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EVALUATING THE FEASIBILITY OF INCORPORATING MOBILITY-BASED WORK ZONE TRAFFIC CONTROL PERFORMANCE MEASURES IN HIGHWAY CONSTRUCTION PROJECT SPECIFICATIONS: VOLUME I. FEASIBILITY OF CONTINUOUS MONITORING OF PERFORMANCE MEASURES

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16. Abstract

Utah Department of Transportation desired to investigate the feasibility of implementing mobility-based performance specifications for highway construction projects. Multiple methods for gathering information on this topic were used, including a literature search, interviews, and an online survey. The literature review examined mobility-based performance measures; mobility-based performance specifications; and seven technologies: automatic license plate recognition, Bluetooth, magnetic sensors, automatic vehicle identification, microwave radar, cellular phones, and global positioning systems. Current practices concerning implementation of mobility-based performance specifications were investigated on 7800 South and Bangerter Highway projects in West Jordan, Utah, for example. An online survey was developed and distributed to representatives of 50 STAs in the United States to collect information on current practices of incentive/disincentive specifications and mobility-based performance specifications for highway construction contracts. The survey showed that three STAs (South Carolina, Pennsylvania, and Wyoming) have considered investigating the practice of mobility-based performance specifications in highway construction projects. Overall, the study found that the current technology is capable of continuously collecting mobility data necessary for implementing mobility-based performance specifications in highway construction projects. While this type of specification is found to be feasible to implement, it is important to understand that a large amount of data will be collected and extra personnel are needed to monitor and execute the mobility-based performance specifications.

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TABLE OF CONTENTS

LIST OF TABLES ix
LIST OF FIGURES xi
LIST OF ACRONYMS xiii
EXECUTIVE SUMMARY 1
1.0 INTRODUCTION 3
1.1 Background 4
1.2 Objectives and Study Methodology 4
1.3 Organization of the Report 6
2.0 LITERATURE REVIEW 7
2.1 Mobility Data Collection Technology 7
2.2 Incentives and Disincentives 8
2.2.1 Type of I/D Contracts 8
2.2.2 Methods for Establishing I/D Amounts 10
2.2.3 Considerations with Implementing Incentive and Disincentive Contracts 17
2.3 Performance-based Specifications and Assessments 18
2.3.1 Maintenance Contracts 18
2.3.2 Work Zone Evaluations 19
2.4 Chapter Summary 20
3.0 MOBILITY DATA COLLECTION TECHNOLOGY 23
3.1 Automatic License Plate Recognition 23
3.1.1 Advantages 25
3.1.2 Disadvantages 26
3.2 Bluetooth 27
3.2.1 Advantages 27
3.2.2 Disadvantages 29
3.2.3 Companies Offering Bluetooth Data Collection Services 31
3.2.4 Examples of Existing Practices 37
3.3 Magnetic Sensors 39
3.3.1 Advantages 40
3.3.2 Disadvantages 40

3.3.3 Company Offering Magnetic Sensor Systems 41
3.3.4 Examples of Existing Practices 44
3.4 Automatic Vehicle Indentification 48
3.4.1 Advantages 49
3.4.2 Disadvantages 49
3.4.3 Examples of Existing Practice 49
3.5 Microwave Radar 52
3.5.1 Advantages 52
3.5.2 Disadvantages 53
3.5.3 Companies Offering Microwave Radar Equipment 53
3.5.4 Example of Existing Practices 57
3.6 Cellular Phone 62
3.6.1 Advantages 63
3.6.2 Disadvantages 63
3.6.3 Company Offering Cellular Phone Data Collection Services 64
3.6.4 Existing Practices 65
3.7 Global Positioning System 69
3.7.1 Advantages 69
3.7.2 Disadvantages 70
3.7.3 Company Offering GPS Data Collection Services 70
3.7.4 Existing Practices 71
3.8 Chapter Summary 73
4.0 PERFORMANCE MEASURES AND SPECIFICATIONS 77
4.1 Purpose of Using Performance Measures Specifications 77
4.2 Selecting Performance Measures 78
4.2.1 Exposure Measures 78
4.2.2 Safety Measures 79
4.2.3 Mobility Measures 79
4.3 Current Practices 80
4.3.1 Pilot Tests for Mobility Performance Data Collection in Work Zones 80
4.3.2 Mobility-based Performance Specifications 85

4.4 Chapter Summary 95
5.0 ONLINE SURVEY ON CURRENT I/D PRACTICES AND PERFORMANCE SPECIFICATIONS 99
5.1 Methodology 99
5.1.1 Survey Participants 99
5.1.2 Organization of the Survey 100
5.2 Survey Results 100
5.2.1 Section 1: General I/D Practices 100
5.2.2 Section 2: Mobility-based Performance Specifications 107
5.2.3 Section 3: Mobility-based Performance Data Collection in Work Zones 108
5.2.4 Section 4: Data Collection Technology 112
5.3 Chapter Summary 112
6.0 CONCLUSIONS AND RECOMMENDATIONS 115
6.1 Research Findings 115
6.1.1 Literature Review 115
6.1.2 Mobility Data Collection Technology 116
6.1.3 Performance Measures and Specifications 116
6.1.4 Online Survey on Current I/D Practices and Performance Specifications 117
6.2 Recommendation for Future Work 117
6.2.1 Developing Guidelines for Mobility-based Performance Specifications 117
6.2.2 Pilot Tests 118
REFERENCES 119
APPENDIX A: CURRENT MOBILITY PERFORMANCE SURVEY 125

LIST OF TABLES

Table 2-1. NJDOT Daily I/D Amounts Based on Total Project Cost 9
Table 2-2. Type of Maximum Incentive Cap for Various STAs 12
Table 2-3. Advantages and Disadvantages of Using I/D Clauses 18
Table 2-4. Examples of Selected Performance Measures and Standards from the Trans-Canada Highway Project 19
Table 3-1. Checkpoint Spacing for ALPR 24
Table 3-2. Symbols and Meaning Used in "Trend" Column 33
Table 3-3. Queue Length Based on Data Collected through Video Camera or Magnetic Sensors 46
Table 3-4. Error Comparison for TRANSMIT Estimate versus GPS Probe Data 51
Table 3-5. Missed and Phantom Vehicles during Wavetronix Study on US-50 58
Table 3-6. MnDOT iCone Speed Accuracy Results 60
Table 3-7. Average Absolute Speed Difference between AirSage and GPS Data 67
Table 3-8. Absolute Error Break Down for AirSage System 68
Table 3-9. Percentage of Time Observed for Each Relative Error of Reported Travel Time 68
Table 3-10. Error Comparison for Bluetooth and INRIX Data against GPS Probe Vehicle Data 72
Table 3-11. Descriptions of Investigated Technologies 74
Table 3-12. Advantages and Disadvantages for the Seven Investigated Technologies 75
Table 4-1. NCDOT Performance Measure on Queue Length and Queue Duration 81
Table 4-2. Comparison of Queue Measures Collected by Field Crew and Traffic Sensors 84
Table 4-3. Proposed Alerts for Individual Turning Movements on Bangerter Highway 90
Table 4-4. Project Proposed Alerts for through Movements on Bangerter Highway 91
Table 4-5. Concerns and Recommendations for Performance-based Specifications 97
Table 5-1. Number of I/D Projects within the Past Five Years 101
Table 5-2. I/D Project Information 102

LIST OF FIGURES

Figure 2-1. Process Diagram for Establishing I/D 15
Figure 2-2. Example User Screen for Sillars and Riedl's Model 16
Figure 3-1. Process for License Plate Vehicle Recognition 25
Figure 3-2. Examples of Misidentified License Plate Numbers 27
Figure 3-3. Bluetooth Traffic Monitoring Operation Concept 28
Figure 3-4. Various Deployment Locations for Portable Bluetooth Data Collection Devices: (a) and (b) behind a guardrail and (c) behind a VMS 30
Figure 3-5. Screenshot of BluFAX Web "Links" Page 33
Figure 3-6. Calculated Travel Time Chart in BluFAXWeb 34
Figure 3-7. Screenshot of Map Feature in BluFAXWeb 35
Figure 3-8. Screenshot of Travel Time Results Using BluSTAT Software 36
Figure 3-9. Screenshot of Summary Interval 37
Figure 3-10. Visual Diagram of Magnetic Sensors 39
Figure 3-11. General Process to Match Vehicle Signatures 40
Figure 3-12. Sensys Network Sensor 41
Figure 3-13. Screenshot of System Status Page in SNAPS Dashboard 42
Figure 3-14. Screenshot of SNAPS Traffic Statistic Report Output 43
Figure 3-15. Location of Entrance and Exit Sensors Group 44
Figure 3-16. Wireless Magnetic Sensors Configuration at Entrance of Ramp 45
Figure 3-17. Travel Time Comparison for AM and PM Peak – January 2012 47
Figure 3-18. Concept of Radio Frequency (RF) Toll Tag 48
Figure 3-19. Set up for Microwave Radar Data Collection 52
Figure 3-20. Screenshot of Daily Peak Report 54
Figure 3-21. Multiple RTMS G4 Units 55
Figure 3-22. iCone Traffic Drum 56
Figure 3-23. Screenshot of Sample iCone Data 57
Figure 3-24. Typical Layout for Monitoring Devices 62
Figure 3-25. Diagram of AirSage Processing System 65
Figure 3-26. Graphical Comparison of AirSage (Left) and Existing Sensors (Right) Coverage in Salt Lake City 66

Figure 4-1. PTMD Layout of I-95 Pilot Test 82
Figure 4-2. Comparison of the Field Crew and Traffic Sensor Data 84
Figure 4-3. Aerial Photograph of Fairchild Creek Culvert Replacement Project and Location of Bluetooth Units 86
Figure 4-4. Location of Bluetooth Sensor 89
Figure 5-1. Project Characteristics for Using I/D Provision in Work Zone Contracts 103
Figure 5-2. How STAs Define the Maximum Incentive and Disincentive Amount per Project 104
Figure 5-3. Relationship between Incentive and Disincentive Amount 105
Figure 5-4. Benefits of Implementing I/D Projects 106
Figure 5-5. Problems Encountered with Applying I/D Provisions 106
Figure 5-6. Responses for Investigating or Implementing Mobility-based Performance Specifications in Highway Construction Contracts 108
Figure 5-7. Mobility Performance Data Collection Technology in Work Zones 109
Figure 5-8. Type of Mobility Performance Data Being Collected in Work Zones 110
Figure 5-9. Data Application for Collected Mobility Data Responses 110
Figure 5-10. Responsible Parties for Collecting and Managing Data, Managing Data Collection Equipment, and Interpreting Data 111

LIST OF ACRONYMS

AASE	Average absolute speed error
AASHTO	American Association of State Highway and Transportation Officials
AGM	Absorbed glass mat
ALPR	Automatic license plate recognition
ASTME	American Society of Tool and Manufacturing Engineers
ATR	Automatic traffic recorder
AVI	Automatic vehicle identification
BLS	Bureau of Labor Statistics
BlueTOAD	Bluetooth Travel-time Origin and Destination
BYU	Brigham Young University
CA4PRS	Construction Analysis for Pavement Rehabilitation Strategies
CAC	Contractor's additional cost
Caltrans	California Department of Transportation
CFI	Continuous flow intersection
CSAH-81	Country Road 81
DOD	Department of Defense
EMS	Emergency medical services
FAP	Flashing arrow panel
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GPS	Global positioning system
HCM	Highway Capacity Manual
I/D	Incentive and disincentive
I-290	Interstate 290
I-35E	Interstate 35 East
I-35W	Interstate 35 West
I-394	Interstate 394
I-405	Interstate 405
I-65	Interstate 65

I-95	Interstate 95
IDOT	Illinois Department of Transportation
INDOT	Indiana Department of Transportation
IR	Infrared
IRI	International roughness index
ITS	Intelligent transportation systems
JUB Engineers	JUB Engineers, Inc.
LOS	Level of service
MAC	Media access control
MnDOT	Minnesota Department of Transportation
MTO	Ministry of Transportation of Ontario
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NEWS	Node Event Warning System
NJDOT	New Jersey Department of Transportation
O-D	Origin destinations
ODOT	Oregon Department of Transportation
ORITE	Ohio Research Institute for Transportation and the Environment
PennDOT	Pennsylvania Department of Transportation
PTMD	Portable traffic monitoring device
RF	Radio frequency
RFP	Request for proposal
RTMS	Remote traffic microwave sensor
RUC	Road user cost
SD	Secure digital
SDI	Surface damage index
SE	Southeast
SEB	Speed error bias
SEM	Standard error of the means
SNAPS	Sensys Networks Archive, Proxy and Statistics
SPUI	Single point urban interchange

STA	State transportation agencies
TAC	Technical advisory committee
tagID	Tags identification
TMC	Transportation management centers
TMP	Transportation management plans
TOC	Traffic operation center
TOPS Lab	Traffic Operation and Safety Laboratory
TRANSMIT	TRANSCOM System for Managing Incidents and Traffic
UDOT	Utah Department of Transportation
v/c	Volume-to-capacity
VDOT	Virginia Department of Transportation
VMS	Variable message sign
WATER	Wide Area Traffic Event Reporting
WSDOT	Washington State Department of Transportation
WYDOT	Wyoming Department of Transportation

EXECUTIVE SUMMARY

In recent years, implementing mobility-based performance specifications has been a topic of interest for many state transportation agencies (STAs). However, a National Cooperative Highway Research Program (NCHRP) domestic scanning tour of best practices in work zone assessment, data collection, and performance evaluations found that no STA has implemented mobility-based performance specifications for highway construction contracts due mainly to the difficulty in obtaining real-time performance data in work zones throughout the duration of the construction. Hence, Utah Department of Transportation desired to investigate the feasibility of implementing mobility-based performance specifications for highway construction projects. Multiple methods for gathering information on this topic were used, including a literature search, interviews, and an online survey. The literature review examined mobility-based performance measures; mobility-based performance specifications; and seven technologies: automatic license plate recognition, Bluetooth, magnetic sensors, automatic vehicle identification, microwave radar, cellular phones, and global positioning systems. Current practices concerning implementation of mobility-based performance specifications were investigated on 7800 South and Bangerter Highway projects in West Jordan, Utah, for example. An online survey was developed and distributed to representatives of 50 STAs in the United States to collect information on current practices of incentive/disincentive specifications and mobility-based performance specifications for highway construction contracts. The survey showed that three STAs (South Carolina, Pennsylvania, and Wyoming) have considered investigating the practice of mobility-based performance specifications in highway construction projects.

Overall, the study found that the current technology is capable of continuously collecting mobility data necessary for implementing mobility-based performance specifications in highway construction projects. While this type of specification is found to be feasible to implement, it is important to understand that a large amount of data will be collected and extra personnel are needed to monitor and execute the mobility-based performance specifications.

1.0 INTRODUCTION

Highway construction projects can cause delay and congestion to road users. In order to minimize the negative effects for the road users, many state transportation agencies (STAs) have implemented incentive and disincentive (I/D) provisions in highway construction contracts. These I/D provisions award and/or penalize contractors when certain conditions are met. A common criterion is schedule-based, where contractors are awarded or penalized for an early or late project completion, respectively. Schedule-based I/D provisions have proven to be successful in reducing the time needed to complete projects and delays for the road users. In recent years, adding performance-based I/D provisions to highway construction project specifications is a topic of interests for many STAs. Performance-based I/D provisions assess the contractors on certain performance measures such as safety or mobility. Safety-based performance specifications focus on improving safety in the work zones. Mobility-based performance specifications are intended for ensuring a baseline speed or travel time for the traveling public in work zones.

For mobility-based performance specifications, the type of performance measures to be used, the measurement methods, and the expected accuracy level have not yet been well defined. If these items are not well defined, it will be difficult to implement such measures as part of highway construction contracts. In addition the feasibility of implementing a performance-based specification in highway construction contracts is unknown. In an effort to better define these items and determine the feasibility of mobility-based performance specifications in highway construction contracts, Brigham Young University (BYU) conducted a research study for the Utah Department of Transportation (UDOT). The study consisted of investigating technologies for collecting mobility-based performance data in work zones and evaluating performance criteria. The feasibility of measuring mobility-based performance data in work zones will be based on research findings. If mobility-based performance measurements are found to be feasible, key criteria for implementing such specifications and recommendations for future direction will be identified. The remainder of this chapter presents background information, study objectives, methodology, and organization of the report.

1.1 Background

In order to collect data for mobility-based performance specifications for work zones, static or real-time analysis can be performed. Static analysis only analyzes one instant in time. The data are collected at a determined time and are analyzed using methods outlined in the Highway Capacity Manual (HCM) or other standard methods. Static analysis is simple to implement; however, there are limitations in portraying dynamic changes in performance measures and characterizing impacts on highway users. Real-time analysis involves collection and analysis of data continuously during the duration of the project. This method can better estimate the impact of construction work on highway users; however, real-time data collection for mobility-based performance measures is still a developing topic. Until data collection methods that are feasible and reliable become available, implementation of mobility-based performance specification in highway construction contracts will not take place.

From 2009-2010, the National Cooperative Highway Research Program (NCHRP) conducted a domestic scanning tour to investigate best assessment, data collection, and performance measurement practices in work zones. The domestic scanning tour findings are documented in NCHRP *Scan 08-04: Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation Scan Team Report* (Bourne et al. 2010). The scanning team found that there was no case of using real-time mobility-based performance measurements among the 15 STAs the scanning team visited. In order to better understand the requirements for applying mobility-based performance specifications, this study was conducted.

1.2 Objectives and Study Methodology

The purpose of this study is to evaluate the feasibility of implementing mobility-based performance specifications in highway construction contracts and, if found feasible, develop guidelines and criteria for applying mobility-based performance specifications.

The study project has four objectives:

1. Evaluate thoroughly the findings of NCHRP *Best Practices in Work Zone Assessment, Data Collection, and Performance Measurement* and other literature related to real-time data collection of mobility-based performance measures to find how much effort is involved to obtain accurate real-time measurements of selected performance measures.

2. Identify potential performance measurement technologies currently available, such as microwave sensors and license place identification technology, and technologies under development or testing, such as Bluetooth technology or vehicle signal identification technology.

3. Identify stakeholders, both UDOT and contractors, and invite them to organize a task force for determining guidelines and criteria for applying mobility-based performance specifications in highway construction contracts, once current technology is found to be able to continuously monitor mobility-based performance measures in work zones.

4. Recommend future directions for applying mobility-based performance measures to UDOT's highway construction contracts to maintain traffic flow through work zones.

The study consists of two phases. Phase I focuses on achieving the first and second objectives, while Phase II focuses on achieving the third and fourth objectives.

The first phase began in January 2012. Three tasks were associated with the first phase, which includes conducting a literature search, investigating current use of mobility-based performance measures in work zones, and studying the state-of-the-art of mobility data collection technologies. For the literature search, publications found in transportation engineering and construction journals were obtained and evaluated. Information for the second task was gathered from interviews with UDOT employees who have been involved in projects with performance-based specifications and from a survey that was developed and sent to STAs. The third task was conducted through in-person interviews and web conferences with company representatives and technology users. The results and findings of the first phase of the study are summarized in this report, which serves as an interim report for the project.

For Phase II, a task force will be formed in order to develop criteria for applying and implementing mobility-based performance specifications in UDOT's highway construction contracts, followed by recommendations for future research and potential tests for evaluating how mobility-based performance specifications will work for actual highway construction projects. The findings from Phase II will be presented in the final project report.

1.3 Organization of the Report

This report is organized into the following chapters: 1) Introduction, 2) Literature Review, 3) Mobility Data Collection Technology, 4) Performance Measures and Specifications, 5) Online Survey on Current I/D Practices and Performance Specifications, and 6) Conclusion and Recommendations. A list of references and appendices follow these chapters.

Chapter 2 presents a brief summary of findings for the literature review conducted for the study. Detailed findings of the literature search will be discussed in subsequent chapters. Chapter 3 discusses the state-of-the-practice and state-of-the-art traffic data collection technologies. Seven technologies are described with their advantages and disadvantages. The seven technologies discussed in this chapter include automatic license plate recognition (ALPR), Bluetooth, magnetic sensor, automatic vehicle identification (AVI), microwave radar, cellular phone and global positioning system (GPS). Chapter 4 describes mobility-based performance specifications. Mobility-based performance specifications set criteria for contractors to maintain a certain level of work zone performance based on mobility measures such as travel time and delay. Chapter 5 presents the purpose, methodology, and results of the online survey that was sent out to 50 STAs in order to gather information on current practices for I/D specification, mobility-based performance specification, mobility-based data collection in work zone, and data collection technology. Chapter 6 presents the conclusion of this study as well as recommendations for future research in this area.

2.0 LITERATURE REVIEW

A literature review was conducted on topics concerning mobility-based performance data collection technologies, I/D practices, and performance-based specifications. In recent years the idea of mobility-based performance evaluations of traffic flow in work zones has been an active topic for STAs. Data collected from work zone projects are useful in many ways. For example, mobility performance data such as travel time or delay may be displayed on variable message signs (VMSs) to highway users to inform them of current traffic conditions. Such data can also be used to evaluate how well the work zone traffic control plan is working.

This chapter presents a brief summary of three main topics studies in this study, which are mobility data collection technology, I/D practices, and performance-based specifications and assessments. Details on mobility data collection technology and mobility-based performance evaluation are presented in subsequent chapters.

2.1 Mobility Data Collection Technology

The data necessary for mobility-based performance specifications can come from the same technologies used for travel time and delay evaluation studies. Mobility-based data have been collected since the 1920s by engineers and planners to evaluate the performance of transportation facilities and to plan for future transportation needs (Turner et al.1998).

In 1998, the Federal Highway Administration (FHWA) published the *Travel Time Data Collection Handbook*, which offers guidance specifically for travel time data collection purposes. The document describes four data collection techniques, the advantages and disadvantages of each technique, their costs, and the associated equipment requirements. The four techniques included test vehicle, license plate matching technique, intelligent transportation systems (ITS) probe vehicles technique, and emerging and non-traditional techniques. Since the publication of the *Travel Time Data Collection Handbook*, new and emerging technologies have been introduced, and they have changed the way travel time data are collected. Discussions of these new and emerging technologies are presented in Chapter 3.

2.2 Incentives and Disincentives

Roadway construction can negatively affect roadway users. Lane closures and detours cause inconvenience and add travel time to roadway users. Over the years there has been increasing pressure for STAs to reduce construction time. To reduce construction time, STAs have included I/D clauses in their highway construction contracts. The purpose of I/D contracts is to award or penalize contractors based on criteria set in the contracts. Adding I/D clauses creates a win-win situation for STAs and contractors. STAs can benefit from I/D projects with reduced construction time and lower road-user costs. I/D contracts help contractors by increasing their profits when incentive criteria are met (Choi and Kwak 2012).

Mobility-based performance specification involves the use of I/D provisions in the contract. It is important to understand the basics of I/D contracts, which would help identify and define criteria and terms for mobility-based performance specifications in highway construction contracts. To help build a foundation, research into I/D contract was conducted. This section discusses the findings about the type of I/D contracts, methods for establishing I/D amounts, and considerations with implementing I/D contracts.

2.2.1 Type of I/D Contracts

In the literature, there are three major types of I/D contracts: 1) schedule-based, 2) performance-based, and 3) cost-based. Highway contracts can include one or more of these types of I/D provisions.

2.2.1.1 Schedule-based

Schedule-based or time-based I/D contracts reward or penalize contractors based on scheduling criteria. This type of I/D contract is commonly used by STAs. The STA may choose to use one or more different scheduling criteria to assess the contractors. One criterion used by many STAs is a completion deadline. The deadline can be for the final project completion date, intermediate milestone periods, physical completions, or a combination of milestones and the finished product (Abu-Hijleh and Ibbs 1989). The I/D amount is decided based on two approaches: 1) linear or 2) escalating incentives (Choi and Kwak 2012). Linear incentives award or penalize based on a fixed, set, or daily rate. The amount is usually based on the project

construction cost. For example, Table 2-1 lists the daily amount used by the New Jersey Department of Transportation (NJDOT) for various total project costs (Sillars and Riedl 2007). Escalating incentives have daily award or penalty amounts based on a function of comparing actual and expected project completion time. The earlier or later a project is completed, the greater the award or penalty is, respectively.

Table 2-1. NJDOT Daily I/D Amounts Based on Total Project Cost

Total Project Costs ($ millions)	Daily I/D Rate ($)
0-0.5	1,000
0.5-1.5	2,000
1.5-5.0	5,000
5.0-10.0	6,000
10.0-15.0	8,000
15.0-20.0	10,000
20.0-30.0	13,000
30.0-40.0	16,000
40.0-50.0	17,000
50.0+	0.3% of Total Project Costs

Source: Sillars and Riedl 2007

Another way to assess schedule-based I/D is through the practice of lane rentals. For lane rentals, contractors are charged for closing a lane of the traffic during construction. The charging rate is established by the contracting agency and is based on a rate of dollars per day, per hour, or per a fraction of an hour. Contractors bid on the number of lane rentals that are needed to complete the project (Fick et al. 2010).

2.2.1.2 Performance-based

Performance-based I/D evaluates how well the contractor executes the project based on standards set by the contracting agency. The performance criteria can be any items that have an effect on the schedule or cost of a project, such as quality, safety, utilization of resources, productivity, and responsiveness (Bubshait 2003). The criteria should be an area of performance that needs to be enhanced, such as safety or mobility. A common application for performance-based I/D is for maintenance contracts for pavement smoothness or cleanliness of rest areas (Hyman 2009).

2.2.1.3 Cost-based

Award and penalty amounts for cost-based I/D are associated with the final project cost of construction. Cost-based I/D have three elements: 1) target cost, 2) target fee, and 3) share formula (Bower et al. 2002). The target cost is the best estimate of what the cost will be when the construction work is done. This cost is mutually agreed upon by both contracting parties. The second element, the target fee, is the amount of profit payable if the cost is equal or close to the target cost. The share formula describes the way the difference between the actual and the target costs will be distributed between the contracting parties. For cost-based I/D there is usually an acceptable price range for the target cost and fee. If the actual cost falls within this range, the incentive is given.

2.2.2 Methods for Establishing I/D Amounts

I/D rates should reflect the public and extra administration costs to STAs. The I/D amounts should include four aspects: 1) safety of the users, 2) time loss of road users due to construction, 3) increase in gasoline consumption, and 4) increased administration and monitoring associated with the use of an I/D contract (Shr and Chen 2004). The I/D amounts are normally determined by the owner and negotiated with the contractors (Bubshait 2003).

When deciding on an I/D amount, it is important for STAs to choose an appropriate amount. Many STAs use road users costs (RUC) as a basis for determining I/D amounts (Sillars and Riedl 2007). However, this approach may not be the most ideal because with time population increases, which increases traffic demand and RUC. If RUC still remains as the basis for I/D amounts, the STA may over-compensate contractors for the accelerated work. STAs also need to ensure they do not underestimate the I/D amounts. If the incentive amount is less than the contractor's additional cost (CAC), there is no economic justification for the contractors to accelerate the work (Sillars and Riedl 2007; Choi and Kwak 2012). To avoid overestimating or underestimating the I/D amount, there needs to be balance as shown in Equation 2-1 (Sillars and Riedl 2007; Choi and Kwak 2012). The lower bound of the equation should be greater than or equal to the CAC to reimburse the contractors for their cost and to encourage them to achieve the desired criteria. The upper bound for I/D amounts should also be less than or equal to the RUC

so that STAs can justify I/D projects on a public cost-benefit basis (Sillars and Riedl 2007). Methods to determine the upper and lower bounds are discussed in the following sections.

$$\boldsymbol{CAC \leq I/D \leq RUC} \tag{2-1}$$

where

CAC = *Contractor's additional cost*

I/D = *Ideal I/D amount*

RUC = *Road User Costs*

2.2.2.1 Upper Bounds RUC

Most STAs have developed methods for calculating the upper bounds of Equation 2-1. As mentioned in the previous section, STAs can use RUC as an upper bound; however, there is the possibility of overestimation. Another method is to use a fixed dollar amount or fixed percentage of the construction cost as the maximum incentive amounts (Sillars and Riedl 2007; Shr and Chen 2004). Table 2-2 lists the type of maximum incentive cap amounts for various STAs (Shr and Chen 2004). California, Indiana, Kansas, Maine, New Jersey, Utah, and Virginia have a fixed dollar amount. Maryland, Michigan, New York, North Dakota, Ohio, Pennsylvania, Washington, and Wyoming use a fixed percentage of cost, varying from 5 to 10 percent. Arizona is the only state that has set a maximum number of days a reward can be given (Shr and Cen 2004).

2.2.2.2 Lower Bound CAC

There is not a standard method among STAs to determine the lower bound of Equation 2-1 (Sillars and Riedl 2007). Individual highway contractors determine CAC for their own firm but do not feel comfortable with disclosing profits; hence, the CAC value is not always available to STAs (Choi and Kwak 2012). In order to determine the CAC for a project, there have been models developed such as Shr and Chen's model (Shr and Chen 2004) and Sillars and Riedl's model (Sillars and Riedl 2007), or analysis software can be used (Choi and Kwak 2012).

Table 2-2. Type of Maximum Incentive Cap for Various STAs

State	Cap	State	Cap
Alabama	None	Missouri	Percentage
Arizona	Schedule	Montana	Varies
Arkansas	None	Nevada	Varies
California	Dollar amount	New Hampshire	None
Colorado	None	New Jersey	Dollar amount
Delaware	None	New York	Percentage
Florida	Varies	North Carolina	Varies
Georgia	None	North Dakota	Percentage
Idaho	Varies	Ohio	Percentage
Illinois	N/A	Pennsylvania	Percentage
Indiana	Dollar amount	South Dakota	None
Iowa	None	Tennessee	None
Kansas	Dollar amount	Utah	Dollar amount
Maine	Dollar amount	Virginia	Dollar amount
Maryland	Percentage	Washington	Percentage
Massachusetts	None	Wisconsin	Varies
Michigan	Percentage	Wyoming	Percentage
Minnesota	None		

Source: Shr and Chen 2004

Shr and Chen's model applied regression analysis on historical bidding data from the Florida Department of Transportation (FDOT) to develop Equation 2-2, which calculates construction cost as a function of construction duration. Equation 2-2 then can be used to forecast the maximum number of incentive days or maximum amount for linear I/D projects (Shr and Chen 2004).

$$\frac{C-C_0}{C_0} = 0.03214 + 0.10481\ \frac{D-D_0}{D_0} + 0.46572\ \frac{D-D_0}{D_0}^{\ 2}$$

(2-2)

where

C = *Final construction cost*

C_0 = *Award bid*

D = *Days used*

D_0 = *Final contract time in days*

The model was tested to determine if the model would predict acceptable I/D amounts for FDOT. Results from the model were compared with actual I/D amounts and construction duration for two sets of example projects from FDOT. The maximum incentive amounts for the example projects were based on a fixed percentage of the project cost. According to the model, it appeared that FDOT overestimated the maximum incentive amount and maximum incentive construction time. Shr and Chen's model could be used by other STAs; however, Equation 2-2 would need to be adjusted for the location and project (Shr and Chen 2004).

Sillars and Riedl's model estimates the CAC based on the cost to the contractor for accelerating the work. The total cost is the sum of different components such as direct and indirect costs and markup. The model identifies the CAC in two stages as shown in Figure 2-1. In Stage I the STA estimates the CAC based on a variety of factors, which include bidding market condition, project type, project cost, and schedule estimates. The schedule of the project is included because the schedule of the project can affect the cost of materials, which can in turn affect the cost to accelerate construction. The cost is broken down into different cost elements such as direct cost, indirect cost, and markups. Each of the cost elements are assigned an estimated percentage of the CAC as a starting point for Stage II (Sillars and Riedl 2007).

