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Final Report

Improving Safety in Pavement Field Testing

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DISCLAIMER

SI (MODERN METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		Area		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		Volume		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		Mass		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		Temperature (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		Illumination		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		Force and Pressure or Stress		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When You Know	Multiply By	To Find	Symbol
		Length		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		Area		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		Volume		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		Mass		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		Temperature (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		Illumination		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		Force and Pressure or Stress		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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16. Abstract

The Florida Department of Transportation (FDOT) collects pavement condition and performance data each year, using both site-specific equipment that requires temporary traffic control (TTC) operations (either moving or closed operations) and full-sized survey vehicles that run at highway speeds. While many safety features have been implemented in the pavement field testing processes, additional safety features that minimize distractions, enhance the pavement testing operator’s (PTO’s) awareness of surrounding conditions, and improve TTC operations are still greatly needed. The purpose of this research was to better understand the risk to PTOs when they measure pavement data in the field, both at highway speeds and within TTC or work zone, and to investigate methods and technologies that would improve the safety of pavement field testing.

As a result, this study found that the most common cause of incident is careless drivers in other vehicles. Tests within TTC or work zone need safety improvement more than the tests at highway speeds. There are several technologies or measures available which may be implemented by FDOT to increase the safety of pavement field testing. A summary of findings and recommendations is provided in the report.

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EXECUTIVE SUMMARY

The Florida Department of Transportation (FDOT) collects pavement condition and performance data using both site-specific equipment that requires temporary traffic control (TTC) operations (either moving or closed operations) and full-sized survey vehicles that travel at highway speeds. While many safety features have been implemented, the implementation of new technologies and methods practiced by other agencies and industries that have the potential to improve the safety of the pavement testing operator (PTO) and travelling public may be warranted. The purpose of this research is to determine the state-of-the-practice of pavement field testing at both highway speeds and within TTC or work zone and to recommend practical methods for improved safety during testing.

In this study, an exhaustive literature review and a nationwide questionnaire survey were performed. The literature review covered information related to the practice of collecting pavement condition and performance data, safety measures of various survey vehicles and TTC operations, and new data collection techniques that may potentially improve safety during testing. A variety of literature sources were reviewed, including the safety-related reports and manuals from various state DOTs and manufacturers of data collection equipment. In the nationwide questionnaire survey, four questions under three testing scenarios were sent to relevant pavement engineers in all state DOTs. These are documented in Section 3.1.3. Responses were received from 32 state DOTs, and they are included in Appendix A.

Based on the project's findings, potential measures to increase safety during testing generally include improvement of equipment and development of safety systems:

- For survey vehicles at highway speeds, the following safety features may be added: in-vehicle warning systems (i.e., forward collision and lane departure warning system; driver fatigue and distraction warning system), and voice recognition applications (e.g., Freesr).
- For field testing with mobile operations, some cell phone applications (e.g., iOnRoad) may be adopted for analysis and pre-warning of traffic condition; placement of shadow vehicles and work vehicles may also be further adjusted.
- For field testing with full lane closure, various detection devices and warning devices may be explored and assembled to build several smart work zone systems (e.g., work zone intrusion warning system and queue warning system).

The following recommendations for safer testing operations and features are provided in the report for potential implementation:

- For pavement field testing at highway speeds
    - Upgrading data acquisition software with voice recognition application
    - Adding advanced driving assistance systems
- For pavement field testing with mobile operations
    - Refining the spacing standards between shadow vehicle and work vehicle
- For pavement field testing with full lane closure
    - Exploring devices for smart work zone systems
    - Developing a mobile work zone barrier system
    - Improving visibility of PTOs at night.

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CHAPTER 1 INTRODUCTION

The Florida Department of Transportation (FDOT) is responsible for driving over totally 500,000 miles in its mission to collect pavement condition and performance data each year, using both site specific equipment that requires temporary traffic control (TTC) operations (either moving or closed operations) and full-sized survey vehicles that run at highway speeds.

While many new safety features have been implemented to minimize or help eliminate lane closures, several pavement evaluation methods still require TTC operations. For all forms of pavement testing, Pavement Testing Operators (PTOs) are typically required to perform several functions that are potentially distracting. For data collection at highway speeds, currently the State Materials Office employs several full-sized vehicles equipped with sensors. Depending on the manufacturer, the data collection process may require input from the PTOs at key locations along the testing route, which could lead to distracted driving. A PTO is responsible for driving the test vehicle, operating the on-board computer system(s), and surveying the pavement surface while navigating through challenging traffic conditions.

Given these requirements, additional safety features that enhance the PTO's awareness of surrounding conditions and improve the state-of-the-practice for TTC operations (either moving or closed operations) are greatly needed.

The purpose of this research is to better understand the risk of PTOs when they measure pavement data in the field, both at highway speeds and within TTC or work zone, and to investigate methods and technologies that would improve the overall safety of pavement field testing. The research objectives include:

1. Determine the state-of-the-practice for safely operating a full-sized test vehicle at highway speeds for the collection of pavement condition and pavement performance data,
2. Determine the state-of-the-practice for the collection of pavement condition and pavement performance data within a TTC operation or work zone, including stop-and-go operations,
3. Develop recommendations for improved safety during testing.

In this study, a comprehensive literature review and a nationwide questionnaire survey were conducted to understand the risk of PTOs when they measure pavement data in the field and to investigate methods and technologies that would improve the safety of pavement field testing. Based on analysis of the collected information from the literature review and the survey, general recommendations on safety improvement during pavement field testing and specific recommendations for potential implementation are provided.

CHAPTER 2 LITERATURE REVIEW

A comprehensive literature review was performed to gather and analyze information related to the practice of collecting pavement condition and performance data, safety measures of various survey vehicles and TTC operations, and new data collection techniques that may potentially improve the safety of PTOs. Sources reviewed include Transportation Research Board publications, state research and practice reports, Department of Transportation (DOT) websites, international journals in various areas such as pavement engineering, transportation safety, literature (e.g., operation manuals, related newspaper articles and web pages) of manufacturers of data collection equipment, and any other information available as deemed relevant. Focus of the reviewing effort was put on the following three aspects:

- Current FDOT safety features for field testing
- Recommendations based on other state DOTs' data collection practice that may improve safety
- Advanced methods or technologies applied in other states or fields that may improve safety

2.1 Relevant Safety Manuals Used by FDOT

FDOT has published or adopted several safety manuals and documents (e.g., Florida Strategic Highway Safety Plan [SHSP], Survey Safety Handbook [SSH], FDOT Loss Prevention Manual [LPM], Job Safety Analysis [JSA], and FDOT Design Standards [FDS]) that describe various test methods in detail with specific safety instructions to follow. These methods are designed to ensure safety on roadways and to minimize risks during test operations. Most of them involve two or three test scenarios, including testing at highway speeds, testing with mobile operations, and testing with full lane closure. The detail guidelines outlined in those manuals related to improving safety in pavement field tests are discussed in Sections 2.1.1 through 2.1.5. FDOT also prepares a safety indoctrination (SI) document for new employees to ensure that they completely understand their job functions in accordance with the Department's safety policies. Most safety related points in the SI document are also detailed in the FDOT LPM.

