Program is to be established on all Interstate routes within 4 years (November 8, 2014) and on other significant roadways as identified by the States and local agencies within 6 years (November 8, 2016)." Travel time systems on major rural routes may be important in meeting these requirements.

What are the Funding and Schedule Constraints?

Project funding mechanisms often place constraints on how funds can be used, or for what purposes. It is essential to ensure that an RTT program is within the scope of available funding. For example, depending on how it is implemented, an RTT program could potentially be funded as a congestion or emissions mitigation program, or as part of an integrated corridor management program. A project may also face schedule constraints. If a project faces a tight implementation schedule, the scope of the project and the data collection technologies selected should consider these constraints. For example, purchasing data from a private sector vendor may be the fastest approach to program implementation but sensor technologies such as Bluetooth detectors can also be installed and calibrated relatively quickly. Finally, consider any requirements to demonstrate system benefits, and the data that would be required to do so.

What Is the Desired RTT Coverage Area?

A clear definition of the project objectives should help to identify the target coverage area. If the objective is to provide travel times to motorists to help them choose between multiple routes, sufficient coverage of alternate routes is required, as well as a means to disseminate the data in ways that allow drivers to make timely route choices.

What Are the Needs for Scalability?

When first implementing an RTT program, it is often simplest to begin with a relatively small-scale implementation. Once system functionality has been verified, coverage can be expanded. If using this approach, agencies should ensure that the system architecture can be scaled up in the future.

What Are the Needs for Mobility?

It is also important to consider whether the system should be semi-permanent or mobile. For example, if intended to provide travel time data in a work zone, mobility may be an important factor. A mobile system should be capable quick installation, calibration, and removal. Mobility also has implications for data and power requirements: a mobile travel time system may require solar and/or battery power, as well as wireless data transmission.

Are Real-time Data Required?

Real-time data require sensors that can transmit data shortly after capture via wired or wireless transmission methods. If data are not needed in real-time, or for an extended period of time, a battery-powered, self-contained Bluetooth data collection device can be used for a period of a few weeks.

What Secondary Benefits Can be Achieved?

Secondary benefits of an RTT program can include use of travel time data for non-travel-time purposes and the use of other types of data that the data collection technology can obtain. Secondary uses of travel time data could include origin-destination studies and other evaluations of travel patterns. However, ideal sensor locations for these secondary purposes might not be the same as for the primary travel time purpose. Different RTT data collection technologies have varying capabilities in terms of non-travel-time data. Technologies with very high vehicle detection rates (e.g., in-pavement magnetometers and loop detectors) can be used to collect vehicle count data that could be used for a variety of planning and evaluation purposes. Some technologies can determine vehicle class. Others can perform automated enforcement functions such as detection of unregistered vehicles (e.g., ALPR). Additional benefits of RTT data should be considered early in the planning process.

What Are the Requirements for Data Accuracy and Timeliness?

While perfectly accurate and timely travel time data may be ideal, there are a variety of limiting factors. Low vehicle detection and match rates can limit travel time system's ability to generate travel time estimates with high confidence, and may result

in delayed processing in order to acquire enough matches to generate an estimate. These challenges may be more significant in the rural environment than the freeway environment due to the potential for lower traffic volumes and greater travel time variability.

Data accuracy and timeliness can be influenced by the data collection technology selected. Technologies with relatively high detection and match rates (e.g., in-pavement magnetometers) may be least prone to delays and inaccuracies caused by low traffic volumes. Travel time measurement methods that use spot speed measurements rely on a limited set of data points to generate travel time estimates, and are therefore prone to error, especially on rural roads where speeds are variable due to traffic control devices, varying speed limits, and so forth. Probe vehicle technologies that calculate vehicles' actual travel times for a road segment can be much more accurate than spot speed measurements, but these estimates are delayed by the time it takes each vehicle to traverse a segment between two sensor locations. Delay will increase if segments between sensors are long, if travel times increase (e.g., due to congestion), or if traffic volumes are low. Probe vehicle technologies that track vehicles in real-time (e.g., using GPS transponders) have the highest potential for accuracy and timeliness, but still rely on appropriate processing algorithms to achieve high accuracy. Across many data collection technologies, predictive algorithms can be applied to factor historical trends and current network conditions into travel time estimates to account for some of the inaccuracies inherent in travel time estimates.