In Stage II the cost estimate is subjectively adjusted for local and unique characteristics of the individual project. Here three sets of inputs are required, which include: 1) global breakdown proportions, 2) estimation of acceleration impact on cost elements, and 3) assignment of incentive profit. For the global breakdown proportions, the percentages estimated in Stage I

are adjusted to account for the accelerated process. For example, labor cost may generally be 25 percent of the direct costs; however, in order to increase productivity, this percentage may increase to 30 percent, which in return would decrease the percentages in other areas. During the estimation of acceleration impact on cost elements, engineering judgment is used to estimate the percentage increase of each cost element over the duration of the construction. Finally, the assignment of incentive profit inputs helps to estimate the incentive profit that would encourage contractors to accelerate the work to receive the incentive bonus.

The model can be implemented through a spreadsheet produced by Sillars and Riedl (2007) that is illustrated schematically in Figure 2-2. However, further research is necessary to establish the effectiveness and accuracy of this model.

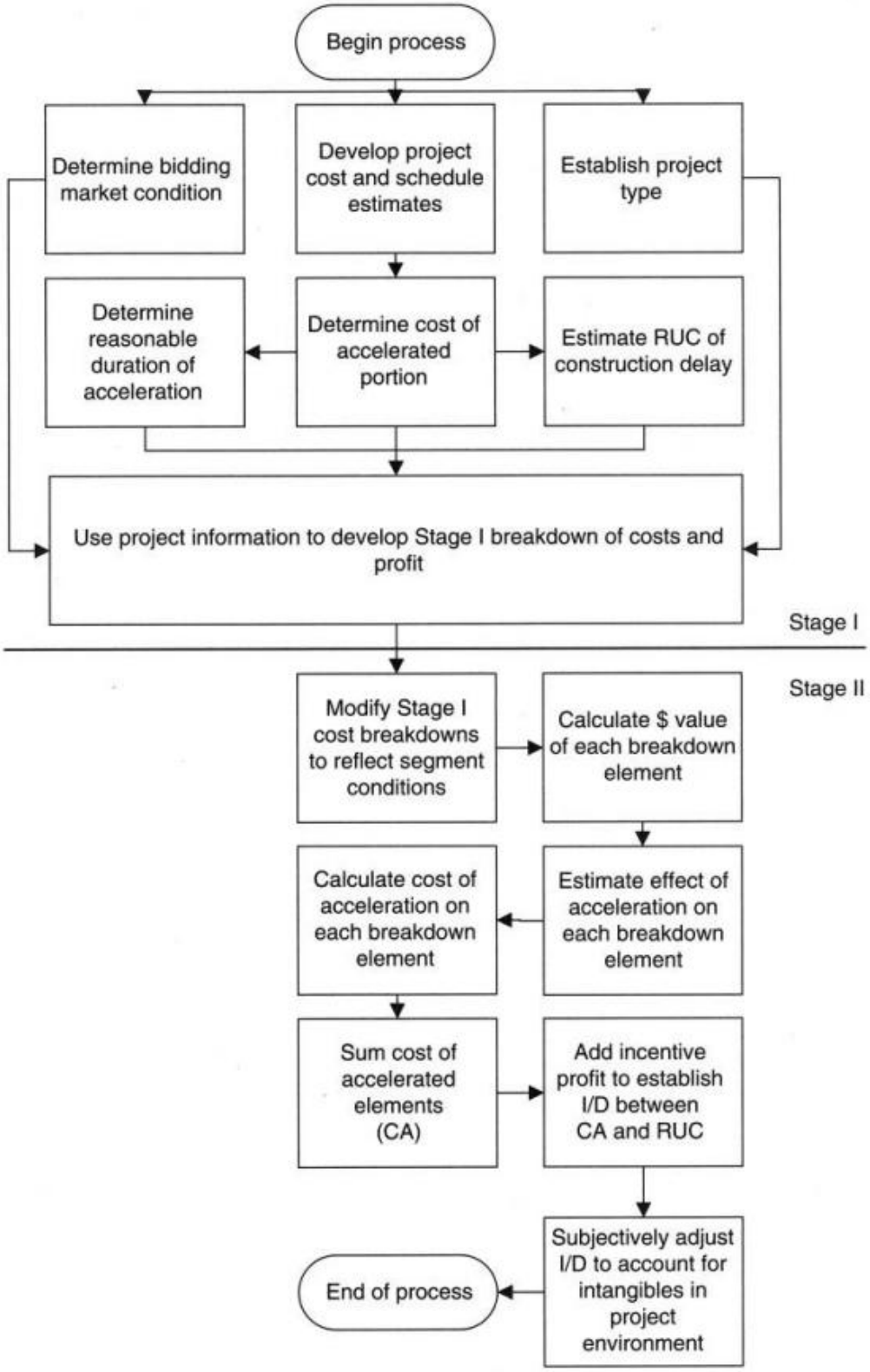


Figure 2-1. Process Diagram for Establishing I/D (Sillars and Riedl 2007)

Stage I

		Worksheet
Project:	Example	
Type:	A	
Market Cond.:	CC	
Date:	11/14/2006	
Project portion:	INTERCHANGE	
Total project estimate: $		20,000,000
Total project direct cost estimate: $		15,232,292
Total I/D portion direct cost estimate $		2,000,000
Reasonable acceleration target (Days)		10
Estimated RUC/Day for I/D portion ($)		35,000

13%

Project Types:		Market Cond's:	
A	Roaoadway	AA	Busy
B	Interchange	BB	Normal
C	Bridge	CC	Slow
D	Complex		

Calculated cells
Reference values
Entered values

Element	Sub-element	Stage I Value (%)	Segment-specific Pct (%)	Note	Segment specific value ($)	Acceleration impact (+/- %)		Acceleration cost (+/- $)
Direct cost		**81%**	**76%**	**< Stated as % of total**	**1,000,000**	**8%**		**152,200**
	Labor	25%	30%	<Stated as % of Direct Cost	600,000	20%		120,000
	Materials	45%	43%	(Must sum to 100%, values	860,000	5%		43,000
	Equipment	30%	27%	incorrect if this square is	540,000	-2%		(10,800)
	Subcontract	0%	0%	read.)	-	0%		-
Indirect Cost		**6%**	**8%**	**<Stated as % of total**	**20,000**	**1%**		**3,000**
	Supervision	2%	2%		40,000	10%		4,000
	Time-related facilities	1%	1%		20,000	-5%	**<Stated as % of line item**	(1,000)
	Non-time-related facilities	1%	1%	<Stated as % of Direct Cost	20,000	0%		-
	Mobilization/demobilization	3%	5%		100,000	0%		-
	Insurance and taxes	1%	2%		40,000	0%		-
Markup		**12%**	**15%**	**<Stated as % of total**	**406,000**	**12%**		**50,000**
	Risk	3%	5%		100,000	50%		50,000
	Home Office G&A	8%	10%	<Stated as % of Direct Cost	200,000	0%		-
	Profit	4.3%	5.3%		106,000	See below		See below
Total			**100%**		**2,626,000**	**8%**		**205,200**
Estimated Total Project Profit		**$**	**807,312**					

Acceleration cost per day		$ 20,520
I/D incentive profit per day (to be added to above acceleration cost per day)	Profit-neutral value = $807	$ 3,000
Net I/D daily amount		**$ 23,520**
Total I/D profit incentive for period		**$ 30,000**
Total I/D amount for period		**235,200**
Total I/D profit incentive as a % of Total Project profit		**3.7%**
Total RUC amount for period		**$ 350,000**
Incentivized portion		**$ 2,831,200**

Stage II

Figure 2-2. Example User Screen for Sillars and Riedl's Model (2007)

In addition to these models, analysis software may be used to determine the lower bound. In 1999, the FHWA developed the analysis software Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS) (Choi and Kwak 2012). This software program can analyze schedule, cost, and work zone traffic impacts. The CA4PRS software was used to generate a baseline schedule and cost data that can be used to quantify CAC amounts. In a study conducted by Choi and Kwak (2012), data from an example project in California were used to compare the schedule and cost estimate computed in CA4PRS with actual project values. The example project rewarded the contractors $100,000 per weekend closure, while CA4PRS found the lower bound to be $75,776 per weekend closure. Even though CA4PRS found I/D amount to be lower, the California Department of Transportation (Caltrans) felt the project had a high time completion priority, which justified a larger incentive amount to better motivate the contractors (Choi and Kwak 2012).

2.2.3 Considerations with Implementing Incentive and Disincentive Contracts

Although benefits are achievable, including I/D clauses may not be desirable for every project. There are advantages and disadvantages associated with I/D-based projects as shown in Table 2-3. One major benefit of including I/D clauses is, typically, the shorter construction time. Using I/D provisions can reduce construction time by 50 percent (Choi and Kwak 2012). A shorter construction time reduces the amount of inconvenience to the public. I/D-based projects also transfer some risk to the contractors. However, there are disadvantages with I/D contracts. There can be higher cost and probability of budget overflows for the STA if I/D contracts are not implemented effectively. Projects with I/D provisions do require more coordination and administration efforts for contractors (Choi and Kwak 2012). To increase productivity, contractors may increase the working hours of the employees. One study reported that working at least 60 hours per week or working at least 12 hours per day would increase the risk of worker injury by 23 and 37 percent, respectively (Fick et al. 2010).

Table 2-3. Advantages and Disadvantages of Using I/D Clauses

Advantages	Disadvantages
• Shorter construction time • Less inconvenience to traveling public and affected enterprises • Lower STA risk by transferring risk to the contractors • Better definition of project • More innovations initiated by contractors • Improved construction performance	• Higher cost to contract STA if not effectively implemented • Higher probability of budget overflows • Higher frequency and magnitude of change orders • Difficult administration • Greater effort required in project coordination and administration

Sources: Choi and Kwak 2012; Fick et al. 2010

2.3 Performance-based Specifications and Assessments

The purpose of this research project is to evaluate the feasibility of mobility-based performance specifications in highway contracts. A mobility-based performance specification is one application of performance-based specifications. Performance-based specifications and evaluations focus on the outcome of the project. The outcome can vary from quality assurance to ensuring a certain level of service. This section presents a summary of the literature findings on this subject, specifically about performance-based specifications in maintenance contracts and performance-based assessments in work zones. A more detailed discussion of mobility-based performance specifications and assessments is presented in Chapter 4.

2.3.1 Maintenance Contracts

Many STAs have used performance-based specifications for maintenance contracts. The NCHRP Synthesis 389 *Performance-Based Contracting for Maintenance* (Hyman 2009) presents information gathered by a literature review of international and domestic experiences and survey results conducted by NCHRP. According to the report, performance-based maintenance contracts were first implemented on a wide scale in British Columbia, Canada. Other countries such as Australia, New Zealand, and England have practiced performance-based maintenance contracts. In the United States, Virginia, Texas, and Florida have pursued the use of

performance-based maintenance contracts (Hyman 2009). These maintenance contracts can be used to ensure that a specific standard is met.

For performance-based specifications, it is necessary to identify the performance measure, measurement procedure, and target. Table 2-4 lists example performance measures and standards used in the Trans-Canada Highway project. The measurement procedure can be an American Society of Tool and Manufacturing Engineers (ASTME) procedure, an inspection, or a measurement. The target can be a type of index, such as international roughness index (IRI) or surface distress index (SDI), or completing an action within a certain time period.

Table 2-4. Examples of Selected Performance Measures and Standards from the Trans-Canada Highway Project

Measure	Measurement Procedure	Target
Roughness	IRI through high-speed data collections using ASTM E950 Class I profiler	IRI of 2.28
Rutting	Rut depth through high-speed data collection using ASTM E950 Class I profiler	Rut depth of 20 mm
Surface Distress	SDI Index through high-speed data collection using ASTM E950 Class U profiler	SDI of 7.9
Potholes	Potholes greater than 150 mm in width and 75 mm in depth	Repaired within 48 hours
Grass Control	Mowing of foreslopes	Twice per year
Fence Maintenance	Annual inspections	By May 31 each year
Snow Plowing	Maximum allowable accumulation allowed on the facility	40 mm

Source: Hyman 2009

2.3.2 Work Zone Evaluations

In September 2004, the FHWA amended regulation 23 CFR Part 620, which governs traffic safety and mobility in highway and street work zones (Ullman et al. 2011a). With the update, STAs are required to consider and establish three key components as part of their overall

work zone safety and mobility programs. The three key components include: 1) requiring the implementation of an overall, state-level work zone safety and mobility policy; 2) developing and implementing standard processes and procedures to support policy implementation, including procedures for work zone impact assessment, analysis of work zone data, training, and process reviews; and 3) developing and implementing procedures and transportation management plans (TMPs) to assess and manage work zone impacts on individual projects (Ullman et al. 2011a). This provision encourages agencies to collect and analyze safety and mobility data to support the STA's assessment and procedure in regards to work zone impacts.

One method STAs use to can assess work zone impacts is through performance-based evaluation and specifications. Performance evaluations and specifications focus on achieving desired outcomes for pavement quality, safety, or mobility. The FHWA developed *A Primer on Work Zone Safety and Mobility Performances Measurement* (Ullman et al. 2011a) to assist STAs in developing their own work zone safety and mobility performance measures. The document offers information on how to select performance measures, sources of data for work zone performance measurements, and estimation of performance measures for programs in STAs.

2.4 Chapter Summary

This chapter summarized the key findings from the literature search conducted for this study. Three main topics researched include mobility-based performance measurement technologies, state-of-the-practice of I/D specifications, and mobility-based performance evaluations. More discussion on mobility data collection technology and mobility-based performance specifications and assessments is presented in subsequent chapters.

The data necessary for assessing mobility-based performance specifications are very similar to data collected for evaluating mobility-based performance measures. There is literature that discusses technologies and methods for collection of mobility-based performance data. One resource developed by the FHWA is the *Travel Time Data Collection Handbook* (Turner et al. 1998), which offers STAs guidance for conducting travel time data collection. Since the handbook was published in 1998, many new technologies have emerged and changed data

collection methods. For this study new technologies were investigated, and the findings are presented in Chapter 3.

To reduce the negative effects of work zones, many STAs have implemented I/D provisions in their highway construction contracts. There are three different types of I/D contracts, which include schedule-based, performance-based, and cost-based contracts. One or more of these types can be included in a contact. I/D contracts create a win-win situation for the STAs and the contractors. The contractors can increase their profits by receiving the incentive bonus, and the STAs can reduce the road-user cost by reducing construction time.

Performance-based specifications establish standards for contractors to achieve desired performance outcomes. These specifications may include performance-based I/D clauses. The performance measures used in this type of contract can include any aspect of performance that can affect the traffic flow, such as quality of the pavement, traffic safety, or mobility. Currently, performance-based specifications are mostly used in maintenance contracts for maintaining roadway pavement quality. In recent years, however, application of mobility-based performance specification has been a topic of interest for STAs. This literature review has shown that data collection technologies are becoming available to help STAs implement mobility-based performance specifications.

3.0 MOBILITY DATA COLLECTION TECHNOLOGY

One distinct observation from the NCHRP *Scan 08-04: Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation Scan Team Report* was the lack of real-time mobility-based performance measurement (Bourne et al. 2010). To implement mobility-based performance specifications in highway construction contracts, there needs to be real-time performance data being collected throughout the duration of the project. To determine if current technology is capable of monitoring traffic flow in a work zone continuously, different technologies were investigated.

In 1998, the FHWA published the *Travel Time Data Collection Handbook*, which discussed mobility-based data collection methods using GPS and ALPR (Turner et al. 1998). Since 1998, new technologies such as Bluetooth and magnetic sensors have emerged that may be viable options for collecting continuous mobility-based performance data. For Phase I of this study, seven technologies were investigated including: 1) ALPR, 2) Bluetooth, 3) magnetic sensor, 4) AVI, 5) microwave radar, 6) cellular phone, and 7) GPS.

This chapter contains eight sections. The first seven sections describe each of the investigated technologies in the order listed above. Each section contains a description of the technology, advantages and disadvantages of the technology, and examples of existing practices. The last section of this chapter summarizes key features of the technologies discussed here.

3.1 Automatic License Plate Recognition

In ALPR a camera is used to identify and collect license plate numbers from vehicles passing the ALPR system. Some common applications of ALPR include parking lot monitoring, security control, law enforcement, congestion pricing, and automatic toll collection (Chang et al. 2004). For mobility-based data collection application, travel times and speeds of vehicles are calculated using the arrival times at consecutive checkpoints of matching license plate numbers. The recommended checkpoint spacing is listed in Table 3-1 (Turner et al. 1998). The checkpoint spacing will vary depending on if the roadway is a freeway or an arterial. In addition, shorter checkpoint spacing may be necessary for sections of freeway or arterials with higher frequency of access points or cross streets.

Table 3-1. Checkpoint Spacing for ALPR

	Checkpoint Spacing (miles)
Freeway/Expressway	
High frequency of access points	1-3
Low frequency of access points	3-5
Arterial Street	
High frequency of cross street/driveway	0.5-1
Low frequency of cross street/driveway	1-2

Source: Turner et al. 1998

Figure 3-1 shows the overall data collection method for ALPR systems. The method consists of two major tasks: 1) extraction of the license plate region and 2) recognition of characters on the license plate (Lee et al. 1994).

For the first task, the location of the license plate region is identified using the license plate color, height-to-width ratio, shape, symmetry, and texture contrast (Chang et al. 2004; Lee et al. 1994). Once key characteristics and properties are identified, the license plate region is extracted and the process moves to the second stage, character recognition.

During the second task each character on the license plate is identified. This task can be accomplished through character recognition programs such as genetic algorithms, artificial neural networks, fuzzy *c*-means, support vector machines, Markov processes, and finite automata (Chang et al. 2004). These techniques first extract each character by identifying spaces in-between characters or the contrast of color between the character and the plate background. After the characters have been extracted, the characters are compared to character templates (Lee et al. 1994).

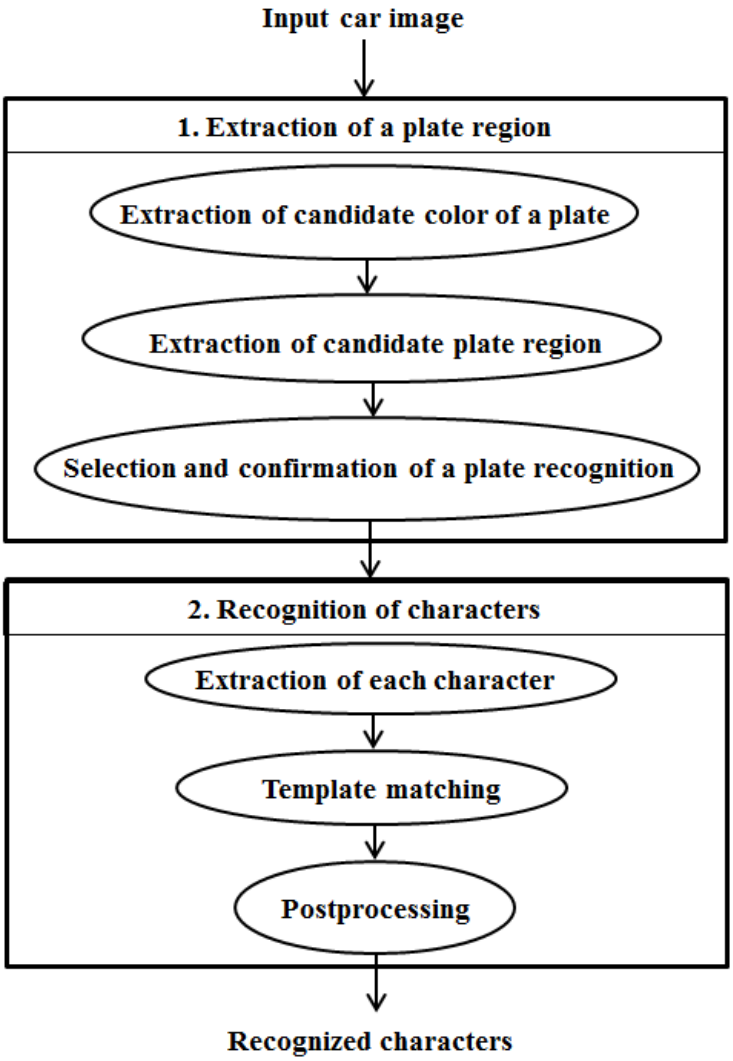


Figure 3-1. Process for License Plate Vehicle Recognition (Lee et al. 1994)

3.1.1 Advantages

The use of an ALPR system has several advantages. The main advantage is a large sample size. Since vehicles are required to have license plates, any car is a potential sample. Also current cameras have the capability to move, pan or zoom to make it easier to adjust and improve the camera view (Chang et al. 2004). In addition, multiple license plates can be captured and identified in a single frame. Besides collecting travel time and other mobility-based performance measures, ALPR can gather other information such as vehicle classification.

3.1.2 Disadvantages

Although ALPR has several advantages, it has a number of disadvantages. One disadvantage is the high installation cost. The Oregon Department of Transportation (ODOT) reported a cost of $15,000 per lane (Porter et al. 2011). Other disadvantages include factors that affect image quality, the possibility of misidentifying license plate characters, and privacy issues as discussed in the following paragraphs.

Since ALPR relies heavily on camera images, there are many factors that can affect the performance of the system. These factors can be grouped into two categories: 1) controllable and 2) uncontrollable factors. Controllable factors involve attributes that can be changed such as the position of the camera and camera angle. Uncontrollable factors, ambient (environmental) or vehicle factors, can create distorted images. Ambient or environmental factors such as precipitation, angle and intensity of the sun, or shading of the pavement can affect the quality of the image. Vehicle factors such as dirty or deformed plates or vehicles changing lanes when the picture is being taken can create unrecognizable images of the license plate (Porter et al. 2011).

There is the possibility that the character recognition program may misidentify characters on the license plate. Distorted license plate images can cause similar-looking characters to be mistaken for each other. For example, in Figure 3-2 the middle image is distorted due to the camera angle and the number “1” is mistaken by the character recognition program to be the number “7” (Chang et al. 2004). Other common misidentified pairs include the number “8” and the letter “B,” the number “5” and the letter “S,” and the number “0” and letter “D.”

For data collection purposes, there is also a privacy concern with ALPR systems. The ALPR systems can identify specific vehicles and their owners based on the license plate numbers. The information about the vehicle owner can be very detailed and personal. To address these privacy concerns, the collected license plate numbers need to be encrypted (Porter et al. 2011).

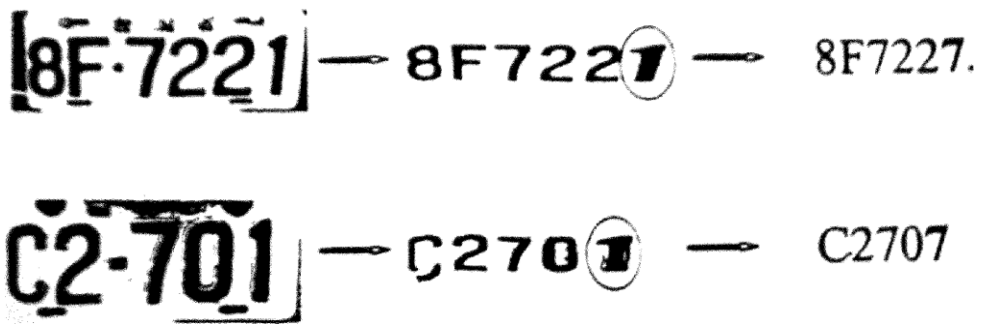


Figure 3-2. Examples of Misidentified License Plate Numbers (Chang et al. 2004)

3.2 Bluetooth

Recently, the application of Bluetooth as a traffic monitoring device has been a topic of interest for many STAs (Bourne et al. 2010). Bluetooth is short-range wireless communication technology available on many electronic devices, such as cellular phones, computers, car radios and other digital devices. Each electronic device has a 12-character identifier called a Media Access Control (MAC) address (for example, 00:24:9F:E1:FE:89). This MAC address is unique and is associated with one device. Since every MAC address is unique, Bluetooth can be a feasible technology used to gather mobility-related performance data on roadways. MAC addresses are gathered through Bluetooth detectors, which can detect Bluetooth devices within 300 feet of the detectors (Haghani et al. 2010).

The methodology for travel time or speed data collection by Bluetooth is shown in Figure 3-3 (Haseman et al. 2010). Bluetooth detectors are set up at known intervals to collect Bluetooth MAC addresses of passing vehicles. To determine travel time or speed of the vehicle, the MAC addresses are matched at the successive detection stations.

3.2.1 Advantages

There are several advantages to using Bluetooth technology, including high accuracy, low cost, portability, and non-intrusive installment. The Bluetooth device provides very accurate data. A ground truth study was conducted comparing the travel time collected with Bluetooth and by probe vehicle. The study showed that Bluetooth sensors were a good representation of the ground truth at speeds below 45 miles per hour (mph). However, the data collected by the two

technologies differed more when speeds were greater than 45 mph. The study attributed the difference to greater variability in traveling speeds than the average speed of traffic (Haghani et al. 2010).

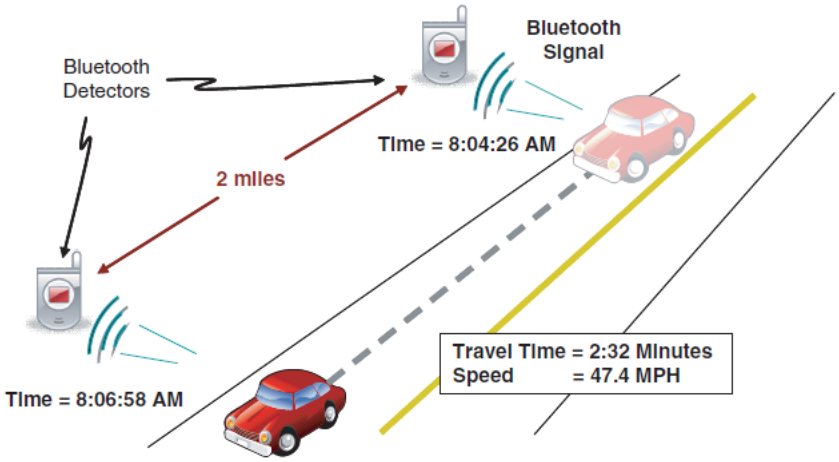


Figure 3-3. Bluetooth Traffic Monitoring Operation Concept (Haghani et al. 2010)

The use of Bluetooth technology costs much less than other technologies. Today, many drivers own Bluetooth-enabled devices and those devices can be used to collect data. ODOT reported that installation of Bluetooth detectors would cost less than $2,000 to cover multiple lanes, while an ALPR system costs $15,000 per lane (Porter et al. 2011).

Bluetooth sensors are portable and non-intrusive, which make them very useful for work zone monitoring. Work zones are a temporary condition on the road and it is not necessary to install permanent equipment to monitor the work zone. Also, depending on the nature of construction, the work zone may move along the road and it may be necessary to move the monitoring device along with the construction work. The portable Bluetooth devices can be deployed in a variety of locations as shown in Figure 3-4. Both Figures 3-4a and 3-4b show a battery-powered Bluetooth device in a portable Pelican case placed between the guardrails to collect data. An external antenna can be used for help collect MAC address. The Bluetooth device can also be placed behind VMSs, as show in Figure 3-4c. This particular setup in Figure 3-4c used a solar power and had a wireless link to help transfer the data.

All of these examples in Figure 3-4 require non-intrusive installation. Non-intrusive installation avoids damaging the pavement, unlike intrusive equipment that requires cutting and coring of the pavement. Also non-intrusive installation reduces the risk of workers injury during installation of the Bluetooth equipment. Workers installing the Bluetooth are usually located away from the paths of passing vehicles.

3.2.2 Disadvantages

While Bluetooth has several advantages, there are also disadvantages such as low sampling rates and privacy issues. Like with any other data collection methods, to obtain accurate results there needs to be an adequate sample size. For data collection with Bluetooth, the sample size is dependent on the capture rate of discoverable Bluetooth devices and traffic volume. For example, the capture rate found in a study conducted in Maryland and Delaware was between 2.0 percent and 3.4 percent (Haghani et al. 2010). However, the capture rate varies depending on location and type of roadway. Some states have a “hands-free” driving law that prohibits the use of handheld cellular devices while driving, but drivers may use a hands-free device like a Bluetooth headset. These states are more likely to have a higher capture rate than a state without a “hands-free” law because of the increased number of discoverable Bluetooth devices. Another factor is the type of roadways. Freeways usually have a constant flow, but arterials and collector roads have low traffic volumes during off-peak periods. It is during these off-peak periods where some difficulties in collecting enough data for producing accurate results may exist.

One major concern with Bluetooth technology is privacy. Since the MAC address is unique to a single device, it is possible to tie the MAC address back to the user. However, there are many ways to minimize privacy concerns. First, many Bluetooth detectors will only collect MAC address from users, which choose to have their device to be discoverable. If users do not wish to have their information taken for data collection purpose, they can turn off the discovery function of the Bluetooth settings (Puckett and Vickich 2010). Another way to address the privacy issue is to encrypt the MAC address (Haghani et al. 2010; Puckett and Vickich 2010). The encrypted MAC address would be transformed so no one would be able to determine the original MAC address by looking at the encrypted address. For example, the original MAC address 00:24:9F:E1:FE:98 can be encrypted to MjM6RDc6REQ6MzI6QkM. Even if the MAC

address is encrypted, the processing software can still analyze the data (Puckett and Vickich 2010).

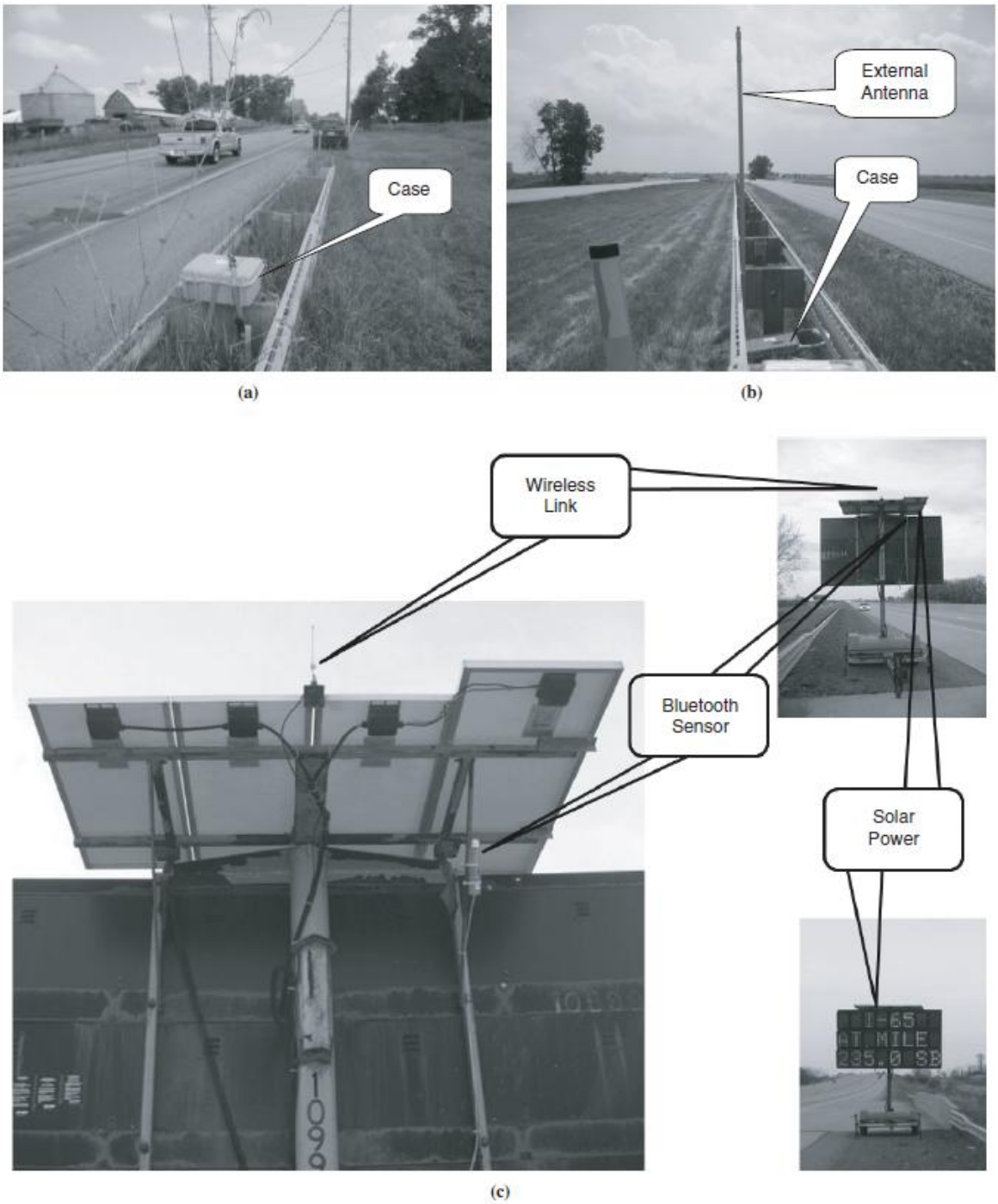


Figure 3-4. Various Deployment Locations for Portable Bluetooth Data Collection Devices: (a) and (b) behind a guardrail and (c) behind a VMS (Puckett and Vickich 2010)

3.2.3 Companies Offering Bluetooth Data Collection Services

This section discusses the features and services offered by two traffic monitoring services that use Bluetooth technology. The intent of this section is to give examples of what features are available for Bluetooth systems; it does not attempt to suggest or recommend specific monitoring services.