2.1.1 Florida Strategic Highway Safety Plan

FDOT updated its draft Strategic Highway Safety Plan (SHSP) in October 2016. Based on the crash data in 2011 through 2015, this plan lists several priority areas to help focus corresponding implementation activities on the sides of engineering, enforcement, education, and emergency response (4E) (FDOT, 2016). Although most emphasis areas in the plan do not directly deal with the safety issues in pavement field tests, this plan provides several findings that may help reduce accidents during pavement field testing (FDOT, 2016), as follows:

- Lane departure is one of the main factors causing accidents on highways, so it should be reduced.
- When allowable, avoiding intersections is one of the most important factors to be considered while planning the route of pavement field tests, since more potential conflict points will be generated when setting temporary traffic control devices during slow or static field tests.

- Impaired drivers and aggressive drivers should be detected before they enter a work zone or get close to a test van. Safety person shall pay more attention to them using detection devices (e.g., non-intrusive detection devices, radio frequency guns, cameras).

The SHSP lists the following four strategies to prevent accidents in work zone (FDOT, 2016), which are related to the safety of pavement field testing in work zone:

- *"Apply advanced technology to improve work zone safety such as automated work zone information system, simplified dynamic lane merge systems, portable changeable message signs, and queue warning systems."*
- *"Educate road users about work zone safety and provide timely and accurate information regarding active work zones."*
- *"Determine the feasibility and effectiveness of other improvements including installing reflectors on barrier walls, spacing on curves, changes in the penalties and fines to contractors for getting out of the roadway late, using of crash cushions, and correcting pavement marking errors."*
- *"Work with law enforcement, contractors, and DOT personnel to reduce speeding in and around work zones through a comprehensive approach of increased fines and increased law enforcement contacts."*

2.1.2 Survey Safety Handbook: Safety for Surveyors

The personal protective equipment introduced in the FDOT Survey Safety Handbook (SSH) is largely taken from the Manual on Uniform Traffic Control Devices (MUTCD) (FHWA, 2009). Several safety rules that are beneficial for operators working on active roads or highways are recommended in this handbook, including (FDOT, 1999):

- *"Always face traffic when working on the traveled way of a divided road or on shoulders of highways. If you cannot do this yourself, have a co-worker act as a lookout. When working in a zone between two-way traffic stand parallel to the traveled way and again use a lookout."*
- *"Do not make sudden movements that might confuse a motorist and cause him or her to take evasive action that could result in injury to the motorist as well as to surveyors."*
- *"Avoid interrupting traffic as much as possible. There are several ways to do this. One of the best ways is to use offset lines as much as possible. This procedure should keep you and your crew safe from oncoming traffic. Minimize the crossing of traffic lanes on high-speed heavily traveled highways. Do not try to walk or run across traffic lanes. On highways with wide shoulders and medians the best way to cross is with your vehicle. If necessary go around by way of a ramp or service road to assure a safe crossing. If traffic lanes must be crossed on foot, wait for a natural break in traffic. A break in traffic in this instance is defined as all lanes being clear."*
- *"Protect your crew with the use of an approved barrier to shield them from traffic. Whenever possible place a truck mounted attenuator between your workers and traffic."*
- *"Proper equipment carrying procedures: When working near a heavily traveled highway, or when working parallel to traffic, be careful to keep level rods, range poles, etc., from extending into a lane of traffic."*

2.1.3 FDOT Loss Prevention Manual

The FDOT Loss Prevention Manual (LPM) is a general safety manual for ensuring a safe working environment for all FDOT employees (FDOT, 2010). After a review of the manual it was found that the following points are worth mentioning (FDOT, 2010):

- As mentioned in the LPM, an emergency action plan shall be implemented to ensure employees safely and orderly evacuation from any emergencies. A specific emergency action plan may be designed particularly for the PTOs working in the work zone.
- Based on the LPM, signaling shall be accomplished by flaggers in conformance with the MUTCD and FDOT design standards. Red flags are only to be used for (1) emergency operation, (2) intersections, and (3) when working between active traffic lanes with traffic flow in the opposite direction.
- The LPM also suggests several types of training for PTOs and relevant employees, such as first aid and cardiopulmonary resuscitation (CPR) training, equipment operation training, training for work zone safety (TTC training), and defensive driving courses.

2.1.4 Job Safety Analysis

FDOT has prepared Job Safety Analysis (JSA) documents for its pavement field tests at highway speeds or with mobile operations, which cover the potential hazards and countermeasures at each step of the tests. A summary of them is given in Table 2-1 through Table 2-5.

As can be seen from the tables, the FDOT job safety analysis for the phase of field testing on roadways mainly focuses on traffic accidents as potential hazards, and the recommended countermeasures are to follow TTC design standards (typically index 607 or 619) for the mobile operation scenario (e.g., the FWD test), and to request operators to drive safely (e.g., being alert, using signals, flashing lights, and warning signs) for the tests at highway speeds. The driving experiences and skills of operators will significantly affect the potential hazard risk. Any additional safety features or strategies that may help improve the traffic safety of pavement testing operators will improve their job safety.

Table 2-1 Potential Hazards with Countermeasures during Operation of Friction Testing Vehicle

Operation of Friction Testing Vehicle		
Steps	**Potential Hazards**	**Actions/Procedures to Reduce/Eliminate Hazards**
Pre-trip inspection	Traffic/Vehicle Safety	Ensure vehicle maintenance is up to date, tires are properly inflated, and all lights are working properly.
Project Layout	Traffic/Heavy Equipment	Analyze work zone, identify hazards, identify direction of traffic, wear safety vest.
Computer Processing	Traffic, Pedestrian	Pull off roadway into a safe parking area.
Pretesting	Traffic, TTC	Become familiar with project limits.
Testing	Traffic, pedestrian	Be alert for large trucks, emergency vehicles, pedestrians and construction.
Calibration	Back Injury, Force Plate Chain	Calibration equipment is heavy, lift properly. Chain is under pressure, keep people and equipment clear of area.

Table 2-2 Potential Hazards with Countermeasures during Operation of Falling Weight Deflectometer

Operation of Falling Weight Deflectometer (FWD)		
Steps	**Potential Hazards**	**Actions/Procedures to Reduce/Eliminate Hazards**
Pre-trip inspection	Pinch, crush, and shock. Underinflated tire blowout, non-operational warning lighting, improper trailer hook up, unsecured parts and equipment	Follow procedure outlined in FDOT FWD Operator's Manual.
Attaching and detaching of FWD trailer and tow vehicle	Crush and Shock	Ensure trailer wheels have been chocked and the tow vehicle is off.
Releasing/Setting of Transport Locks	Pinch hazard when setting spring-loaded locking mechanism. Traffic hazard when being performed on the side of a road	Ensure fingers are clear of mechanism when releasing/setting the Transport Locks. Use of Safety vest required during operation on site.
Operation of FWD	Crush and Traffic Hazards	Ensure all appendages are clear of FWD mechanisms during FWD loading operation. Use of the proper 600 series TTC design standards required, typically index 607 or 619. If another TTC index is used, ensure the TTC conforms with standard index guidelines. Safety vest required when out of the tow vehicle and on site.

