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

Arterial Data Collection Technology

April 2013

U.S. Department of Transportation
Federal Highway Administration

Notice

Quality Assurance Statement

Technical Report Documentation Page

1. Report No. FHWA-HOP-13-028	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Travel Time on Arterials and Rural Highways: State-of-the-Practice Synthesis on Arterial Data Collection Technology		**5. Report Date** April 2013
		6. Performing Organization Code
7. Authors Jeremiah Singer (Westat), A. Emanuel Robinson (Westat), Jessica Krueger (Westat), Jennifer E. Atkinson (SAIC), Matthew C. Myers (SAIC)		**8. Performing Organization Report No.**
9. Performing Organization Name and Address Westat 1600 Research Blvd. Rockville, MD 20852	SAIC 1710 SAIC Dr. McLean, VA 22102	**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Highway Administration 1200 New Jersey Ave. S.E. Washington, D.C. 20590		**13. Type of Report and Period Covered** Synthesis Report August 27, 2012 – April 30, 2013
		14. Sponsoring Agency Code HOTM-1, FHWA
15. Supplementary Notes Government Task Monitor (GTM): Jimmy Chu		

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 arterials. The current report focuses on arterial highway travel time data technology considerations and is not a primer for general travel time best practices. Also, a companion report on rural travel time data collection technology can be found in Singer, Robinson, Krueger, Atkinson, & Myers (2013). The core of the report discusses available and emerging arterial travel time (ATT) 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 ATT data collection are also discussed. In addition, two case studies are reviewed in detail (Chandler, AZ and St. Louis, MO). 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 ATT data collection is a relatively new and rapidly evolving area, ATT 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.

17. Key Words Intelligent Transportation System (ITS), real-time travel time, arterial travel time (ATT), travel time data collection technology, Advanced Traveler Information System (ATIS), Transportation Management Center (TMC)		**18. Distribution Statement** No restrictions	
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No of Pages** 60	**22. Price** N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

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Acknowledgements

The research reported herein was performed under the Federal Highway Administration's TMC Pooled Fund Study under contract DTFH61-06-D-00007 by Westat and SAIC. SAIC was the prime contractor, with Westat having the technical lead. Dr. Emanuel Robinson, Senior Research Scientist at Westat, was the Project Director and Principal Investigator. The other authors of this report are Jeremiah Singer and Jessica Krueger, both Research Associates at Westat, and Jennifer Atkinson and Matthew Myers, both Transportation Engineers at SAIC. Mrs. Atkinson also served as overall Task Manager. We would like to give special thanks to Lisa Bedsole who served as the Technical Editor, provided helpful comments throughout, and ensured 508 compliance of the final reports. In addition, we would like to thank Rick Huey, Senior Research Engineer at Westat, for helpful comments on the final reports. We would also like to thank Westat's Graphics Services, especially Brandy Gruner and Kenneth Von Alt, for producing the final layouts and formatting of the reports.

The authors acknowledge Jimmy Chu, who served as the Federal Highway Administration Government Task Monitor for this project, as well as the Transportation Management Center Pooled Fund Study panel members who provided advice and review throughout the project:

Elizabeth Birriel
Florida Department of Transportation

Mark Demidovich
Georgia Department of Transportation

Jeff Galas
Illinois Department of Transportation

Mike Jenkinson
California Department of Transportation

Jim McGee
Nebraska Department of Transportation

Cathy McGhee
Virginia Department of Transportation

Chris Quesnell
Wisconsin Department of Transportation

Jason Sims
Missouri Department of Transportation

The authors also thank the experts and practitioners who contributed to the case studies, review of practice, and review of technologies:

Jeff Jenq
OZ Engineering

Ben McCawley
City of Chandler

Ben McKeever
Federal Highway Administration

Donna Nelson
Traffax Inc.

Gregory Owens
Missouri Department of Transportation

Edward Smaglik
Northern Arizona University

List of Acronyms

ALPR	Automatic License Plate Reader
AVI	Automatic Vehicle Identification
ATMS	Advanced Traffic Management System
ATT	Arterial Travel Time
CCTV	Closed-Circuit Television
CHATTS	Chandler Automated Travel Time System
DMS	Dynamic Message Signs
DOT	Department of Transportation
DSRC	Dedicated Short Range Communications
FHWA	Federal Highway Administration
FMPO	Flagstaff Metropolitan Planning Organization
GDOT	Georgia Department of Transportation
GPS	Global Positioning System
IRIS	Intelligent Roadway Information System
ITS	Intelligent Transportation System
LIDAR	Light Detection and Ranging
MAC	Media Access Control
MCDOT	Maricopa County Department of Transportation
MoDOT	Missouri Department of Transportation
RADS	Regional Archived Data System
RFID	Radio Frequency Identification
RFP	Request for Proposal
RFQ	Request for Quotation
RML	Radar, Microwave, and LIDAR
TCC	Traffic Control Center
TMC	Transportation Management Center
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

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, travel time messages are now being communicated on arterial roadways.

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 arterials.

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 arterials,
- 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 arterial travel time (ATT) 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 rural 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 arterial 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 arterial highways.

For example:

- Travel times are not collected in isolation and often their use are determined by the local goals and communication needs—and these can be quite different for and between arterials.
- Arterial roadways can vary greatly in their location and use.
- Arterials present unique issues such as signal timing disruptions and dropping out of the route at various points such as parking lots, side streets, alternate routes, etc.
- Urban arterials may be part of a dense and complex roadway network that creates challenges in distinguishing between "signal" and "noise" (i.e., detected motorists/vehicles that should be used to calculate travel times versus those that should not).

Table 1 Candidate ATT 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 arterial locations, it is important to ask the following questions:

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

The core of the report discusses available and emerging ATT data sources as well as implementation considerations, advantages, and limitations on 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 ATT 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, though use for ATT data collection is rare; 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 ATT data collection are also discussed: a) I-95 Corridor Coalition; b) Utah County, UT, I-15; c) multiple routes in Houston; TX, d) Flagstaff, AZ, US 180; e) Atlanta area, GA; f) Essex County, United Kingdom.

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

Chandler, AZ

- There are advantages to using open-source software
- Conduct preliminary tests
- Weigh options across multiple vendors
- Bluetooth detection-based travel time is an inexpensive way to add valuable information to existing dynamic message signs (DMS)
- Limit exposure to system failures
- Consider additional data uses
- Eliminate barriers to data sharing

St. Louis, MO

- Deploy system slowly
- Verify travel time data using other methods
- Keep accurate implementation and asset management records
- Seamless integration between agencies is beneficial
- Involve public in issues relevant to them

The report synthesizes the prior information and brings together the state-of-the-art in ATT data collection technologies and the state-of-the-practice in ATT implementations to develop a set of best practices that are based on systematic evaluation (where possible) and real-world experiences. The best practices related to the data collection technology only; a complete set of best practices for ATT programs is beyond the scope of this effort. These were developed with the understanding that every implementation of ATT 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 ATT 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:

Needs Assessment, Planning, and Specifications Development

- What are the ultimate outcomes desired?
- What are the funding and scheduling constraints?
- What is the desired ATT 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 testing 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 ATT data collection is a relatively new and rapidly evolving area, ATT 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 arterial 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 arterials are relatively rare. Figure 1 shows examples of typical arterial 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 arterials 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 arterial settings, such as the use of Bluetooth dectection technology (e.g., Hardigree, 2011; Puckett & Vickich, 2010), toll tag readers (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 (e.g., Jeng, 2010), crowdsourcing (e.g., INRIX, 2012), connected vehicle, cell phone signal monitoring (e.g., Avni, 2007), and inductive loop detectors (e.g., Blokpoel, 2009). As this list

Figure 1

ATT Signs in Chandler, Arizona

Source: City of Chandler & Oz Engineering, 2011

Source: Video capture from Wimmer, 2010 on ksl.com demonstrates, there is a litany of data collection technologies which have been used for ATT, 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 arterial highways has unique challenges for the practitioner.