3.2.3.1 TrafficCast

TrafficCast is a company that offers Bluetooth data collection and analysis services, called Bluetooth Travel-time Origin and Destination (BlueTOAD). The BlueTOAD devices process data and calculate travel time and speed in real time. The BlueTOAD self-enclosed sensors can be mounted on a pole or wall and can be solar powered. TraffiCast also offers a smaller device, Mini-BlueTOAD, for situations where live real-time data are not required (TrafficCast 2012).

To help manage the data, users can use TrafficSuite. TrafficSuite is a traffic management system, which manages the collection and integration of traffic information. The system can take information on speed, traffic flow, weather, crashes, and construction data from multiple sources and display it seamlessly in one place. In addition to information management, TrafficCast offers a speed forecasting product called Dynaflow. Dynaflow uses historical road speed trends to forecast road speeds up to 48 hours in advance (TrafficCast 2012).

3.2.3.2 Traffax, Inc.

Traffax, Inc. is another company that offers Bluetooth data collection and analysis services. Traffax, Inc. offers three Bluetooth products: 1) BluFAX sensors; 2) a real-time data website, BluFAXWeb; and 3) data analysis software, BluSTATS. Traffax, Inc. does offer a rental program for customers for short-term studies or for gaining experience using the BluFAX equipment (Traffax, Inc. 2009).

Traffax, Inc. offers three types of BluFAX Bluetooth sensors: 1) standard portable, 2) urban portable, and 3) solar-powered BluFAX. The Standard BluFAX portable is a portable device in a water-proof Pelican case. The BluFAX Urban Portable is an unobtrusive, rectangular,

non-metallic cabinet that can be mounted on existing pole structures. Both the standard and urban portable devices run on an absorbed glass mat (AGM) battery that lasts 14 days. The BluFAX Solar Unit is similar to the Urban Portable, but uses solar power energy instead of a battery. All the sensors have a secure digital (SD) card slot where data can be saved. Every day the raw data from the previous day can be sent to a pre-arranged email address (Traffax, Inc. 2009).

BluFAXWeb is a website that displays real-time data for monitored roadways and helps monitor deployed and active sensors. The site shows in real time average travel times and speeds, as well as information about the battery life and location of the sensors. In addition, threshold levels can be configured to send out email or text message notifications. If necessary the raw data can be downloaded for subsequent analysis (Traffax, Inc. 2009). Some features of BluFAXWeb that will be discussed in detail include information about roadway links, travel time charts, and maps that show current traffic conditions.

For BluFAXWeb, data are collected for a section of roadway between two nodes or two BluFAX sensors. Figure 3-5 shows a screenshot of the “Links” page, which lists information for the links in the network, such as the average speed and travel time that are listed along with the historical travel time and the “Trend” column (Traffax, Inc. representative, personal communication, May 14, 2012). The “Trend” column offers a quick visual comparison between the current value and the historical trend using three symbols shown in Table 3-2.

Links							
		Speed		Travel Time (mins)			
Network	Description	(mph)	(km/h)	Current	Predicted	Historical	Trend
Maryland I-95	L1 I95 NB - through MD212 and MD198 any-other [6.1 mi / 9.82 km] Show Details	unknown	unknown	0.0	5.5	5.42	
Maryland I-95	L2 I95 NB - through MD216 and MD32 any-other [6.1 mi / 9.82 km] Show Details	33.5	54.0	10.92	10.05	6.93	
Maryland I-95	L3 I95 NB - through MD175 and MD100 any-other [3.8 mi / 6.12 km] Show Details	41.7	67.1	5.47	5.37	4.58	
Maryland I-95	L3 I95 SB - through MD100 and MD175 any-other [3.8 mi / 6.12 km] Show Details	45.6	73.4	5.0	4.9	3.18	
Maryland I-95	L2 I95 SB - through MD32 and MD216 any-other [6.1 mi / 9.82 km] Show Details	48.9	78.7	7.48	7.72	5.28	
Maryland I-95	L1 I95 SB - through MD198 and MD212 any-other [6.1 mi / 9.82 km] Show Details	unknown	unknown	0.0	5.17	5.12	
Maryland I-95	I95 S. of MD 212 to MD on I495 mile marker 31 any-other [6.2 mi / 9.98 km] Show Details	unknown	unknown	0.0	6.0	6.22	
Maryland I-95	MD on I495 mile marker 31 to I95 S. of MD 212 any-other [5.9 mi / 9.5 km] Show Details	unknown	unknown	0.0	5.63	7.48	

Figure 3-5. Screenshot of BluFAX Web "Links" Page (Traffax, Inc. representative, personal communication, May 14, 2012)

Table 3-2. Symbols and Meaning Used in "Trend" Column

Symbol	Meaning
	Current value is above threshold
	Current value is within threshold
	Current value is below threshold

Source: Traffax, Inc. representative personal communication, May 14, 2012

The three symbols are a red, upward-pointing arrow; a grey, right-pointing arrow; and a green downward-pointing arrow meaning the current values are above, within, and below the historical trend, respectively (Traffax, Inc. representative, personal communication, May 14, 2012).

BluFAXWeb can produce several charts for travel time, average speed, and number of detections. Figure 3-6 is a screenshot of a travel time chart, where the mean travel times (red), vehicle traversals (blue), and predicted travel time (green) are shown. The time range being displayed can be adjusted (Traffax, Inc. representative, personal communication, May 14, 2012).

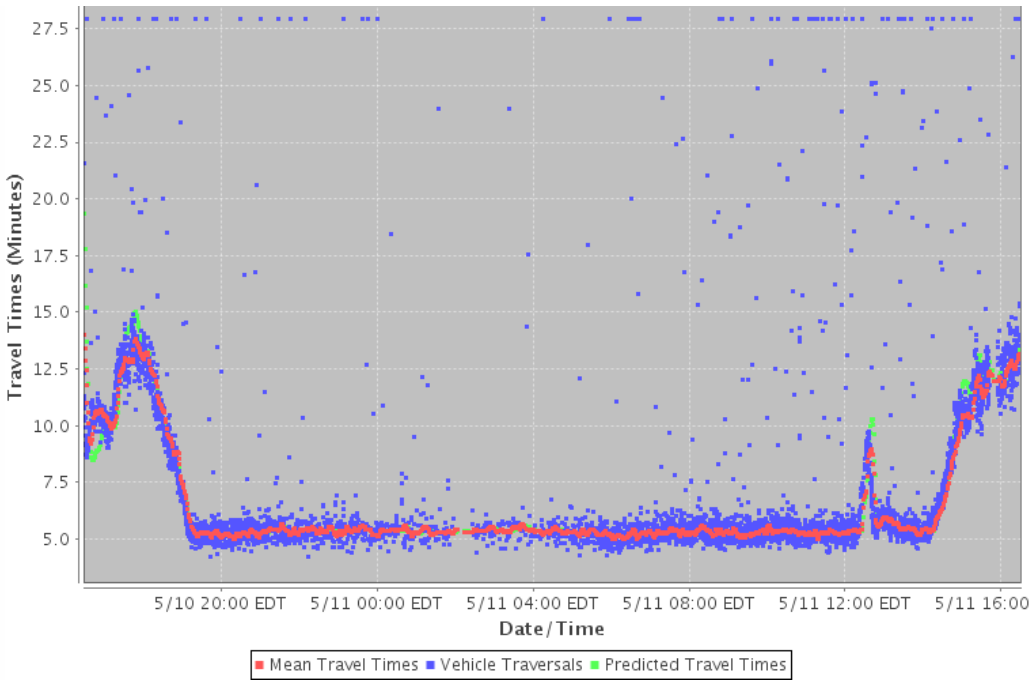


Figure 3-6. Calculated Travel Time Chart in BluFAXWeb (Traffax, Inc. representative, personal communication, May 14, 2012)

BluFAXWeb also contains a map that displays real-time traffic conditions and locations of deployed Bluetooth sensors. When a roadway is selected, the average travel time and speed are displayed. When a node, or Bluetooth sensor, is selected, information on its status (active or inactive), location, last detection, and number of volts the battery has is listed. All of these features are shown in Figure 3-7 (Traffax, Inc. representative, personal communication, May 14, 2012).

Figure 3-7. Screenshot of Map Feature in BluFAXWeb
(Traffax, Inc. representative, personal communication, May 14, 2012)

BluSTATS is the analysis software that comes with any BluFAX sensors. BluSTATS can perform origin destinations (O-D) and travel time analysis. The software can analyze data from current or previous projects. An example output for travel time analysis is shown in Figure 3-8, where statistics are summarized in hourly intervals. The summary level or time interval used for the analysis can be adjusted for 15-, 30-, and 60-minute intervals, as shown in Figure 3-9 (Traffax, Inc. representative, personal communication, May 14, 2012). The user can also select the type of summary statics used in the report, such as mean travel time and average speed.

Time		Segment		6F3_ADB	ADB_6EB	6EB_6ED	6ED_6EF	6EF_6DA	6DA_6EC	6EC_6DE	6DE_7A2
		Label		Segment 1 EB	Segment 2 EB	Segment 3 EB	Segment 4 EB	Segment 5 EB	Segment 6 EB	Segment 7 EB	Segment 8 EB
		Length (miles)		2.000	2.690	0.940	1.850	4.760	3.360	3.250	1.560
		Begin Time	End Time								
	Midnight	12:00 AM	1:00 AM	1.904	2.719	0.683	1.733	4.867		3.237	1.600
		1:00 AM	2:00 AM	2.036	2.686		1.983	5.183	3.600	3.417	1.658
		2:00 AM	3:00 AM								1.708
		3:00 AM	4:00 AM	2.021	2.728	0.904	1.827	5.200	3.617		
		4:00 AM	5:00 AM	2.020	2.771		1.637	4.802	3.708	3.400	1.400
		5:00 AM	6:00 AM	1.919	2.526	0.856	1.622	4.377	3.150	2.933	
		6:00 AM	7:00 AM	1.863	2.513	0.828	1.665	4.197	3.056	2.811	1.479
		7:00 AM	8:00 AM	1.918	3.183	0.946	1.826	4.351	3.191	3.103	1.429
		8:00 AM	9:00 AM	1.927	2.886	0.981	1.786	4.401	3.183	3.094	1.475
		9:00 AM	10:00 AM	1.910	2.558	0.843	1.713	4.416	3.269	3.251	1.585
		10:00 AM	11:00 AM	1.930	2.582	0.832	1.758	4.508	3.219	2.992	1.483
		11:00 AM	12:00 PM	1.968	2.569	0.843	1.716	4.434	3.201	3.050	1.403
	Noon	12:00 PM	1:00 PM	1.955	2.543	0.856	1.719	4.496	3.297	3.263	1.518
		1:00 PM	2:00 PM	2.015	2.526	0.882	1.730	4.485	3.160	3.156	1.500
		2:00 PM	3:00 PM	1.975	2.584	0.877	1.702	4.386	3.222	3.142	1.511
		3:00 PM	4:00 PM	2.010	2.612	0.879	1.739	4.562	3.356	3.256	1.425
		4:00 PM	5:00 PM	1.971	2.620	0.879	1.738	4.758	5.155	3.255	1.484
		5:00 PM	6:00 PM	1.945	2.540	0.865	2.008	7.118	6.451	3.478	3.092
		6:00 PM	7:00 PM	1.961	2.564	0.854	1.721	5.158	4.179	3.127	2.078
		7:00 PM	8:00 PM	1.927	2.515	0.817	1.720	4.534	3.210	2.930	1.497
		8:00 PM	9:00 PM	1.959	2.614	0.849	1.736	4.630	3.365	3.276	1.483
		9:00 PM	10:00 PM	2.035	2.596	0.826	1.753	4.595	3.475	3.300	1.542
		10:00 PM	11:00 PM	2.037	2.713	0.883	1.813	4.503	3.335	3.155	1.550
	Midnight	11:00 PM	12:00 AM	2.140	2.750	0.863	1.851	4.864	3.333	3.400	

Figure 3-8. Screenshot of Travel Time Results Using BluSTAT Software (Traffax, Inc. Representative, personal communication, May 14, 2012)

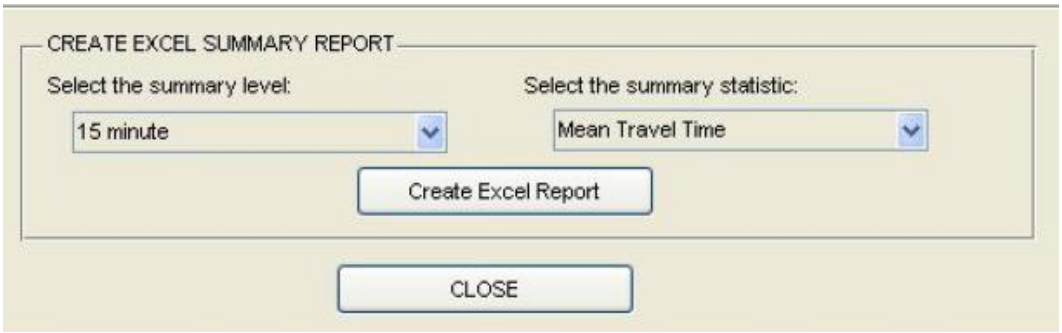


Figure 3-9. Screenshot of Summary Interval
(Traffax, Inc. representative, personal communication, May 14, 2012)

3.2.4 Examples of Existing Practices

Bluetooth technology has been used in several transportation projects for travel time or speed data collection. This section will discuss three projects that used the Bluetooth technology in the United States.

3.2.4.1 Indiana

In the summer of 2009, a 10-mile stretch, between mile marker 230 and 240, of Interstate 65 (I-65) in Indiana was resurfaced. For a 12-week period, Bluetooth was used to collect travel time data of vehicles through the work zone. The data were processed in order to display delay times to the driving public, to assess driver diversion rates, and to develop a metrics for the Indiana Department of Transportation (INDOT) to assess work zone mobility performance. There was an automatic traffic recorder (ATR) south of the work zone, which collected northbound traffic to help validate the Bluetooth data collection. The portable Bluetooth units were placed behind guardrails, while semi-permanent Bluetooth units were attached to VMSs. The Bluetooth units only took about 10 minutes to set up and had a capture rate of about 8 percent of the passing vehicles (Haseman et al. 2010).

The findings from the project showed several benefits associated with future application of Bluetooth data collection in work zones. For the I-65 project, one purpose for collecting travel times in the work zone was to display traffic conditions within the work zone. The delay time information displayed on the VMSs was able to divert drivers to alternative routes, if the routes were effectively communicated. The continuous measurement of the work zone travel time

provided quantitative data that INDOT could use to evaluate alternative traffic maintenance techniques and identify best practices. For future application, Haseman et al. (2010) stated that, with Bluetooth technology, there is the potential to facilitate more flexible contracting methods.

3.2.4.2 Illinois

During 2010, the Illinois Department of Transportation (IDOT) deployed TrafficCast's BlueTOAD Bluetooth sensors in a resurfacing project on the Eisenhower Expressway. The project resurfaced 27 miles along Interstate 290 (I-290) from Thorndale to the Circle Interchange near downtown Chicago and from Army Trail Road to I-290 (TrafficCast 2010). Twenty-two sensors were installed on light poles throughout the work zone to monitor vehicle travel time (Varon 2010). Traffic conditions were communicated to the drivers through overhead signs and the regional traveler information website, Gary-Chicago-Milwaukee Corridor Transportation Information (www.gcmtravel.com) (TrafficCast 2010). The articles on the project did not state how effective the Bluetooth devices were but stated that there were concerns about privacy from drivers. To address this concern, IDOT officials informed the public that there was no connection between the MAC address of the Bluetooth device and the actual identity of the person (Varon 2010).

3.2.4.3 Utah

UDOT has used Bluetooth devices for data collection and processing purposes for several projects testing mobility-based performance specifications. In Region 2 BluFAX Bluetooth sensors were used on a design-build project on Bangerter Highway to assess travel time in the work zone (UDOT Region 2 representatives, personal communication, May 14, 2012). In Region 4, two trailers equipped with BlueTOAD sensors were used to monitor speed in a work zone (UDOT Region 4 representative, personal communication, March 2012). Details for both projects are presented in section 4.3.2.

3.3 Magnetic Sensors

Magnetic sensors, or magnetometers, measure the perturbation of the earth's magnetic field caused by the presence of a vehicle. When no vehicle is present, the oscillator in the magnetic sensors is at its resting frequency, but the frequency changes once a vehicle passes over the sensor. This change in frequency is called the "vehicle signature," as shown in Figure 3-10 (Klein et al. 2006).

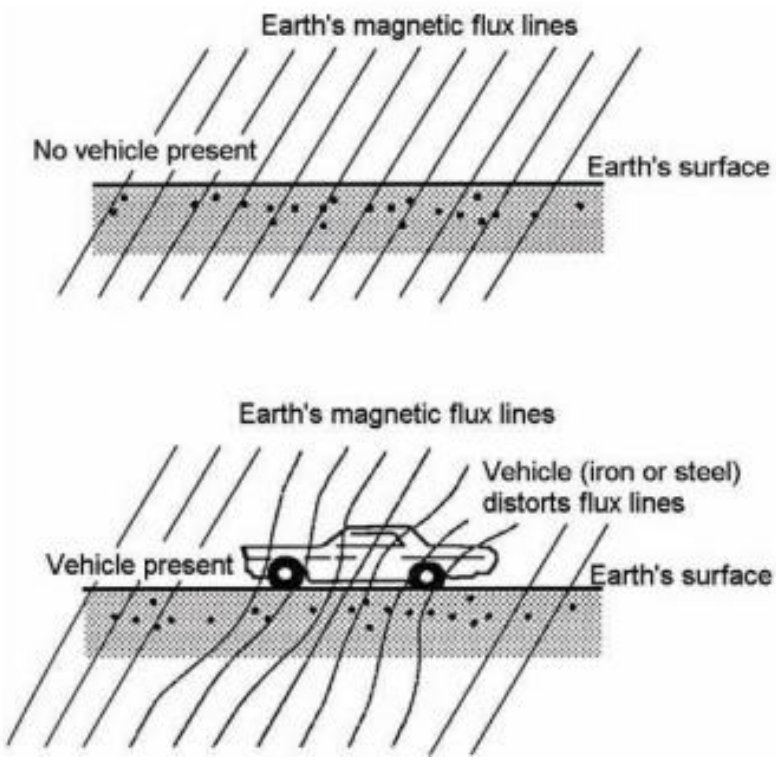


Figure 3-10. Visual Diagram of Magnetic Sensors (Klein et al. 2006)

For mobility data collection, the vehicle signatures measured at consecutive sensors are matched, and the timestamps at these sensors are used to calculate travel time and speed. Figure 3-11 shows the general process of vehicle signature matching algorithms (Ernst et al. 2011). The downstream vehicle signature is matched from candidate upstream signatures that falls within a maximum and minimum travel time from the downstream sensor. From this vehicle signature pool, the upstream vehicle signatures are matched with the best matching downstream signature,

and travel time is calculated. Studies show a 95 percent re-identification rate (Ndoye et al. 2011) with these matching algorithms.

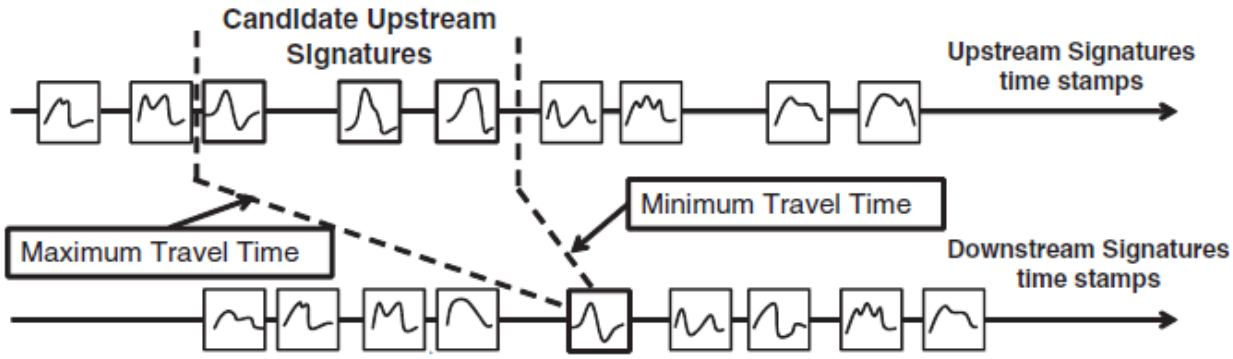


Figure 3-11. General Process to Match Vehicle Signatures (Ernst et al. 2011)

3.3.1 Advantages

There are a couple of advantages when using magnetic sensors. First, magnetic sensor detection can be very sensitive. A magnetic sensor can detect two vehicles, if there is a distance of 1 foot between the two vehicles. These sensors are also sensitive enough to detect bicycles (Klein et al. 2006). Another advantage is that there are no privacy issues with magnetic sensors, unlike other technologies such as ALPR or Bluetooth (Kwong et al. 2009). Since the vehicle signature is developed based on how the vehicle disturbs the earth's magnetic field, it is impossible to identify the source vehicle based on its vehicle signature.

3.3.2 Disadvantages

There are a few disadvantages associated with magnetic sensors. These disadvantages include the permanent infrastructure, intrusive installation, and factors affecting vehicle signature matching accuracy. To measure the disturbance of the earth's magnetic field, the magnetic sensors need to be permanently installed in the pavement (Ernst et al. 2010; Ernst et al. 2011; Ndoye et al. 2011). Once installed, the sensors are permanent and cannot be moved from project site to project site. The installation of magnetic sensors can also cause damage to the pavement. Installation of a magnetic sensor requires coring or cutting of the pavement. If done incorrectly, the installation can cause damage to the pavement and reduce the service life of the pavement (Klein et al. 2006). Last, distorted vehicle signatures can cause problems for the matching

algorithm. Distorted vehicle signatures can occur if a vehicle accelerates or decelerates while passing over the sensors. However, there are methods to adjust for acceleration or deceleration distortions (Ernst et al. 2010; Ernst et al. 2011; Kwong et al. 2009; Ndoye et al. 2011).

3.3.3 Company Offering Magnetic Sensor Systems

This section discusses features and services offered by one company, Sensys Networks. It is meant to give an example of what features are available and is not intended to recommend specific monitoring services.

Sensys Networks provides magnetic sensors, data management, and analysis software. The Sensys Networks VDS2-40 detection system uses wireless magneto-resistive sensors to detect vehicle presence and movement. These sensors, shown in Figure 3-12, have a 10-year battery life and can self-calibrate and self-tune (Sensys Networks 2012a). Unlike other in-pavement sensors, there is no need for wires or saw cutting since the detectors fit in a small puck hole and communicate to nearby data transfer cabinets wirelessly. The sensors can send data collected from the previous 24 hours to an email address.

Figure 3-12. Sensys Network Sensor (Sensys Networks 2012a)

Sensys Networks Archive, Proxy and Statistics (SNAPS) is the software that manages Sensys Networks detectors and processes collected data. Through the SNAPS software, the health and performance of the detectors can be managed, and configuration prior to installation can be done. A brief overview of the monitored road network is shown on the SNAPS Dashboard System Status, shown in Figure 3-13 (Sensys Networks 2012b). Here the user can see the volume, occupancy, and speed data collected by different sensors, as well as the location and status of Sensys Networks sensors actively being deployed.

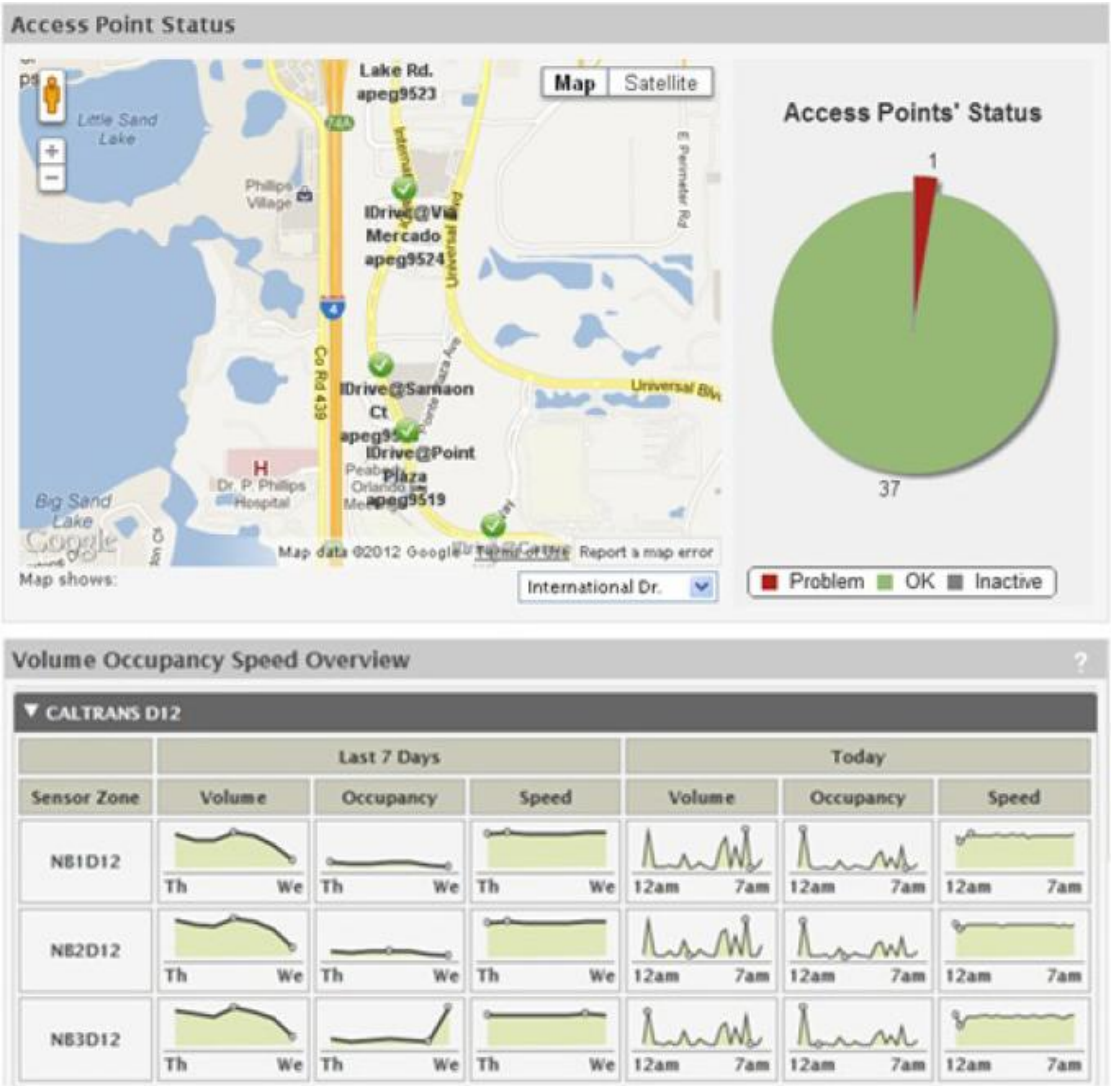
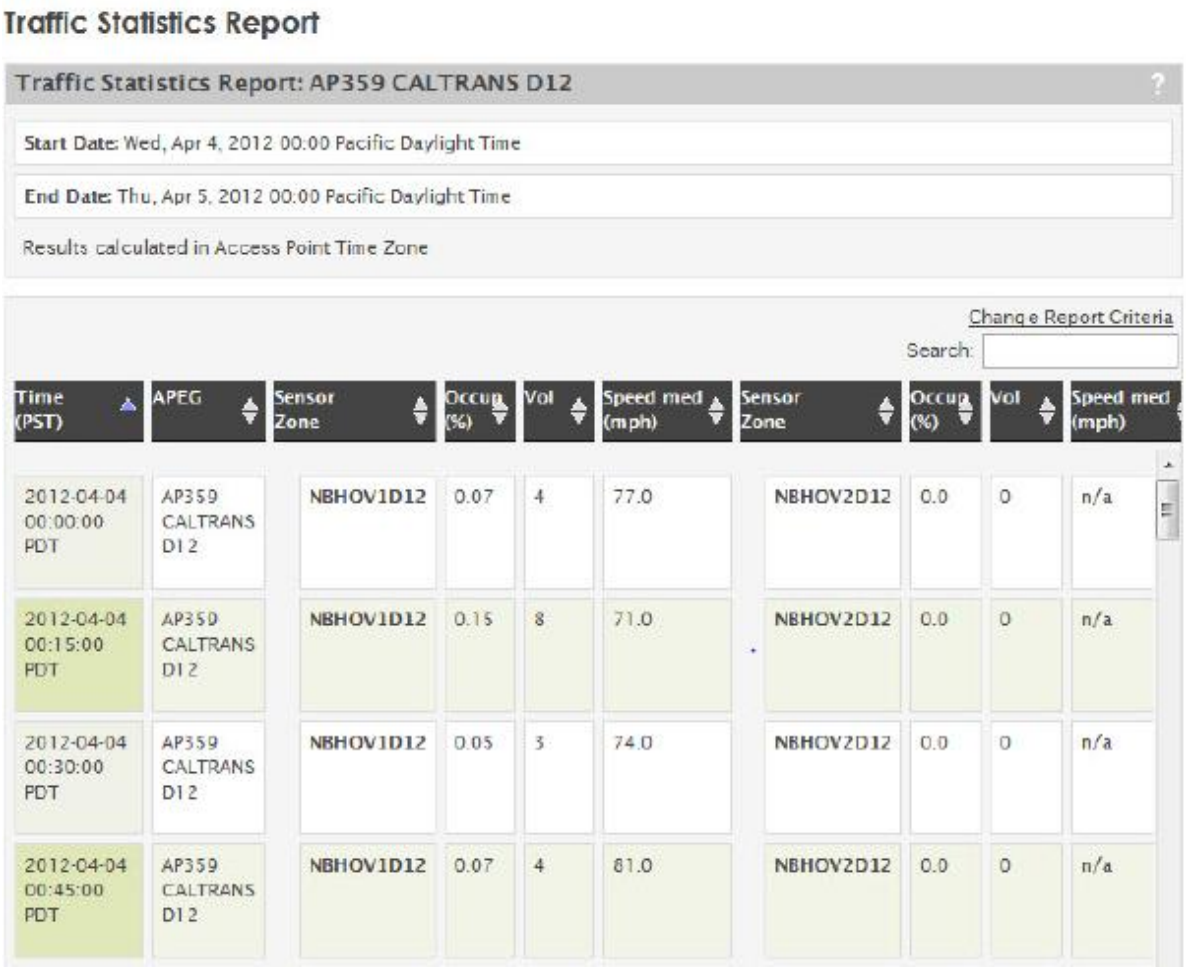


Figure 3-13. Screenshot of System Status Page in SNAPS Dashboard (Sensys Networks 2012b)

In addition to monitoring tools, SNAPS comes with analysis features that can help users create traffic analysis reports. These reports can provide statistics from all the Sensys Networks sensors installed on the road network summarized at an adjustable fixed time interval such as 15-, 30-, or 60-minute intervals. The report files can be exported to four file types: 1) HTML, 2) Plots, 3) .xls, and 4) .csv (Sensys Networks 2012b). A screenshot of a report output is shown in Figure 3-14 (Sensys Networks 2012b). This screenshot shows the Traffic Statistics Report, which includes occupancy, volume, and average speed for a sensor zone.