What Partnerships May be Necessary or Beneficial?

An RTT program must fit into the broader traffic management context. Often, this involves sharing resources and ensuring compatibility with other agencies, including contractors. For instance, a major rural route may traverse multiple jurisdictional boundaries. Data-sharing and fusion of data from multiple sources and agencies could be particularly valuable and provide a more complete picture than data from a single source alone. One particular case in which partnerships may be useful involves the combination of freeway and alternate route travel times for dissemination to the public.

What Are the Infrastructure Requirements?

Each RTT data collection technology has its own set of requirements and options for infrastructure compatibility. For instance, magnetometers must be installed in pavement and have a wireless access point or repeater within 150 feet (50 meters), machine vision benefits from a high vantage point and has relatively high data transmission and power requirements, Bluetooth detectors are particularly flexible in terms of installation location and power requirements, and crowdsourced data using GPS sensors likely requires no infrastructure elements at all. If the rural road lacks power and data infrastructure, wireless and solar powered technologies might be most desirable. If additional infrastructure is required for a technology, it is important to consider the costs and other implications. On many rural roads, new structures such as mounting poles and cantilevers might be undesirable or infeasible due to aesthetic concerns, safety impacts, or lack of available right-of-way. Some new infrastructure components may also require environmental assessments. Rural roads without available network lines may require cellular communications for real-time data transmission. If this is the case, it is important to evaluate the availability of cellular signal on available cellular providers' networks. An inexpensive sensor can be purchased for this purpose. A strong signal is preferred because a weak signal can lead to sporadic data transmission and increased power drain on detectors' cellular modems.

Are Travel Time Data Needed During Periods of Low Traffic Volume?

Travel time data collection technologies require some minimum number of vehicle detections and matches to be capable of calculating travel times reliably and in a timely manner. Research suggests that on routes with relatively low speed variability, between four and eight vehicle probe data points are sufficient to generate a travel time estimate (Click & Lloyd, 2012). However, when traffic volumes are especially low (e.g., overnight hours), travel time data collection technologies may not function reliably, and technologies with relatively low detection and matching rates are likely to be especially hindered. Agencies should consider whether travel times are required during low volume periods, given that travel

time delays are unlikely to occur when traffic volumes are low. If travel time data are required during low volume periods, technologies and data processing algorithms that work well during low volume periods should be considered.

4.2 Selecting and Acquiring Data Collection Technology

The following questions may help practitioners identify key factors in determining which travel time technology is right for their specific implementation.

What Software, Hardware, and Other Architectural Requirements Exist?

When selecting RTT technology, it is important to consider compatibility with existing systems and data sources. Some data collection technology vendors provide proprietary software for data visualization and analysis. While effective for some purposes, some agencies have found that vendor-provided software does not provide all of the features and flexibility that they desire. Ideally, RTT data and other features (e.g., device diagnostics) should be capable of integration with existing traffic management software, hardware, power, and transmission systems. Compatibility between different data sources and cooperating organizations can significantly increase the efficiency with which data can be processed and used. If new software is required to make optimal use of RTT data, a potential solution is use open source software such as IRIS (Intelligent Roadway Information System, iris.dot.state.mn.us). Open source software from a reliable source can provide a customizable platform that saves significant development time and effort compared to creating a new platform from scratch (Guerra, 2012). For any RTT program, it is critical to ensure that the system is capable of providing the data integration, visualization, analysis, and dissemination tools required, as well as remaining flexible enough to be able to adapt the system to future needs.

What Are the Initial and Ongoing Costs Associated with Each Candidate Technology?