For example:

- Travel times are not collected in isolation, and often the uses are determined by the goals and communication needs at a location—and these can be quite different for and between arterials.
- Arterial roadways can vary greatly in their location and use: urban arterials often parallel major freeways in more densely populated areas while rural arterials often act as major alternates through less densely populated areas.
- Although the access to technologies may be similar to freeways, arterials present unique issues such as signal timing disruptions, dropping out of the route at various points such as parking lots, side streets, etc.

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 arterial 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 arterial 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 arterials. 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 arterials, 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 an ATT 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 an ATT 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 ATT 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 rural 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 a substantial body of literature on data collection technologies and numerous evaluations of ATT systems, often comparing novel ATT data collection approaches against other data collection approaches or ground truth data.

The search effort then expanded to include targeted searches to explore the state of the art technologies and practices used for ATT. 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 to 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 ATT have not been widely publicized and do not appear to be widely known among transportation engineers.

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 ATT 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 United States and international practices in ATT 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 systematic evaluation, where possible, 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 ATT data collection system.

Table 2 Table of Search Terms and Categories

Core Concept	Data and Technology	Location	Specific Technologies	Supplementary
Travel time	Data/data collection	Arterial	RFID	Network
Journey time	Monitor*	Off-freeway	Connected vehicle	Guidelines
Traveler information	Real-time	En-route	Video/camera	Best practices
	Calculat*	Freeway approach	Satellite	Operations
	Estimat*	On-ramp	License plate reader	Implement(ation)
	Technology	Surface street	Bluetooth	Traffic
	Infrastructure	Remote	GPS	Integrated corridor management
	Communicat*	Stand-alone	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

2 Data Source Summaries

A variety of technologies and data sources can be used as the basis for travel time calculations. This chapter summarizes technologies that can be used to capture ATT data. Each of the following technologies will be discussed in separate sections:

- Bluetooth detection
- Toll tag reader
- In-pavement magnetic detectors
- Automatic license plate reader (ALPR)
- Machine vision
- Connected vehicle
- Radar, microwave, LIDAR (RML)
- Inductive loops
- 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 arterial roads. 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 ATT 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 ATT 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 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 among the most commonly used technologies for calculating ATT.

Hardware and Installation

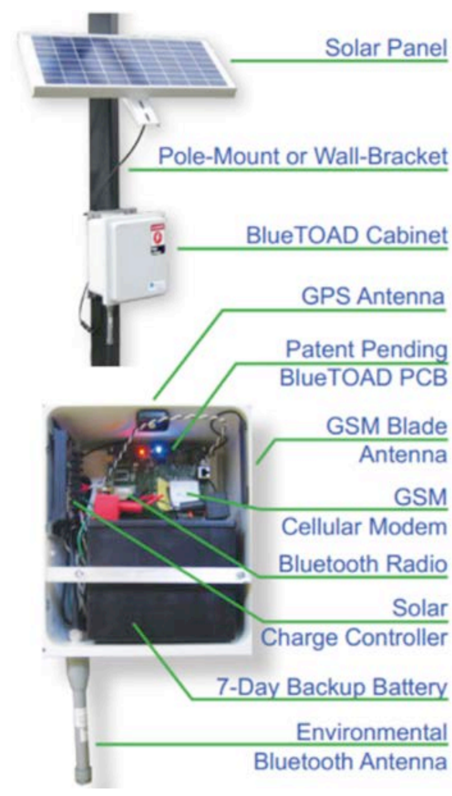
Bluetooth detection offers a wide range of hardware and installation options. Because Bluetooth is an open standard, it is possible to assemble detector systems using off-the-shelf components, though complete systems can also be purchased or leased from vendors. An example of a solar-powered, pole-mounted 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 and the opportunity to detect two-way traffic on broad arterial roads. Detection 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 roadside hardware 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. Data can be logged through existing communications infrastructure or recorded to local hard drives. When given protection from precipitation and extreme temperatures, device maintenance requirements and failure rates can be very low.

Implementation Considerations

Bluetooth detection sensors detect any "discoverable" Bluetooth-enabled devices within a radius of about 328 feet (100 meters), if using a high-powered antenna. Detection range can be reduced by using a lower gain 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 sensor near a major intersection could potentially provide data on signal queue). Some Bluetooth detection devices include global positioning systems (GPS), which allow each device to be precisely located

Figure 2

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



Source: trafficcast.com

Table 3 Candidate ATT 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

and provides automatic time synchronization between devices, ensuring accurate travel time calculations (see Quayle, Koonce, DePencier, & Bullock, 2010).

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 4.3.

Another potential limitation of some versions of Bluetooth detection is the system's "inquiry time." The system initially deployed in Houston, TX (in various locations west of the city), 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 data measurement could lead to travel time inaccuracies, especially over short segment lengths. Furthermore, 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). 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 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 and $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, which are unique and permanent identifiers 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 applications 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 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. 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 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 radio frequency identification (RFID) devices could also be used as an identifier, but no viable plan exists to use such a system.

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 (i.e., overhead on multi-lane facilities). 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). The directionality of toll tag readers can be an advantage when detecting traffic in congested areas such as urban arterials.

Implementation Considerations

Toll tag readers are only feasible for collecting travel time data on routes where a sufficient percentage of vehicles have toll tags. 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 (e.g., operating temperature, power conditioning), 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

Figure 3

Toll Tag Reader (AVI) in Houston, TX

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

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. 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 ATT 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, therefore, 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 (Gregory 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, have limited effect on traffic disruption, and are 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

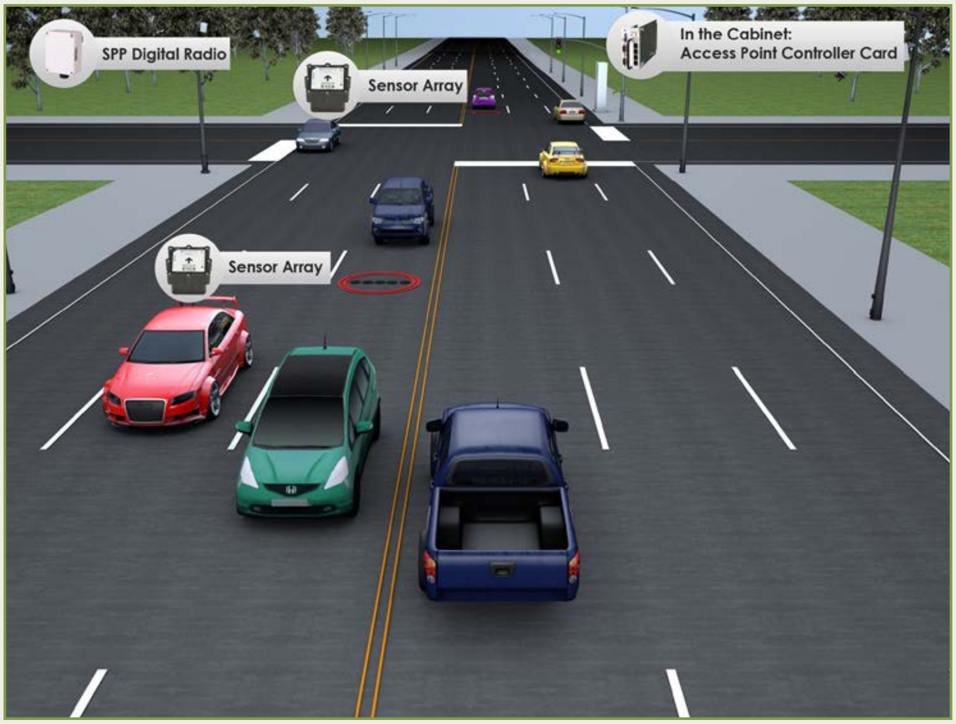
Source: www.sensysnetworks.com

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 volume data that can be used for various purposes. A comparison to ground truth video data ("ideal" output of perfect detection/tracking applied to the video stream) conducted by Sensys showed that in-pavement magnetometers achieved a 70 percent vehicle 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 magnetometers are not likely to be practical for short-term deployments. Additional data such as vehicle class can also be derived from this technology, though additional sensors may be required in an

Figure 5

Typical Sensys Implementation Showing Sensor Array, Repeater, and Access Point



Source: www.sensysnetworks.com

array. However, research by Medina, Hajbabaie, and Benekohal (2010) cautions that magnetic detectors may over count 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 ATT data collection 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 theorectically 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 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 many 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 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

Figure 6

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

Source: FHWA, 2004

Institute estimated that ALPR would cost $25,000 for a four-lane installation, where each lane has its own sensor (ITS International, 2010).