Finally, SNAPS has a Cloud Connect feature, which allows remote access to certain features of the SNAPS system. Cloud Connect users have access to real-time data services, congestion map, travel time, and per-vehicle statistic reports (Sensys Networks 2012b).



Traffic Statistics Report

Traffic Statistics Report: AP359 CALTRANS D12

Start Date: Wed, Apr 4, 2012 00:00 Pacific Daylight Time

End Date: Thu, Apr 5, 2012 00:00 Pacific Daylight Time

Results calculated in Access Point Time Zone

Change Report Criteria

Search:

Time (PST)	APEG	Sensor Zone	Occup (%)	Vol	Speed med (mph)	Sensor Zone	Occup (%)	Vol	Speed med (mph)
2012-04-04 00:00:00 PDT	AP359 CALTRANS D12	NBHOV1D12	0.07	4	77.0	NBHOV2D12	0.0	0	n/a
2012-04-04 00:15:00 PDT	AP359 CALTRANS D12	NBHOV1D12	0.15	8	71.0	NBHOV2D12	0.0	0	n/a
2012-04-04 00:30:00 PDT	AP359 CALTRANS D12	NBHOV1D12	0.05	3	74.0	NBHOV2D12	0.0	0	n/a
2012-04-04 00:45:00 PDT	AP359 CALTRANS D12	NBHOV1D12	0.07	4	81.0	NBHOV2D12	0.0	0	n/a

Figure 3-14. Screenshot of SNAPS Traffic Statistic Report Output (Sensys Networks 2012b)

3.3.4 Examples of Existing Practices

There have been several projects were magnetic sensors were used. This section discusses two examples where magnetic sensors were used in California and Utah.

3.3.4.1 California

Caltrans conducted a field test to verify the accuracy of on-ramp queue length estimation algorithms based on re-identification data collected by Sensys Networks sensors. The vehicle re-identification-based queue length estimation was compared to queue length estimation based on occupancy, speed, and vehicle counts. To collect the data, the sensors were placed at the entrance and the exit of the Hegenberger on-ramp as shown in Figure 3-15 (Horowitz et al. 2011). The Hegenberger on-ramp length is 616 feet and has a vehicle storing capacity ranging between 17 and 25 vehicles.

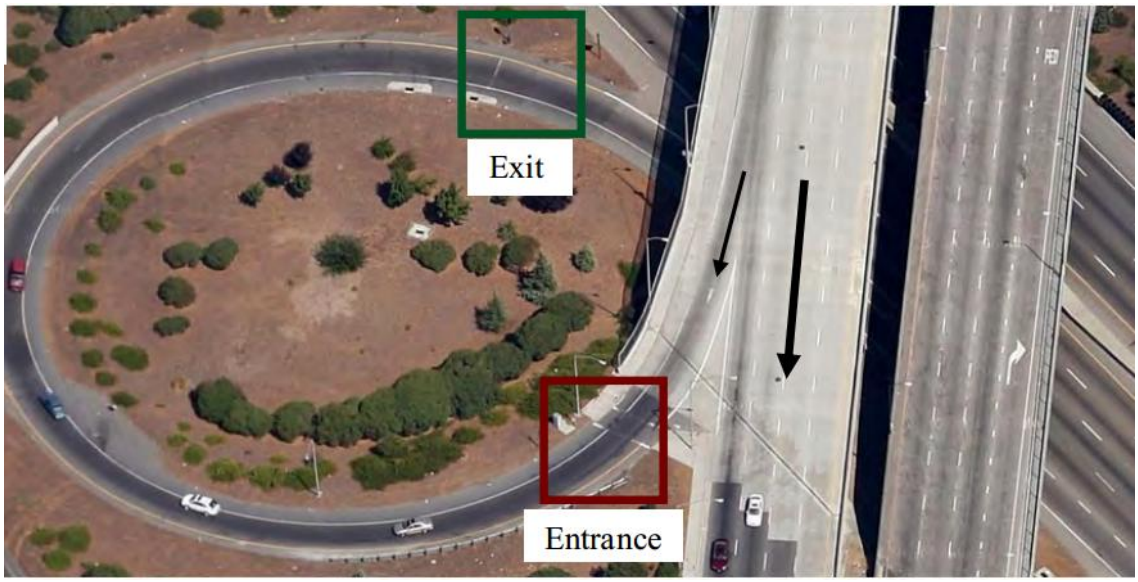


Figure 3-15. Location of Entrance and Exit Sensors Group (Horowitz et al. 2011)

The installation configuration of the sensors at the entrance is shown in Figure 3-16. An array of seven sensors, the vehicle re-identification (re-id) array in Figure 3-16, was installed to re-identify vehicles and to provide vehicle counts. In addition, two leading detectors (SL1 and

SL2) and two trailing detectors (ST1 and ST2) were installed before and after the vehicle "re-id" array, respectively. The purpose of these four sensors was to increase the detection zone to capture vehicles that may be traveling off-centered of the traveling lanes. The data collected from the sensors were processed through the Sensys SNAPS software, and vehicle speed, length, and headway were computed. The sensors at the exit of the ramp followed the same configuration (Horowitz et al. 2011).

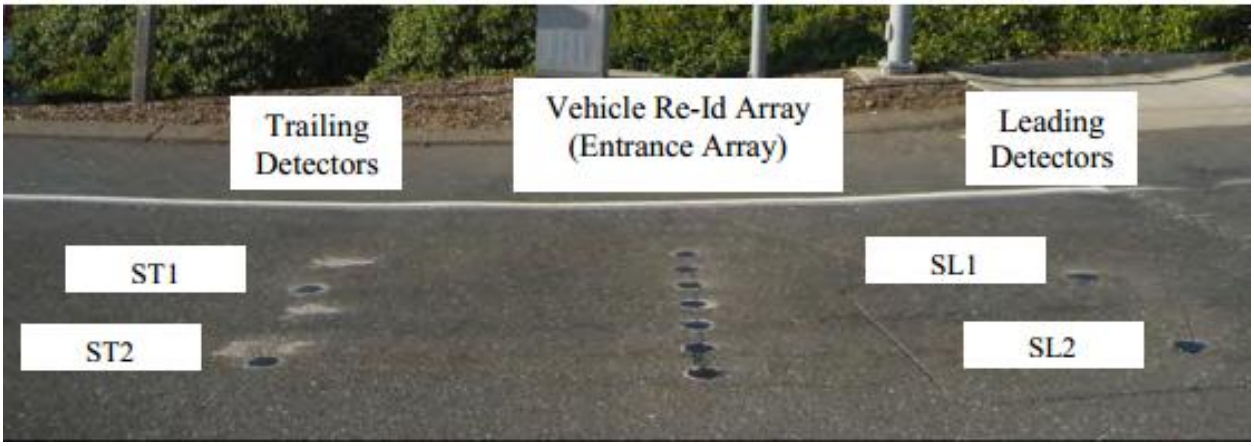


Figure 3-16. Wireless Magnetic Sensors Configuration at Entrance of Ramp (Horowitz et al. 2011)

To validate the queue estimation method and the capability of magnetic sensor, the data from the magnetic sensors were compared to ground-truth data taken from videotape recordings of the on-ramp. The vehicles at the on-ramp were videotaped on three different days: April 13, May 5, and May 11, 2010. Table 3-3 lists the vehicle count collected from the video and the magnetic sensor between 4:07 PM and 5:35 PM on May 5th (Horowitz et al. 2011).

Table 3-3. Queue Length Based on Data Collected through Video Camera or Magnetic Sensors

	Entrance	Exit
Total Vehicle (Video Camera)	543	522
Trucks	21	20
Motorcycles	1	1
Total Vehicle (Magnetometer)	527	520
Multiple Detection	21	15
Multiple Detection due to Trucks	9	5
Undetected Vehicles	40	19

Source: Horowitz et al. 2011

There were times when the magnetic sensor counted multiple vehicles or did not detect a vehicle. The total vehicle counts at the entrance and exit were 2.9 and 0.3 percent less than the ground truth, respectively, which are not significant errors. At times, the magnetic sensors would count trucks as multiple vehicles. The magnetic sensors would also detect multiple vehicles when one vehicle passed or missed detection. When there was congestion on the ramp, vehicles tended to drive closer together, which resulted in multiple cars being counted as one vehicle. Missed detection would also occur when motorcycles or vehicles traveled off-center within the lane (Horowitz et al. 2011).

From the study, it was determined that the ramp queue estimates based on vehicle re-identification performance was significantly better than the other methods tested. The occupancy queue estimation method can only determine if the ramp is either empty or full. The estimation based on vehicle counts is not acceptable because it cannot account for detector miscounts. The queue estimation based on speed can determine if the ramp is under-saturated, saturated or in transition. (Horowitz et al. 2011).

3.3.4.2 Utah

In Utah, Sensys Networks sensors were installed as part of the I-15 CORE Project. The sensors were installed along 24 miles of the project between Lehi and Provo (UDOT I-15 CORE representative, personal communication, February 24, 2012). The installation of sensors was not part of the original project specifications but was given as an option from the contractors in the bid. Six detectors were installed on the curb lane of major streets and on freeway ramps. The sensors gather travel time data, which is sent wirelessly to nearest traffic cabinet, which then

connects to the Traffic Operation Center (TOC) of UDOT (UDOT I-15 CORE representative, personal communication 2012). The calculated travel times associated with using the freeway or the arterial were displayed on signage installed throughout the network and provided drivers with travel time information that could be used for route selection.

In the beginning of using the Sensys Networks system, there were some issues with the Sensys Networks system. There were some bugs with the display signals, which would cause other parts of the system to fail, and the removal of the display signals was considered. However, after a year and a half, the system stabilized as more data were collected and the bugs were fixed. After stabilization, the system received positive public feedback about the travel time displays. The UDOT I-15 CORE representative reported that drivers felt the posted travel time for the two routes were helpful and reasonably accurate. Every month, the I-15 CORE project conducted travel time comparison of the Sensys Network devices and GPS devices. The travel time was collected for northbound travels from Provo to Lehi using State Street (US-89) or I-15. The travel time comparison for the month of January is shown in Figure 3-17. The maximum difference between the two methods was 2 minutes (UDOT I-15 CORE representative, personal communication, February 24, 2012).

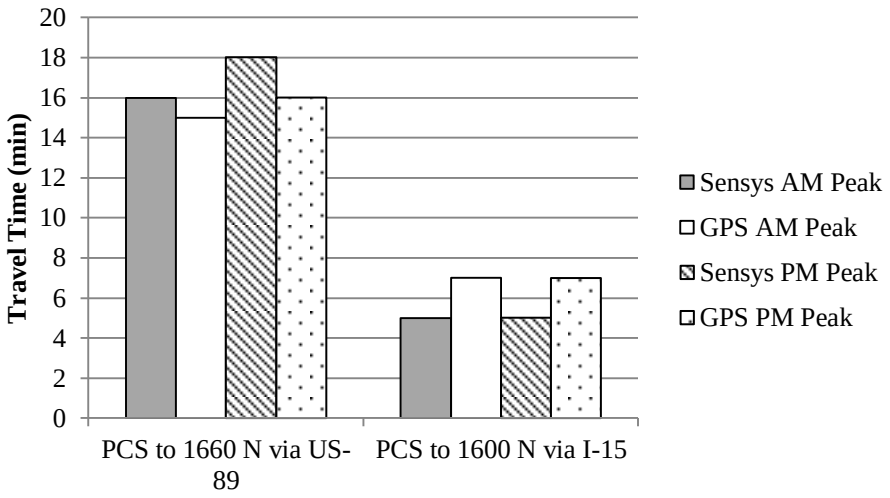


Figure 3-17. Travel Time Comparison for AM and PM Peak – January 2012 (UDOT I-15 CORE representative, personal communication, February 24, 2012)

3.4 Automatic Vehicle Identification

AVI systems monitor, track, and collect data about vehicle movements throughout the network. To enable location tracking, the vehicle is equipped with a sensor, and the time is recorded for every detection sensor the vehicle passes. One common application of AVI includes vehicle monitoring, such as supervising taxis for dispatch or tracking transit for managing schedule. However, AVI systems can be used for traffic data collection; the most common method of AVI data collection is the use of toll tags.

There are three types of toll tags: 1) laser, 2) radio frequency (RF), and 3) infrared (IR). For laser toll tags, vehicles have a bar code on a sticker attached to the vehicle windshield. The scanner reads the bar code as the vehicles passes. For RF and IR, a vehicle tag or transponder is mounted on the windshield, bumper, or antennas of the vehicle. Toll tag identification (tagID) readers are installed along the road and detect the vehicle tag as the vehicle passes, as shown in Figure 3-18. When a vehicle passes a tagID sensor, information such as the detection time and location is collected from each toll tag. Over the years, lasers have become less popular, and RF and IR tags are becoming more commonly used (Turner et al. 1998).

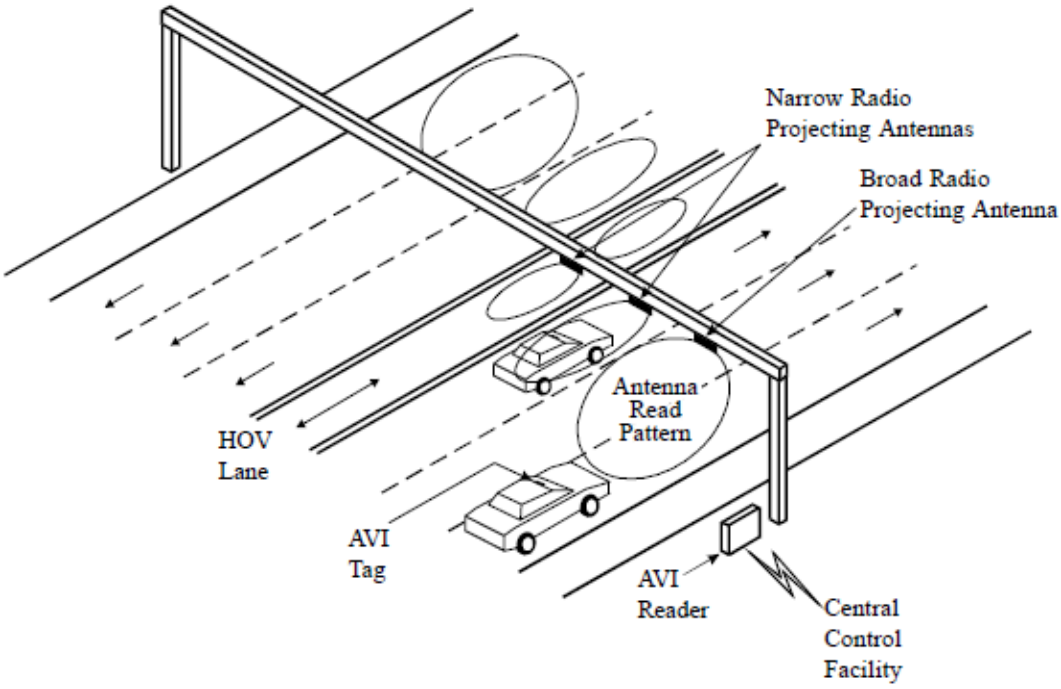


Figure 3-18. Concept of Radio Frequency (RF) Toll Tag (Turner et al. 1998)

AVI systems are helpful for monitoring traffic within or near tolling facilities. Travel time and speed are collected by using the records of toll tags as vehicles pass consecutive tagID detectors. Performance measurements such as travel time can be calculated from the time difference between the two detectors.

3.4.1 Advantages

The biggest advantage of using AVI toll tag technology comes from its utilization of the existing tolling system. AVI toll tags can use the same communications infrastructure used for the tolling, and the data are collected continuously throughout the day. By using the tolling system, there is a potential for a large sampling pool (Turner et al. 1998).

3.4.2 Disadvantages

Even though using the toll tag is a great way to gather information, there are several disadvantages with this technology. The start-up cost to install a toll facility is very high. Also, the tolling facility requires significant physical and communication infrastructure, as well as maintenance in collecting data (Puckett and Vickich 2010). The sampling size is very dependent on the number of drivers that choose to install a toll tag device in their car. The location for implementing toll tags is limited to roads within toll ways. With using toll tags, there are some privacy issues because the tagID can be used to identify the person who purchased the equipment. To protect the end users, any sort of information that could identify the driver of the car needs to be protected through encryption or any other type of security measures (Porter et al. 2011).

3.4.3 Examples of Existing Practice

In the United States, toll tags have been used in many programs to collect travelers' information. This section will discuss three AVI toll tag programs used in the country.

3.4.3.1 TransGuide Travel Tag Program – San Antonio, Texas

In 1996, the TransGuide Travel Tag Program began in San Antonio, Texas. Since there was not a toll facility in the area, the program recruited volunteers to participate. There were some troubles in attracting volunteers, so the distribution projection was reduced from 200,000

to 78,000 toll tags (Wright and Dahlgren 2001). The system had 53 detection sites that were spaced 1 to 2 miles apart (Wright and Dahlgren 2001) and covered 26 miles of freeway (Purcell 2010). Information about travel time or crashes could be accessed from a public kiosk, which was updated every hour. The program originally started out as a five-year program but continues to exist. Recently, the TransGuide was expanded to cover 130 miles of freeway and uses a variety of ITS technology such as inductive loop, radar, and video-recognition traffic detectors (Purcell 2010). Instead of kiosks, road users may access information from the internet (TxDOT 2010).

3.4.3.2 TranStar Traffic Monitoring System – Houston, Texas

In 1992, the TranStar traffic monitoring system began in Houston, Texas. The system has 290 detectors, roughly 2 to 3 miles apart, and has over 500,000 tags (Wright and Dahlgren 2001). On the TranStar website, road users could access information about travel time and road conditions. The TranStar system was originally a three-year project but, due to its popularity, has kept on going. Today, information on traffic condition is gathered through toll tags and Bluetooth technology (Houston TranStar 2012).

3.4.3.3 TRANSMIT System – New Jersey and New York

The TRANSCOM System for Managing Incidents and Traffic (TRANSMIT) System uses the E-ZPass tags along 22 miles on the Garden State Parkway in New Jersey and the New York State Thruway in New York. The system has 22 road readers, placed 0.5 to 2 miles apart with a detection antenna for each direction (Wright and Dahlgren 2001). Many vehicles on that roadway have the E-ZPass toll tags. During rush hour on the Garden State Parkway, roughly 65 percent or 2 million vehicles have these tags (Wright and Dahlgren 2001). The transmission rates for all the locations except one ranged from 98 percent to 100 percent (Niver et al. 2000). The one exception was the Tappan Zee Bridge, which used a radio transmitter and had many sources of interference. The TRANSMIT System is also equipped with an incident alert algorithm. If there is an excessively long time interval for vehicles to reach the next detection site, a potential incident alarm is triggered, and local authorities are notified. An evaluation study of the TRANSMIT System showed that the probability of a false alarm ranged from 5 percent to 67 percent. The highest percentage of false alarms occurred during the morning off-peak period, 9

AM to 11 AM, and the evening off-peak period, 6:30 PM to 6:30 AM on average (Niver et al. 2000).

In 2009, a case study on I-287 in New Jersey compared the accuracy of the estimated travel time based on data collected by various technologies. The investigated technologies (AVI TRANSMIT toll tag readers, Bluetooth sensors, and the GPS INRIX system) were compared against the traditional GPS probe vehicle. The GPS probe vehicle collected data during 12, 15-minute intervals from 7:00 AM to 10:00 AM between April 6 and April 17, 2009. For each time interval, two vehicles were dispatched. The GPS probe vehicle data were compared to data from INRIX, TRANSMIT, and Bluetooth systems along 4 links. Table 3-4 lists the standard error of the mean (SEM), average absolute speed error (AASE), and speed error bias (SEB) that was calculated for each system (Kim et al. 2010). The AASE was the difference between the estimated speeds and the true speed from the GPS probe vehicles. The SEB was the difference between the estimated speeds based on the tested technology and the data collected by the GPS probe vehicle. The results for the GPS INRIX system are discussed in section 3.7.4.

Table 3-4. Error Comparison for TRANSMIT Estimate versus GPS Probe Data

Link Number	Link Length (mi)	SEM (mph)			AASE (mph)			SEB (mph)		
		North	South	Both	North	South	Both	North	South	Both
1	6.78	1.55	1.97	1.31	4.75	7.41	6.11	-1.14	-6.59	-3.92
2	5.79	1.43	1.13	0.93	4.29	4.76	4.53	-0.41	2.80	1.23
3	4.16	1.14	0.99	0.75	4.36	3.88	4.13	2.30	1.24	1.78
4	3.78	1.11	1.31	0.85	4.51	5.66	5.10	2.86	3.17	3.02
5	20.76	1.13	1.13	0.79	4.36	4.51	4.44	1.45	2.42	1.94
ALL	41.27	0.58	0.69	0.45	4.45	5.26	4.87	0.99	0.57	0.78

Source: Kim et al. 2010

Overall, the TRANSMIT speed estimates were close to the actual speed. The SEB for both northbound and southbound movements were 0.78 mph. However on Link 1, the TRANSMIT underestimated the speed with an overall SEB of -3.92 mph. The author did not state whether this underestimate was significant or not (Kim et al 2010).

3.5 Microwave Radar

Microwave radar collects data by emitting a microwave radar beam. The sensors are mounted, usually on a pole, and as vehicles pass through the beam the microwave is reflected and detected by the sensor as shown in Figure 3-19 (Wavetronix LLC 2012). The sensors can detect volume, presence, vehicle length, speed, and headway (Minge et al. 2010).

The sensors can be placed in two positions: 1) forward fire and 2) side fire. Forward fire aims a microwave unit up along a lane of oncoming traffic. The unit can only monitor one lane of traffic, and additional units are needed for every additional monitored lane. The forward fire allows for more accurate speed measurements. Side fire aims the sensors perpendicular to the roadway. The accuracy of speed and vehicle length is less accurate, but multiple lanes can be monitored (Zwahlen et al. 2005).

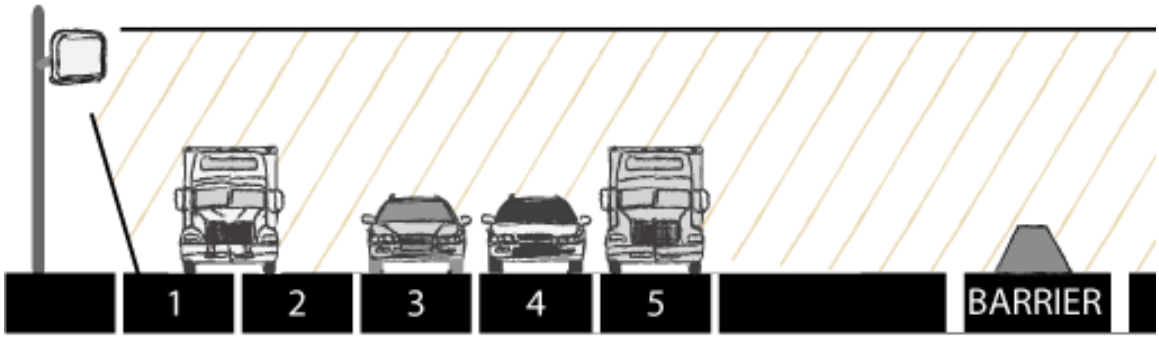


Figure 3-19. Set up for Microwave Radar Data Collection (Wavetronix LLC 2012)

3.5.1 Advantages

The advantages of microwave radar technology include non-intrusive installation and no privacy issues. Unlike intrusive sensors such as inductive magnetic sensors, installing microwave radar sensors does not require a lane closure, as the microwave radar sensors are mounted on roadside poles. Roadside installation also reduces the risk of injury and death of workers (Wavetronix LLC 2012). The setup can be relatively simple, where the microwave radar just needs to be mounted at the recommended height of 28 feet and an offset of 30 feet from the road (Minge et al. 2010). Another advantage is that there are no privacy concerns when using microwave radar technology. Microwave radar emits microwaves that measure vehicle speed.

Detection is based on how and when the waves are reflected back to the sensor. This makes the sampled vehicles anonymous, and there are no privacy issues with the use of microwave radar.

3.5.2 Disadvantages

There are a couple of disadvantages associated with the use of microwave radar technology. One disadvantage of microwave radar is the accuracy of the data, which is dependent on the position of the device. If the device is not positioned correctly, then accuracy of the measurement will drop. Another disadvantage is that the microwave radar can also miss a vehicle when large trucks are traveling in an intervening lane. The system can also register a phantom vehicle if radar waves echo back (Zwahlen et al. 2005).

3.5.3 Companies Offering Microwave Radar Equipment

There are multiple companies that produce microwave radar technology. The purpose of this section is to discuss the capabilities of products provided by three selected companies, but it is not to recommend the use of any company's product.

3.5.3.1 Wavetronix

Wavetronix provides several types of microwave radars. Wavetronix's digital wave radar actively prevents the radar signal from slipping out of wavelength bandwidth range, which can occur over time or when the temperature changes. The high definition radar emits and receives two separate microwave beams, which allows the units to detect the direction of travel (Wavetronix LLC 2012).

Command Collector is the main Wavetronix software for data analysis. The software is used for collection, management, and distribution of traffic data. Command Collector has a web-based interface that allows the user to remotely manage sensors, change system settings, and view data graphs. Email alerts may also be set up for certain warning thresholds (Wavetronix LLC 2012).

In addition to alerts, four different reports can be generated in Command Collector: 1) missing intervals, 2) validation, 3) daily peak, and 4) monthly reports (Wavetronix LLC 2011). The missing intervals report shows the sensors and time for which intervals are missing data.

The validation report determines if data holes exist in the Command Collector database. The daily peak report presents data by sensors for a defined amount of days. This report also includes total volume, average speed, and average occupancy along with vehicle classification, which is shown in Figure 3-20 (Wavetronix LLC 2011). The monthly report is similar to the daily peak but presents totals for selected months. The Command Collector allows users to select the data interval size in 5-, 15- or 60- minute intervals.

Sensor: 2 **Monday, 18 February 2008**

Approach: East-Bound

Total Volume: 11,843 Average Speed: 44 Average Occ: 2.4%

Class Information

Class: Small	Value: 94.0%	Volume: 11,843
Class: Medium	Value: 3.0%	Volume: 291
Class: Large	Value: 1.0%	Volume: 173

AM Peak Hour: 11:00 - 12:00

AM Volume: 682 AM Average Speed: 45 AM Average Occ: 2.1%

AM Peak Intervals

Time: 11:00	Volume: 147	Speed: 46	Occ: 1.6%
Time: 11:15	Volume: 170	Speed: 46	Occ: 2.0%
Time: 11:30	Volume: 162	Speed: 44	Occ: 2.2%
Time: 11:45	Volume: 203	Speed: 43	Occ: 2.4%

PM Peak Hour: 17:00 - 18:00

PM Volume: 1,175 PM Average Speed: 44 PM Average Occ: 4.0%

PM Peak Intervals

Time: 17:00	Volume: 290	Speed: 44	Occ: 4.4%
Time: 17:15	Volume: 271	Speed: 44	Occ: 3.3%
Time: 17:30	Volume: 327	Speed: 42	Occ: 4.4%
Time: 17:45	Volume: 287	Speed: 47	Occ: 3.7%

Figure 3-20. Screenshot of Daily Peak Report (Wavetronix LLC 2011)

3.5.3.2 Econolite

Econolite provides microwave radar, the Remote Traffic Microwave Sensor (RTMS) G4. RTMS G4, shown in Figure 3-21, is a small roadside pole-mount radar sensor (Econolite 2012). The sensors can provide per-lane presence, volume, occupancy, speed, and classification information for up to 12 separate zones or lanes. The sensors are reliable in all weather conditions (Econolite 2012).

Figure 3-21. Multiple RTMS G4 Units (Econolite 2012)

Econolite's Node Event Warning System (NEWS) detects and sends notifications of traffic irregularities for eight RTMS stations. NEWS processes the traffic measurements in real time and can provide alarms based on programmed event criteria. Up to 16 event criteria can be programmed, and the alerts can be used to display information on VMS or can alert TOC operators. Wide Area Traffic Event Reporting (WATER) can monitor real-time traffic measurement and data collection for traffic in thousands of locations. Data are collected by multiple side fired RTMS data collection stations (Econolite 2012).

3.5.3.3 iCone

iCone is another radar equipment and software company. The radar units, which can measure the speed of traffic, are housed in a standard channelizing drum or construction traffic barrel, as shown in Figure 3-22 (SRF Consulting Group, Inc. 2010). At first glance, the iCone barrel looks like a standard barrel, which allows the device to observe traffic unobtrusively, but

up close there are features that distinguish the iCone barrel from regular traffic barrels. The units also contain a GPS device, which provides the location of iCone barrel. There are some issues with iCone devices. Since the device looks like a standard barrel, the device may be damaged if struck by vehicles or construction equipment (UDOT Region 2 representatives, personal communication, May 14, 2012).

iCone also provides data processing and reporting features (iCone LLC 2009). Figure 3-23 shows a screenshot of an iCone data summary (SRF Consulting Group, Inc 2010). The iCone collected the number of vehicles and the average vehicle speed for a one-hour interval. The Fahrenheit, Celsius, days elapsed, and voltage columns can help monitor the battery life of the iCone devices.

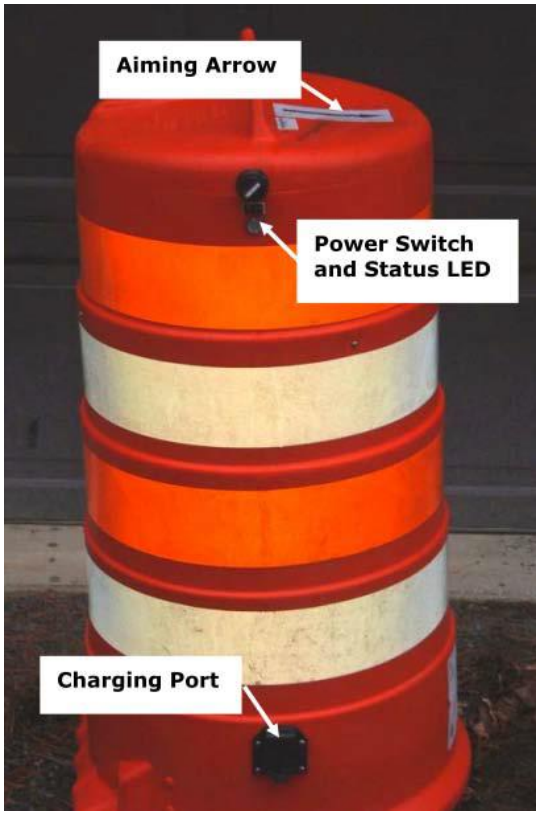


Figure 3-22. iCone Traffic Drum (SRF Consulting Group, Inc. 2010)

iConeID	localTime	avgSpeed	count	fahrenheit	celsius	daysElapsed	voltage
218	8/13/2010 12:00	53	395	77	25	12.08	13.30
218	8/13/2010 13:00	61	502	71	22	12.13	13.24
218	8/13/2010 14:00	61	506	75	24	12.17	13.20
218	8/13/2010 15:00	62	463	71	22	12.21	13.22
218	8/13/2010 16:00	62	457	71	22	12.25	13.19
218	8/13/2010 17:00	63	425	69	21	12.29	13.20
218	8/13/2010 18:00	63	486	66	19	12.33	13.19
218	8/13/2010 19:00	68	423	75	24	12.38	13.19
218	8/13/2010 20:00	70	437	73	23	12.42	13.19

Figure 3-23. Screenshot of Sample iCone Data (SRF Consulting Group 2010)

3.5.4 Example of Existing Practices

This section discusses five examples of microwave radar throughout the United States, specifically in Ohio, California, Minnesota, Utah, and North Carolina.