The FHWA Knowledge Resources database (www.itskrs.its.dot.gov/) is a valuable resource for exploring the costs, benefits, and lessons learned related to a variety of technologies and programs, though the database currently provides few resources directly related to RTT.

As discussed in Chapter 2, the reported costs of RTT data collection technologies vary widely. In addition to cost differences between technologies, reported costs for any single technology have also differed. Initial material costs can be considered as a function of the price of each sensor unit and associated hardware (including power and data connections), the number of sensors units required per site, and the number of sites required per implementation. Additional initial costs can include installation and calibration.

Ongoing costs can include hardware maintenance, electricity and data transmission costs (usually negligible), and data processing labor. Over the long term, life cycle cost is a useful measure of the expected costs over the life of the technology. The expected life span of many travel time data collection devices is up to about 10 years, though actual life span of individual units can vary. To ensure a long technology life span, it is useful to also consider the future viability of the technology and its associated systems.

A less predictable cost is the fee for vendor services. Different data collection technology vendors offer different options for system services and support. Options may range from purchase of data collection technology with no additional support to complete turnkey solutions initiated and managed by a vendor. While vendor services can add significantly to the cost of a system, an effective vendor can save the agency significant labor costs and offer a degree of protection from unanticipated costs. Interested agencies should explore vendor support options to find the most appropriate model.

Should the Data Collection Technology be Purchased or Rented?

Some data collection technology vendors offer the option to rent or purchase equipment. The best option may depend on a variety of factors. Renting may be an appropriate choice for a temporary application (e.g., work zone project) or proof of concept study. Renting may also be more compatible with certain contracting requirements, and may make it easier for an agency to change or upgrade equipment in the short term. Purchasing may prove to be more affordable in the long term, and may provide an agency with more control over how it uses the equipment.

How Long is the Data Path?

It is not uncommon for travel time data to pass through numerous physical locations and processing steps. For instance, data may travel from a sensor to a field processing unit to a vendor's server to the agency's server. Each location and transmission process introduces additional risk of a failure somewhere along the path. Furthermore, should a failure occur, a long data path may make it more difficult to determine exactly where the problem occurred.

What System Features can be Automated?

Raw travel time data generally goes through many stages of processing before information is provided in its final form to users. Automating many of these processes can save labor hours, reduce processing lag, and reduce the likelihood of errors. Examples of effective uses of automation include processing and generating of travel time messages for dms and websites, generation of reports and summary data, and provision of alerts to system operators (e.g., via text message or email) when certain conditions are met (e.g., travel time in excess of threshold value or sensor failure/error).

How Will Data Security and Motorist Privacy be Protected?

Some data collection technologies capture information that could be used directly or indirectly to identify individuals or vehicles. Data of this sort should be encrypted at the capture point to prevent unauthorized access. To the extent possible, personally identifiable information should not be recorded or provided to staff, vendors, or other partners, in its original form. Information such as license plate numbers or Bluetooth Mac addresses should be truncated, randomized, or otherwise obscured to protect individuals' privacy.

How Can Preliminary Data Collection Technology Testing be Conducted?

The introduction of a new RTT program can come with many uncertainties and unexpected challenges. Preliminary testing of a technology can help to narrow specifications (e.g., Determining the feasibility of a particular technology or the proper spacing of detector units) and reveal potential issues during the planning process, allowing them to be accounted for in the planning and contracting process. For preliminary testing, a small number of devices can be purchased or rented, and collaboration with a vendor or other third party with experience using the technology can help substantially in learning how to use the technology.

How Should a Technology Vendor/Provider be Solicited?