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" along corridors 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. One common use is signal actuation (i.e., detecting vehicles at stop bars). 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 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, and systems can vary substantially in bandwidth requirements. 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 set up 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. Before implementation, it should be confirmed that sufficient communications connectivity can be provided at the site.

Costs

License plate recognition 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-led connected vehicle 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 intelligent transportation systems (ITS), including ncluding 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 arterial roads prone to high speed variability and traffic signal queues, the relatively low cost and variety of other uses and benefits of DSRC might make this technology viable for ATT 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

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 for ATT calculations, however, is relatively uncommon. Sidefire radar is used for ATT calculations in Auckland, New Zealand.

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 as a basis for ATT, given the speed variability and signal queues that are usually inherent on this functional class of roadway. Measurement locations must be selected carefully to ensure applicability. The functional range of radar 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 in order to generate accurate travel time estimates. GPS crowdsourcing has only recently become a viable ATT 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 ATT data 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. While it is theoretically possible for a transportation agency to pursue its own crowdsourced data (e.g., by providing a downloadable data-logging application 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 application on their devices. Such applications 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 arterial 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, though vehicle localization errors can occur on routes with multiple adjacent roads

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 compares it with a map database to determine devices' locations on roadways. In addition, another system uses changes in location over time 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). The location inaccuracy of cell phone handoff systems makes such systems potentially infeasible for arterial use in some areas.

State of the Technology

Cell phone use in the United States is ubiquitous and cell phone network coverage along arterial roads is very high, especially in urban areas. While the base technology has virtually reached saturation, 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 taking 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 are successfully 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 arterials, 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. However, evaluation of a different vendor's cell phone signal monitoring technology found that the data were not highly reliable on arterial roads. In a comparison with ground truth data (or data collected on location), only about two-thirds of monitored urban arterial road segments had an absolute speed error within 10 miles per hour, and fewer than half of segments had a maximum speed error bias within 5 miles per hour (Lattimer, 2010). Data from rural arterials and limited access roads had less error. 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, which 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 arterial 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 Arterial Travel Time Data Collection

This section provides summaries of ATT data collection implementations in the United States and abroad. 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 ATT implementations addressed in this section (Chandler, AZ and St. Louis, MO) are described as detailed case studies, whereas the following implementations are described more briefly.

3.1 Case Study: Chandler, AZ

3.1.1 Background and Planning

Background

The City of Chandler, Arizona has a unique implementation of ATT in which DMS on arterials approaching freeways display travel times that combine the ATT to the freeway and the freeway travel time to one or more destinations. In other words, each travel time estimate includes both the travel time to get to the freeway plus the travel time on the freeway to reach the destination.

Defined Need

Chandler is a city in the southeast corner of the greater Phoenix metropolitan area. Many Chandler residents commute to the adjacent cities of Phoenix, Tempe, and Mesa using a combination of arterial and freeway routes. When the City of Chandler received Federal funding to deploy DMS, it chose to develop a travel time system that would allow the signs to provide useful information to drivers at most times of the day rather than leaving them blank most of the time. The travel time information was expected to aid drivers' en-route decision making, especially during the morning and evening rush hours. Congestion is rare at other times.

Technology Selection

Bluetooth detection was selected for ATT data collection largely due to the relatively low price and ease of deployment. The project was also undertaken on a compressed schedule of three months to develop and deploy equipment, and Bluetooth was seen as more feasible to deploy than other technologies, particularly given the time constraints. Before the bid process began, the city acquired one Bluetooth detection unit for testing and specification development. Preliminary testing showed that with detectors about 0.5 to 1 mile apart, match rates of about 5 to 10 percent of traffic could be achieved, which was expected to be sufficient for accurate travel time estimates during the daytime hours when traffic congestion was most likely (Ben McCawley, personal communication, January 2013). The city put out a request for quotes for a Bluetooth detection system and received three quotes. Chandler selected TPA North America, a distributor of Traffax's BluFAX system. In addition to the system's successful history of use, a major factor in this choice was long-term price: BluFAX had no recurring costs after purchase other than as-needed equipment maintenance. The system was completed and began operation in June 2011. The entire project had a budget of $400,000, including $50,000 for seven Bluetooth detectors and $40,000 for data integration.

3.1.2 Implementation and Management

Location

Seven Bluetooth detectors were acquired and installed in traffic signal cabinets or on light poles where power and communications were available (see Figure 7), and two additional "floating" detectors were acquired that could be dynamically deployed at different locations. The Bluetooth detector locations were selected to provide travel times for three major arterial commute routes. Chandler installed three DMS on those same routes to provide arterial/freeway travel times, each located between about one and two miles from a freeway entrance ramp. The signs are positioned to allow drivers to make route choices before entering the freeway. Each sign shows travel times from the current location to one or two destinations on the freeway. Figure 8 shows each sign in context with its default travel time message. Figure 9 shows the route covered by each DMS as well as the default message format for each sign.

Figure 7

Bluetooth Detector on Light Pole that Taps into a Pedestrian Signal Head Using Power over Ethernet

Source: City of Chandler & Oz Engineering, 2011

Data Collection

The Bluetooth detectors capture raw MAC address data, which are transmitted over City of Chandler's fiber communications network and over a secured internet connection to the BluFAX server hosted by the vendor. (The initial plan called for data to be housed on the vendor's server for the first six months after deployment so that algorithms could be refined to ideally suit the data. However, the data continue to be housed by the vendor so that the City of Chandler and TPA North America can continue to refine the algorithms.) TPA North America processes the data and raw travel times are generated and sent to the City of Chandler, where the data are encrypted and MAC addresses are replaced by random identifiers. The data are then combined with the freeway travel time data (from Arizona Department of Transportation). The travel time data are then used to update the travel time signs in near real-time, and the data are also archived by the City of Chandler in support of planning and performance monitoring.

Multi-Source Data and Data-Sharing Between Agencies

A particularly interesting feature of City of Chandler's travel time system is the use of data from multiple sources. One of the three travel time signs receives all of its arterial and freeway travel time data from Bluetooth detectors. The other two signs, however, receive ATT data from Bluetooth and freeway data from loop detectors. The freeway speed and travel time data are collected by Arizona DOT as part of the Freeway Management System, whereas the arterial data are collected by the City of Chandler. Interagency cooperation has allowed Arizona DOT and the City of Chandler to share data using the Regional Archive Data System (RADS) developed by OZ Engineering. RADS is a regional ITS database system created by AZTech, an ITS consortium involving all regional agencies led by the Maricopa County Department of

Figure 8

ATT Signs in Chandler, AZ

Source: City of Chandler & Oz Engineering, 2011

Figure 9

Locations of DMS and Recommended Routes

Source: City of Chandler & Oz Engineering, 2011

Transportation (MCDOT). The data can be accessed via FTP connection by a variety of regional transportation agencies and private sector companies. For this project, a system named Chandler Automated Travel Time System (CHATTS) was developed to process and fuse Bluetooth travel time with RADS freeway travel time for posting on DMS.

Travel Time Calculations and Messaging

The data are then merged in the Intelligent Roadway Information System (IRIS), which was also used to control DMS message display. IRIS is an open-source advanced traffic management system software package originally developed by Minnesota Department of Transportation, and is made available to other organizations through the Open Source Consortium. It is available for general public use and open-source development, making it an inexpensive and customizable tool for transportation agency use. Once the arterial and freeway travel times are merged in IRIS, travel time calculations basically involve simple addition of ATT and freeway travel time to create a combined travel time. The calculations and message generation are performed automatically, though operators have the ability to override default travel time messages with custom messages.