3.5.4.1 Ohio

The Ohio Department of Transportation conducted a study on a four-lane section of US-50 east of Athens, Ohio. The purpose of the study was to validate the ability of the Wavetronix trailer to unobtrusively collect vehicle data such as speed, vehicle length, classifications, and vehicle counts. Researchers from the Ohio Research Institute for Transportation and the Environment (ORITE) validated the microwave radar measurements with time-stamped video recording of the traffic. Video was recorded on June 14 and July 10, 2004, for 1.5 hours (Zwahlen et al. 2005).

The speed measurement was less accurate because of the large speed variability in the side fire mode. In side fire mode, only the moving average speed of 16 vehicles was reported. The moving average speed was two to three times greater than what was observed from traffic. Since the speed was not accurate, it affects the accuracy of the vehicle length and vehicle classification data. The running average speed of the vehicle was used to determine vehicle length and vehicle classification. Vehicle classification was determined based on vehicle length.

If the vehicle speed had a speed greater than average speed, the vehicle speed was measured to be shorter than the actual length. Based on vehicle length, the number of right-lane trucks was undercounted by 80 percent on one of the study days. These results imply that the Wavetronix devices do not provide reliable vehicle lengths or vehicle classifications (Zwahlen et al. 2005).

The study also evaluated the accuracy of vehicle counts from the Wavetronix system. It was found that the system occasionally missed detecting a vehicle or registered a phantom vehicle. Table 3-5 lists the missed and phantom vehicles observed during the test runs (Zwahlen et al. 2005). Negative net errors indicate an underestimate by the Wavetronix system. Overall, the net errors ranged from -4.28 to 4.32 percent. The net error range was within an acceptable reliability range because some misses are inevitable due to large trucks blocking smaller cars.

Table 3-5. Missed and Phantom Vehicles during Wavetronix Study on US-50

Date	Time	Direction	Lane	Total Vehicle	Misses		Phantoms		Net Errors	
					Number	%	Number	%	Number	%
6/14/2004	1:45 PM to 3:16 PM	EB	Right	357	17	4.76	2	0.56	-15	-4.20
			Left	185	5	2.70	13	7.03	8	4.32
			Both	542	22	4.06	15	2.77	-7	-1.29
6/14/2004	3:29 PM to 4:59 PM	WB	Right	368	5	1.36	2	0.54	-3	-.082
			Left	151	2	1.32	2	1.32	0	0.00
			Both	519	7	1.35	4	0.77	-3	-0.58
7/10/2004	2:58 PM to 4:29 PM	EB	Right	374	18	4.81	2	0.53	-16	-4.28
			Left	122	4	3.28	2	1.64	-2	-1.64
			Both	496	22	4.44	4	0.81	-18	-3.63
7/10/2004	4:38 PM to 6:12 PM	WB	Right	310	8	0.65	5	1.61	3	0.97
			Left	158	4	2.53	4	2.53	0	0.00
			Both	468	6	1.28	9	1.92	3	0.64

Source: Zwahlen et al. 2005

3.5.4.2 California

In California, iCone was used to monitor the traffic during the Bay Bridge closure in 2009. The bridge was closed over Labor Day weekend while work was being done to remove and replace a 300-foot-long section of the bridge. There were a total of 13 iCone units deployed, five monitoring traffic on Interstate 92 and eight on Marin County Road 2. The iCones were used primarily to monitor the queue lengths and automatically notify the Caltrans workers when high delays occurred. During the closure, there were some queues that did exceed the target maximum queue length. Afterwards, Caltrans reviewed the iCone data to identify sources of problems during the closure. Caltrans employees found the iCone system to work well. It allowed them to be aware of traffic conditions for multiple locations at any given time (Jeffrey 2009).

3.5.4.3 Minnesota

The Minnesota Department of Transportation (MnDOT) conducted a field test in order to evaluate the capabilities of the iCone equipment in work zones in Minneapolis, Minnesota. The study considered four main types of operational scenarios: 1) closure restriction and traffic control modifications, 2) enforcement, 3) mobility measurement, and 4) traffic responsive systems. The study included three sites. The first study site was located on Interstate 394 (I-394) near the exit at Penn Avenue and detecting the eastbound traffic. The other two study sites were located along Interstate 35 West (I-35W). One study site was the I-35W junction with I-35 East (I-35E) in Lino Lakes, Minnesota, and the other site was near the Main Street overpass in Lino Lakes, Minnesota (SRF Consulting Group Inc. 2010).

At each testing site, the iCone collected vehicle speed at one-minute intervals. On the I-394 testing site, data were collected on three different days: August 14, August 17, and September 2, 2009. On the I-35W and I-35E study site, data were collected continuously between August 15thand August 20th. Table 3-6 shows the summary of the speed accuracy results. The I-394 test site had a maximum average percent difference of 5 percent, while the same value measured at the junction of I-35W and I-35E was 18 percent. The difference between the test sites can be related to the type of detector the iCone data was compared to. The iCone data collected on the I-394 and I-35 W sites were compared against dual loop detectors and single

loop detectors, respectively. The single loop detector was not as accurate as the baseline for the double loop detectors (SRF Consulting Group 2010).

Table 3-6. MnDOT iCone Speed Accuracy Results

Test Location	Test Date	Test Time of Day	Average Difference (mph)	Speed Standard Deviation (mph)	Average Percent Difference
I-394	8/14/2009	Midnight to 7:00 am	3	2.6	5%
I-394	8/17/2009	8:00am to 10:00am	2	2.0	4%
I-394	9/2/2009	Midnight to 7:00 am	2	3.6	4%
I-35W at I-35E	8/15/2009 to 8/20/2009	Continuous	11	8.2	18%

Source: SRF Consulting Group 2010

MnDOT learned several lessons from the iCone field study. The iCone System can give an approximation of volume data. To provide a better estimate of the volume, the iCone needs to be placed perpendicular to the direction of traffic. However, in this position, the iCone cannot detect speeds. MnDOT also suggested recommendations for future work. Since the field study focused on speed, the iCone was not tested for volume performance. MnDOT also made comparisons between iCone and other non-intrusive technologies. Other non-intrusive technology such as Wavetronix microwave radar sensors are designed to collect speed, volume, and vehicle classification data but require more set up equipment and calibration time than the iCone. The iCone was easy to set up, which allowed the system to be placed on the roadway on short notice.

In the field study, MnDOT made recommendations for future deployments. One suggestion includes studying traffic flow through the work zone. The iCone devices would be placed at fixed spacing in the work zone to identify how long drivers will maintain the posted speed limits. The speed information would determine if new signing plans are needed. Another

suggestion would include additional integration of iCone data into the local traffic information website.

3.5.4.4 Utah

UDOT Region 2 rented iCone sensors in order to test the capability of the system (UDOT Region 2 representatives, personal communication, May 14, 2012). The iCone sensors were deployed in various locations to test if the device could continuously monitor vehicle speeds on different roadways and terrains. Region 2 felt that the iCone sensors were not a good data collection system. To ensure continuous monitoring of the system, additional units were needed, and batteries had to be replaced frequently. The data were not always accurate due to the short time-interval over which the average speed was calculated. When the iCones were moved to other sites, the data collection time interval needed to be adjusted. There was also a concern regarding the placement of iCone device. There was a risk that the iCone device could be damaged or stolen. Drivers might hit the iCone, or construction workers might accidently take the iCone drum to their storage shed. However, missing iCone devices could be located from the in-house GPS units (UDOT Region 2 representatives, personal communication, May 14, 2012).

3.5.4.5 North Carolina

In 2009, the North Carolina Department of Transportation (NCDOT) conducted a study testing how portable temporary traffic sensors could provide real-time traffic conditions and determine if the data could be used by NCDOT to improve safety and mobility in work zones. The devices were used to monitor an asphalt overlay project on I-95 and U.S. Route 64. The project involved closing one lane of traffic for a length of 1 to 5 miles depending on the day of the week. As the week progressed, the closure length increased up to 5 miles. The study also evaluated mobility-based performance measures, which are discussed in detail in Section 4.3.1.

The portable traffic-monitoring device (PTMD) used in this study to collect vehicle speed was a K-band radar and GPS unit housed in a construction drum (Chandler et al. 2010). To monitor the work zone, six radar units were deployed. Three units were deployed upstream, and three units were deployed downstream of the work zone, as shown in Figure 3-24 (Chandler et al. 2010).

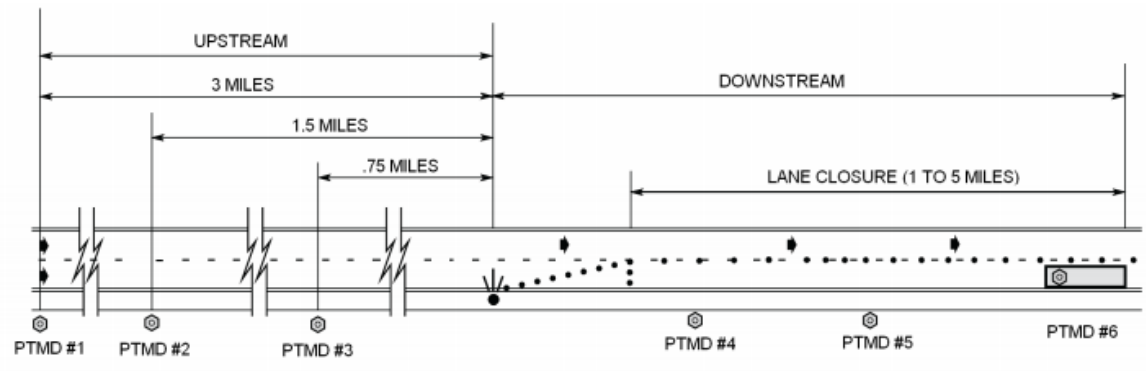


Figure 3-24. Typical Layout for Monitoring Devices (Chandler et al. 2010)

There were some challenges associated with the deployment of PTMD in the NCDOT study. First, there were some technical difficulties. Two of the three battery chargers were wired incorrectly and would blow a fuse when the batteries were being charged. After two weeks of investigation, the source of the problem was that the battery chargers were not wired properly (Chandler et al. 2010). After the issue was resolved, the chargers worked perfectly. Another challenge was that the monitoring devices could be hit or removed. During the testing period, two monitoring devices were damaged beyond repair. This happened because the devices looked like regular construction drums and were susceptible to being hit by vehicles or construction equipment. To protect the equipment, the device was placed in line with other drums in the work zone. Sometimes if the construction crew was not paying attention the radar devices were hauled off to the contractor's storage location at night or on the weekend. The devices could be easily located due to the built-in GPS unit. However, locating the device was more difficult if the device's battery had died (Chandler et al. 2010).

3.6 Cellular Phone

Over the years, cellular phone ownership has increased. According to a Pew Survey, in February 2012, 88 percent of adults in the United States owned a cell phone (Smith 2012). This large percentage shows the potential for utilizing cellular phones for traffic data collection purposes. There are two major methods for collecting travel time data from cellular phones: 1) cellular telephone reporting and 2) cellular geolocation.

The first method, cellular telephone reporting, asks volunteer drivers to call a central facility when they pass checkpoints along the freeway (Turner et al. 1998). In addition to getting travel times, the drivers can provide qualitative assessment of current traffic conditions. However, many drivers forget checkpoints or report their location at the wrong time. There is also a safety concern with using cell phones while driving.

The second method, geolocation, uses cellular signals to identify the vehicle's location. Cellular geolocation involves three basic tasks: location determination, map matching, and determination of traffic information. The first task, location determination, locates the probe vehicle. Then, during the map matching task, the estimated position of the vehicle is matched to a specific road. During the last task, the system analyzes the data of all the probe vehicles to estimate the average speed or travel time for the roadways (Smith et al. 2003).

3.6.1 Advantages

Advantages of using cellular phone technology for mobility data collection include a large potential sampling pool and a low cost of data collection. As mentioned in the previous section, 88 percent of adults own a cellular phone in the United States (Smith 2012). This large quantity of cellular phones can potentially be used to gather information on the roadway. The cost of using cellular phones is low compared to other technologies. Unlike other sensing technologies, there is no in-vehicle equipment or detectors that need to be installed on the road (Turner et al. 1998).

3.6.2 Disadvantages

Along with advantages, there are disadvantages with using cellular phone technology for mobility technology data collection. These disadvantages include privacy issues, safety concerns, and a sample size that is dependent on cellular phone use. Geolocation uses cellular phone signals to track vehicles, which can cause privacy concerns (Turner et al. 1998). If this method is used to track vehicles, there needs to be a way to ensure some encryption of collected data to make the drivers remain anonymous. There are safety concerns with the use of distracted drivers using cell phones while driving. A Harvard research study estimated about one in 20 traffic crashes involves a driver talking on a cell phone (Cohen 2003). It is important to ensure that the

cellular phone technology does not cause any distraction to drivers. Last, while there is the potential for a large sampling pool, this volume is dependent on the usage of cellular phones and the existence of cellular infrastructure (Turner et al. 1998). The smaller volume of phone calls, the smaller the sampling pool.

3.6.3 Company Offering Cellular Phone Data Collection Services

There are several travel time provider companies that utilize cellular phone technology. These companies include AirSage, Cellint, Delcan, Blobis Data, and IntelliOne (Wunnava et al. 2007). While this section focuses on AirSage as an example, the objective is to provide information on possible cellular-based services; it is not meant as a provider recommendation.

AirSage is a software company that provides real-time and historical traffic information through data collected from individual cellular phones on a broad cellular network. AirSage is partnered with a nationwide wireless cellular phone carrier, Sprint, in gathering data (Wunnava et al. 2007). Figure 3-25 is diagram depicting how the AirSage system works (AirSage 2012). The cellular phone signal is gathered and sent to an AirSage's wireless network operators. There, the collected cellular signal data are encrypted, and the location and other data are determined. The traffic data are updated every 1 to 2 minutes every day (AirSage 2012). In order to get good information, about 5 percent of the cellular phones need to be in use (Wunnava et al. 2007). AirSage has been used in many cities such as Salt Lake City, Utah; Fresno, California; Atlanta-Macon, Georgia; and Norfolk, Virginia (Wunnava et al. 2007).

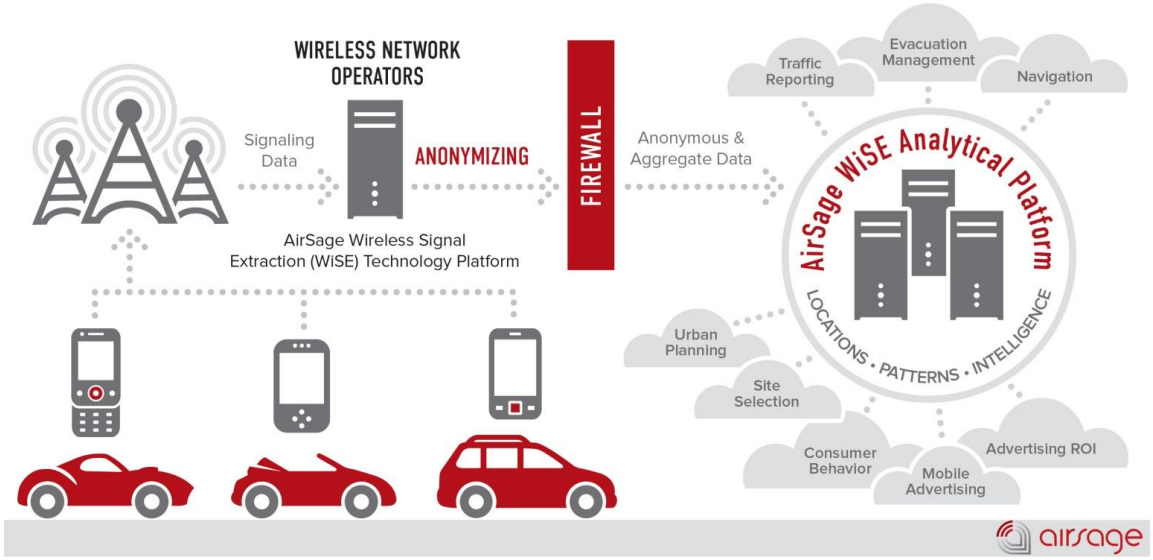


Figure 3-25. Diagram of AirSage Processing System (AirSage 2012)

3.6.4 Existing Practices

This section presents four examples of existing practices using cellular phones in California, Utah, Virginia, and Minnesota.

3.6.4.1 California

In Fresno, AirSage is used by the local television channel 30, KFSN, as part of its morning traffic report. Speed and traffic flow information on highway and backcountry roads in the Fresno area were provided by AirSage systems. After the system was used for two weeks, there were positive responses (Wunnava et al. 2007). The television channel appreciated knowing the speed of the roadway in real time and being able to better forecast traffic conditions. While there were positive responses, some of the public express privacy concerns with the AirSage system (Mobility Techzone 2006).

3.6.4.2 Utah

In 2006, there was a study conducted to compare the AirSage system and the existing inductive loop sensor system in Salt Lake City, Utah. A graphical comparison of the two systems is shown in Figure 3-26. Both images show the traffic condition in the Salt Lake City area based on information gathered by the AirSage and existing system on the left and right, respectively.

With the existing system, only traffic condition on the interstate was collected, while the AirSage system provided traffic condition along major arterials in addition to the interstate. While AirSage provided information on additional roadway, the accuracy of the data on these roads could not be verified since there were no sensor data for comparison (Wunnava et al. 2007). However, this study showed the potential use of cellular phone technology as an alternative source for mobility data.

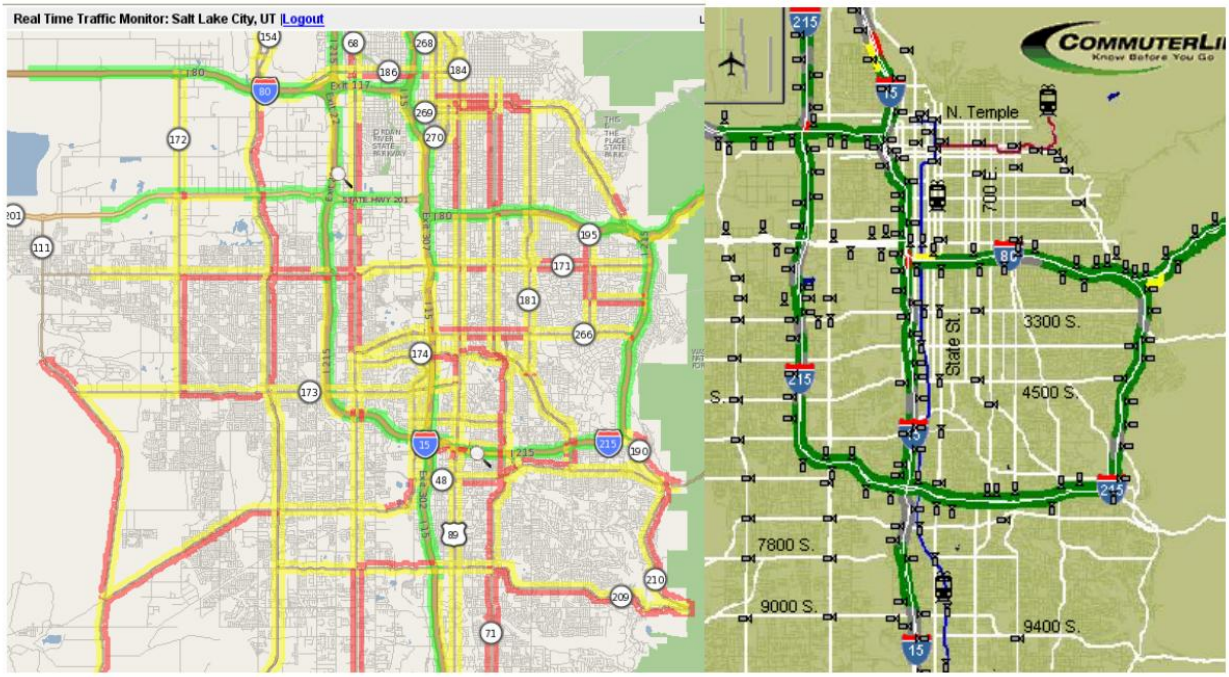


Figure 3-26. Graphical Comparison of AirSage (Left) and Existing Sensors (Right) Coverage in Salt Lake City (Wunnava et al. 2007)

3.6.4.3 Virginia

Two separate tests were conducted to verify the AirSage product in Hampton, Virginia. The first test was an independent study conducted by the University of Virginia Smart Travel Laboratory for the Center for Transportation Studies in 2005 for the Virginia Department of Transportation (VDOT). The AirSage data were compared with data collected by probe vehicles with GPS units. Table 3-7 lists the absolute speed difference between the two data collection methods for four different traffic conditions (Wunnava et al. 2007).

Table 3-7. Average Absolute Speed Difference between AirSage and GPS Data

Traffic Condition	Speed Range (mph)	Average Speed Difference (mph)
Severe Congestion	0 – 30	24.69
Moderate Congestion	30 – 45	8.52
Light Congestion	45 – 60	8.65
Free Flow	> 60	9.49

Source: Wunnava et al. 2007

The average speed difference under free-flow to moderately congested traffic conditions ranged between 8.52 and 9.49 mph. However, the accuracy decreased greatly under severe congestion, or speeds between 0 to 30 mph. The average speed difference increased to 24.69 mph. From the test, the University of Virginia concluded that AirSage did not have sufficient quality for VDOT because of the low speed accuracy (Wunnava et al. 2007).

In 2006, AirSage conducted an in-house test on 90 miles of the Hampton Roads. The test roads included urban and rural freeways and urban arterials and were broken into 299 segments. The data collected from the AirSage system were compared with 612 ground-truth measurements. From the test it was found that the absolute error for all 299 segments was 8.7 mph. Table 3-8 shows the breakdown of absolute error for the AirSage System. Almost half of the segments had an absolute error less than 5 mph, which showed an improvement of the AirSage system since the University of Virginia test conducted the year before (Wunnava et al. 2007).

Table 3-8. Absolute Error Break Down for AirSage System

Absolute Error	Number of Segments	Percentage (%)
Less than 5 mph	145	48.5
Between 5 and 10 mph	78	26.1
Greater than 10 mph	76	25.4

Source: Wunnava et al. 2007

3.6.4.4 Minnesota

From May to June 2007, the University of Minnesota conducted a study to evaluate the accuracy of the AirSage system. The data were collected on three roads using the AirSage system. The three roads were I-394, County Road 81 (CSAH-81), and State Truck Highway 55. The AirSage reported speeds within 10 mph of the observed speeds. The frequency of the time observed for each relative error range was collected, as shown in Table 3-9 (Liu et al. 2008).

Table 3-9. Percentage of Time Observed for Each Relative Error of Reported Travel Time

	Relative Error				
	Less than -10%	-10% to -5%	-5% to 5%	5% to 10%	More than 10%
I-394 Test Site					
AM peak	6.7	3.6	10.4	10.9	68.4
PM peak	2.7	0.9	4.8	3.9	87.7
CSAH-81 Test Site					
AM peak	0.0	16.7	41.7	8.3	33.3
PM peak	11.8	20.6	26.4	20.6	20.6

Source: Liu et al. 2008

For the I-394 test site, the AirSage reported an overestimated travel time during the AM and PM peak hours. The relative error was more than 10 percent greater than the observed travel time 68.4 and 87.7 percent of the time for the AM and PM peak, respectively. However, the AirSage system was more accurate on CSAH-81 than I-394. Both the AM and PM peak periods

had relative errors between -5 to +5 percent 41.7 and 26.4 percent of the time, compared to 10.4 and 4.8 percent of the time for the I-394 AM and PM peak periods, respectively (Liu et al. 2008).

In June 2007, the full capacity of the cellular phone tracking system was activated. Liu et al. (2008) suggested that further travel time comparison should be conducted on the new system to determine if the accuracy improved.

3.7 Global Positioning System

GPS devices uses satellite signals to determine and collect latitude and longitude information. This technology was developed by the Department of Defense (DOD) in order to track military ships, aircrafts, and ground vehicles. Today the technology is available to the public and can be found in civilian-grade GPS devices, cellular phones, or GPS-enabled vehicles.

For collecting mobility-based performance data, a GPS unit is placed in a probe vehicle, and the locations and speed are recorded at set time intervals. When using a probe vehicle, the driver is asked to drive the vehicle using one of three different driver styles: 1) average car, 2) floating car, and 3) maximum car. For the average car style, the driver travels based on the driver's judgment of the average speed of the traffic stream. For the floating car style, the driver safely passes as many vehicles that pass the test vehicle. For the maximum car style, the driver drives at the posted speed limit unless traffic conditions prevent the driver from doing so (Turner et al. 1998). In addition to the probe vehicle method, there companies that utilize the GPS devices in cellular phone and GPS-enabled vehicles.

3.7.1 Advantages

GPS has many advantages. First, GPS can produce accurate and detailed data. The devices can be configured to automatically record data at set time intervals. The use of automatic GPS units can reduce human errors that can occur, such as missing checkpoints or incorrectly recording information. Another benefit of using GPS is the low maintenance cost. While other technology systems require on-site maintenance, the GPS infrastructure is operated by the DOD, which monitors and maintains the system closely and makes necessary repairs and updates (Turner et al. 1998).

3.7.2 Disadvantages

There are some disadvantages associated with the use of GPS technology. One disadvantage is the interference that can occur while gathering data. GPS units rely on receiving satellite signals in order to determine the location of the device. However, this signal can be lost due to interference caused by adjacent tall buildings, trees, and power lines or tunnels. Another disadvantage is the high cost of using GPS as a data source. When using a probe vehicle, that vehicle only represents one vehicle in the traffic stream. To gather more data, multiple driving runs are needed. These runs can be costly and take up time of those driving the probe cars (Turner et al. 1998).

3.7.3 Company Offering GPS Data Collection Services

This section presents a description of one company that offers GPS data collection and analysis services. The objective is to provide information on GPS-based mobility data collection and is not meant as a recommendation.

INRIX is a software company that provides internet and cellular phone traffic-related software. The company aggregates data from a variety of GPS devices, such as stand-alone GPS devices, GPS-enabled vehicles, and cellular phone with GPS, as well as historical data from STAs. INRIX has industry partners including Ford Motor Company, MapQuest, Microsoft, and Telmap. INRIX has information that covers 1 million miles of roads in North America and 1 million kilometers in 28 European countries (INRIX 2012).

INRIX also created an application, INRIX Traffic, for smart cellular phones. INRIX Traffic provides traffic information such as real-time traffic report, traffic-optimized routes, weather and crashes alerts, and traffic forecast (INRIX 2012). This application tracks the movement of users through the GPS system in the phone. If the application is displaying wrong information, users can submit or report correct traffic condition (PC Advisor 2011).

For traffic flow data solutions, INRIX provides real-time, predictive, and historical traffic flow data. Congestion alerts help provide information for reports regarding unusual and severe congestion in real time. INRIX also offers INRIXTraffic.us, a free service for STAs to assist

them in operating and managing their roadway. Currently, 46 states in North America are using the INRIXTraffic.us software (INRIX 2012).

3.7.4 Existing Practices

This section discusses two examples of projects using GPS technology. The first example is a case study located in New Jersey. The second example focuses on the I-95 Corridor Coalition Vehicle Probe Project that took place in multiple states including Delaware, Maryland, New Jersey, and Virginia.

3.7.4.1 New Jersey

A case study on I-287 in New Jersey compared the accuracy of the estimated travel time based on data collected by various technologies. The study compared the AVI TRANSMIT toll tag readers, Bluetooth sensors, and the INRIX system against the traditional GPS probe vehicle. For the GPS probe vehicle, data were collected during 12 15-minute intervals from 7:00 AM to 10:00 AM between April 6 and April 17, 2009. For each time interval, two vehicles were dispatched to collect data. The GPS probe vehicle data were compared to data from INRIX, TRANSMIT, and Bluetooth systems along 4 links. Since the locations of the TRANSMIT responders differed from the other systems, the analysis was conducted in two parts: 1) INRIX and Bluetooth estimates versus GPS probe vehicle data and 2) TRANSMIT estimates versus GPS probe vehicle data. Table 3-10 lists the standard SEM, AASE, and SEB that were calculated for each system (Kim et al. 2010). The SEM is the standard deviation of the speed estimate. The AASE was the difference between the estimated speeds against the true speed from the GPS probe vehicles. The SEB was the difference between the estimated speeds based on the tested technology and the data collected by the GPS probe vehicle.

The Bluetooth data provided estimates that were close to the reported speeds from the GPS with a SEB of 0.32 mph. However, the INRIX system showed potential to underestimate the speed with a SEB for all the links of -2.84 mph. Depending on the average speed of the roadway, an SEB of -2.84 mph may be acceptable. The report did not state the average speed for all to the links, so the significance of the SEB cannot be assessed. However, Kim et al. (2010) stated that possible reasons for the underestimation included delay in transmitting GPS data to

satellite, biased samples with large percentages of trucks, or additional historical data that the INRIX system used in its analysis program.

Table 3-10. Error Comparison for Bluetooth and INRIX Data against GPS Probe Vehicle Data

Link Number	Device	SEM (mph)		AASE (mph)		SEB (mph)	
		North	South	North	South	North	South
1	Bluetooth	1.16	1.04	4.35	4.29	0.62	-2.14
	INRIX	1.46	1.28	6.78	5.07	-3.63	-3.49
2	Bluetooth	1.25	1.16	5.25	4.55	2.30	2.52
	INRIX	1.49	1.02	5.98	3.29	-1.89	-0.85
3	Bluetooth	1.64	1.28	4.92	4.89	1.45	-1.16
	INRIX	3.49	1.18	11.22	4.92	2.10	-3.76
4	Bluetooth	1.13	1.39	4.15	4.76	-0.55	-0.98
	INRIX	1.11	1.33	6.70	7.21	-5.58	-6.14
All	Bluetooth	0.46		4.65		0.32	
	INRIX	0.66		6.52		-2.84	

Source: Kim et al. 2010

3.7.4.2 I-95 Corridor Coalition

The I-95 Corridor Coalition is an alliance of STA, toll authorities, and related organization such as public safety from Maine down to Florida. Since 2009, INRIX has been providing comprehensive and continuous real-time information for the I-95 Corridor Coalition Vehicle Probe Project (I-95 Corridor Coalition 2012a). During four months in 2009, the I-95 Corridor Coalition analyzed traffic on 111 miles of highway across Delaware, Maryland, New Jersey, and Virginia. Data from INRIX and Bluetooth systems were compared with ground-truth technology. The study showed that INRIX data were within 5 mph for 85 percent of the ground-

truth comparisons (INRIX 2009). The I-95 Corridor Coalition found that there were some economic benefits with using INRIX (I-95 Corridor Coalition 2012b). With the INRIX system, the coalition could get better traffic monitoring at a fraction of the cost. The NCDOT stated that previous approaches for traffic data collection had a life cycle cost of nearly $50,000 per mile, but the INRIX vehicle probe would deliver the same amount of coverage for a fourth of the life cycle cost per mile. The South Carolina Department of Transportation (SCDOT) reported that maintaining INRIX speed and travel time data would allow coverage of 1,200 miles of South Carolina roads compared to the 300 miles of coverage afforded by traditional methods.