Table 2-3 Potential Hazards with Countermeasures during Operation of Vehicle-Mounted Ground Penetrating Radar

Operation of Vehicle-Mounted Ground Penetrating Radar (GPR)		
Steps	**Potential Hazards**	**Actions/Procedures to Reduce/Eliminate Hazards**
Pre-trip inspection	Traffic/Vehicle Safety	Ensure vehicle maintenance is up to date, tires are properly inflated, and all lights are working properly.
Antenna removal and setup	Pinch and lifting hazards	Use proper lifting techniques to remove antennas from the back of the vehicle. Ensure fingers are clear of mounting plates during setup.
Creation of calibration file using metal plates	Lifting, sharp edges, and burn hazards	Use proper lifting techniques with 4' x 4' metal plates. Edges of plates should be treated with caution as constant placement on the ground causes scratches and burrs. During hot weather metal plate may cause minor burns. Use of canvas gloves encouraged.
Power systems maintenance or replacement	shock and electrocution hazards	Ensure vehicle is off and electrically insulated tools are used when disconnecting battery from GPR system.

Table 2-4 Potential Hazards with Countermeasures during Operation of Mobile Retroreflectivity Unit

Operation of Mobile Retroreflectivity Unit (MRU)		
Steps	**Potential Hazards**	**Actions/Procedures to Reduce/Eliminate Hazards**
Pre-trip inspection	Traffic/Vehicle Safety	Ensure vehicle maintenance is up to date, tires are properly inflated, and all lights are working properly
Equipment removal and setup	Lifting hazards	Use proper lifting techniques to remove equipment from the back of the vehicle.
Equipment calibration / verification	Eye damage, sharp edges and burn hazards	Use eye protection when in direct contact of the equipment during calibration. Edges of measuring tape should be treated with caution placing calibration standard on the ground. During hot weather metal plates may cause minor burns. Use of canvas gloves encouraged.
Power systems maintenance or replacement	shock and electrocution hazards	Ensure vehicle is off and electrically insulated tools are used when disconnecting battery from MRU system. Wrap ends of battery wires with electrical tape to avoid accidental shock
Project Layout and Computer Processing	Traffic	Pull the vehicle off of the roadway and park safely out of traffic. Turn on vehicle safety lights if appropriate.
Pulling into or out of traffic	Traffic	The MRU have operational blind spots. Visually ensure that the way is clear before pulling out or changing lanes and that there is sufficient room to accelerate/decelerate. Use signals and flashing lights.
Testing	Traffic	Follow traffic laws, signal appropriately for lane changes, and use flashing lights if appropriate. Display "Testing In Progress" sign on the rear of the vehicle.

Table 2-5 Potential Hazards with Countermeasures during Operation of Multipurpose Survey Vehicle/Inertial Profiler

Operation of Multipurpose Survey Vehicle (MPSV)/Inertial Profiler		
Steps	**Potential Hazards**	**Actions/Procedures to Reduce/Eliminate Hazards**
Pre-trip inspection	Traffic/Vehicle Safety	Ensure vehicle maintenance is up to date, tires are properly inflated, and all lights are working properly.
Project Layout and Computer Processing	Traffic	Pull the vehicle off of the roadway and park safely out of traffic. Turn on vehicle safety lights if appropriate.
Before Testing	Traffic	Drive through the project once to familiarize yourself with the traffic patterns and to check for work crews with TTC. Verify that any TTC on the project is properly set up and does not present a hazard to testing.
Pulling into or out of traffic	Traffic	The vans have operational blind spots. Visually ensure that the way is clear before pulling out or changing lanes and that there is sufficient room to accelerate/decelerate. Use signals and flashing lights.
Testing	Traffic	Follow traffic laws, signal appropriately for lane changes, and use flashing lights if appropriate. Display "Testing In Progress" sign on the rear of the vehicle.

2.1.5 FDOT Design Standards

As mentioned in the previous section, the TTC series of the FDOT Design Standards (FDS) are followed in the pavement field testing. For testing with mobile operations, typically TTC index 607 or 619 is followed, in which one or more shadow vehicles (SVs) and/or an advanced warning vehicle (AWV) are placed behind a work vehicle (WV). Recently, in order to reduce the likelihood of public vehicles inadvertently travelling in and out between the shadow vehicle and the work vehicle, FDOT revised the TTC indices 607 and 619 by adding one more option to shorten the spacing between the SV and the WV when an AWV is placed in the lane behind the SV. A summary of this revision is shown in Table 2-6. To avoid rear-end collision between the SV and the WV, the revised spacing can only be used when the WV is moving on the outside lane (FDOT, 2015a; FDOT, 2015b). The placement of SVs in the FDOT Design Standards (more details are provided in Section 2.3.2.2) is generally in accordance with that in the MUTCD.

Table 2-6 Spacing between SV and WV Specified in FDOT TTC Plans

	Spacing between SV and WV (feet)	
	Original Standard	Current Optional Standard (if WV is on the outside lane)
In Rural Area	500-800	100-500
In Urban Area	300-500	50-300

2.2 Advanced Safety Features for Field Testing at Highway Speeds

Field testing at highway speeds is generally safer than traditional manual survey approaches (Okine and Adarkwa, 2013; Mullis et al., 2005; UDOT, 2012). Very few accidents during field testing at highway speeds have been reported to date. The potential for distraction and fatigue of an operator during testing while driving a test vehicle, however, still highlights the needs for additional features to increase the safety of PTOs and road users (Vavrik et al., 2013).

2.2.1 Advanced Safety Devices

With the advancement of digital technology, new and improved techniques have been devised for pavement field testing at highway speeds. The use of laser and image processing technology, in-vehicle warning systems, and voice recognition application may make PTOs and road users safer. The details of certain technologies are reviewed and summarized in this section.

2.2.1.1 3D laser scanner/camera

Some state DOTs, such as California Department of Transportation (Caltrans) and Minnesota Department of Transportation (MnDOT), have already started using three-dimensional (3D) technologies in pavement field survey. Caltrans evaluated the performance of 3D laser scanners and found that laser scanning can reduce lane closure and injury risk, and increase productivity. Moreover, the 3D model built by laser scanning can provide all the required data, without requesting surveyors to return to the site for additional measurements **(**Hiremagalur et al., 2007). MnDOT collects 3D images of pavement surface by two lasers and analyzes pavement distresses based on these images (MnDOT, 2015a). Similarly, North Carolina Department of Transportation (NCDOT) uses a testing van with half-dozen 2D and 3D cameras to record pavement images and reconstructs these images later to form a virtual reality of the pavement surface. Arkansas State Highway and Transportation Department (AHTD) uses the Multimedia Highway Information System (MMHIS) to process images from six different camera views (five right-of-way cameras and one pavement camera) on an Automatic Road Analyzer (ARAN) (AHTD, 2015) . The MMHIS uses imagery provided from the ARAN and displays the image with corresponding data from the Pavement Management System, Road Inventory, Bridge, Safety, and Project History databases for better comparison of other data with real pavement scenario. However, such an approach to measuring pavement conditions is still imperfect due to its limited accuracy (Vilacoba, 2015).

A few major vendors in the U.S., such as Dynatest Consulting, Inc., Fugro-Roadware Inc., Mandli Communications, Inc., and Pathway Services, Inc., offer 3D line-scan automated distress rating systems (Vavrik et al., 2013). Based on the discussion by Vavrik et al. on the available automated rating systems for Ohio DOT, the features of three automated rating systems are summarized in Table 2-7. Generally, all these systems include high quality cameras, routing assistant technologies, backup locating system, and light detection and ranging system (LiDAR). Based on the comparison between the ratings from vendors and from Ohio DOT, all automated distress rating systems are actually semi-automated with expected high accuracy (correlations generally above 75 percent) (Vavrik et al., 2013).