ATT messages are shown on the signs from 6:00 am to 7:00 pm, Monday through Saturday. The signs typically show only travel times, but in the case of an incident, the signs can be phased to alternate between travel times and incident information. When traffic volumes are especially light, the signs will default to show a free-flow travel time value representing segment travel time at the speed limit. Engineers initially planned for each sign to be able to show travel time information for multiple routes, but pilot testing showed that travel information for multiple freeway routes could not be easily communicated in an understandable way on DMS.

Public Involvement

The City of Chandler released a press release when sign construction began and another when the signs were activated. A web-based survey found that public reaction to the signs has been largely positive. Seventy-six percent of respondents agreed that the travel time information is helpful, 86% found the information easy to understand, and 88% found the travel time estimates to be accurate (City of Chandler & Oz Engineering, 2011). The survey findings suggest that even though the ATT signs do not specifically state what route the travel times are calculated for, respondents generally understood them. The accuracy of travel time estimates provided by the system has been validated only anecdotally to date.

System Maintenance

The City of Chandler reported that the Bluetooth detection system has been virtually maintenance free for 2 years. No Bluetooth units have failed or required maintenance, and as a result, there has been no need to implement a maintenance plan. The system is also capable of automatically alerting operators by email or text message if there is a failure or if other triggers are activated (e.g., travel time for a segment exceeds a threshold value, indicating the possibility of an incident).

Public Relations

When it was first unveiled, the Bluetooth detection system was referred to by some media outlets as a motorist tracking system. This description initially caused some public concern, but these issues were short-lived.

Future Plans

The City of Chandler is seeking funding to add additional Bluetooth detection coverage. The adjacent City of Mesa is in the process of procuring Bluetooth detection for a citywide implementation that will include the use of six DMS. Pending the completion of the Mesa project, Chandler may consider its own city-wide installation, which could provide seamless travel time data for both cities.

3.1.3 Lessons learned

Advantages of Open-Source Software

The City of Chandler opted to use the open source IRIS software as part of the system for automatic posting of travel times on the DMS. The project team found that this approach provided many benefits. First, it saved two to three months of software development time, which led to significant cost savings. Second, features can be customized without the need for advanced coding skills, allowing implementers to adapt the software to their needs rather than being tied to a software package provided by a product vendor. Finally, in the case of IRIS, the software is well documented and was developed and maintained by a reputable agency (Guerra, 2012).

Conduct Preliminary Tests with the Preferred Technology

For the City of Chandler, preliminary testing was invaluable in understanding how Bluetooth detection works and what the key implementation considerations are. This testing helped Chandler to better understand the capabilities and limitations of the technology and allowed the City to clearly specify functional requirements in its request for quote (RFQ) and vet responses to the RFQ.

Weigh Options Provided by Multiple Product Vendors

In the case of Bluetooth detection, there are multiple vendors whose detector packages provide similar capabilities. However, there are notable differences in aspects of services offered and pricing. Some vendors charge ongoing fees for data provision while others charge only an initial outlay for equipment. Vendors also offer different software for data processing and visualization as well as different degrees of customization and cooperation.

Bluetooth Travel Time is an Inexpensive Way to Add Value to Existing DMS

The City of Chandler estimates that the cost of a Bluetooth detector is about 5 percent of the cost of a typical arterial DMS. Therefore, Bluetooth travel time systems can be a relatively inexpensive way to generate useful information to present to drivers on DMS.

Limit Exposure to System Failures

Chandler's travel time data are currently processed by the product vendor on servers far from the Chandler region. If the vendor's servers were to go down due to power loss or other failures, Chandler's travel time system would not be able to function properly. Ben McCawley at the City of Chandler notes that it would be hard to explain to the public in Chandler that the travel time system is down because of a major storm on the east coast. By keeping data processing local or by having backup servers, agencies can limit their exposure to system failure.

Consider Additional Uses of Data

Bluetooth detectors provide data that can be used for many purposes other than generating travel times. Chandler intends to use historical data to understand travel trends, including the effects of seasonal residency in the region. Chandler also intends to use the data for origin-destination study, and may expand its Bluetooth coverage in the city to provide a more complete picture of traffic patterns.

Make Data Easily Available to Partners

Chandler makes its travel time data available to public and private entities that want to use it. By eliminating barriers to sharing, Chandler's travel time data can be made available to travelers via a wider variety of outlets.

Engage Media Outlets

When the Bluetooth detection system was unveiled in Chandler, some media outlets referred to it as a "tracking" system, which caused some public concern. By engaging with media outlets early and describing the system and privacy controls, an agency can minimize the likelihood of misleading media stories.

3.2 Case Study: St. Louis, MO

3.2.1 Background and Planning

Defined Need

By 2009, Missouri Department of Transportation (MoDOT) had completed instrumenting urban freeways in the St. Louis area for travel time using sidefire radar and felt that the next logical step was to expand travel time coverage to arterial roads. Travel time technology in the area serves two primary purposes: travel time dissemination to the public and data collection for internal purposes (e.g., volume, speed, and occupancy).

Technology Selection

MoDOT contracted Sensys Networks to provide its travel time data using its in-pavement magnetometer technology (see Section 2.3). At the time, Bluetooth device saturation rates were not considered to be sufficiently high and MoDOT was not convinced of its efficacy for an arterial network under these conditions. The Sensys system, however, provided nearly 100 percent detection rates and a high vehicle match rate of about 30 to 40 percent. MoDOT's investigation of available technologies convinced them that the magnetometer system was the best technology for their needs, so the project was sole-sourced to Sensys without soliciting other bids.

The Sensys system was more expensive than alternatives such as Bluetooth, but the system was considered a "fairly deluxe solution" that offered benefits in terms of high vehicle detection and match rates that allowed the system to work well with in the arterial environment, along with the ability to collect a full range of data (volume, spot speed, occupancy, and classification). The relatively high cost of the Sensys system is attributed to the technology itself (i.e., five sensors per travel time array, sensors for data collection, repeaters, and access points) system integration costs, and the ongoing services provided by Sensys.

3.2.2 Implementation and Management

Location

The MoDOT ATT system provides coverage on 15 arterial corridors, with a total of more than 130 instrumented miles of roadway. MoDOT considers its Sensys deployment virtually complete because the only uninstrumented arterial corridors are too minor to justify sensor deployment.

Installation

Sensys sensors are installed in the pavement in arrays of five "pucks" aligned perpendicular to the direction of travel. Although installation requires lane closures and a truck-mounted core drill, installation is relatively quick; an array can be installed in 30 minutes. Sensys initially expected that each array would require only three sensors per array, but revised their practice when a new processing algorithm was implemented. This change came late in the design phase and nearly derailed the project due to the extra cost and labor involved, though MoDOT ultimately was able to accommodate the change by cutting back on other costs. Because each array of five sensors is tasked towards the sole purpose of vehicle identification, MoDOT uses additional sensors placed near the travel time arrays to collect other data (volume, speed, occupancy).

This approach provides a more complete picture of traffic conditions to MoDOT than travel time alone, and allows data to be more effectively used to study travel patterns for a variety of purposes. Raw data from the wireless sensors are collected by an "access point." At sites where the access point cannot be installed within wireless range, additional repeaters are required. From the access point, data are sent to the Sensys server at the MoDOT TMC, which uses vehicle matches to generate travel times. The refined data are then streamed to MoDOT's ATMS for live travel time display and data collection/reporting.

Sensor Locations

Sensor arrays were installed approximately every 1 to 1.25 miles at most arterial locations, though some were placed closer together near busy interchanges where complicated traffic patterns could potentially reduce match rates. Arrays were only installed in the far left-hand lane because the left lane carries the highest proportion of through traffic and is least influenced by the effects of vehicles entering and exiting the road. Installation locations were selected by Sensys based on their experience in setting up travel time systems.