3.8 Chapter Summary

To collect data for mobility-based performance specifications in highway construction contracts, real-time data collection is necessary to provide better estimates of construction impacts. For this study, the purpose of investigating different technologies was to determine if current technologies are capable of monitoring traffic in a work zone continuously. The seven technologies that were investigated included 1) ALPR, 2) Bluetooth, 3) magnetic sensors, 4) AVI, 5) microwave radar, 6) cellular phones, and 7) GPS. A brief description of each of the investigated technologies is listed in Table 3-11.

The research findings include advantages and disadvantages for each of the technologies, listed in Table 3-12. Example advantages include no privacy issues with magnetic sensors and microwave radar technologies; high potential sample sizes with ALPR, AVI, and cellular phone; and non-intrusive installment with Bluetooth and microwave radar technologies. Major disadvantages to consider include privacy issues with ALPR, Bluetooth, AVI, and cellular phones or permanent infrastructure with ALPR, magnetic sensors, and AVI systems.

Overall, the literature review found that there are multiple technologies capable of collecting real-time data in work zones continuously. Multiple available technologies are accurate and can provide real-time mobility-based performance data. There are many companies that can provide mobility data collection and data analysis services. Most often these services provide websites that display real-time conditions and can provide statistical analyses. In additional, alerts can be configured to alert the STA and contractor when traffic conditions

exceed performance measurement thresholds. With these features, there are technologies available that are reliable enough to collect and analyze data for implementing mobility-based performance specifications in highway construction contracts.

Table 3-11. Descriptions of Investigated Technologies

Technology	Description
ALPR	Captures and matches images of license plates of vehicles passing the sensors
Bluetooth	Captures and matches MAC addresses of Bluetooth devices
Magnetic Sensors	Measures the disturbance of the earth's magnetic field and matches disturbance patterns
AVI	Captures and matches vehicles using identifications tags, such as toll tags
Microwave Radar	Emits microwave waves toward vehicles in order to measure vehicle presence and speed
Cellular Phones	Identifies vehicle position based on cellular phone signals
GPS	Utilizes satellite signals to locate vehicles

Table 3-12. Advantages and Disadvantages for the Seven Investigated Technologies

Technology	Advantage	Disadvantage
ALPR	• Large potential sampling pool • Collection of vehicle classification data	• High installation cost • Many factors affecting image quality • Misidentification of similar looking characters • Privacy issues
Bluetooth	• High accuracy • Lower cost • Non-intrusive equipment • Fixed or portable device	• Sample size affected by capture rates • Privacy issues
Magnetic Sensors	• Sensitive detection • No privacy issues	• Permanent infrastructure • Installation causes damage to pavement • Accuracy of calculation is based on matching algorithm
AVI	• Uses existing electronic tolling infrastructure • High sampling pool	• High installation and maintenance costs • Sample size affected by tolling market • Permanent installation • Privacy issues
Microwave Radar	• Non-intrusive equipment • No privacy issues	• Accuracy affected by sensor position
Cellular Phones	• Large potential sampling pool	• Privacy issues • Accuracy can be affected by geolocation algorithm • Sample size affected by cellular phone use
GPS	• High accuracy with location data • Low maintenance cost	• Signal interference • High cost and time-consuming data collection

4.0 PERFORMANCE MEASURES AND SPECIFICATIONS

STAs are expected to demonstrate sound management, decision-making, and resource allocation of public resources. To quantify the efforts of the STAs, standards and performance measures are established and data are collected and analyzed. To ensure that standards of the STAs are enforced, performance-based specifications containing I/D provisions are used to assess the contractors to (Hyman 2009). Mobility-based performance specifications are a specific type of performance specifications, which set criteria for contractors to maintain certain traffic flow during construction.

This chapter presents several topics on performance measures and performance-based specifications. The first section discusses the purpose of using performance measures and performance-based specifications. The second section presents three categories of performance measures that can be used in highway construction contracts. The third section presents current practices involving mobility-based performance measurements in work zones and mobility-based performance specifications in highway construction contracts. The fourth section summarizes highlights of major items discussed in the chapter.

4.1 Purpose of Using Performance Measures Specifications

There are many reasons for STAs to use performance measures and performance-based specifications. Performance measurements and performance-based specifications are useful tools for STAs to quantify and improve performance. Data from performance measurements can assist STAs in making investment decisions, developing and improving policies, and defining priorities. Through these performance measures, work zone impacts of construction are monitored, and a more reliable traveling experience can be maintained through the duration of construction work. Performance measures can also assist engineers and staff of STAs in communicating with elected officials and with the public about the status of construction (Ullman et al. 2011a).

Since performance-based specifications include I/D provisions, they share similar reasons for using I/D contracts. Performance-based specifications can help STAs to increase the level of

service of the work zone and foster innovation on the part of the contractor (Hyman 2009). Just like I/D contracts, performance-based specifications may not be ideal for every project.

4.2 Selecting Performance Measures

To select the most appropriate performance measures, STAs need to understand what type of performance standard is being measured, how it is measured, and why it is measured. Once the performance measures have been selected, it is important to define data sources, data collection techniques, and analysis methodologies that will be used (Ullman et al. 2011a). There are three categories of performance measurements used to quantify work zone performance: 1) exposure, 2) safety, and 3) mobility (Ullman et al. 2011a). Depending on the project characteristics, certain performance measures are more appropriate than others.

4.2.1 Exposure Measures

Exposure measures are expressed in units that describe road user exposure to the work zone. Example measures include the time, the distance, or the amount of traffic that is affected by construction, such as vehicle-miles traveled through the work zone, number of vehicle passing through the work zone, and number of hours of work activity (Ullman et al. 2011a). Exposure measures can also be used in the denominators for safety or mobility performance measures, like per million-vehicle miles traveled.

There are three categories of exposures measurement: 1) project characteristics, 2) work zone information, and 3) traffic volumes (Ullman et al. 2011a). Project characteristics present information such as project length and project phasing. Work activities focus on data related to construction activities, such as the day and time of lane closures or the number of construction workers. For traffic volume, data such as annual daily traffic or vehicle classification are used.

Sources for collecting exposure measurements can vary depending on the category of exposure measure selected. Information about project characteristics can be gathered from the project plans, such as traffic control plans or agency construction management databases. Work activities information can be gathered from daily project records and activity logs. Finally, traffic

volume data can be collected from ATR data, periodic volume counts before and during the projects, or from the Transportation Management Center (TMC) traffic sensors.

4.2.2 Safety Measures

Safety measures describe the safety conditions within or surrounding the work zone. Safety performance measures are used to improve safety and reduce the number of crashes in work zones. Examples of possible safety measures include crash statistics, frequency of work zone intrusion, percent of motorist exceeding the speed limit, work zone inspection scores, and worker fatalities and injuries (Ullman et al. 2011a).

Safety measures data can be broken into four categories: 1) traffic crashes, 2) accidents and injuries involving workers, 3) agency work zone inspection scores, and 4) dispatches to the project site for service patrol or emergency medical services (Ullman et al. 2011a). For each of these categories, information such as the time, location, severity, and contributing factors are important information to gather.

Traffic crash information can be obtained from statewide crash databases or from local police agency crash reports. Information on worker accidents and injuries can be available from the agency's occupational safety division records, highway contractor injury records, and the Bureau of Labor Statistics (BLS) of the U.S. Department of Labor. Agency work zone inspection scores can be retrieved from agency work zone inspection records or field reviews. Finally, the time and location of the dispatches and the type of response can be gathered from service patrol dispatch or Emergency Medical Service (EMS) dispatch logs of the respective agency.

4.2.3 Mobility Measures

Mobility, or traffic operation, measures describe how construction affects traveling conditions for road users (Ullman et al. 2011a). These measures are the best way to know what drivers experience as they travel through the work zone. Possible mobility measures include travel time, delay, queue length, queue duration, speed, volume-to-capacity (v/c) ratios, level of service (LOS), and percent of time operating at free-flow speed. While there are many mobility measures that can be considered, travel time, queue, and delay are the most popular choices because they are used to estimate RUC (Ullman et al. 2011a).

Mobility data are usually obtained by traffic sensors or through on-site observations by field personnel (Ullman et al. 2011a). For traffic sensors, STAs can deploy technologies discussed in Chapter 3 or other technologies available for traffic data collection purposes. In addition to traffic sensors, periodic drive-through inspections or probe vehicle tests can be conducted. Observations by field personnel can be obtained by having contractors record starting and ending times for queues, queue length, or other mobility measures.

4.3 Current Practices

The use of mobility-based performance specifications in highway construction contracts is a current topic of research. Today there are technologies that can provide continuous and reliable mobility data, which facilitates the use of mobility-based performance specifications in highway construction contracts. However, these technologies need to be tested to determine if mobility-based performance data can be collected under conditions in work zones. Section 4.3 discusses two pilot tests that evaluated collecting data for mobility performance measures in work zones and then describes three examples of mobility-based performance specifications.

4.3.1 Pilot Tests for Mobility Performance Data Collection in Work Zones

This section presents two pilot tests that evaluated mobility data collection in work zones. The first example is a pilot test conducted in North Carolina, and the second example is a pilot test conducted in Washington State.

4.3.1.1 I-95 Pilot Test – Lumberton, North Carolina

In 2009, NCDOT conducted a pilot test using PTMDs in a work zone. The work zone was a resurfacing project located on a 10-mile section of I-95 near Lumberton, North Carolina (Ullman et al. 2011b). To resurface the travel lanes, one lane of traffic was closed for 1 to 5 miles, depending on the day of the week (Chandler et al. 2010). On Monday, the contractor closed one mile of roadway and, as the week progressed, additional miles were closed until a total of 5 miles of roadway was closed. On Friday, the work zone was removed by noon to open for weekend traffic (Chandler et al. 2010).

The NCDOT developed a set of mobility-based performance measures for work zones on interstates or other access-controlled, high-speed freeways that were applied to the project. For work zones on these roadway facilities, queue length and queue duration criteria were developed as shown in Table 4-1 (Chandler et al. 2010).

Table 4-1. NCDOT Performance Measure on Queue Length and Queue Duration

Queue length (X) (miles)	Acceptable Duration
$X < 0.75$	Any length of time
$0.75 \leq X \leq 2.0$	2 hours per day
$2.0 < X$	Not acceptable for any time period

Source: Chandler et al. 2010

To gather data to monitor the performance measures, six PTMDs were placed upstream and downstream of the work zone. A typical layout is shown in Figure 4-1 (Chandler et al. 2010). Three upstream devices were placed 3 miles, 1.5 miles, and 0.75 miles upstream of the flashing arrow panel (FAP). One downstream device was placed within 1,000 feet downstream of the FAP. Another device was located half of the length of the total lane closure for that particular day, and the device was moved downstream every day. The last downstream device was located within the active work zone area to monitor the traffic speed adjacent to the construction workers. All the devices used to gather the data were K-band radar housed in a traffic drum (Chandler et al. 2010). NCDOT found that the installation of the PTMDs was straightforward and that they were relatively easy to maintain.

During the I-95 project, NCDOT encountered several challenges. First, there were some technical difficulties with the PTMDs. Two of the three battery chargers were wired incorrectly and damaged batteries that were being charged (Chandler et al. 2010). Another difficulty was keeping the devices in the correct location during construction. During the week, it was necessary for two of the downstream devices to move with the construction, and there were instances when the PTMDs were placed in locations that were not the most ideal. NCDOT also encountered some physical risk for the PTMDs. Since the monitoring device is housed in a

traffic drum, it was at risk of being hit by motorists or construction equipment. During the pilot test, two devices were damaged beyond repair (Chandler et al. 2010). To protect the device, the PTMDs were placed further away from active traffic. Also, since the device looked very similar to regular traffic control devices, the construction crew would accidentally take the device to the contractor's storage area for the weekends. The location of the PTMDs was known due to the built-in GPS function; however, the devices could have been lost if the battery had died.

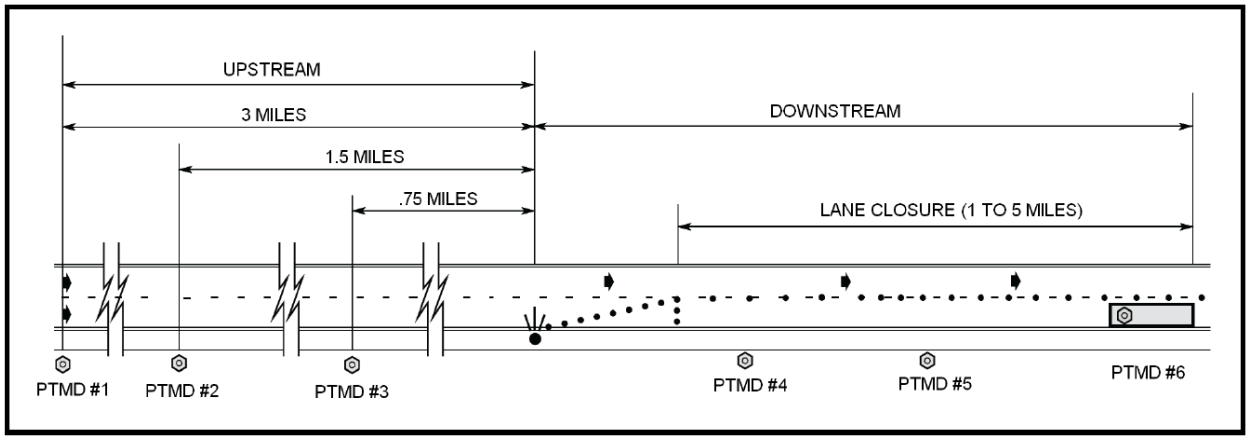


Figure 4-1. PTMD Layout of I-95 Pilot Test (Chandler et al. 2010)

NCDOT found benefits with using PTMDs in work zones. One benefit NCDOT saw was that PTMDs provided data that described the traffic conditions of the work zone for a lower cost (Chandler et al. 2010). Employees could also check traffic conditions remotely on a website that displayed data collected by PTMDs. This information could be stored and archived for five years, which allowed the STA to analyze historical data at a later date. In the future, PTMDs could be used to gather information on rural roadways where ITS equipment is not available for gathering mobility data (Chandler et al. 2010).

4.3.1.2 I-405 Pilot Test – Bellevue, Washington

The purpose of the Bellevue pilot test was to verify the effectiveness of data collected by field personnel and by electronic traffic sensors in work zones. From July 2007 to late 2009, construction was conducted on a 2.6-mile section of Interstate 405 (I-405) between Southeast

(SE) 89th street and 112th Avenue SE (Ullman et al. 2011b). The project consisted of reconstructing and widening I-405 to add a travel lane in each direction, reconstructing and widening several bridges, and removing the Wilburton tunnel. During construction, a pilot test took place for a period of 92 days, from July to October 2008. During the test period, multiple lanes were closed at night, except for Friday and Saturday nights (Ullman et al. 2011b).

Mobility data were collected from multiple sources. One source of data came from a series of inductive loops and other traffic sensors that measured volume and occupancies. Speed data were available from selected sensor locations. Filled-out field data forms were another source of data. Project field personnel would record information on night work zone activities, lane closure information, and approximate hourly queue length when queues formed. The data from the field personnel helped in validating the pilot test effort. In addition, ground-truth travel time studies were conducted in September 2008 to compare the field personnel data and the traffic sensor data to the ground-truth measurements (Ullman et al. 2011b).

The forms the field personnel filled out were very accurate, as the contractor was meticulous in the documentation efforts. Table 4-2 and Figure 4-2 summarize the queue measurements from the field crew and traffic sensor data (Ullman et al. 2011b). The field crew data indicated that a queue occurred during roughly 82 percent of the time for both directions, while the traffic sensor data were not as sensitive, suggesting an occurrence of queuing only 35 and 59 percent of the time for southbound and northbound traffic, respectively. From Figure 4-2, which shows the average queue length, the data collected by the field personnel and by the sensors were within 0.3 miles of each other. However, the average queue duration for both directions and the southbound maximum queue length between the two data sources differed greatly. For the average queue duration, the field crew data was double the amount reported by the traffic sensors. The southbound maximum queue length differed by 3 miles between the two data sources. It was found that the sensors were less sensitive to detecting a queue because of the limited number of sensors. Also, the sensors had a large spacing of roughly 1 mile apart, which also affected the accuracy of the data.

Table 4-2. Comparison of Queue Measures Collected by Field Crew and Traffic Sensors

Queue Measures	Southbound		Northbound	
	Field Crew Data	Traffic Sensor Data	Field Crew Data	Traffic Sensor Data
Days of work activity when queuing occurred (%)	81.4	34.9	82.9	59.0
Amount of work activity when queue > 1 mi (%)	17.1	1.2	21.3	4.7
Amount of work activity when queue > 2 mi (%)	11.8	0.0	12.6	1.9
Amount of traffic volume through active work zone that encountered a queue (%)	19.0	4.3	13.6	9.2

Source: Ullman et al. 2011b

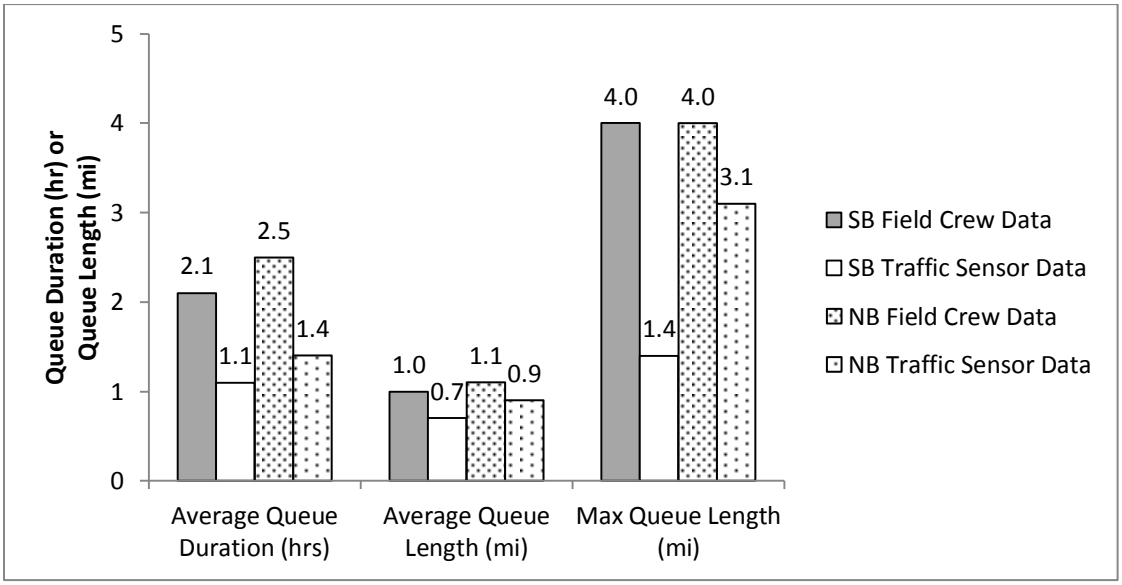


Figure 4-2. Comparison of the Field Crew and Traffic Sensor Data (Ullman et al. 2011b)

It was found that extracting the data collected from the electronic sensors required a significant effort. After extracting the data, it was found that some data were incomplete due to interference from construction (Ullman et al. 2011b). There were some nights where the sensors

stopped functioning for a time when there was construction work being done in the vicinity. As a result, when selecting the data collection technology, it is important to account for situations where data collection equipment may be negatively affected by construction work. The test found that the field personnel were accurate and meticulous in their documentation. All instances of queuing identified during the ground-truth time studies were noted as queued conditions on the field crew data collection forms. One suggestion for future work includes documenting information on queue location, such as within or beyond the work zone area, in addition to queue length and duration.

4.3.2 Mobility-based Performance Specifications

This section discusses three projects that incorporated mobility-based performance specifications. One project was located in Ontario, Canada, and two projects were located in Utah.

4.3.2.1 Fairchild Creek Culvert Project – Ontario, Canada

During the spring of 2010, the Ministry of Transportation of Ontario (MTO) was the first transportation agency in Canada to use Bluetooth for delay compliance monitoring (MTO 2011) for the Fairchild Creek culvert replacement project. The MTO used the performance specification in their design-build contract, which monitored allowable traffic delay to the traveling public through the work zone (MTO 2011).

Bluetooth devices were used to monitor travel time through the work zone. Before construction, the Bluetooth units were deployed in the work zone in order to fix any possible placement or equipment issues. To establish a base travel time and speed profile, data were collected two weeks prior to construction. During construction, two Bluetooth units were placed 3 kilometers east and 3 kilometers west of the work zone, as shown in Figure 4-3 (MTO 2011).

The results from the project showed that the contractor did not exceed the maximum allowable travel time specified for the project. The report did not describe how effective the Bluetooth technology worked. However, the MTO plans to continue deploying Bluetooth units for future travel time studies and monitoring of mobility-based performance measures. The MTO also identified additional procedures to improve continuous real-time data collection. One

suggestion was to inform the local police of the use and location of monitoring devices in order to avoid “suspicious package” complaints (MTO 2011).

= Bluetooth sensor

Figure 4-3. Aerial Photograph of Fairchild Creek Culvert Replacement Project and Location of Bluetooth Units (MTO 2011)

4.3.2.2 I-15 Anderson Junction to Blackridge Project – Utah

UDOT Region 4 planned to implement performance specifications on the I-15 Anderson Junction to Blackridge project. The project was located 21 miles north of St. George, Utah. The criteria used in the mobility-based performance specification were speed and queue length. During construction, any speed lower than 40 mph would be considered a queue, and there was a maximum specified queue length of 1.5 miles (UDOT Region 4 representative, personal communication, March 2012).

To collect the data necessary for the I-15 Anderson Junction to Blackridge project, two trailers were set up in the work zone. Each trailer had Wavetronix HD and BlueTOAD Bluetooth equipment. Since the trailer had microwave radar and Bluetooth equipment from multiple manufacturers, more time was required for data processing, which eventually forced Region 4 to halt the experiment (UDOT Region 4 representative, personal communication, March 2012).

In general, there was a lack of personnel available to collect the data, monitor the system, and move the trailers when needed (UDOT Region 4 representative, personal communication,

March 2012). This implies the need for workers dedicated to managing performance measurements when implementing mobility-based performance specifications.

4.3.2.3 Bangerter Highway Design Build Project – West Jordan, Utah

The Bangerter Highway Design-Build Project was an intersection reconstruction project, improving three traditional intersections at 7800 South, 7000 South, and 6200 South along Bangerter Highway in West Jordan, Utah. A continuous flow intersection (CFI) was built at 7000 South and 6200 South, and a grade-separated single point urban interchange (SPUI) was built at 7800 South (UDOT Region 2 representatives, personal communication, May 14, 2012; JUB Engineers, Inc. representatives, personal communication, May 21, 2012).

UDOT worked with JUB Engineers, Inc. (JUB Engineers) to develop a mobility-based performance specification that was to be included in the original project contract; however, the mobility-based performance specification clause was dropped before sending out the official request for proposal (RFP) due to some difficulties in developing the mobility-based performance specification in time for bidding (UDOT Region 2 representatives, personal communication, May 14, 2012). Instead, a traditional schedule-based incentive provision was used for early completion. Even though the mobility-based specification was not included in the official contract, the contractor worked as if they were being assessed by the performance-based specification. During the construction project, JUB Engineers monitored and processed the mobility data on behalf of UDOT and worked with the contractor, Ralph L. Wadsworth Construction, to continue to develop the specification throughout the project.

In developing the mobility-based performance specification for the Bangerter Highway Design-Build project, many performance measures such as delay, travel time, and queuing were considered (UDOT Region 2 representatives, personal communication, May 14, 2012; JUB Engineers representatives, personal communication, May 21, 2012). In the end, travel time was selected for the specification. Extensive amounts of data were gathered to establish the baseline travel times for monitored movements. Approximately 14 hours of turning volume counts were collected and used to calibrate a VISSIM model, which was used to determine the baseline travel time thresholds for all 48 monitored movements (JUB Engineers representatives, personal communication, May 21, 2012). All the turning movements were monitored instead of

monitoring a few critical movements to prevent the contractor from increasing delay on minor movements in order to meet the requirement for critical movements.

The travel time for each turning movement at each intersection, a total of 48 movements, was monitored with 10 BluFAX Bluetooth sensors units, the locations of the Bluetooth sensors being shown in Figure 4-4 (JUB Engineers representatives, personal communication, May 21, 2012). The Bluetooth sensors were attached to permanent poles or to sound walls with a custom bracket. For this project, the Bluetooth capture rate was 2 to 3 percent for the side streets and 5 percent on Bangerter Highway (JUB Engineers representatives, personal communication, May 21, 2012).

The mobility-based performance specification for this project included three travel-time thresholds. The first level was a baseline or warning threshold to notify the contractors that travel times were above the baseline threshold, but were acceptable, and no penalties would be assessed (UDOT Region 2 representatives, personal communication, May 14, 2012; JUB Engineers representatives, personal communication, May14, 2012; Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). The other two thresholds were Tier 1 and Tier 2 delays which corresponded to minor and major delays, respectively. A fine of $1,000 and $5,000 per 15 minutes intervals would have been assessed for Tier 1 and Tier 2 threshold violations, respectively (JUB Engineers representatives, personal communication, May 21, 2012). An alert notification was sent to JUB Engineers and the contractor when traffic delay reached each of the thresholds. A copy of the alerts for each threshold for each turning movements and for the through movements through the work zone are listed in Tables 4-3 and 4-4, respectively (JUB Engineers representatives, personal communication, May 21, 2012). The two tables list the lower limit of each threshold as of April 27, 2012.

JUB Engineers handled the data collection and processing for the project. Every night the raw data for the day were stored on a BluFAX server and sent to JUB Engineers via email. Due to the large amount of data, JUB Engineers had to set up a separate email account just for the daily reports (JUB Engineers representatives, personal communication, May 21, 2012). The

collected data were analyzed using the analysis software BluSTAT. The results from the analysis were presented in bi-weekly meetings with UDOT and the contractors.

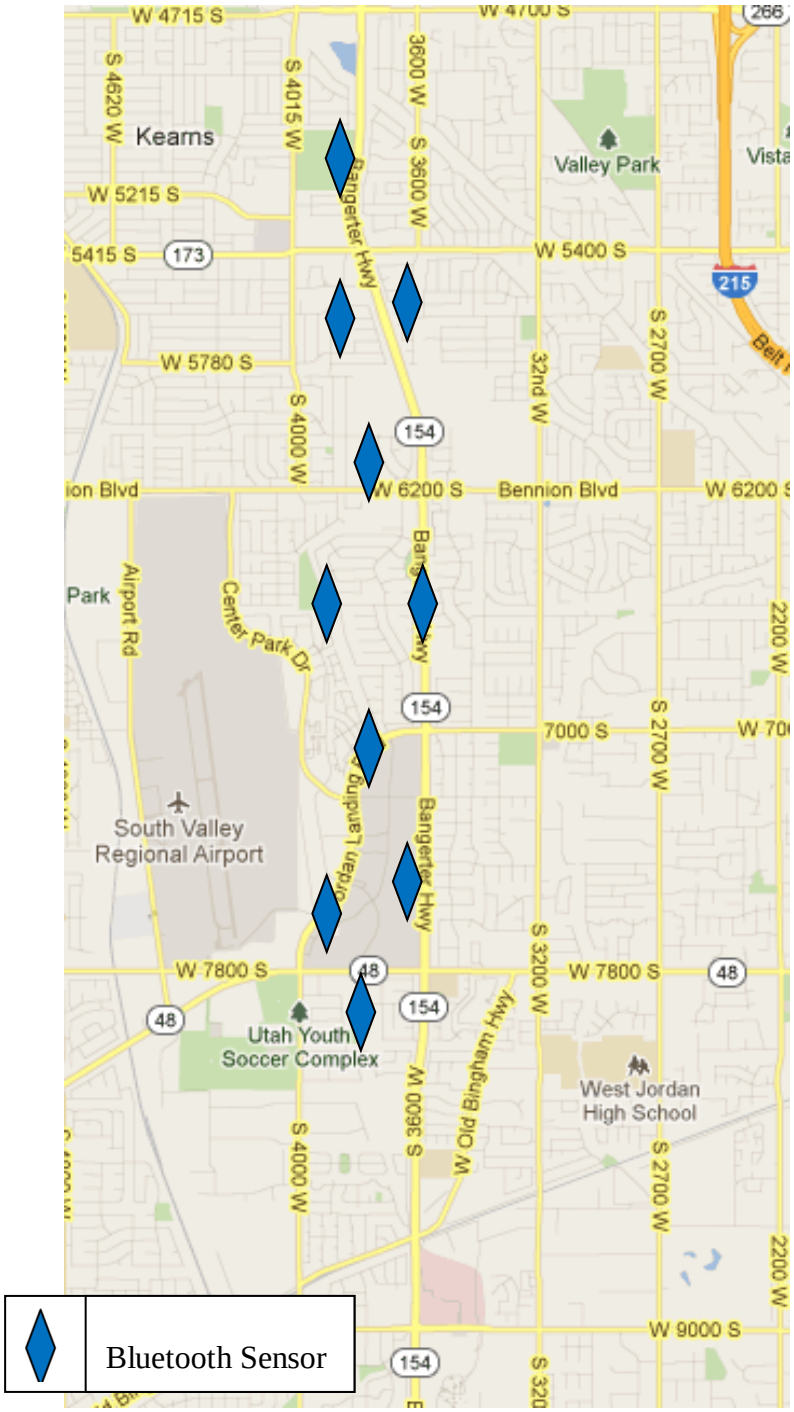


Figure 4-4. Location of Bluetooth Sensor
(JUB Engineers representatives, personal communication, May, 21 2012)

Table 4-3. Proposed Alerts for Individual Turning Movements on Bangerter Highway

Movement		Alerts (min)		
		Warning	Tier 1	Tier 2
6200 S	NBL	4.20	4.80	7.80
6200 S	NBT	3.70	3.90	6.90
6200 S	NBR	1.85	3.15	6.15
6200 S	SBL	4.30	5.10	8.10
6200 S	SBT	3.50	4.00	7.00
6200 S	SBR	4.40	4.95	7.95
6200 S	EBL	7.35	8.65	11.65
6200 S	EBT	2.65	4.00	7.00
6200 S	EBR	3.40	4.65	7.65
6200 S	WBL	4.35	4.75	7.75
6200 S	WBT	4.20	5.80	8.80
6200 S	WBR	4.35	5.10	8.10
7000 S	NBL	5.00	7.50	10.50
7000 S	NBT	6.70	7.65	10.65
7000 S	NBR	4.85	5.55	8.55
7000 S	SBL	4.55	5.40	8.40
7000 S	SBT	3.05	3.85	6.85
7000 S	SBR	3.10	3.25	6.25
7000 S	EBL	5.10	6.00	9.00
7000 S	EBT	3.10	3.90	6.90
7000 S	EBR	3.90	4.60	7.60
7000 S	WBL	3.90	4.60	7.60
7000 S	WBT	3.80	4.45	7.45
7000 S	WBR	3.65	4.20	7.20
7800 S	NBL	7.50	10.00	13.00
7800 S	NBT	5.00	7.50	10.50
7800 S	NBR	5.00	7.50	10.50
7800 S	SBL	9.90	11.80	14.80
7800 S	SBT	3.50	6.00	9.00
7800 S	SBR	4.00	6.50	9.50
7800 S	EBL	8.25	10.00	13.00
7800 S	EBT	2.95	3.85	6.85
7800 S	EBR	3.25	3.95	6.95
7800 S	WBL	3.85	4.55	7.55
7800 S	WBT	5.90	6.85	9.85
7800 S	WBR	5.10	6.25	9.25

Source: JUB Engineers, personal communication, May 14, 2012

Table 4-4. Project Proposed Alerts for through Movements on Bangerter Highway

Movement	Alerts (min)		
	Warning	Tier 1	Tier 2
NB 7800 S to 6200 S	15.40	19.05	28.05
NB 7800 S to 7000 S	11.70	15.15	21.15
NB 7000 S to 6200 S	10.40	11.55	17.55
SB 6200 S to 7800 S	10.02	13.85	22.85
SB 6200 S to 7000 S	6.55	7.85	13.85
SB 7000 S to 7800 S	6.55	9.85	15.85

Source: JUB Engineers, personal communication, May 14, 2012

As part of the design-build contract, the contractor had hired traffic engineers who also acted as a liaison for the construction company. This liaison monitored the traffic notifications. When a Tier 1 or Tier 2 alert was received, the liaison would contact the traffic control manager or other proper personnel to investigate the area and determine the source of delay (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). Important sources of delay that were noted by the liaison included vehicle crashes or large construction equipment moving into the work zone, thus creating unexpected congestion.