Table 2-7 Information of Three Main Automated Distress Rating Systems

Vendor	Fugro	Mandli	Pathway
System	Roadware Pave3D System	Communications LCMS	3D Data Acquisition System
Cameras	Six right-of-way (ROW) Sony high-definition cameras which are better than trigger-based cameras	Three industrial ROW cameras	Three industrial forward ROW cameras; Side and rear view cameras (optional)
Backup locating /positioning system if satellite lock is interrupted (without GPS)	DMI, IMU	DMI, IMU	DMI, IMU
Routing Assistant Technologies	Pre-established routing information	Google earth	Real-time onboard routing
Light detection and ranging system (LiDAR)	Optech or Dynascan	(Supplemental LiDAR 360-degree imaging)	Velodyne
Average confidence rating (3-high, 2-moderate, 1-low)	2.7	2.4	2.4
Average process rating (3-automated, 2-semi-automated, 1-manual)	2.6	2.1	2.3
Some states that use the automated system	Colorado; California; Iowa; Louisiana; Michigan; Pennsylvania; Vermont	Alaska; Iowa; Kentucky; Rhode Island; Utah	Alabama; Colorado; California; Indiana; Iowa; Mississippi; Nebraska; New Hampshire

2.2.1.2 High quality camera and real-time digital image processing

With the availability of new, high quality cameras, Maryland State Highway Administration (SHA) recently purchased a new Automatic Road Analyzer (ARAN 9000) data collection system from Fugro in 2016. This new ARAN implements an imaging system with a 4K broadcast quality camera (Fugro, 2016a). Fugro Roadware's latest ARAN 9000 vehicle can be used as a road profiler, a video logger, or a full scale roadway data collection system. It has several benefits over existing roadway profilers.

Fugro's SDP/2 (South Dakota Profiler) can operate within a range of speeds, which includes low speeds for collecting roughness data, stop and go environments, and regions where there is no sufficiently long lead-in (Fugro, 2016b). This feature is safer than the current practice in the aspect that currently used technology restricts operators to drive the vehicle at a constant speed or within a small speed range. The method of recording images in the field and rating in the office is used in a number of state DOTs (SDDOT, 2009; AHTD, 2015). However, pavement images are limited in their ability to capture and reproduce everything a rater needs to see in order to assign a reliable value (SDDOT, 2009).

A high quality camera with real-time digital image processing can be used in many high-speed field tests and significantly improves worker safety. For example, Caltrans uses lasers and cameras to display existing pavement structure and collect pavement data (cracking, the roadway pictures, and the amount of each pavement distress) during automated pavement condition survey (APCS). Relying on those high quality cameras and lasers, Caltrans developed a new pavement management system, called PaveM, to recommend the best strategies, predict how long pavements will last, and recommend more cost-effective treatments.

For another example as shown in Figure 2-1, LTL-M, a mobile retroreflectometer unit by Delta uses a couple of advanced technologies in measuring nighttime visibility of pavement markings at highway speeds. Delta uses camera-based techniques and real-time digital image processing instead of conventional laser technology to ensure more accuracy under all types of driving conditions (Delta, 2016). The system can also be coupled with a GPS and Distance Measuring Instrument (DMI) to ensure precise data collection for specific location. This setup helps to easily locate the defective signs and markings. The system has an embedded overhead camera that relieves the operator from manually recording defective signs above the roadway grade, hence giving the system its uniqueness over present mobile retroreflectometers. The system has advanced features such as compensation of vehicle bouncing, vertical lifting, tilting, as well as handling of difficult measurement conditions such as curved roads and large variations in stripe profile height (Delta, 2016).

Figure 2-1 LTL-M, a mobile retroreflectometer unit by Delta (Delta, 2016)

2.2.1.3 Friction tester with laser technology

Pavement friction is typically measured with a locked wheel friction tester (LWFT) according to the ASTM E274 standard test method, which requires a supply of water and is typically conducted at a testing speed of 40 mph. There is research associated with the use of laser technology to measure Mean Profile Depth (MPD) (ASTM E1845) at highway speeds in conjunction with ASTM E274 friction testing. Jackson et al. (2007) verified MPD of pavement with a 64 kHz laser and establish a viable option to simultaneously measure Friction Number (FN) and collect the MPD data. Resulting data compared to site specific tools indicated very good correlation between the high speed MPD technology versus site specific equipment such as a Circular Track Meter (CTM) (Choubane et al., 2012). Recently there is also research that uses laser technology to measure the microtexture of pavement surface (Oeser, 2017). Currently the measurement can only be conducted in a laboratory environment, not in the field at highway speeds (Oeser, 2017).

2.2.1.4 Smartphone used to measure pavement roughness

Conventional methods of collecting pavement roughness data involve significant cost and sometimes are risky. A safer and less costly approach can be the use of smartphone accelerometer data to measure pavement roughness. One Nextrans sponsored project carried out a study in 2014 to determine the application of smartphone accelerometer data to measure roadway roughness. As illustrated in Figure 2-2, irregularities in pavement surface cause vertical acceleration in moving vehicles. A three-axis accelerometer in the smartphone placed in survey vehicles can measure acceleration in three orthogonal axes and a built in Android application stores the accelerometer data. Then a post processing of the stored data is conducted by a MATLAB script in order to convert accelerometer data to pavement roughness data that also considers vehicle shock absorbing technology while measuring the vertical acceleration. The smartphone application can also record the position of the vehicle by using smartphone's built in GPS and timestamps are also measured during whole data collection process. When combined all of these data together, pavement roughness profile along the roadway is reconstructed. The user can control the rate of data collection and the higher the data collection rate the higher the accuracy of roughness up to an optimum limit. Results showed that the IRI found from using smartphone is very close to that of a high precision inertial road profiler system. The repeatability of roughness data in this technology was also found satisfactory (Buttlar and Islam, 2014). If applied, this method may improve the safety of field testing since its data collection process is fully automatic and an operator does not need to execute any other task except only driving. Wix, however, indicated that smart phone measurements are not as repeatable and accurate as inertial profilers and should not be relied upon for pavement management purposes. In other words, this is not a viable replacement for inertial profilers yet (Wix, 2016).

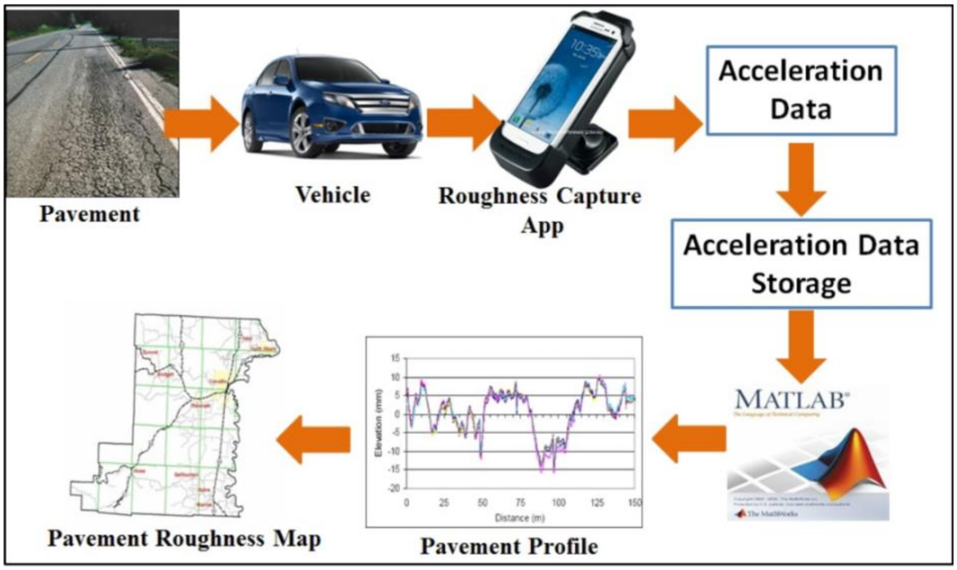

Figure 2-2 Pavement roughness measurement using smartphone (Buttlar and Islam, 2014)