Data Integration

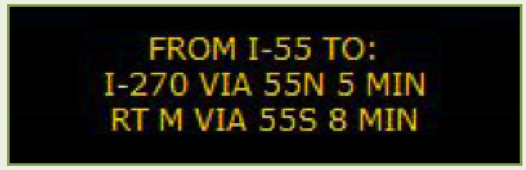
MoDOT currently uses sidefire radar as its primary means of collecting freeway travel time data, with Bluetooth sensors soon to enhance travel time reporting through freeway interchanges. Because MoDOT is responsible for both freeways and most major arterials in the St. Louis area, the process of data integration is simplified due to a lack of institutional barriers, and all travel time data can be integrated in MoDOT's advanced traffic management system (ATMS).

Data Visualization and Dissemination

With the refined data, MoDOT is able to visualize travel time data as a layer on a Google Map and send the data out for display on an arterial DMS. Although the travel time data provided by Sensys are sufficient for dissemination, the usefulness of the data in its basic output format requires additional manipulation to serve other purposes. For example, to compare one arterial corridor to another, MoDOT uses its own ATMS to sort through the Sensys data and reformat it to better suit their needs.

Figure 10

Arterial-based Display on Approach to I-55



Source: King, 2011

Figure 11

Arterial-based Display on Route 94

Source: King, 2011

Arterial DMS Practice

ATT displays are positioned before key diversion routes and are intended to help drivers decide whether to travel on the freeway or take an arterial route. To avoid any problems that might arise from drivers trying to read the DMS rather than focusing on a traffic light, signs were installed at least 500 feet from signalized intersections. They were also positioned to allow a 750 foot sight distance. Most of the ATT signs display only arterial travel times. Some mix freeway and ATT information. Others display only freeway travel times because, near the terminus of some arterial roads, few destinations besides the freeway are available. Most signs are capable of displaying three lines of text and are formatted as in Figure 10. Figure 11 shows an ATT sign along an arterial road. During peak hours, travel time is updated approximately once every minute. When there is less traffic during off-peak hours, travel time is updated less frequently, with a maximum of once every 5 minutes. The signs are operated from 5 am to 10 pm. The signs are turned off overnight to prevent drivers from becoming desensitized to the information due to exposure at times when congestion does not occur. By not disseminating travel times during the overnight hours, MoDOT also limits concerns about insufficient traffic volumes leading to incomplete travel time data. Because some signs are within view of residential areas, it was also seen as a courtesy to residents to turn the signs off outside of peak hours.

Responsibilities of Vendor

MoDOT left most of the travel time system design decisions up to Sensys because they had the expertise and experience. Once the system was online and producing data, MoDOT still had many questions for Sensys and requested changes to the data processing algorithms as unusual outputs were detected. MoDOT had to continuously work with Sensys to modify and adjust algorithms to account for lower than expected speeds.

System Maintenance

This installation does not lend itself to extensive maintenance. In the words of one MoDOT representative, "There is no field work to be done other than plopping the sensors into the pavement." The wireless sensors, however, do need to be replaced every 7-8 years when the batteries run out of power. The system also presents issues if the roadway needs to be repaved. If any of the arterial corridors were simply repaved (without removing the sensors first), MoDOT would lose the ability to find the sensors later. If repaving is necessary, MoDOT recommends first removing the wireless sensors and filling the resulting holes with epoxy. To re-install the wireless sensors, the same process would need to be repeated: the holes would be re-drilled and the sensors placed in those holes and again secured with epoxy.

Future Plans

MoDOT has provided nearly complete coverage on its urban freeways and major arterial roads, and does not foresee any significant changes to this implementation in the near future. The current focus is on expanding freeway coverage on Interstates. MoDOT does not yet have any plans for when the Sensys sensors reach the end of their battery life, which could begin to occur in about 6 years.

3.2.3 Lessons learned

If possible, deploy the travel time system slowly. Although it took years for MoDOT to deploy its entire ATT system, portions of the system were often instrumented and brought online quickly, as funding became available. In retrospect, MoDOT suggests deploying the travel time more incrementally to allow time to identify issues and "fine-tune" the system (Gregory Owens, personal communication, October 2012).

Use Observation and Experience to Verify the Travel Times Provided

As mentioned above, MoDOT noticed some oddities and below-average speeds in its arterial data. MoDOT has had to work with Sensys to tweak the processing algorithms on an ongoing basis.

Keep Accurate, Up-To-Date Records

MoDOT did not keep detailed records of sensor deployments, in part because the ITS project expanded so quickly. These records are especially important so that MoDOT does not lose sensors to repaving or other construction efforts. Although Sensys Networks does have a log of the exact location of each sensor, these data have to be made available to MoDOT.

Seamless Integration Offers Significant Benefits

MoDOT is responsible for "major roadways" in Missouri, including freeways and most of the major arterials. For this reason, the integration of arterial and freeway travel time deployments and other systems was seamless, without any institutional barriers.

Involve the Public in Issues Relevant to Them

MoDOT received some complaints from the public due to dissatisfaction with DMS located near residential neighborhoods being seen as eyesores, especially due to their height and bright lights after dark (Tyson King, personal communication, October 2011). Public involvement early in the process could have helped to place DMS in more acceptable locations.

3.3 I-95 Corridor Coalition

The I-95 Corridor Coalition is a multi-State and multi-jurisdictional organization that functions to improve transportation system performance through coordinated effort. The Coalition serves I-95, which runs from Maine to Florida, passing through 16 States along the east coast. Its members include State and local transportation authorities, toll authorities, and various other organizations (e.g., Amtrak).

In 2008, the Coalition launched its Vehicle Probe Project, a public-private partnership with the University of Maryland and INRIX. The purpose of the project was to create a traffic monitoring system that could be shared amongst members, seamlessly, and at low cost. Using third-party data from INRIX, the project provides travel time and speed data on a network of freeways and arterials along the I-95 corridor. INRIX "fuses" data from a variety of travel information sources including GPS probe data and traffic sensors using their proprietary software and algorithms to generate travel time data. Arterial coverage was included in the project primarily for support purposes. The covered arterials link major freeways and metropolitan areas, and they may serve as alternate routes in the case of significant freeway congestion.

Although the original contract detailed plans for data on 1500 centerline miles of freeways and roughly 1000 miles of arterials, the project has since been expanded. Table 4 shows the project's current coverage by State. These data have been used for the dissemination of travel information on 511 phone lines and websites, as well as on DMS (in Maryland, Virginia, and South Carolina only). According to information on the project's webpage, "The network includes full coverage of freeways and major arterials in North Carolina and the Tidewater area of Virginia, full or nearly full coverage of limited access roads in New Jersey, Maryland and South Carolina and the northern and eastern portions of Florida." Figure 12 shows the freeway and arterial coverage (as built) in Philadelphia, PA.