During the project, UDOT, JUB Engineers, and the contractor had a meeting every other week to discuss movements that had received the most alerts and to adjust the experimental mobility-based performance specification (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). Between these meetings, there were communications between the engineer from JUB Engineers and the liaison for the contractor when Tier 1 or Tier 2 alerts were issued. The contractor would relay information related to the alert, such as the source of the delay, to JUB Engineers.

The major difficulty in developing the mobility-based performance specification for the Bangerter Highway project was the lack of any examples or other test cases to which to compare or validate the specification (JUB Engineers representatives, personal communication May 21, 2012). To validate the penalty amount, a comparison was made between the calculated penalty

using the traditional lane closure restriction clauses and the mobility-based performance specification assessment. During the project, there was one event where the contractor caused a major delay. During night work, a piece of equipment broke down, and the contractor did not have time to open the closed lanes prior to the morning peak hour, and significant delays were experienced. The penalties were calculated using the traditional lane closure restriction clauses and the new mobility-based performance measure, and the two values were compared. The penalty assessed with the mobility-based performance specification was approximately $5,000 lower than the amount assessed using the traditional specification, which was considered to be within the appropriate assessment range (UDOT Region 2 representatives, personal communication, May 14, 2012; JUB Engineers representatives, personal communication, May 21, 2012).

During the project, there were some technical difficulties. The locations of the Bluetooth sensors were adjusted due to some interference from nearby businesses in Jordan Landing and other commercial areas adjacent to Bangerter Highway (JUB Engineers representatives, personal communication, May 21, 2012). There were also adjustments made to the real-time BluFAXWeb software to address the issue of erroneous alerts during unexpected time periods with low traffic volumes. On the first day that the alert notification system was turned on, over 100 alerts were issued between 3:30 AM and 6:30 AM when delay notification was unexpected due to the low traffic volume during that early morning time period (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). The software was adjusted to take into account the low traffic volumes that the streets in the work zone experienced during off-peak hours (UDOT Region 2 representatives, personal communication, May 14, 2012; JUB Engineers representatives, personal communication May 21, 2012). After the adjustment, the number of erroneous alerts decreased.

The contractor experienced challenges in monitoring the work zone. One issue was the number of alerts being received. In the beginning of the experiment, there were a large number of erroneous alerts. As mentioned earlier, the alert notification system issued alerts between 3:30 AM and 6:30 AM, when delay notification was unexpected due to the low traffic volume during the early morning time period. Also since 48 movements were being monitored, there were times

when alert notifications for every movement would go off. This would make it difficult for the personnel to investigate the causes for each individual alert.

Another challenge the contractor experienced was responding to alerts. For the contractor, monitoring and addressing alerts were a secondary task in the project because the mobility-based performance specification was not officially part of the contract (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). This made it difficult at times for the liaison to find someone who was available to investigate the nature of the alerts. There was also 2 minutes of delay between the time when the traffic reached an alert threshold and the time the alert notification was received (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). If an alert was for a movement on the opposite end of the work zone compared to the location of the current work, it required several minutes for the workers to reach the problem location. By the time the worker drove to the alerted location, the traffic had oftentimes already returned to normal (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012).

The Bangerter Highway Design Build project resulted in many informative findings. The first finding was that a mobility-based performance specification may not be suitable for all projects. A mobility-based performance specification would be more difficult to implement for traditional bid projects. Since this project was a design-build project, the contractor had access to more resources, such as traffic engineers, for creating traffic simulation models (UDOT Region 2 representatives, May 14, 2012). The contractor mentioned that the type of roadway in this project may not be the most suitable for applying a mobility-based performance specification. The project was on a major arterial, which had multiple access points to the work zone and 48 movements for the contractor to manage. The contractor suggested that a roadway facility with limited access, such as an interstate or a rural freeway, may be more ideal. If this type of specification is used on another arterial roadway, they suggested that only key, critical movements should be monitored instead of every movement. Monitoring all possible movements requires more data collection prior to construction in order to establish thresholds values and more time required during construction to monitor all defined movements.

From the Bangerter Highway project, many concerns for future implementation of mobility-based performance specifications were identified. One concern came from the contractor in regards to the Bluetooth devices belonging to the construction workers possibly impacting the collected data. During construction, some personnel would need to travel through the work zone to check on certain job sites. If the worker stayed within a monitored link for an extended amount of time, the data points collected from their Bluetooth devices would indicate very high travel times. The Bluetooth analysis software program does allow exceptions for MAC address matching activities, but it may be difficult to collect the MAC address from all Bluetooth devices of the workers (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012).

Another concern from the contractor was the amount of time the contractor would be penalized for delays. The contractor felt there should be a grace period where they would not be penalized while they were addressing and mitigating any delays. The grace period should also account for the delay time for receiving alert notifications. Also, the idea of adjusting thresholds came up. One reason to re-evaluate the thresholds would be attributed to changes in the traffic patterns due to incidents on nearby roads or major events. For projects on arterials, delays in the work zone can be caused by detours through the project resulting from incidents on adjacent streets (JUB Engineers representatives, personal communication, May 21, 2012). During this project, the thresholds were re-evaluated for traffic increase due to a closure made by another project on a parallel street.

There were many suggestions made during the course of this project. JUB Engineers suggested that the “before” data collection be done with the same technology used to monitor the performance measurements required in the performance specifications (JUB Engineers representatives, personal communication, May 21, 2012). By collecting data using the same monitoring equipment, it would be easier to identify adjustments in equipment placement prior to the construction, as opposed to during construction. Also, the contractor expressed the need for some construction personnel to be dedicated to monitoring the work zone and responding to alert notifications (JUB Engineers representatives, personal communication, May 21, 2012; Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). This dedicated team would be more focused on performance monitoring and be able to respond to

alerts quicker. Hence, the specification should state that at least one worker be dedicated to monitoring the alerts. Another suggestion made by the contractor was the use of cameras to help monitor the work zone (Ralph L. Wadsworth Construction representative, personal communication, October 2, 2012). When a notification alert is received, the person responsible for monitoring the work zone can check the cameras, determine the cause of the alerts, and dispatch someone to go to the site. The use of cameras would reduce the number of unnecessary trips to the work site.

Overall, the Bangerter Highway Design-Build project showed that it would be feasible to implement a mobility-based performance specification in a highway construction contract. The Bluetooth equipment and analysis software were capable of collecting and analyzing the required data for assessing the performance of the contractor. While the mobility-based performance specification is feasible, further discussions between UDOT and the contractor should take place to reach an agreement between the two parties for future applications. The contractor felt that this type of specification does require more personnel to monitor and respond to alert notifications. The contractor also mentioned that the mobility-based performance specification would be better suited for a roadway with limited access and that, for arterial cases, only major movements should be included in the performance monitoring.

4.4 Chapter Summary

This chapter discussed the purpose of mobility-based performance measures and performance specifications, the selection of performance measures, and the current practices of performance measures and mobility-based performance specifications in work zones.

Performance monitoring is a method that allows STAs to regulate and evaluate projects in regards to meeting STA goals and objectives. Performance measures define qualitative standards that should be obtained in order to reach the goals and objectives of a STA. Performance-based specifications incorporate performance monitoring in an I/D specification. In the work zone, there are three major categories of performance measures that can be used to help evaluate work zone performance, which include exposure, safety, and mobility measures. Exposure measures describe the amount of times, distance, or traffic volume that is affected by

the work zone. Safety measures are used for evaluating how safe the area is within or surrounding the work zone. Mobility measures describe vehicular traffic conditions through the work zone. Depending on the objective of the project, one or more types of performance measures are employed to assess the project.

This chapter discussed two pilot tests conducted to test mobility data collection methods used in work zones. The first pilot test was a resurfacing project on I-95 in North Carolina. Radar devices housed in construction drums were used to gather data to monitor queue length and queue duration. The second pilot test was a reconstruction and widening on I-405 in the state of Washington. Data were gathered from both field personnel and electronic sources. Both tests found that mobility data collection in work zones is feasible.

This chapter also examined three mobility-based performance specification examples. The first example was located in Ontario, Canada, where Bluetooth units were deployed to monitor delay. The second and third projects involved Bluetooth technologies in Utah. The first project was construction along I-15 in Region 4, and the second was a reconstruction of three intersections along Bangerter Highway.

There are benefits associated with collecting data on mobility-based performance measures and using performance specifications for highway construction contracts. PTMDs can provide means of collecting data at a lower cost and help reduce the exposure to traffic for workers while collecting the data. Several equipment providers offer data storage for the information collected so that STAs can go back and perform additional analysis if needed at a later date.

There were many concerns and recommendations made from the pilot tests and examples of performance-based specifications. A summarized list of the concerns and recommendations are shown in Table 4-5. One concern includes possible sources of data error, such as construction activities near data collection sensors or spacing of sensors. There were also some technical difficulties with the equipment such as equipment being unable to gather data, sending out erroneous alerts, or malfunctioning. Other concerns include the additional administration staff and extensive amount of data collection needed to implement performance-based specifications.

For recommendations, it is important to keep detailed documentation of traffic conditions in the work zone. Information that should be documented includes travel time, sources of delay, queue length, queue duration, and queue location. This information can help validate data gathered through the sensors, but this task necessitates increased administrative efforts to continuously monitor the work zone. Another recommendation is to conduct frequent ground-truth studies to assess the current baseline. Depending on the length of the construction project, traffic patterns and conditions may change. It is important to adjust for these changes. While challenges were encountered in these test projects, overall, they showed potential for implementing mobility-based performance specifications in work zones.

Table 4-5. Concerns and Recommendations for Performance-based Specifications

Concerns	Recommendations
• Possible sources of data error (e.g. physical risk, construction activities near sensors, sensor spacing) • Technical difficulties (e.g. erroneous alerts, malfunctioning equipment) • Additional administration staff necessary to address alerts • Extensive amount of data collection required to establish baseline threshold • Extensive amount of data processing required to assess contractors • Time period allotted for contractors to respond to alerts • Number of movements to monitor	• Field documentation should contain details of traffic condition in the work zone (ex. duration, length, and location of queues) • Data collection technology should be the same technology used to establish the baseline threshold and evaluate contractor performance • Ground-truth studies should be conducted during construction to evaluate if baseline thresholds should be adjusted • Local authorities should be informed of location of monitoring devices to avoid “suspicious package” complaints • Specifications need to require contractors to have staff specifically assigned to monitor traffic condition

5.0 ONLINE SURVEY ON CURRENT I/D PRACTICES AND PERFORMANCE SPECIFICATIONS

Since the publication of NCHRP *Scan 08-04: Best Practices in Work Zone Assessment, Data Collection, and Performance Evaluation Scan Team Report* in 2010 (Bourne et al. 2010), some STAs may have contemplated the use of collecting mobility performance measurements in work zones or may have even started investigating the use of mobility-based performance specifications in highway construction contracts. In order to get up-to-date information of current practices in this topic since the report was published, a survey was developed using an online survey software program. The survey was sent out to STA representatives through email. This chapter explains the methodology used to conduct the survey and then presents the results of the survey analysis. The chapter summary section presents key findings of the survey.

5.1 Methodology

The survey of current I/D practices and performance specifications was created and administered through the online survey software program Qualtrics. The survey program allows users to create surveys with different types of questions, such as multiple-choice, multiple-answer, short-answer, or essay. The survey was distributed by email to STA representatives. Survey respondents filled out the survey online, and the responses were automatically recorded once the survey was completed. The survey responses were accessed from the survey website and exported to a .csv file. The results were analyzed in Microsoft Excel. Details on the selection of survey participants and organization of the survey are discussed in the following section.

5.1.1 Survey Participants

Surveys on current I/D practice and performance specifications were sent out to 50 participants, one for each STA in the United States. The participants were chosen from the members of the American Association of State Highway and Transportation Officials (AASHTO) Highway Subcommittee on Construction. The surveys were distributed twice: the first round at the end of July 2012 and the second round at the end of September 2012. The purpose of the second round was to solicit additional participation due to the slow summer

months. For both rounds, participants were given two and a half weeks to complete the survey. In October 2012, a follow-up survey email was sent to participants who previously submitted a blank survey.

5.1.2 Organization of the Survey

The survey was organized into four sections. The first section consisted of questions about the current general I/D practices of the STA responding. The questions in this section gathered information about the number of projects that included I/D provisions, the criteria for I/D awards and penalties, and the maximum I/D award and penalty amounts. The second section asked participants about mobility-based performance specifications used in highway construction contracts. The third section contained questions about which technologies are being used to collect mobility performance data in work zones and the applications of the collected data. The last section solicited specific information, benefits, and challenges about the data collection technology the STA used. A copy of the survey can be found in Appendix A.

5.2 Survey Results

Out of the 50 surveys sent out, 19 responses were received. Five of the 19 responses were returned blank and were excluded from the analysis. In addition to the five blank surveys, two participants did not fill out a survey, indicating that their STAs do not have any mobility-based performance specifications in highway construction contracts. Due to the length of the survey, many responses were only partially completed. The total number of responses varied among the four sections. This section will present the key findings from each of the four survey sections.

5.2.1 Section 1: General I/D Practices

The first section asked participants questions about general I/D practices for highway construction contracts. Questions in this section included the number of I/D projects, details of I/D projects, criteria for maximum I/D amounts, and benefits and challenges with I/D projects. A total of 12 STAs responded to the questions in this section.

5.2.1.1 Number of I/D Projects

Within the past five years, the number of I/D projects varied considerably from state to state. The number of projects with an I/D provision in a highway construction contract is shown in Table 5-1. The number of projects ranged from none in Hawaii to 728 projects in Pennsylvania. Oklahoma mentioned that approximately 18 percent of their projects, 320 out of 1824 projects, included an I/D provision for early completion and/or pavement smoothness.

Table 5-1. Number of I/D Projects within the Past Five Years

State	Number of Projects
Hawaii	0
Kentucky	20+
Maine	2
Nebraska	5 to10
Nevada	100+
Oklahoma	320
Pennsylvania	728
South Carolina	12
Tennessee	8 to10
Washington	50
Wisconsin	76
Wyoming	7

5.2.1.2 I/D Project Details

To get a better appreciation of current practices for I/D projects, the survey gathered the maximum I/D amounts, the award and penalty criteria, and the results of the projects for three different project sizes. The three project sizes were based on the project cost; a large project had a cost greater than 5 million dollars, a medium project had a cost between 1 and 5 million dollars, and a small project had a cost less than 1 million dollars. The results from this question are listed in Table 5-2.

Table 5-2. I/D Project Information

State	Project Size	Maximum Incentive Amount ($)	Award Criteria	Maximum Disincentive Amount ($)	Penalty Criteria	Amount Awarded (Y/N)	Dollar Amount ($)
Maine	Large	2,000,000	S	Unlimited	S	Y	2,000,000
Nebraska	Medium	1,200,000	S	Unlimited	S	Y	1,200,000
	Small	600,000	S	Unlimited	*	Y	600,000
Nevada	Large	*	S	*	S	N	
	Medium	*	S	*	S	N	
	Small	*	S	*	S	N	
Oklahoma	Large	*	P	Unlimited	P	Y	
	Medium	*	P	Unlimited	P	Y	
	Small	*	P	*	P	Y	
Pennsylvania	Large	Varies	S	Varies	S	Y	
	Medium	Varies	S	Varies	S	Y	
	Small	Varies	S	Varies	S	Y	
Tennessee	Large	1,000,000	P	Unlimited	S	N**	
	Medium	75,000	P	Unlimited	S	Y	75,000
Washington	Large	*	S	20,000***	S	N	
	Medium	*	*	4,000/day	S	N	
	Small	*	*	1,000/day	S	N	
Wisconsin	Large	150,000	S	10,000/day	S	Y	150,000
	Medium	200,000	S	20,000/day	S	Y	200,000
	Small	4,000	S	1,000/day	S	Y	4,000
Wyoming	Large	1,000,000	P	10,000/day	P	Y	1,000,000
	Medium	50,000	P	10,000/day	P	Y	40,000

P= Performance-based

S= Schedule-based

*Data are unavailable

**Project is still under construction

***Penalized for late opening of lanes

Many projects included a maximum incentive amount and an unlimited disincentive amount. Many STAs award or penalize the contractor based on schedule-based criteria. In some states, such as Oklahoma, Tennessee, and Wyoming, the award was given based on performance criteria. The performance specification was not mobility-related but was based on the final quality of a roadway, for example, the pavement surface smoothness. Table 5-2 also shows that projects that were awarded an incentive bonus usually received incentives equal to the maximum incentive amounts. While not noted in the table, Oklahoma mentioned that, over the past five years, a net total of $23 million was awarded as incentives.

I/D provisions may not be suitable for all types of projects. I/D provisions may be included to accelerate construction because the roadway has a high amount of traffic or is time

sensitive. To gather information about which project characteristics would qualify for the use of I/D clauses, one question presented five choices: 1) high volume roadway, 2) high profile project, 3) high user delay cost, 4) time sensitive, and 5) "Other." Survey participants could select all that applied. Figure 5-1 shows the number of responses to the question.

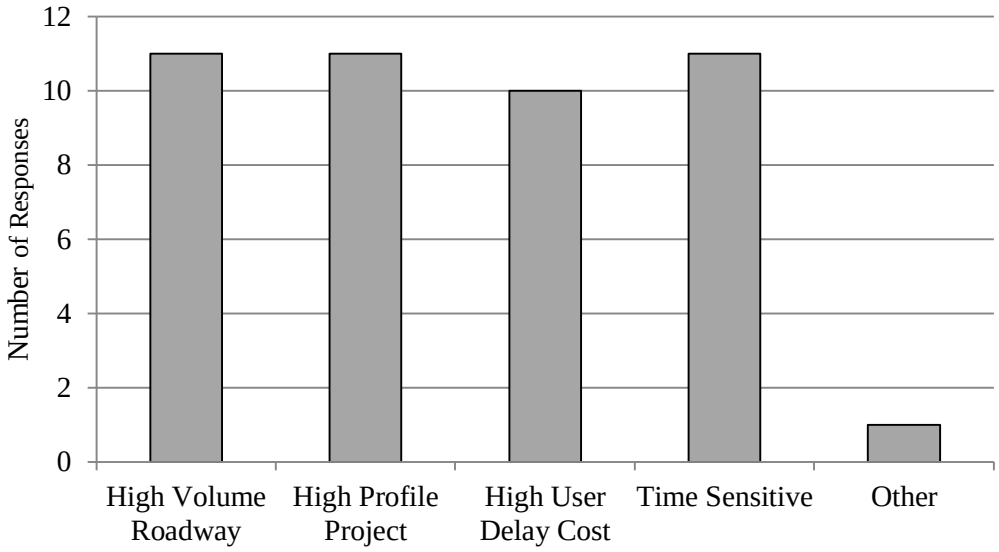


Figure 5-1. Project Characteristics for Using I/D Provision in Work Zone Contracts

The majority of STAs indicated that all four main reasons (high volume roadway, high profile project, high user delay cost, and time sensitive) were all qualities that would qualify a project for the use of an I/D contract. The one "Other" response was that a disincentive clause was included to penalize the contractor for failure to complete the project on time.

5.2.1.3 Criteria for I/D Amounts

In order to identify how a STA defines the maximum I/D amount per project, the survey participants were asked to select from four options for maximum I/D amounts: 1) percentage of project cost, 2) a fixed amount, 3) road user cost, and 4) "Other." The respondent could choose any options that applied and was asked to specify the percentage or fixed amount if that option was chosen. Figure 5-2 shows the number of responses for each option.

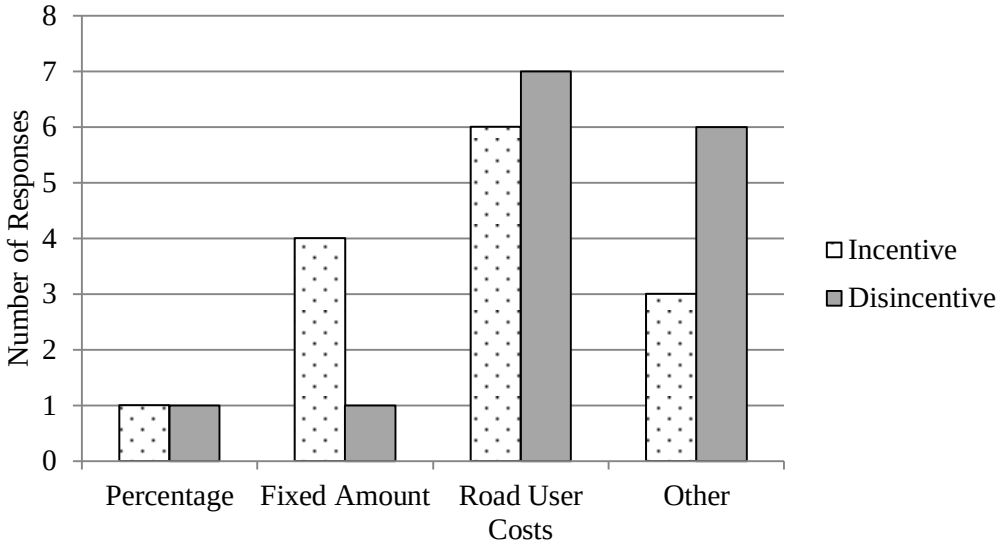


Figure 5-2. How STAs Define the Maximum Incentive and Disincentive Amount per Project

For the maximum incentive amount, many STAs said that they use either road user cost or a fixed amount. In Tennessee, the maximum incentive amount varies by project, but there is a maximum cap at 5 percent of the project estimate. In Nevada, the maximum incentive amount is determined by the Director's Office of the Nevada Department of Transportation (NDOT). One STA, Kentucky, has stopped using incentives and only applies disincentives.

The majority of respondents said the maximum disincentive amount was based on road user cost. One of the "Other" definitions was that the maximum disincentive amount was equal to 15 percent of the contract amount divided by the number of working days for the project. Three STAs said that there was an unlimited disincentive amount because, if the project was late, the road user cost would continue to increase.

Information about the relationship between the I/D amounts was gathered. Survey participants were presented four mutually exclusive choices: 1) the incentive and disincentive amounts are equal, 2) the incentive amount should be greater than the disincentive amount, 3) the disincentive amount should be greater than the incentive amount, or 4) "Other." The results are shown in Figure 5-3.

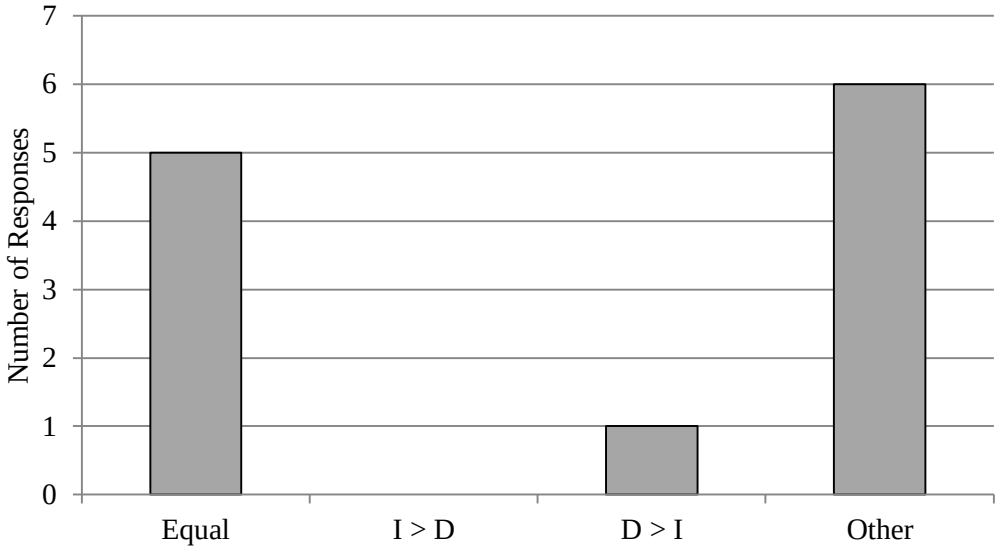


Figure 5-3. Relationship between Incentive and Disincentive Amount

Five STAs said that the incentive and disincentive amounts should be equal. Four of the six "Other" results stated that the incentive and disincentive amounts are equal, on a per day basis, but there is a cap on the maximum incentive amount.

5.2.1.4 Benefits and Challenges with I/D Projects

In order to gather information about the benefit and challenges associated with I/D projects, the participants were given four choices and selected all options that applied to their STA. The four choices were 1) early completion of project, 2) schedule flexibility for contractor, 3) allocation of some risk to contractors, and 4) "Other." Figure 5-4 shows the responses to this question.

All of the participants said that one benefit of using I/D provisions is that there is an early completion of the project, while five responses said that I/D provisions allocate some risk to the contractors. There were two "Other" responses that stated I/D provisions encourage high quality construction in a low-bid-based project selection system.

Regarding problems encountered in applying I/D provisions, survey participants selected all of the four options that applied to their STA: 1) increased cost to the agency, 2) greater coordination required between STA and contractor, 3) contractor struggling to optimize

construction crew schedule, or 4) "Other." From the results shown in Figure 5-5, the increased cost to the agency was the major concern with applying I/D provisions. There is also greater coordination required between the STA and the contactor. The "Other" responses included an observation that I/D provisions required greater resource allocation, a concern about the time required for claims to be processed, and a comment about the difficulty in determining the I/D values based on user cost since user cost varies significantly over time.

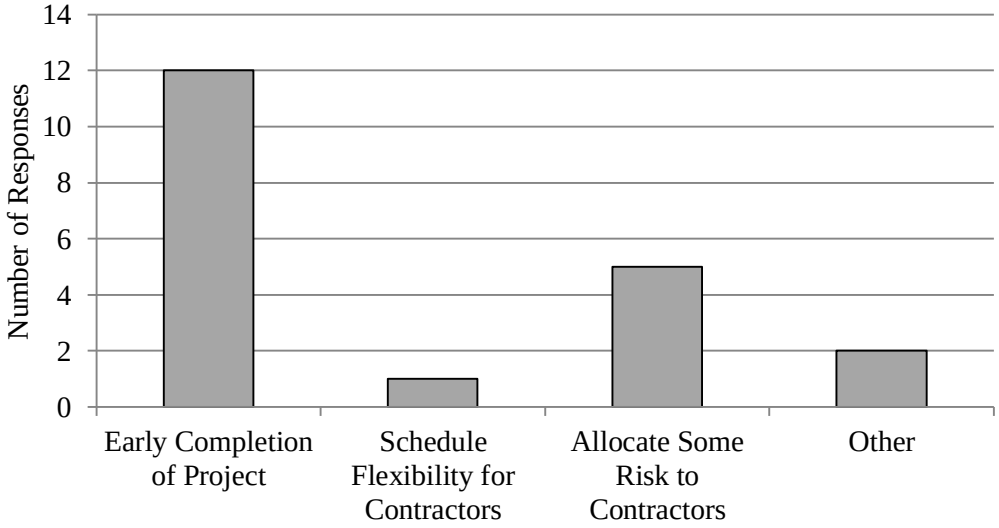


Figure 5-4. Benefits of Implementing I/D Projects

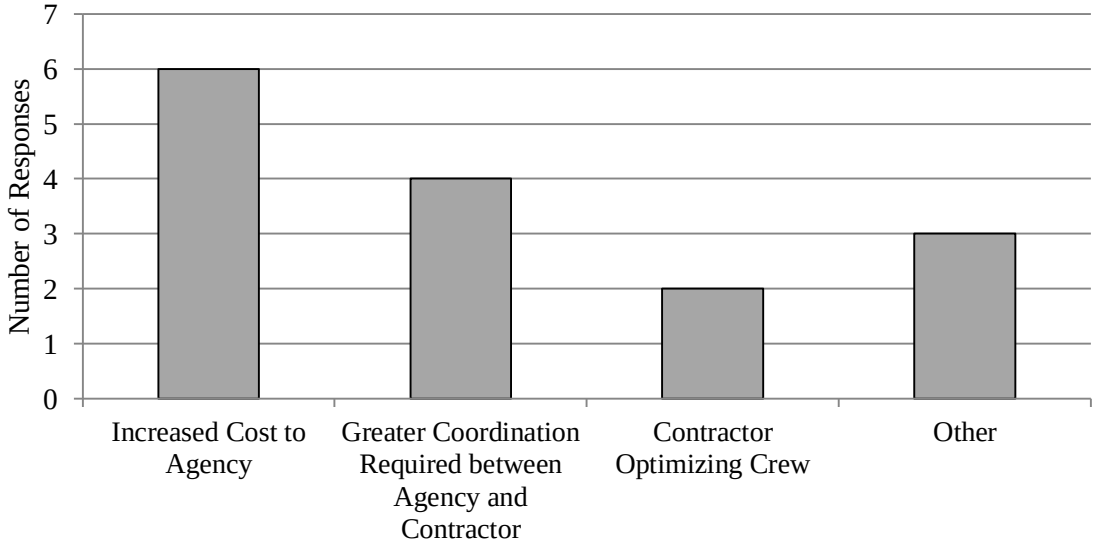


Figure 5-5. Problems Encountered with Applying I/D Provisions

5.2.2 Section 2: Mobility-based Performance Specifications

The second section of the current I/D practices and performance specifications survey focused on mobility-based performance specifications in highway construction contracts. The questions in this section were very similar to the questions in the previous section but were focused specifically on mobility-based performance specifications. Any answers in this section would be beneficial to the research and would indicate new developments since the completion of the NCHRP Scan Tour 08-04 (Bourne et al. 2010).

The first questions on the mobility-based performance specification section inquired if there was any investigation or implementation of mobility-based performance specifications in highway construction contracts being done by the STA. The results are shown in Figure 5-6. The number of responses for the implementation is greater than the number of responses for the investigation because it included the two email responses from New Hampshire and North Dakota. Neither of these STAs participated in the survey but indicated in the email that no mobility-based performance specifications have been implemented in highway construction contracts. Overall, the majority of the STAs responded that mobility-based performance specifications in highway construction contracts were not being investigated or implemented. However, three STAs said that they were considering investigation into this practice. The three STAs included South Carolina, Pennsylvania, and Wyoming.

In addition, there was one STA, Wyoming, which responded that mobility-based performance specifications have been implemented in highway construction contracts. There have been two projects on a major arterial that have included mobility-based performance specifications. The performance measures that were monitored were delay and queuing. The Wyoming Department of Transportation (WYDOT) was responsible for collecting, managing, and processing the data, while the contractor was in charge of managing the data collection equipment. The use of mobility-based performance specifications allowed flexible scheduling on the part of the contractor, but there were challenges with not having enough personnel to implement the specification. WYDOT stated that the collected information was not adequate enough to assess the mobility-based performance. Currently, WYDOT collects mobility

performance data manually and is planning to use electronic devices for mobility-based performance monitoring in the future.