2.2.1.5 Quad-copter unmanned aerial vehicle (QUAV) for automated asphalt pavement inspection

Zakeri et al. (2016) recently proposed the use of an unmanned aerial vehicle (a quad-copter equipped with sensors necessary to collect pavement condition data) to automatically detect cracks, rutting and potholes in asphalt pavements. An aerial vehicle has high maneuverability, can be operated without any operator present on-site and can collect data from a height without interfering active traffic, as shown in Figure 2-3.

These features indicate that a high degree of safety can be ensured if this method can be implemented properly. They verified the method on an actual pavement with a variety of distresses and compared the result with on-site manual inspection. The comparison showed that the proposed method is reliable and can be used for future practice (Zakeri et al., 2016). However, this system is still at an experimental stage. Further research, experiment, and validation are necessary to prove its application in the industry and use as an alternative to pavement distress surveys.

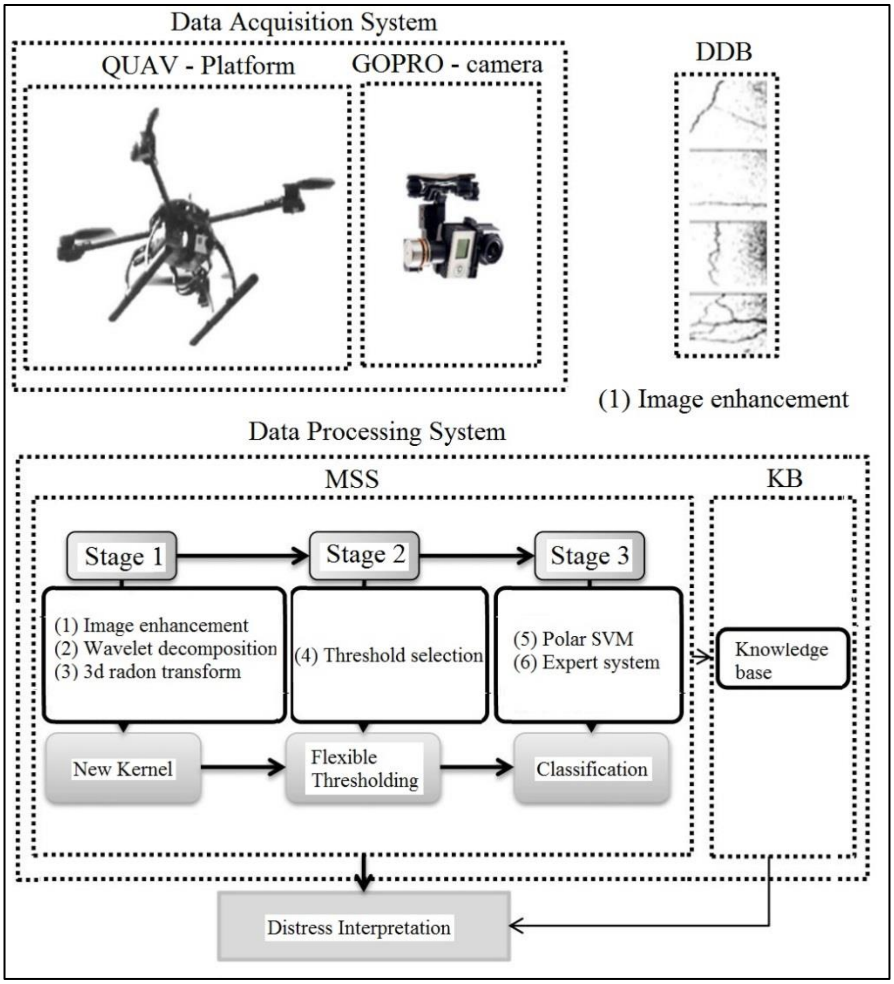

Figure 2-3 A schematic diagram for automated pavement inspection system with QUAV (Zakeri et al., 2016)

2.2.1.6 Forward collision and lane-departure warning system

One potential cause of accidents in pavement field testing at highway speeds is driver distraction due to operating data collection software and driving at the same time. The potential risk involved in this scenario is due to an operator's inability to notice vehicles in front and/or in adjacent lanes. A forward collision and lane departure warning system, which can be easily installed in current test vehicles, may help solve the problem. The system detects leading vehicles and measures the distance from it with the help of a radar detector attached to the front bumper of a facilitated vehicle. Inside the vehicle there is an output unit that can warn the driver visually by changing the color of the warning lights and audibly by an alarm when the car is within a vulnerable distance from the leader vehicle, as shown in Figure 2-4. One such product is manufactured by Save Drive Systems (SDS), which currently installs a complete unit with three years of repairing service in a single purchase (SDS, 2016). A system with both forward collision and lane departure warning features for one vehicle costs approximately $1,500 with installation charge whereas a system with only forward collision warning costs $1,200 including installation cost (SDS, 2016). Some other companies, such as Mobileeye, Delphi, and ZFTRW, also manufacture Forward Collision Mitigation (FCM) systems available in the U.S. This type of system only warns the driver but does not brake automatically.

There are also more advanced systems available on the market that not only warn the driver but also brake automatically, if the driver does not respond. These systems go by different names such as Forward Collision Warning (FCW), Crash Imminent Brake (CIB), Emergency Brake Assist (EBA), etc. In 2014, NHTSA conducted a study to better understand potential safety impact of Forward Crash Avoidance and Mitigation System (FCAM) which includes both FCW and CIB systems. The study estimated that the combined effect of FCW, CIB and Dynamic Brake Support (DBS) would prevent 200,000 minor injuries (Abbreviated Injury Scale [AIS] I-2), 4,000 serious injuries (AIS 3-5), and save approximately 100 lives annually (NHTSA, 2014). However, the study assumed that all light vehicles would be equipped with FCAM systems and would provide speed reductions at a level set by NHTSA for the estimation (NHTSA, 2014).