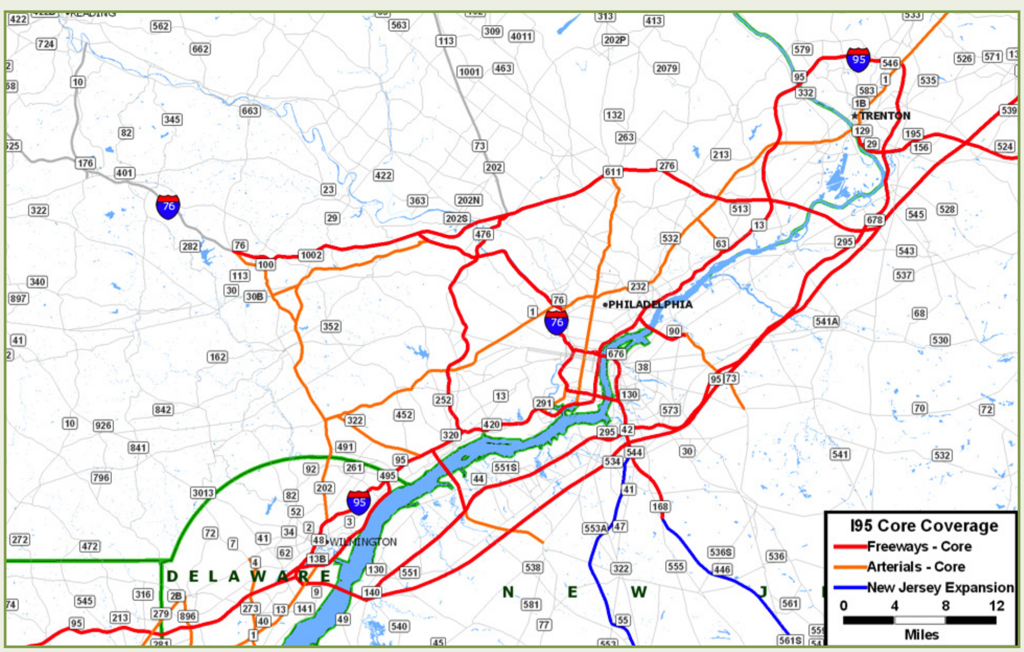
Early evaluations of the INRIX data revealed the following distinct challenges of collecting travel time data on arterial roads (Young, 2010):

Defining and Observing Congestion

Whereas freeway conditions can be fairly easily determined by travel speed, each arterial segment is likely to have a different "free flow" speed depending

Figure 12

Freeway and Arterial Coverage (as Built) in Philadelphia, PA



Source: King, 2011

Table 4 Vehicle Probe Project Current Contracted Coverage

State	Freeway Miles	Other Miles	Total Miles
Maine	66	0	66
New Hampshire	16	0	16
Massachusetts	96	0	96
Rhode Island	162	597	759
Connecticut	111	0	111
New Jersey	895	231	958
Pennsylvania	637	517	755
Maryland	781	3779	4,560
Washington, D.C.	31	233	264
Virginia	1,411	7,213	8,624
North Carolina	1,553	12,996	14,549
South Carolina	934	7,187	8,121
Georgia	357	191	548
Florida	718	0	718
Total	**7,768**	**32,944**	**40,145**

on signal timing and intersection operations, which can also vary through the day. As a result, congestion is relatively difficult to identify.

Variations In Flow Within Arterials

As a result of traffic signal operations, arterial roads are likely to exhibit high variation in travel times between vehicles. These variations often express themselves as bi-modal travel time distributions, where two different travel time clusters appear as a result of vehicle platoons spending different amounts of time stopped at traffic signals.

Temporal Reporting Requirements

The highly variable travel times on arterials, in addition to relatively low traffic volumes, makes average travel time more difficult to characterize over a short period of time. Longer time periods of 10 to 15 minutes may be needed to characterize average travel time on arterials, whereas 5-minute periods are sufficient for freeway travel times.

3.4 Utah County, UT, I-15

I-15 is the major north-south interstate in Utah, passing through Salt Lake City and Provo. As Utah DOT prepared to begin a major 2-year expansion of 24 miles of I-15 (the I-15 CORE project) in Utah County, solutions were sought to help ease the congestion expected as a result of the road work. The construction contractor partnered with TransCore to develop a system to provide travel time signs on arterial roads informing drivers of the travel times on I-15 as well as the travel times on a parallel arterial road, allowing drivers to choose the route that is best for them.

TransCore developed a system using in-pavement magnetic sensors from Sensys (see Section 2.3). Sensors were installed in Utah County on State Street, a major arterial road that runs parallel to I-15. The sensors provide updated travel times every 2 minutes to TransCore's data analysis software, and updated travel times are displayed every 6 minutes on arterial-located travel time signs. Data are also automatically routed to the Utah CommuterLink website so that travelers can use the information for trip planning (TransCore, 2011). Although the system was developed to ease construction-related traffic, it was also intended to remain in place after construction was completed.

Eight ATT signs were installed on westbound approaches to State Street so drivers can see the travel time information, then choose whether continue straight toward I-15 or turn right to drive north on State Street instead. The signs, known as trailblazers, are static signs with a dynamic component on the left side of the sign. The static portion of the sign states the destination (i.e., the city of Lehi, which is a northbound destination). The dynamic portion of the sign is a two phased element that shows travel times to the destination via two routes: Remain on current westbound route toward I-15 North (arrow points up) or turn right to take State Street north (arrow points right). Each phase of the sign is shown for 3 seconds. An example of trailblazer sign operation is shown in Figure 13. According to Sensys, the design, construction, and software development for the system took 6 months and its implementation led to a significant decrease in delays, congestion, confusion, and collisions (Sensys, n.d.).

3.5 Houston, TX, Multiple Routes

Houston TranStar had used toll tag readers as a source of freeway travel time for a number of years, but switched to Bluetooth detectors for a 2011 arterial implementation due to the relative cost savings: Bluetooth detection was estimated to cost nearly half the price of toll tag readers (City of Houston, 2011). Initial investigations found that, on a freeway, Bluetooth detectors and toll tag readers achieved comparable detection and matching rates (Texas Transportation Institute, n.d.).

The City of Houston initially installed six Bluetooth detectors at major intersections using funding for demonstration of ITS technology. This arrangement allowed travel times to be calculated on seven roadway segments spread across five roads, covering a total of 16 directional miles (Puckett & Vickich, 2010). This demonstration showed that ATT could be successfully captured on an urban arterial network. Following this successful deployment, additional Bluetooth detectors were deployed in the area, bringing the total to approximately 50 Bluetooth detectors in a 62-square mile section of West Houston that carries an estimated 12.7 million vehicle miles per day. Detectors were placed at major intersections with distances between sensors ranging from about 0.5 mile to 1 mile (0.8 to 1.6 kilometers).

Figure 13

Both Phases of a Trailblazer Sign

Source: video capture from Wimmer, 2010 on ksl.com

Houston TransStar communicates traffic information via an online map, which can be viewed at: traffic.houstontranstar.org/layers/layers.aspx?mapname=houston_west&inc=true&rc=true. A screenshot of the section of the map showing the arterial traffic conditions is shown in Figure 14. In addition to seeing color coded traffic speeds, users can click on a road segment to see the current average speed for that segment, view incident reports, and view live traffic cameras. The City of Houston expects to expand the Bluetooth detection system to include pan-tilt-zoom cameras and DMS, and to include other areas of Houston.

3.6 Flagstaff, AZ, US-180

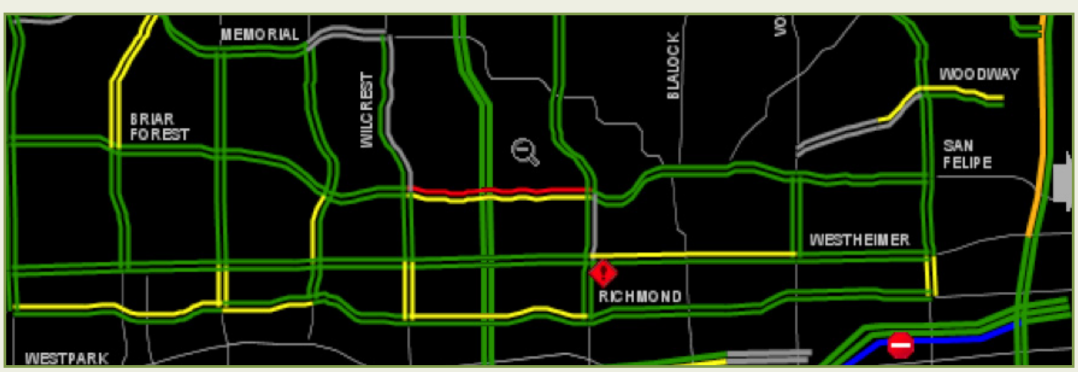
US-180 near Flagstaff, AZ, is a major route to area ski resorts and was experiencing significant congestion from traffic going to and from the resort areas. The Flagstaff Metropolitan Planning Organization (FMPO) considered a variety of approaches to ease congestion. One of the potential approaches was developing a traveler information system that could provide travel times and other information (e.g., alternate route guidance) to motorists.