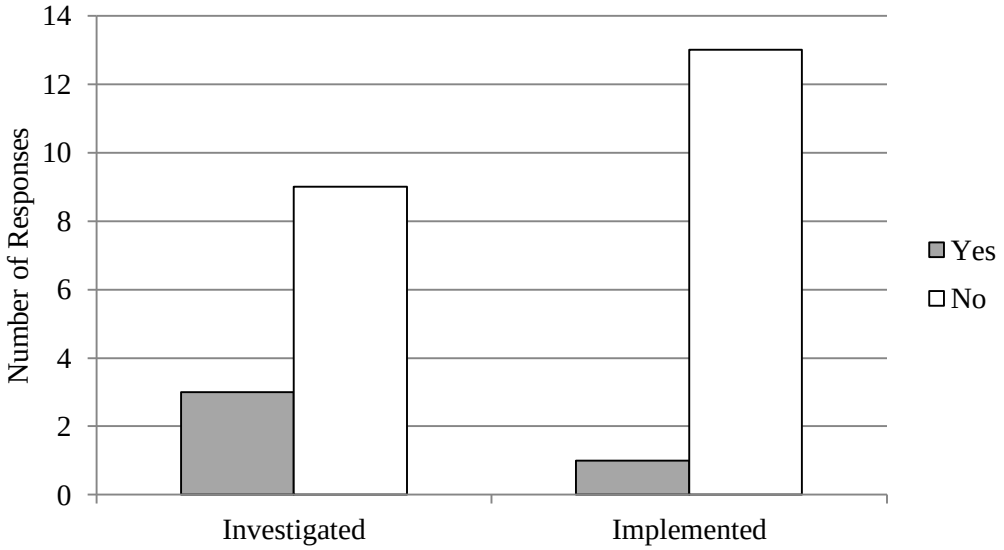


Figure 5-6. Responses for Investigating or Implementing Mobility-based Performance Specifications in Highway Construction Contracts

5.2.3 Section 3: Mobility-based Performance Data Collection in Work Zones

The third section of the survey inquired about mobility-based performance data collection in work zones. Information about the type of technology used by STA, the performance measures collected, applications of collected performance data used, responsible parties for various data collection tasks, and technology selections were gathered. There were nine STAs that gave responses to the questions in this section.

5.2.3.1 Type of Technologies Used by STAs

First, information about the technologies that were used to collect mobility data in work zones was gathered. Figure 5-7 shows that three STAs indicated that they currently use Bluetooth to collect mobility-based performance data. The four "Other" responses indicated that the data were collected manually, the STA just started to collect mobility data in work zones, or mobility-based performance data are currently not collected in work zones.

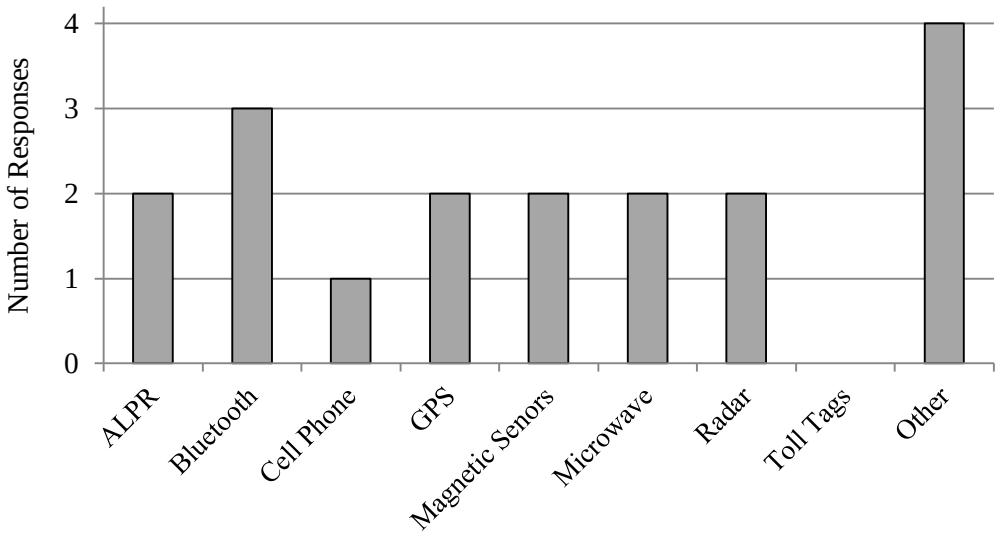


Figure 5-7. Mobility Performance Data Collection Technology in Work Zones

5.2.3.2 Performance Measures Collected

From the survey, the type of mobility-based performance measures being collected in work zones was gathered, and the results are shown in Figure 5-8. Survey participants were able to select all the performance measures that the STAs collected. Delay, speed, and traveling time received the highest number of responses, possibly because many data collection devices can easily measure them. The "Other" responses indicated that no data were being collected in work zones.

5.2.3.3 Applications of Mobility Performance Data

The mobility performance data can be collected for many different applications. For example, the data could be used to monitor traffic, to display travel time or speed on a VMS, or to assess I/D provisions. In the survey, participants were given five data applications and were told to select all that applied. As shown in Figure 5-9, the majority of the STAs responded that the data were used for displaying information on a VMS. Other common applications include both monitoring traffic and monitoring work zone performance. Two out of the three "Other" responses said that no data were being collected in work zones, while the remaining response said the data were used for travel time and delay analysis.

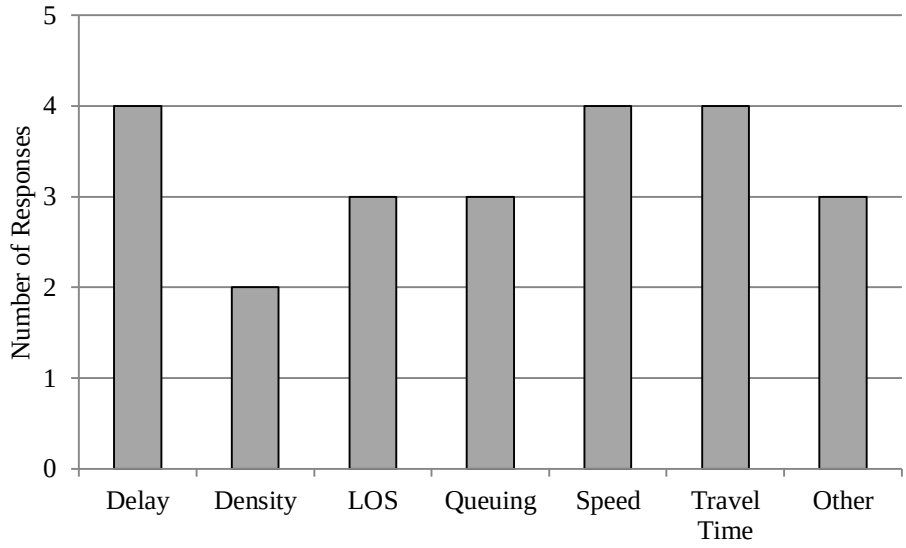


Figure 5-8. Type of Mobility Performance Data Being Collected in Work Zones

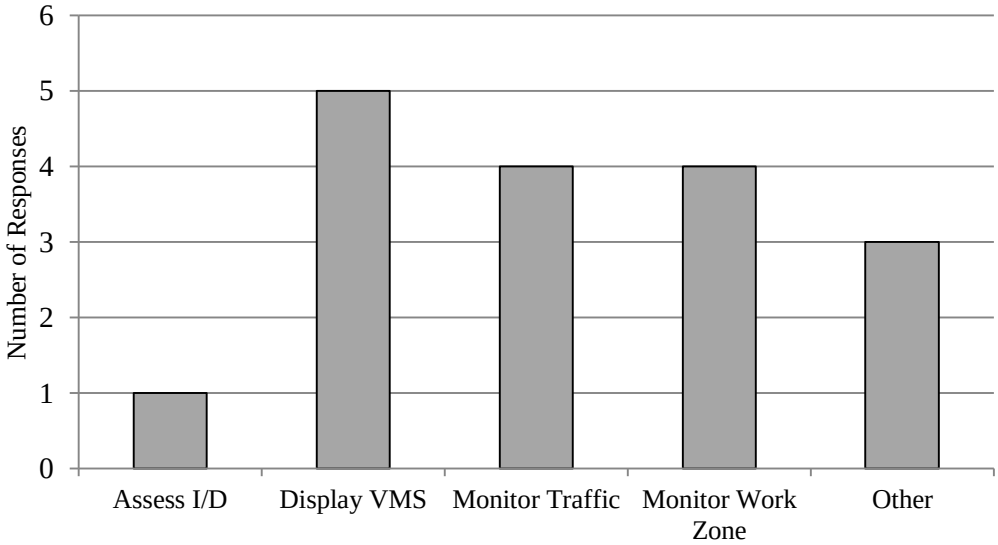


Figure 5-9. Data Application for Collected Mobility Data Responses

5.2.3.4 Responsible Parties for Various Data Collection Task

The data collection process involves multiple tasks such as managing and collecting the data, managing the equipment, and processing the data. The responsibility for completing the task may belong to different parties such as the STA, contractor, equipment supplier, or another third-party company. To understand which party the STA feels should be responsible for the three tasks, the survey participants were asked to choose from among the four responsible party choices for the three different tasks associated with data collection. For each task, multiple parties could be selected for each activity. For all three tasks, the STA received the highest number of responses, as shown in Figure 5-10. Managing the data collection equipment could be delegated to an equipment supplier. Other parties that were mentioned as being potentially responsible for managing the data collection equipment and interpreting the data were third-party consulting firms or research institutions. For example, in Wisconsin, the University of Wisconsin Traffic Operation and Safety Laboratory (TOPS Lab) is responsible for managing the equipment and processing the data.

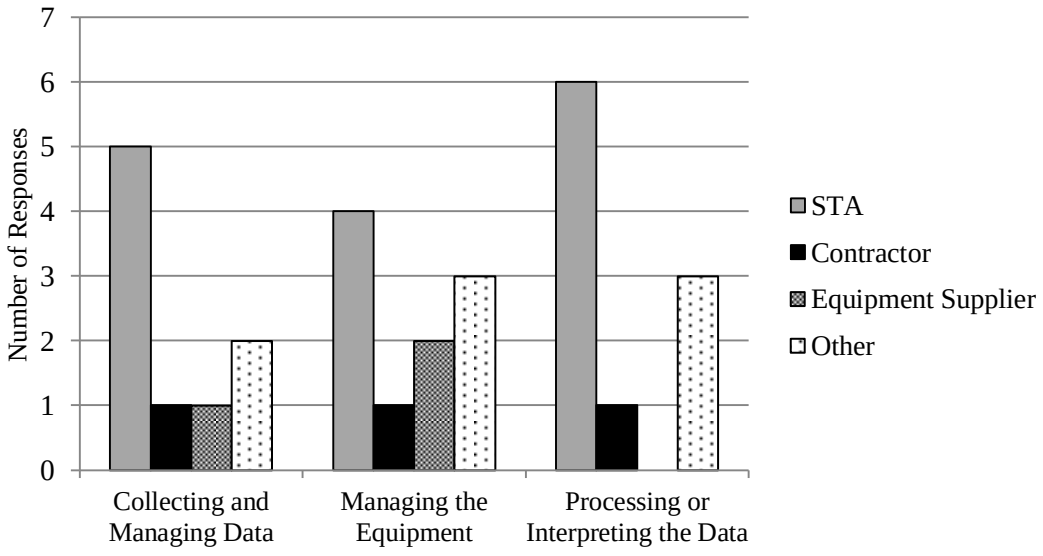


Figure 5-10. Responsible Parties for Collecting and Managing Data, Managing Data Collection Equipment, and Interpreting Data

5.2.3.5 Technology Selection

The last question of the third section of the survey gathered responses on how STAs decide which technology would be used for mobility-based performance data collection. In Washington, the core detection technology is inductive loops, but other technologies are employed on a case-by-case basis. The selection of the type of technology is also project specific in South Carolina. For Pennsylvania, the equipment is selected by following the Pennsylvania Department of Transportation (PennDOT) Work Zone Safety Mobility Policy. Wisconsin conducts pilot projects to test new technologies. Currently, Wisconsin has three projects underway, with one completed and two scheduled to be completed later in 2012.

5.2.4 Section 4: Data Collection Technology

The data collection technology section of the survey had participants go into more detail about the technology selected in the third section. The questions asked included how long the technology has been in use, who provides the equipment, what type of data could be collected, where the technology was deployed, what are the technological advantages or disadvantages, and what are suggestions for those who are interested in using the technology based on experiences of the participants.

This section only received responses from three STAs: Hawaii, South Carolina, and Wisconsin. The ALPR equipment in Hawaii is provided by Speedinfo, Inc. In Wisconsin, Bluetooth and cellular phone technology were used. The Bluetooth technology has been deployed for a year on pilot projects through the assistance of the TOPS Lab. Both Bluetooth and cellular phone technologies were used to collect travel time data on arterials. South Carolina has been using radar for 15 years from various suppliers. Radar was deployed on highways to collect speed data for its high accuracy. South Carolina suggested that the technology should be selected based on the requirements defined by the project specifications.

5.3 Chapter Summary

As part of the study, it was necessary to investigate the current practice of I/D and performance-based specifications used in STAs throughout the United States. To help identify

current practices, an online survey was developed and distributed to 50 STAs in the United States. The purpose of the survey was to collect the most current information about STA practices concerning I/D provisions and mobility-based performance measures to evaluate work zone traffic performance. The survey was sent to the members of the AASHTO Highway Subcommittee on Construction. Out of the 50 surveys that were sent out, 12 completed responses were received.

From the survey, information on current practices concerning the use of I/D specifications was gathered. For I/D specifications, many STAs award or penalize contractors based on scheduling criteria, while some STAs have applied performance-based criteria. In cases of performance-based I/D specifications, the quality of the pavement, such as pavement smoothness, was used as the basis for determining incentives and disincentives.

Out of the STAs that responded, three STAs (South Carolina, Pennsylvania, and Wyoming) have considered investigating the use of mobility-based performance specifications in highway construction contracts. Wyoming has implemented a mobility-based performance specification as a disincentive criterion in two highway construction contracts. Delay and queuing were the mobility performance measures monitored on two construction projects on a major arterial. The respondent from Wyoming stated that one benefit of applying mobility-based performance specifications was flexible scheduling capability on the part of the contractor but also noted that there were some challenges, especially in not having enough personnel to implement the procedure as intended.

Lastly, the survey asked STAs about the type of technology being used for mobility-based performance data collection. From the survey, there was not one specific technology that was being used significantly more than the others. There are some STAs, such as Nevada and Oklahoma, that do not collect mobility-based performance data in work zones. The respondent from Wyoming mentioned that WYDOT was planning to use electronic devices for monitoring traffic in future work zones. For the STAs that do collect mobility-based performance data in work zones, the data are collected and often used to display travel times on a VMS or to monitor traffic conditions in work zones.

Overall, the survey results show that, since the NCHRP Scan Report 08-04, there are STAs that have started investigating or have implemented mobility-based performance measures in work zones. While the number of STAs that have implemented mobility-based performance measures in work zones or mobility-based performance specifications in highway construction contracts is still low, there is the potential for mobility-based performance specifications to be more widely implemented in the near future.

6.0 CONCLUSIONS AND RECOMMENDATIONS

In recent years, implementing mobility-based performance specifications has been a topic of interest for many STAs. The NCHRP Report 08-04 (Bourne et al. 2010) addressed this issue and found that no STA implemented a mobility-based performance specification for highway construction contracts mainly due to the difficulty in obtaining mobility-based performance data in real time from the work zones throughout the duration of the construction. Hence, UDOT desired to investigate the feasibility of implementing mobility-based performance specifications for highway construction contracts. The UDOT study consisted of two phases. Phase I involved research into many aspects of mobility-based performance specifications in order to determine if this type of specification can be implemented with current performance data collection technologies. Since it was found in Phase I that mobility-based performance specifications in highway construction projects are feasible, Phase II is recommended to begin. During Phase II, a task force of contractors and engineers will be formed to develop criteria for a model mobility-based performance specification.

The findings of Phase I are presented in this report. This chapter briefly summarizes the major findings from Phase I of the project and provides recommendations for future work in developing mobility-based performance specifications for highway construction contracts.

6.1 Research Findings

For Phase I of the study, information on mobility data collection technology, performance measures and specifications, and current I/D and performance-based specifications were gathered using a variety of methods, including a literature search, interviews, and an online survey. This section presents the key findings from each of the chapters presented in this report.

6.1.1 Literature Review

The literature search focused on three topics. The first topic consisted of studying state-of-the-practice and state-of-the-art technologies for mobility performance data collection. To implement mobility-based performance specifications in highway contracts, it is necessary to be able to collect real-time data continuously throughout the duration of the construction project.

The second topic that was research was current I/D practices. It is necessary to have a basic understanding of I/D contracts because I/D provisions are a part of mobility-based performance specifications. The last topic included research into current practices concerning mobility-based performance measures and mobility-based performance specifications.

6.1.2 Mobility Data Collection Technology

A total of seven technologies were studied, which included ALPR, Bluetooth, magnetic sensors, AVI, microwave radar, cellular phone, and GPS. The capabilities, advantages, disadvantages, and existing use of each technology were investigated. Depending on the project characteristics, some technologies may be better suited for specific projects than others. For example, Bluetooth and iCone microwave radar devices are portable, which may be suitable for work zones that move along a corridor and do not allow permanent installation. Many technology vendors provide websites that show in real time the summary of performance measurements. The research showed that there are multiple technologies currently available that are capable of continuously collecting mobility-based performance data.

6.1.3 Performance Measures and Specifications

The topic of mobility-based performance specifications is a relatively new topic. There is very little literature on the subject; however, there have been a couple of experiments with mobility-based performance specifications. One project by UDOT was the 7800 South and Bangerter Highway project in West Jordan, Utah. This project was a design-build project that involved reconstruction of three intersections along Bangerter Highway at 6200 South, 7000 South, and 7800 South. As part of the project, the construction company worked with UDOT to test a mobility-based performance specification. The performance specification monitored the travel times for 48 movements measurable along the work zone using 10 Bluetooth sensor units. The contractor and UDOT met regularly to discuss the travel time data and made any adjustments necessary to the specification as the construction work progressed. During the construction period, there were minor technical difficulties experienced with the Bluetooth equipment, which mainly consisted of the Bluetooth data analysis software sending out false alarms due to the low Bluetooth sampling rates. Also, the contractor felt the need for more personnel who could focus solely on monitoring the mobility-based performance measurement

system. Nevertheless, the project showed that adding a mobility-based performance specification to a highway construction contract was feasible.

6.1.4 Online Survey on Current I/D Practices and Performance Specifications

An online survey was developed and distributed to 50 STAs. The purpose of the survey was to collect information on current practices concerning I/D and mobility-based performance specifications for highway construction contracts. The survey participants were selected from the members of the AASHTO Highway Subcommittee on Construction. Out of the 50 surveys sent out, 12 completed responses were returned. The survey revealed that many STAs currently use schedule-based I/D specifications and that the mobility-based performance specification is still a new topic among STAs. There are some STAs that currently do not collect any mobility data in work zones, and those that do collect mobility data in work zones use the data to display information on a VMS or to monitor traffic conditions. However, three STAs (South Carolina, Pennsylvania, and Wyoming) stated that they have considered investigating the implementation of mobility-based performance specifications in highway construction contracts. WYDOT was the only STA among these three STAs that has implemented a mobility-based performance specification at the time this survey was conducted; they used it to determine only disincentives on two construction projects on an arterial.

6.2 Recommendation for Future Work

Based on the findings from the research, implementation of mobility-based performance specifications was found to be feasible for UDOT. Two recommendations are therefore made for future research to enhance the knowledge on the topic as presented below.

6.2.1 Developing Guidelines for Mobility-based Performance Specifications

Now that the feasibility of incorporating mobility-based performance specifications in highway construction contracts has been determined, Phase II of the study should be conducted and has begun. During Phase II, a task force will be organized to determine criteria for applying mobility-based performance specifications in highway construction contracts. The members of the task force should consist of representatives of UDOT, contractors, and other relevant

stakeholders to discuss and develop performance specifications with specific criteria and guidelines that reflect the needs of all parties involved.

6.2.2 Pilot Tests

Once criteria and guidelines for applying mobility-based performance specifications in highway construction contracts have been established, it is recommended that a few pilot tests be conducted on actual construction projects to evaluate any remaining issues that may be found when such performance-based specifications are implemented. It is recommended to test mobility-based performance specifications first on projects with limited access or on rural highways. This would help limit the number of movements to monitor so that UDOT and the contractors would be able to focus on the workability of the proposed performance-based specifications, that is, they would be able to focus on how such specifications perform in actual construction settings rather than addressing the issues related to the performance of a mobility data measurement system selected for the project.

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APPENDIX A: CURRENT MOBILITY PERFORMANCE SURVEY

1. Contract Information

What state is this response from?	
Name	
Address	
City, State Zip Code	
Email Addresses	

2. Incentive/Disincentives (I/D)

This section will ask general questions about any types of incentive/disincentive specifications used in your agency.

a) In the past 5 years, how many projects have you done that included incentive/disincentive (I/D)?

b) In the table below, please include information about large, medium, and small I/D projects. The maximum incentive and disincentive amounts for each projects should be listed under the "Maximum incentive amount" and "Maximum disincentive amount" respectively. Under the "Award Criteria" and "Penalty Criteria" columns, please select the type of incentive and disincentive used to determine the awards and penalties amounts. In the "Result" column, please include the amount that the contractor was awarded or penalized, if applicable.

	Maximum incentive amount	Award Criteria			Maximum disincentive amount	Penalty Criteria			Result	Result		
	($)	Schedule-based	Performance-based	Other	($)	Scheduled-based	Performance-based	Other	Dollar amount ($)	Awarded	Penalized	No amount given
Large (greater than $5 million)		❑	❑	❑		❑	❑	❑		❍	❍	❍
Medium ($1-$5 million)		❑	❑	❑		❑	❑	❑		❍	❍	❍
Small (less than $1million)		❑	❑	❑		❑	❑	❑		❍	❍	❍

c) What type of project would qualify for the use of I/D?

- ❑ High volume roadway
- ❑ High profile project
- ❑ High user delay cost
- ❑ Time sensitive
- ❑ Other _____

d) How does your agency define the maximum incentive amount per project?

- ❑ Percentage of contract amount? (Please specify the percentage amount) _____
- ❑ Fixed amount (please specify the dollar amount) _____
- ❑ Road User Costs
- ❑ Other _____

e) How does your agency define the maximum disincentive amount per project?

- ❑ Percentage of contract amount? (Please specify the percentage amount) _____
- ❑ Fixed amount (please specify the dollar amount) _____
- ❑ Road User Costs
- ❑ Other _____

e) ii) Please describe the method used in calculating the user costs below, attach a copy of the method (hard or electronic copy), or a direct URL to its website.

f) What should be the relationship between the incentive and disincentive amounts?

- ❍ Both incentive and disincentive amounts are equal
- ❍ Incentive should be greater than disincentive amount
- ❍ Disincentive should be greater than the incentive amount
- ❍ Other _____

g) What are some benefits in applying I/D?

- ❑ Early completion of projects
- ❑ Schedule flexibility for contractors
- ❑ Allocate some risk to contractor
- ❑ Other _____

h) What are some problems encountered, if any, in applying I/D?

- ❑ Increase cost to agency
- ❑ Greater required coordination between agency and contractor
- ❑ Contractor optimizing crew
- ❑ Other _____

i) Please rate the following on a scale from 1 to 5 with 1 being the lowest score and 5 being the highest.

	1	2	3	4	5
How was the quality of the project when using I/D compared to a project without I/D?	❍	❍	❍	❍	❍
How was the safety of the work zone when using I/D compared to a project without I/D?	❍	❍	❍	❍	❍
How much input did your agency received from the contractors while developing the I/D?	❍	❍	❍	❍	❍
How positive is the feedback you receive from the contractors about the mobility I.D?	❍	❍	❍	❍	❍

3. Mobility-Based Performance Specification in Work Zone Contracts

This section focuses on mobility-based specification in work zone contracts used in your agency.

a) Has your agency considered investigation into the practice of mobility-based performance specifications in work zone contracts?

- ❍ Yes
- ❍ No

b) Has your agency implemented any mobility-based performance specifications in work zone contracts?

- ❍ Yes
- ❍ No

b) ii) Please describe the incentive criteria

c) How many project(s) have included a mobility-based performance specification?

d) What type of project(s) has included a mobility-based performance specification?

- ❑ Construction
- ❑ Maintenance
- ❑ Pavement
- ❑ Roadway/intersection improvement
- ❑ Signal
- ❑ Study
- ❑ Widening
- ❑ Other _____

e) Where were the project(s) located?

- ❑ Interstate
- ❑ Major Arterial
- ❑ Minor Arterial
- ❑ Collectors
- ❑ Others _____

f) What type of mobility performance measures were monitored and assessed?

- ❑ Delay
- ❑ Density
- ❑ Level of Service
- ❑ Queuing
- ❑ Speed
- ❑ Travel Time
- ❑ Other _____

g) Who is responsible for collecting and managing the data?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment Supplier
- ❑ Other _____

h) Who is responsible for managing the mobility performance monitoring equipment?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment Supplier
- ❑ Other _____

i) Who reduces, processes, or interprets the collected data?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment Supplier
- ❑ Other _____

Please answer Question 3j- 3m by giving a score between 1 and 5, with 1 being the lowest and 5 being the highest.

	1	2	3	4	5
j) How successful has it been to implement mobility-based performance specification in work zone?	❍	❍	❍	❍	❍
k) How successful has it been in collecting mobility-based performance data in work zone?	❍	❍	❍	❍	❍
l) How positive has the state agency's response been in using mobility-based performance specification?	❍	❍	❍	❍	❍
m) How positive has the contractor's response been in using mobility-based performance specification?	❍	❍	❍	❍	❍

n) What were some of the benefits experienced in applying mobility-based performance measures?

- ❑ Better finished project
- ❑ Flexible Scheduling
- ❑ Smoother traffic
- ❑ Other _____

o) What problem, if any, were encountered when applying the mobility-based performance measures?

- ❑ Not enough personnel
- ❑ Inadequate Technology
- ❑ Validating I/D amounts
- ❑ Increased data processing workload
- ❑ Other _____

p) In the table below, please include information about the maximum incentive and disincentive amount and the criteria type used to assess a large, medium, and small project with mobility-based performance specification. The maximum incentive and disincentive should be given

under the “Maximum incentive amount” and “Maximum disincentive amount” columns. Under the “Award Criteria” and “Penalty Criteria” please select which mobility-based performance measure that was monitored to assess the award and penalty amounts. In the “Result” column, please include the amount that the contractor was awarded or penalized, if applicable. Additional information about these questions will be asked in the next question, Question 3q.

	Maximum incentive amount	Award Criteria				Maximum disincentive amount	Penalty Criteria				Result	Result		
	($)	Travel Time	Delay	Speed	Other	($)	Travel time	Delay	Speed	Other	Dollar amount ($)	Awarded	Penalized	No amount given
Large (greater than $5 million)		❑	❑	❑	❑		❑	❑	❑	❑		❍	❍	❍
Medium ($1-$5 million)		❑	❑	❑	❑		❑	❑	❑	❑		❍	❍	❍
Small (less than $1million)		❑	❑	❑	❑		❑	❑	❑	❑		❍	❍	❍

q) In the table below, please give examples of total project cost and data collection cost for the projects used in the previous question, Question 3p. If a dollar amount for Data Collection is unknown, a percentage of Total Project Cost may be given.

	Total Project Cost	Data Collection Cost	
	Dollar Amount ($)	Dollar Amount ($)	Percentage (%)
Large (>$5 million)			
Medium ($1-$5 million)			
Small (			

r) Please select the answer that best describes how your agency arranges to pay for the equipment, software, and/or manpower for collection the necessary mobility-based performance measure data.

	State Agency	Contractors	Other
Equipment	❍	❍	
Software	❍	❍	
Manpower	❍	❍	

s) Is the amount of data you collected or received adequate for assessing the mobility performance in the work zone?

❍ Yes
❍ No

t) What has been your agency's biggest challenge(s) in collecting data to support mobility-based performance specifications? And, how did you agency overcome it?

4. Mobility-Based Data Collection in Work Zone

a) What technology does your agency currently use to collect data for mobility-based performance measures in work zone?

❑ Automatic License Plate Recognition
❑ Bluetooth
❑ Cell Phones
❑ GPS
❑ Magnetic Sensors
❑ Microwave
❑ Radar
❑ Toll Tags
❑ Other _____

b) What is the collected data used for?

- ❑ Assess incentives/disincentives
- ❑ Display travel time on VMS
- ❑ Monitor traffic
- ❑ Monitor work zone performance
- ❑ Other _____

c) What type of mobility performance measures are assessed?

- ❑ Delay
- ❑ Density
- ❑ Level of Service
- ❑ Queuing
- ❑ Speed
- ❑ Travel Time
- ❑ Other _____

d) Who is responsible for collecting and managing the data?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment supplier
- ❑ Other _____

e) Who is responsible for managing the equipment?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment supplier
- ❑ Other _____

f) Who interprets or processes or refines the data?

- ❑ State Highway Agency
- ❑ Contractor
- ❑ Equipment supplier
- ❑ Other _____

g) How does your agency decide which technology would be used for mobility data collection?

5. Data Collection Technology

Answer the Question 5a and 5b for the technology selected in Question 4a in the "Mobility-Based Data Collection in Work Zone" section.

	a) How long has your agency been using this technology?	b) What company provides this technology?
Automatic License Plate Recognition		
Bluetooth		
Cell Phone		
GPS		
Magnetic Sensors		
Radar		
Toll Tags		
Other		

Answer Question 5c and 5d for the technology selected in Question 4a in the "Mobility-Based Data Collection in Work Zone" section.

	c) What data do you collect using this technology?							d) Where do you deploy this technology?			
	Delay	Density	Level of Service	Queuing	Speed	Travel Time	Other	Highway	Arterial	Local Roads	Other
Automatic License Plate Recognitions	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Bluetooth	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Cell Phone	❍	❍	❍	❍	❍	❍		❍	❍	❍	
GPS	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Magnetic Sensors	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Microwave	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Radar	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Toll Tags	❍	❍	❍	❍	❍	❍		❍	❍	❍	
Other	❍	❍	❍	❍	❍	❍		❍	❍	❍	

e) For the technology selected in Question 4a in the "Mobility-Based Data Collection in Work Zone" section, what benefits has your agency experienced while using this technology?

	Easy Installation	Easy Configurations	Easy Maintenance	Easy to Operate Equipment	Easy to Manipulate Data	No Privacy issues	High Accuracy	Other
Automatic License Plate Recognitions	❍	❍	❍	❍	❍	❍	❍	
Bluetooth	❍	❍	❍	❍	❍	❍	❍	
Cell Phone	❍	❍	❍	❍	❍	❍	❍	
GPS	❍	❍	❍	❍	❍	❍	❍	
Magnetic Sensors	❍	❍	❍	❍	❍	❍	❍	
Microwave	❍	❍	❍	❍	❍	❍	❍	
Radar	❍	❍	❍	❍	❍	❍	❍	
Toll Tags	❍	❍	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	❍	❍	

f) For the technology selected in Question 4a in the "Mobility-Based Data Collection in Work Zone" section, what problems, if any, has your agency encountered while using this technology?

	Difficult Installation	Difficult Configuration	Difficult Maintenance	Difficult to Operate Equipment	Difficult to Manipulate Data	Privacy issues	Low Accuracy	Other
Automatic License Plate Recognitions	❍	❍	❍	❍	❍	❍	❍	
Bluetooth	❍	❍	❍	❍	❍	❍	❍	
Cell Phone	❍	❍	❍	❍	❍	❍	❍	
GPS	❍	❍	❍	❍	❍	❍	❍	
Magnetic Sensors	❍	❍	❍	❍	❍	❍	❍	
Microwave	❍	❍	❍	❍	❍	❍	❍	
Radar	❍	❍	❍	❍	❍	❍	❍	
Toll Tags	❍	❍	❍	❍	❍	❍	❍	
Other	❍	❍	❍	❍	❍	❍	❍	

g) Have any changes been made to how you use or implement the technologies selected in "Mobility-Based Data Collection in Work Zone" section since your agency began using them? If so, what were the changes and why were they made?

h) Based on your experience, what advice would you give someone who is still considering whether to use the technologies selected in "Mobility-Based Data Collection in Work Zone" section.