Depending on the preferred approach of the agency, vendors can be approached for direct talks, or a request for proposal (RFP) could be issued. Many vendors are willing to work closely with agencies to understand and accommodate requirements. A key element of this process is effectively communicating needs to potential vendors and discussing approaches to meet those needs. Although vendors may advertise a discrete set of options and features, some can develop custom solutions to meet agency needs. In general, it is advisable to solicit bids from multiple vendors to fully explore options. Although requirements should be clearly stated to potential vendors, they should not be unnecessarily specific to the point of disqualifying or deterring vendors who might be able to offer a solution. Emphasizing performance criteria over design criteria can give potential bidders the flexibility to design the system as they see fit while still ensuring that the system is designed to meet agency needs.

Through ENTERPRISE, Washington State Department of Transportation (2011) has made available for public access its own RFP for contracted traffic data, which may serve as a starting point for other agencies interested in developing their own RFPs. ENTERPRISE also provides a detailed report on the use of third-party travel data and information. The report describes how agencies in the United States are currently using third-party data, including their experiences with these relationships, and provides information on the data providers themselves (ENTERPRISE, 2012).

How Much Ongoing Support Is Offered by the Vendor?

Agency experience shows that issues and questions are likely to continue to arise long after the RTT program is up and running. Agencies should ensure that the vendor will be responsive to such questions, especially where changes to the system may be required. The terms of system support should be documented in a contract.

What Is the Division of Responsibilities and Rights Between the Agency and the Vendor?

The responsibilities of the agency and the vendor must be clearly delineated. For example, who is responsible for installation, calibration, maintenance, repairs, status monitoring and replacement of failed equipment, data housing, and so forth? For any responsibilities assigned to the vendor, performance requirements should be clearly stated as well. For example, minimum performance criteria for travel time estimates and time requirements to replace failed equipment. A problem experienced in multiple implementations is equipment failure being compounded by unavailability of replacement parts or maintenance staff.

Who Owns the Data?

If a vendor processes the data and maintains data on its server, it should be clearly stated who owns the data and who has access to it for what purposes. Similarly, an agency should be aware of what aspects of a vendor's system are proprietary and therefore inaccessible to the agency (e.g., if a vendor uses proprietary travel time calculation algorithms, the agency might not be permitted to explore how the travel times are being calculated. Finally, should there be any significant unanticipated problems with the system, it should be clear who assumes these risk and the financial and liability responsibilities for problems.

4.3 Implementation, Management, and Evaluation

The following questions may assist practitioners in determining answers to implementation dilemmas, establishing management principles and goals, and evaluating the functioning travel time system.

How Should Sensor Locations be Selected?

Ideal sensor location is highly dependent upon the features of the route. Technologies that measure spot speed (e.g., loop detection, radar) are generally only effective on roads where average travel speeds are fairly constant along the route with minimal "friction," and therefore spot speed measurements can be considered to be fairly representative of the road segment. Technologies that measure the segment travel times of vehicles can be used on any type of rural road.

Sensor spacing should be based primarily on traffic patterns. Routes with a high percentage of through traffic that does not turn off or stop along the route can have sensors relatively distant from one another because little data loss is expected. In such cases, sensor spacing may be similar to freeway spacing, though low volume or low speed roads may benefit from closer spacing to minimize data lag. Although there is no general rule of thumb for sensor spacing on rural roads, in current practice, sensor spacing on limited access rural roads has generally ranged from about 3 to 8 miles. The technology vendor may also be a source for guidance on sensor placement.

What Documentation Is Available for the Technology?

To the extent that an agency is implementing or managing the data collection technology, complete documentation should be available describing the functionality and capabilities in detail. An example of the value of documentation is offered by the iFlorida initiative. Florida DOT experienced a high toll tag reader failure rate and devised a relatively labor intensive ad hoc system for checking each device before learning of an undocumented feature of the devices that allowed devices to perform a self-diagnostic check using a web interface (Haas et al., 2009).

How Should the Program Operate in the Case of Missing Data?

To the extent possible, an RTT program should be capable of maintaining functionality when some data are missing due to insufficient data quantity, equipment failures, or other problems. In the case of insufficient data quantity, a travel time value representing free flow speed can be used under the assumption that low traffic volumes are indicative of a no-delay condition. However, especially on rural roads, it is important to ensure that missing data is not indicative of a road blockage due to a collision or other problem.