To explore the feasibility of this approach, 16 Bluetooth detection units were deployed along a six-mile length of US-180 and alternate routes. The units used for this evaluation were portable suitcase-type devices powered by internal batteries provided by Traffax, which was selected by Flagstaff in a noncompetitive process. Each sensor included a cellular modem to upload data to the vendor. Data were processed by Traffax servers and then made available to the project team in Arizona via a Traffax web portal. Travel time data were not made available to the public during the feasibility study.

The study found that travel times were generated successfully for most segments at most times, but that for any given 15-minute period of time, data for the entire instrumented length of road had at least one segment for which data were missing or spurious. Low traffic volumes and low match rates led to an additional difficulty related to filtering outlier data. With few matches in each 15-minute period, the system could not establish a statistically adequate median travel time to be capable of effectively identifying and filtering outlier data. This problem is especially significant in an arterial environment where many vehicles may leave the flow of traffic (e.g., stop at a shopping center) between Bluetooth detection locations. When the system was not effectively filtering outliers, it also made it more difficult to use to travel time data for incident detection, because spuriously long travel time estimates were occasionally recorded.

Figure 14

Houston TranStar Arterial Traffic Map (detail)



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

The results suggested a need to select Bluetooth sensor locations that would allow high match rates and implement travel time algorithms that can accommodate low match rates (e.g., by applying more site-specific filtering and using free-flow speed as a plug value when data are inadequate). In retrospect, the implementing agency felt that more thorough planning before deployment, testing detectors in situ in advance to ensure adequate match rates, and more direct control over travel time algorithms (including outlier filtering) could have led to a more successful implementation (Edward Smaglik, personal communication, October, 2012).

Another lesson learned was related to the sensors themselves. Because the sensors were portable, they relied on cellular communications for data upload. Cellular signal for the selected carrier was unreliable in the study area, so the sensors' cellular modems were often searching for signal, and as a result, sensor battery life was significantly shorter than anticipated (Edward Smaglik, personal communication, October, 2012).

3.7 Atlanta Area, GA

Cobb County is a suburban county northwest of Atlanta. I-75 is a major Interstate passing through Cobb County to Atlanta. The I-75 corridor often experiences congestion as a result of commuter traffic going to and from the Atlanta area. When I-75 experiences heavy congestion, surrounding arterials often experience congestion as drivers seek alternate routes. Since 2003, Georgia DOT (GDOT) has provided I-75 travel times to the public on freeway DMS and its traffic website (www.511ga.org). There are also four arterial DMS showing I-75 travel times on approaches to I-75 to allow drivers to determine whether to take I-75 or an arterial route.

As part of an integrated corridor management initiative, GDOT has recently expanded its travel time system to include travel times for arterial routes themselves. As of July 2012, Bluetooth detection was implemented on select routes in Cobb County (pictured in Figure 15) and Fulton County. Using TrafficCast's BlueTOAD system, 19 sensors were deployed on arterials in Cobb County; 12 sensors were deployed on arterials in Fulton County, and an additional 4 sensors were deployed in the City of Alpharetta (ARCADIS, 2012).

GDOT uses the ATT data to monitor the roadway network for incidents and to determine the effects of heavy I-75 congestion on surrounding arterials. Historical data from the sensors has also helped GDOT to evaluate the performance of its adaptive signal system (TrafficCast, 2012). The arterial travel conditions are shown on a color coded map on GDOT's website, but not on DMS, though GDOT has considered developing DMS signs to present ATT to motorists.

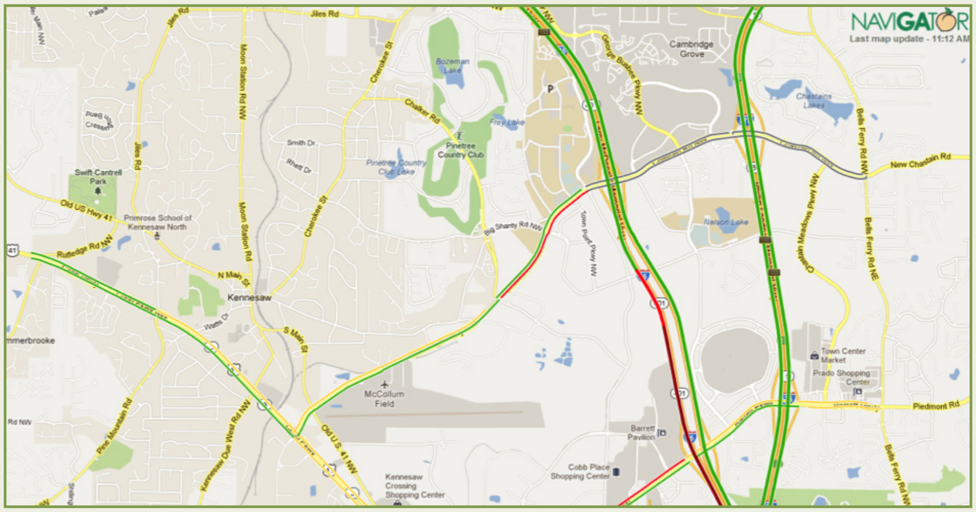
3.8 Essex County, United Kingdom

The county of Essex is located to the northeast of London and is within the "London Commuter Belt." Within Essex, travel time data are collected on two interurban arterial routes: from Chelmsford to Harlow and the M11 motorway (A414) and from Basildon and Southend-on-Sea (A127) to the M25 motorway (see Figure 16). Both motorways are used to commute to London.

To collect travel time data on these two inter-urban routes, the Essex Traffic Control Centre (TCC) uses ALPR, as part of the Comet system provided by Siemens. ALPR is a very well known technology in the area; a huge implementation of ALPR is used in London to conduct automatic tolling and perform security tasks. In Essex, more than 80 ALPR cameras are installed on the arterial roads. One of the most significant challenges reported by the Essex TCC was balancing the need to position cameras to achieve high point-to-point vehicle match rates, while also minimizing overall camera deployment to keep program costs down. Experience showed that achieving high match rates was relatively easy on the interurban arterials because most traffic stays on the road for the full interurban segment. However, matches were much harder to achieve on urban arterials due to the more complex traffic patterns. Where traffic patterns are predictable and match rates are high, ALPR generally only monitors one lane of traffic. Where traffic patterns are less predictable or match rates are low, cameras may observe multiple lanes. The single-lane monitoring approach, however, tended to bias travel time estimates on interurban arterials because heavy trucks were overrepresented in the monitored lane, causing travel times to reflect relatively slow truck speeds. The Essex TCC notes that even with this bias, incidents and congestion can still be easily detected.

Figure 15

ATT Detection Coverage (Shown as Color-coded Arterials) in Cobb County, Georgia: US-41/Cobb Pkwy, Chastain Road, Bells Ferry Road, and Barrett Pkwy



Source: www.511ga.org

As noted on the previous page, travel times were more difficult to calculate on urban arterials than on interurban arterials due to complex traffic patterns. These challenges were compounded by the sites selected for ALPR camera installation. Sites were selected largely on the basis of convenience (e.g., where space and power were available), but were not compatible with drivers' actual traffic patterns. As a result, about one-third of segments provided accurate travel times, one-third provided acceptable data only at peak traffic volume times, and one-third provided no useable data.