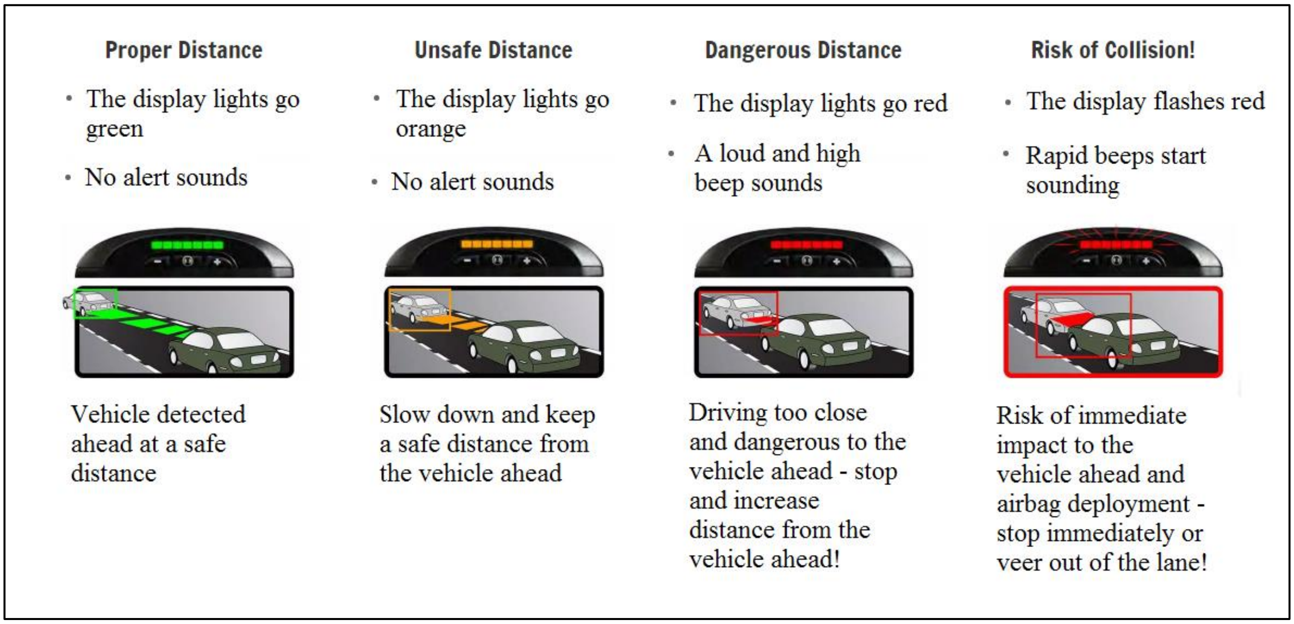

Figure 2-4 Illustration of the operation mechanism of a forward collision warning system (SDS, 2016)

Specifically, Table 2-8 lists advanced driving assistance systems available in market. As Table 2-8 lists, Save Drive's RD 140 model only uses radar technology to detect vehicle in front for their FCW system. Others use video camera based image detection technologies for FCW. The downside of using camera based detection is that there is a possibility that the system will not be able to work in all types of weather condition. One example is that foggy weather may restrict the camera's capability to detect objects or vehicles in front of it. On the other hand, a radar based detection system can work in any type of weather condition, as claimed by the manufacturers of such systems. This difference is reflected in the price difference between the Save Drive's FCW system and other camera based Advanced Driver Assistance Systems (ADAS).

Among the FCW devices listed in Table 2-8, items (b), (c), and (f) have head-up display. The only role of these displays is to show what is in front of the vehicle as recorded by the forward detection camera.

Table 2-8 Driving Assistance Systems Available on the Market

No.	Name/ Model Name	Features	Price ($)	Manufacturer/ Provider	Image
a.	Safe Drive System RD 140 (Only model with radar detection system)	Forward Collision Warning Lane Departure Warning	1500 (FCW and Lane Departure) 1200 (Only FCW RD-140-RDR)	Safe Drive System	
b.	ADAS+ Advanced Driver Assistance System ADAS-1000	Forward Collision Warning Lane Departure Warning Video and Event Recording Location Data	679 (522 at Amazon.com)	Brandmotion	
c.	Garmin DriveAssist ™ 50LMT	Forward Collision Warning Lane Departure Warning Video and Event Recording	300 (With basic features)	Garmin	
d.	Mobileye 560	Forward Collision Warning Lane Departure Warning	800-850	Mobileye	
e.	Lane Departure Warning System with Forward Collision Warning & DVR	Forward Collision Warning Lane Departure Warning Video and Event Recording	389	VOXX Electronic Corporation	

Table 2-8 Driving Assistance Systems Available on the Market (Continued)

No.	Name/ Model Name	Features	Price ($)	Manufacturer/ Provider	Image
f.	LUKAS LK-9390 AD GPS	Forward Collision Warning Lane Departure Warning Video and Event Recording	349-800 (Based on available features)	QVIA Lukas	

2.2.1.7 Driver fatigue and distraction monitoring and warning system

Fatigue and consequent distraction is a common phenomenon in drivers when they have to drive a long distance with no or very little break. This type of distraction is one potential cause of human error related accidents. It is likely that operators of pavement field testing may experience such symptoms. Currently there are fatigue warning systems available on the market to help drivers detect and warn the fatigue and distraction status. One example is the MR 688 fatigue warning system developed by Care Drive. This product uses high-grade image sensors to capture infrared images of the operator and high speed digital signal processors to analyze if the driver has become inattentive either due to distraction or drowsiness, as shown in Figure 2-5.

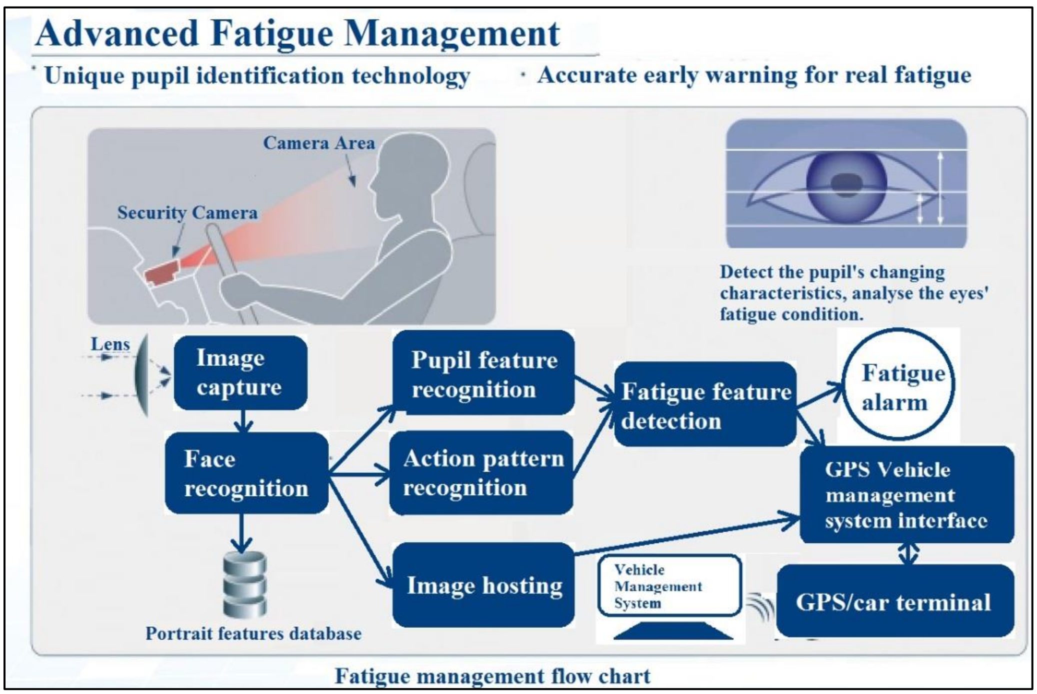

Figure 2-5 Fatigue and distraction monitoring and warning system (Care Drive, 2016)

As the system uses automotive imaging infrared sensors it can detect fatigue or distraction in any weather condition and even if the driver uses sun glasses. As a comparison, a regular camera without such automotive sensors is often not great enough to capture fine details in a backlit, high-glare situation. The system can also differentiate between a sleep and temporal closed eye and warns the driver only when sleep is detected for a substantial span of time that may lead to danger. This system is compact and easy to install in a test vehicle (Mehler et al., 2014). Price for full MR688 package standard version is in the range of $250-$500 and can be purchased from the U.S. dealer named Rearview Safety.