The iFlorida deployment experienced significant arterial data collection sensor outages. An assessment of that deployment (Haas et al, 2009) offers the following guidance:

- Missing data should be replaced with the best-available alternative data, such as historical averages or alternative real-time sources such as traffic cameras.

- TMC software and operators have access to the most data sources, and are therefore likely to be the best sources of replacement data.
- Estimated data should be flagged as such so that downstream software can distinguish measured data versus plug data.
- Estimated data should be inserted as early in the data flow as possible so that the missing data do not cause problems with software.

How Should Field Equipment be Monitored and Maintained?

Appropriate monitoring of data collection technologies can help to ensure that problems are detected and fixed quickly. Some systems may be capable of automatically reporting a malfunctioning device to the agency, while others may only be detected by a review of data.

Common reasons for device failure include exposure to extreme heat (e.g., in a signal cabinet), power surges, and loss of data transmission connection (including fiber line cuts) or power source. These risks can be minimized by ensuring that devices are installed in locations that will not exceed their temperature ratings and installing power conditioning devices and surge protection. However, in the event that a device does fail, down time can be significantly reduced by ensuring that replacement parts are available. It can also be helpful to perform a root cause analysis to determine why a device failed, so that the same problem can be avoided in the future (Haas et al., 2009). If a large amount of new equipment is being installed and brought online in a short period of time, adequate staff should be available to deal with potential startup problems. Finally, from a physical monitoring standpoint, it is important to maintain asset management procedures to clearly document where each device is deployed.

How Can Data Quality be Verified?

Few existing RTT implementers have conducted formal evaluations of data quality, but guidance can be found in evaluations of other travel time implementations. Some have conducted floating car runs as a basic verification, and others consider a lack of negative public feedback an indication that the travel times are accurate. A relatively small number of studies have been conducted to compare the data quality of multiple travel data sources, but these types of studies may be beyond the means of most agencies. One such study conducted in Toronto compared data from four different sources, and provides details of the statistical methodologies used for this effort (Ministry of Transportation Ontario, 2012).

How Should Public and Media Relations be Handled?

It is important to proactively address potential public concerns about an RTT program. If the RTT system collects any type of data that could potentially be seen as personal or sensitive (e.g., ALPR, MAC address), the uses of the data and protections in place to ensure privacy should be clearly stated. In the United Kingdom, experience suggests that when the public perceive a technology as an invasion of privacy or as a law enforcement device, it may be more prone to vandalism. Furthermore, public opinion should be taken into account when installing new infrastructure. For instance, in some environments, a new pole or DMS might be seen as an eyesore.

How Can the Effectiveness of an RTT Program be Evaluated?

To date, there have been few formal evaluations of the effectiveness of RTT programs in meeting their goals. In part, this may be because many goals of RTT programs can be difficult to assess affordably and with statistical rigor. Establishing performance measures for evaluating the RTT system can help to ascertain whether the system is meeting its primary reasons for installation. Developing segment-, corridor-, or agency-wide success indicators can help the implementers fine-tune their systems and can even make the case for potential future expansion. It is important to align performance measures with whether or not the system is meeting the needs of the implementation.

5 Conclusion

Real-time travel time information can be valuable to both motorists and transportation agencies. While travel time practices are relatively well-established on major freeways, rural highways pose unique challenges, and few practitioners have experience collecting travel time data on rural roads. This report provides practitioners with information on the current and emerging technologies available for RTT data collection, summarizes current practice, and provides a set of key considerations and questions to ask when planning and operating an RTT program.

Although RTT data collection is a relatively new and rapidly evolving area, RTT can be successfully implemented when a project is properly planned and executed. The importance of proper planning cannot be overstated. Successful implementers have carefully considered project objectives and have provided detailed implementation plans. Regardless of the latest specific data collection technology released, asking the right questions is paramount, beginning with planning, continuing to the selection stage, and culminating with execution and evaluation. Practitioners who focus on asking the right questions and heed the lessons learned by colleagues will greatly increase the chances of a successful implementation.