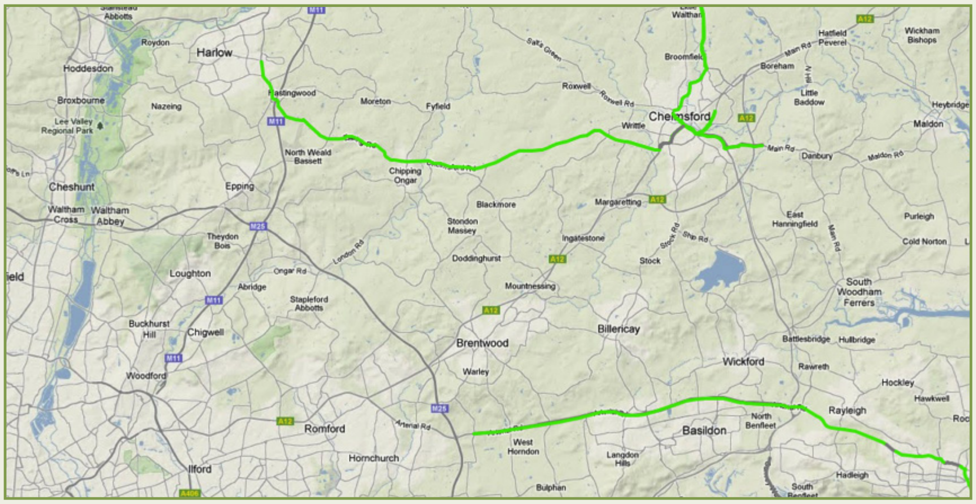
Travel times from the Essex deployment are available to the public through the Essex Traveler Information website (emerge.essexcc.gov.uk), in both map and text format, and on area DMS. Authorities are considering expanding the travel time coverage to other roadways and providing comparative travel times via multiple routes.

Lessons learned in this implementation include:

- The capabilities and limitations of data collection technology must be well understood to ensure that they are used most effectively. In particular, ALPR cameras require a precise location and aim to read license plates at a high rate of accuracy.
- Detection technologies must be placed with consideration of the origin-destination flow of traffic to ensure that sufficient matches can be achieved to calculate travel times.
- While data collection technologies can be configured to report faults to authorities, not all problems are identified as faults. For example, if an ALPR camera is bumped so that its field of view changes, it may not function appropriately, but no fault condition will be reported. Only operator vigilance will detect such issues.
- Vandalism of ALPR cameras was an issue, likely due to incorrect assumptions that the cameras were used for speed enforcement, or due to other concerns about government monitoring.

Figure 16

ATT Coverage (Shown as Green-colored Arterials)
in Essex County, UK



Source: emerge.essexcc.gov.uk

4 Best Practices for Arterial Travel Time Data Collection

This chapter brings together the state-of-the-art in ATT data collection technologies and the state-of-the-practice in ATT implementations to develop a set of best practices that are based on systematic evaluation (where possible) and real-world experiences, focusing on best practices related to the data collection technology; a complete set of best practices for ATT programs is beyond the scope of this effort. The best practices were developed with the understanding that every implementation of ATT 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 ATT 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 ATT implementation.

4.1 Needs 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 ATT Program?

Agencies that have implemented their own ATT programs have done so for a variety of reasons. Some intended to enhance their own abilities to monitor regional traffic conditions. Some intended to ease traffic over a congested corridor by providing traveler information in order to improve drivers' abilities to make efficient routing decisions. Some decided that it was a cost effective way to provide desirable information to motorists, or to make use of underutilized DMS.

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 ATT coverage?

While the primary objectives of an ATT 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, ATT systems can provide data on traffic volumes and vehicle classification, 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 objectives have been defined, the next step is to determine the specifications for the ATT program. Development of specifications for an ATT 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 ATT program will be capable of achieving its objectives.

How can ATT Meet Mandates?

An ATT 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)* (www.ops.fhwa.dot.gov/1201). 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 arterial 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 ATT program is within the scope of available funding. For example, depending on how it is implemented, an ATT 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 ATT Coverage Area?

A clear definition of the project objectives should help to identify the target ATT coverage area. If the objective is to provide travel times to commuters to help them choose between multiple commute routes, instrumenting one or two primary arterials may be sufficient. If the objective is to monitor traffic conditions on an urban grid, a network of arterial roads may need to be monitored. The coverage area has implications for the choice of data collection technology. If ATT data are only desired for one or two arterial roads, sensors placed on those roads may be the most efficient solution. If ATT data are desired throughout an arterial network, private-sector providers that use GPS probe data might offer the most appropriate solution.

What are the Needs for Scalability?

When first implementing an ATT 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 of 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 ATT 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 ATT 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) 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 ATT 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 a 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 are likely to be much more significant in the arterial environment than the freeway environment due to the potential for lower traffic volumes, greater travel time variability, and additional "noise" in the data from vehicles entering and exiting the roadway.

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 in arterial environments where travel speeds are likely to be highly variable due to traffic control devices.

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. Data will be delayed to a greater degree if segments between sensors are long or if travel times increase (e.g., due to congestion). 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 ATT program must fit into the broader traffic management context. Often, this involves sharing resources with other agencies. For instance, the agency implementing ATT might not be the same agency that is implementing a freeway travel time program or an integrated corridor management program. However, 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 arterial travel times for dissemination to the public. Often, different agencies are responsible for freeway and arterial management. In Chandler, AZ, implementers found success in establishing a data sharing architecture in which State DOT data are readily accessible to the city, allowing arterial and freeway travel time data to be merged and presented cohesively to drivers on DMS.

What are the Infrastructure Requirements?

Each ATT 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 may have relatively high data transmission and power requirements
- Bluetooth detectors are particularly flexible in terms of installation location and power requirements
- Crowdsourced data using GPS or cellular tracking likely requires no infrastructure elements at all

If the arterial 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 arterial roads, new structures such as mounting poles and cantilevers might be undesirable due to aesthetic concerns, safety impacts, or lack of available right-of-way. Some hardware may require environmental assessments.

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. When traffic volumes are 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 ATT 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, however, ATT 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 agencies can significantly increase the efficiency with which data can be processed and used.

If new software is required to make use of ATT data, a potential solution is to 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 ATT 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 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 ATT.

As discussed in Chapter 2, the costs of ATT data collection technologies can 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 sensor 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 (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 ATT 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 ATT 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, agencies can develop 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. Finally, should there be any significant unanticipated problems with the system, it should be clear who assumes these risks and the financial and liability responsibilities for problems.

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).

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?

The arterial environment creates a number of challenges when locating ATT sensors. For technologies that calculate individual vehicles' travel times through a segment, vehicles entering and exiting the traffic stream can cause data loss and provide inaccurate data (e.g., if a vehicle makes a stop or detour, then continues along the route). A general rule of thumb used for many arterial probe data technologies is to locate sensors 0.5 to 1 mile apart, though circumstances may require alterative spacings. For example, on roads with a substantial amount of traffic entering and exiting the traffic stream (e.g., near a major shopping center), or on roads with relatively low traffic volumes, closer spacing may be required to achieve an adequate number of matches. Preliminary testing with a data collection technology may help to determine how traffic patterns may influence device placement. The technology vendor should 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 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 ATT 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.

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 (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 or 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 immediately 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 maintenance staff should be available to deal with potential startup problems. 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 ATT implementers have conducted formal evaluations of ATT data quality. 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). Given that the arterial environment may have a high prevalence of "noise" data from vehicles exiting and entering the traffic stream, one way to explore data quality is to view a plot of individual vehicles' travel times to verify that data filters are appropriately removing outlier data.

How Should Public and Media Relations be Handled?

It is important to proactively address potential public concerns about an ATT program. If the ATT 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 arterial environments, a new pole might be seen as an eyesore.

How can the Effectiveness of an ATT Program be Evaluated?

To date, there have been few formal evaluations of the effectiveness of ATT programs in meeting their goals. In part, this may be because many goals of ATT programs can be difficult to assess affordably and with statistical rigor. Evaluations can investigate effects in terms of network performance, driver behavior, or more qualitative outcomes (e.g., driver satisfaction, comprehension). Establishing performance measures for evaluating the ATT 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. Robinson, Jacobs, Frankle, Serulle, and Pack (2012) investigated travelers' use of various types of traveler information including travel time using surveys and focus groups. The researchers found that, across many areas of the United States, travelers overwhelmingly like having en-route travel time information and highly prioritize accuracy, timeliness, and clarity of the information.

5 Conclusion

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

Although ATT data collection is a relatively new and rapidly evolving area, ATT 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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April 2013

FHWA-HOP-13-028