Initially, the user might find some issues when using the system for the first couple of times. The system may seem too sensitive as it may detect some unintended eye blink as distraction or sleep. However, the sensitivity can be adjusted. It should also be noted that the MR688 has only two level of adjustment; the one with higher sensitivity detects drivers sleep and warns the driver in 2-3 seconds (the driver needs to close his/her eye for this period of time for the system to detect a distraction/ sleep). The lower level sensitivity takes a little bit longer (5-6 seconds) to activate the warning alarm (Care Drive, 2016). Review of online comments from users of such a system, however, revealed mixed results. The usefulness of such a system for PTOs who have to frequently check an in-vehicle computer screen still needs further evaluation. MR688 and two other similar fatigue and distraction monitoring devices (FDMD) are listed in Table 2-9. All these systems include a camera based pupil detection device placed on the dashboard and a warning system. The camera of the detection device detects the pupil of the driver and keeps track of her/his head movement. If the eyelid is closed for a significant period of time and so the device cannot detect the pupil (i.e., driver falls asleep), the warning system will warn the driver by an alarm. In this way, the system may prevent accidents related to driver distraction due to drowsiness, sleepiness, or fatigue.

Table 2-9 Fatigue and Distraction Monitoring Systems Available on the Market

No.	Name/ Model Name	Features	Price ($)	Manufacturer/ Provider	Image
a.	MR 688 Driver Fatigue Monitoring System	Fatigue and Distraction Warning	500	Rear View Safety in the US	
b.	Vuemate Driver Fatigue System	Fatigue and Distraction Warning	200	Rear View Safety in the US	
c.	Driver Fatigue Monitor Anti Sleep Car Alarm System	Fatigue Monitoring and Warning	190-280	Shenzhen Feelmax Technology Co.	

2.2.1.8 Voice recognition application to control data acquisition software by hands-free voice command

Some voice recognition applications are currently available on the market which can turn any software into voice controllable. These applications can work with any computer software via a simple process. Specific voice commands can be set in the application for specific operations of the intended software. The command may include pressing a certain key on the keyboard or clicking some place in the usual software interface. Using the application, all these operations can be set and performed by speaking predefined voice commands. Even more than one operation can be incorporated with one voice command. Suppose in the usual interface, the software needs double clicks on the software icon to open it and pressing a certain key to initiate a feature. It is possible to set these two commands together and control the software using one voice command instead with the help of voice recognition application. Templates can be created for specific software which will contain required command setup. This template with those commands setup can be exported to or imported from other computers and used by the same software as in the first computer. One such application is Freesr that contains all the features mentioned so far. This software is free for personal use but needs to be purchased for commercial purpose (Freesr, 2016). Provided the simple operations of FDOT test vehicles' data acquisition software at highway speeds, Freesr can help to perform those operations easily as anticipated. Yet the free version can be installed in one of the vehicle data acquisition software for evaluation. If the accuracy and acceptability of the system is satisfactory then a professional version of the application may be purchased with more advanced features which are relevant to and specifically useful for data acquisition software used by FDOT test vehicles. Among others, Dragon speech recognition software programs from Nuance, Braina, Lilyspeech are some of the best functioning voice recognition software available. While the cost for Freesr professional version needs to be selected through negotiating with the consultant (if FDOT is interested after running the trial version), others vary from $2.90/month (Lilyspeech) to a one-time payment of $29 (Braina for a year) and $75 (Dragon).

2.2.1.9 Voice recognition feature in data acquisition software interface with MRU

A startup company named Leetron Vision made a prototype of a new Mobile Retroreflectometer Unit (MRU) with advanced features such as voice recognition facilitated data acquisition software interface, camera based tracking system to align the sensors perfectly with the retroreflective markings and some other features. Since Leetron MRU is able to measure two lines in a single pass, its measurement rate can be double compared to regular MRU. Moreover, its measurement rate can be further improved because neither hourly calibration nor relocation from side to side on the vehicle is required. The operation cost of Leetron MRU is also lowered as much as 20% by requiring only one operator (Lee, 2011). However, based on the information provided on the company's website and recent communication with Leetron Vision, it seems that a production model is not yet available. They have built a prototype and are still in the process of developing a usable unit that can operate on roads with all of the proposed features. Therefore, this alternative is not ready to use at present and may be considered for future improvement when the technologies mature.

2.2.1.10 Appropriate position of in-vehicle computer screen

The position of a computer screen in a test vehicle may affect the safety of pavement field testing since it will turn the operator's sight away from roadway traffic condition when he/she checks information on the screen during the test. An appropriate position of the computer screen (and the associated keyboard) in a test vehicle should be determined based on the following considerations:

- The position should be such that the PTOs do not get distracted while checking the screen when needed during operations at highway speeds (assurance of safe operation);
- The angle of screen and keyboard placement from the PTOs position should not be such that it may cause neck and back pain to the PTOs;
- The screen should not block the safe extent of driver's front vision;
- Providing the PTOs a comfortable working environment should also be a priority while determining the position of their working station.

Some other disciplines of work also need in-vehicle-mounted computers due to the nature of their operations. For example, patrol police and utility service operators use a computer in their vehicles for mobile operations. The computer screen position in their vehicles and the factors they have considered in selecting such positions may provide some valuable insight in determining the proper computer screen position in pavement test vehicles.

Saginus et al. conducted a study in 2011 to measure the effect of different positions of a computer screen in utility vehicles on operators' biomechanical features (e.g., muscle, neck, joints, and backbone) and task performance. They experimented with four different positions of the computer and tried to determine which position among these was the most comfortable one for the operator. They also kept track of the time required to perform a specific task and the number of mistakes made in each position. The results showed that, the most comfortable position of the computer screen was the one being closest to the steering wheel. Subjective assessment also indicated that, the operators preferred position of the computer was as close as possible to the steering wheel (Saginus et al., 2011).

After a thorough search, no literature or available mount setup was found that suggests any other screen position different from the right side of the driver beside the steering wheel. Possible alternatives to that position may hinder driver's front vision (if it is above the steering wheel and may be attached to the roof of the vehicle) or may be uncomfortable for the driver (if it is to the right side of the driver but not close to the steering wheel causing a large angle with driver's usual position). The discussion so far suggests that the best available position of the in-vehicle computer screen is beside the driver's seat and according to Saginus et al. (2011), the most comfortable position is as close as possible to the steering wheel. Therefore, an appropriate solution would be selection of mounts designed for specific vehicle models to ensure sufficient proximity of position to the steering wheel. Some vendors of in-vehicle computer mounts (e.g., Havis Inc., Gamber Johnson) manufacture vehicle specific mounts. For example, the mount setup they produce for Ford vehicles is not the same as the mount setup for Chevrolet or other vehicles. Even model specific mounts are also available within same automobile brand. As most of the pavement test vehicles used by FDOT are from the Ford Motor Company, an in-vehicle computer mounting solution specifically for the Ford E-series heavy duty vans may be explored from some vendors (e.g., Havis Inc.) for potential benefits of added safety.