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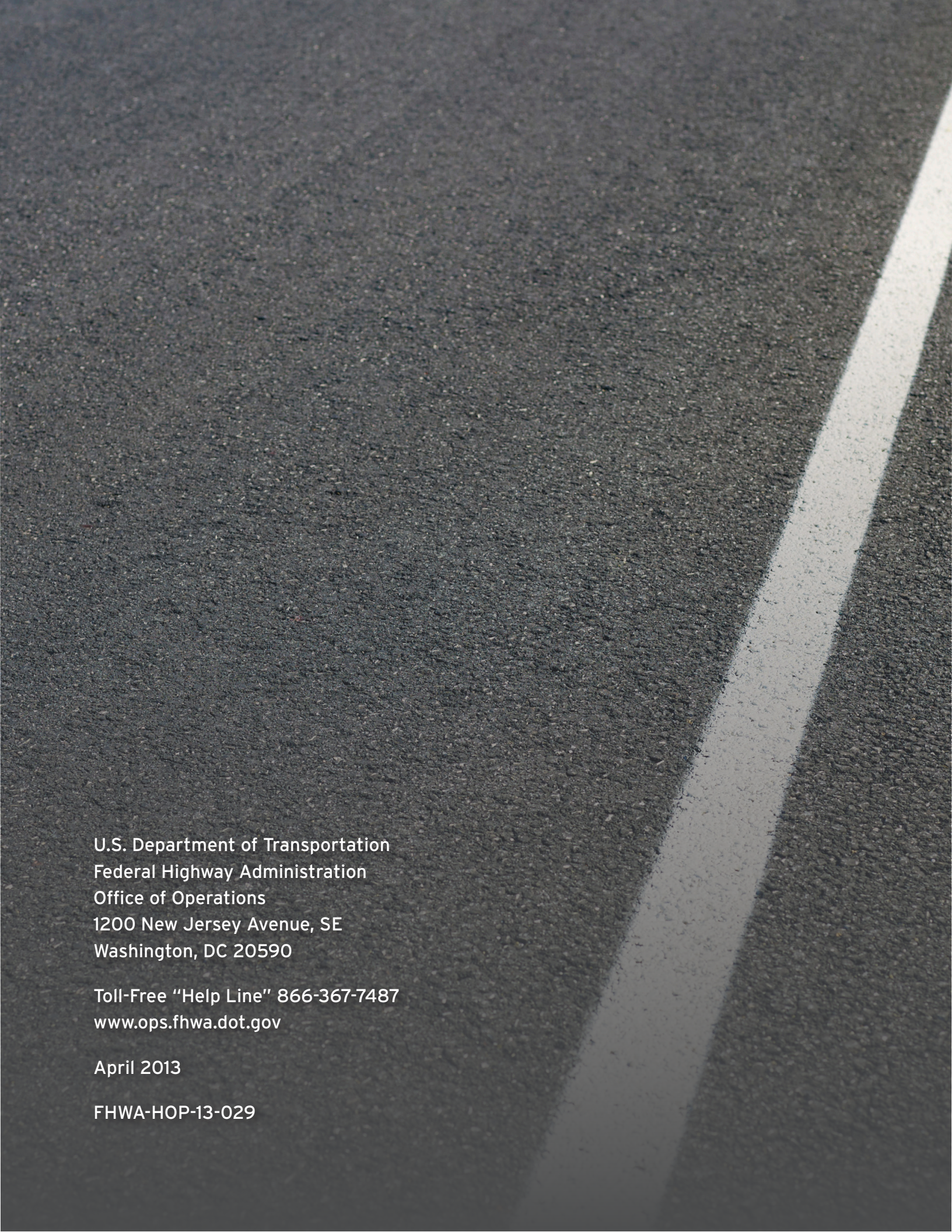

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