Figure 2-6 shows a Havis in-vehicle computer mount setup for a Ford E series van and the computer mount setup in one of the FDOT pavement testing vehicles. As the closeness to the steering wheel is a concern, the computer mount made by Havis is 7 inches out from the right side of the driver seat. Though the setup shown is for a laptop it can be configured for a keyboard and docking stations. The approximate cost for this setup is within the range of $150- $250. As the safety aspect of the computer mount position depends on reduced distraction of the driver which in turn depends on the closeness of the mount position to the steering wheel, a new mount system for specific vehicles may be considered as a potential safety upgrade after a detailed review.

However, it should also be ensured that setting up the mount close to the steering wheel does not affect the PTOs' free maneuverability as a driver. After all, in most of the FDOT pavement field tests at highway speeds, the PTOs do not need to heavily interact with the computer like the utility operators or patrol police while driving or collecting data. So it should be made sure that relocation of the computer mount has positive impact on PTO safety and comfort enhancement before making any change. From a short inspection of FDOT test vehicles it was noticed that the computer mount positions in all the vehicles are not the same. Only vehicles with computers that are at an excessive distance from the driver seat and the PTO is uncomfortable with may be improved by applying the vehicle specific mounting system solution.

(a) Havis version for Ford E series vans (Havis, 2016)

(b) FDOT version currently used in pavement testing vehicles

Figure 2-6 In-vehicle computer mounts

2.2.2 Safety Rules from Other State DOTs

After reviewing all available manuals (e.g., data collection manual, pavement condition rating manual, field survey manual) from other state DOTs, it was found that most relevant manuals follow the general testing procedures with similar safety precautions. The details in those manuals are slightly different on some aspects, such as the PTO team structure and the selections of improper sample locations, as described in following subsections.

2.2.2.1 Organizational considerations

The number of PTOs required in different field tests varies from state to state, depending on the safety priority of individual state DOT, the severity of local PTO-related accidents, various local traffic conditions, and specific field testing technologies. Some state DOTs suggest at least one safety person being involved in the field data collection or field tests. For example, Missouri allows a two-person field crew to operate the air-launch GPR at highway speeds (MoDOT, 2015).

In California, the regulation urges that all operators of state-owned vehicles must receive defensive driver training once every four years. Each operator must drive defensively and observe all applicable traffic laws (Caltrans, 2011). Similar training is also provided by Georgia DOT (GDOT, 2016). As mentioned in Section 2.1.3, the LPM from FDOT also requires all employees who will drive a vehicle take a defensive driver course.

2.2.2.2 Avoid improper sample locations and survey time

Most of the data collection manuals of state DOTs mention that sample locations can be rejected or adjusted if they are on bridges, in construction zones, or at any unsafe site (ALDOT, 2015; AKDOT, 2011; WVDOT, 2014). For example, specifications from AKDOT state that inertial profiler measurements shall not be taken on turn lanes, intersections, ramps, lane transitions, or within 25 feet of bridge abutments (AKDOT, 2015).

Regarding the time of field testing, most state DOTs do not perform pavement field tests in metropolitan areas during peak traffic periods (AKDOT, 2011). Special conditions and events, such as school hours and large public gatherings, should be avoided (AZDOT, 2010a). Some state DOTs also suggest that operators check traffic information on the roadways to be tested, such as traffic volume, truck percentage, and driving time (Bush et al., 2004; Wegmann and Everett, 2010).

2.2.2.3 Report unsafe acts or conditions

If any unsafe roadway situation is noticed while a survey team is in the field, most state DOTs allow the team to immediately notify the nearest maintenance crew by radio or telephone. The appropriate maintenance section shall respond to problems according to the field survey team's request (ALDOT, 2015; WVDOT, 2014). AZDOT survey manual states that "each individual shall be alert for any unsafe act or condition and shall report such act or condition to the immediate supervisor without any delay" (AZDOT, 2010a).

2.3 Advanced Safety Features for Field Testing with Mobile Operations

Pavement field testing with mobile operations at relatively low speeds on a highway is likely more dangerous than other test scenarios. This is reflected in the responses from other state DOTs to a nationwide questionnaire survey conducted in this study, as detailed in the next chapter. Generally, there are several challenges to ensuring the safety of PTOs during mobile operations, for example:

- The speed of most mobile operations on highways is lower than normal traffic speeds. Mobile operations even may frequently stop during testing. Public drivers, therefore, should be effectively alerted by the work vehicle and additional warning or protective vehicles (e.g., advanced warning vehicles and shadow vehicles).
- All warning signs or other protection devices used for field testing with mobile operations should be mobile or portable. Many protection devices used in work zones are inapplicable in mobile operations, such as barriers or devices with large screens or boards.
- Audible warning devices may not be suitable for mobile operations because the devices may get close to the work vehicle driver and create excessive false alarms.

2.3.1 Advanced Safety Devices

Literature review showed few studies on the development of safety features of work vehicles and shadow vehicles for mobile operations. Some safety devices used in testing at highway speeds or with full lane closure, however, may be adjusted and implemented for mobile operations. Moreover, the warning systems to avoid collision due to driver's distraction during field testing at highway speeds, as discussed in Sections 2.2.1.6 and 2.2.1.7, may also be implemented during the field testing with mobile operations. Meanwhile, it is worth noting that FDOT is conducting a separate research project related to mobile operations on two-lane roadways in order to provide potential enhancements to FDOT current standards (NCHRP, 2017).

2.3.1.1 You/Me speed display boards

To better alert drivers of slow-moving work vehicles, Wisconsin DOT developed a device with two numeric screens (known as "You/Me speed display boards") mounted on the back of a shadow vehicle. One screen displays the speed of the work vehicle under "ME" and the other shows the speed of oncoming traffic under "YOU", as shown in Figure 2-7. Based on the field observation by Notbohm et al., the average speed of approaching cars dropped 3 mph after seeing the You/Me speed display boards. They also confirmed that traffic was calmer in the presence of these boards (Notbohm et al., 2001). Vehicle speeds can be measured by a light detection and ranging (LiDAR) device.

Figure 2-7 You/Me speed display boards (Notbohm et al., 2001)

2.3.1.2 Signs with proper messages

TxDOT funded research aiming to decrease the hazards of mobile operation (Ullman et al., 2003; Finley et al., 2004). As results, the following recommendations were provided to TxDOT to modify the messages on the signs so that more important information can be provided to oncoming vehicles (Ullman et al., 2003; Finley et al., 2004):

- *The # VEHICLE CONVOY sign should be used instead of the WORK CONVOY sign. The number needs to be adjustable and easy to change. For example, users were more likely to understand the meaning of a sign stating "3 VEHICLE CONVOY," rather than the more general "WORK CONVOY" sign.*
- *A portable changeable message sign (PCMS) can be substituted for the LANE BLOCKED sign on divided highways with three or less lanes in each direction. TxDOT should require the use of the PCMS messages and a minimum letter height of 12 inches.*

2.3.1.3 Smartphones used to detect vehicle

During mobile operations, rear-end collisions may occur between the work vehicle and the shadow vehicle if their spacing is inappropriately short. In 2013, Ren et al. developed a smartphone-based technology for vehicle detection, and used it as a portable collision warning system. Based on the Haar-like feature detector and a size filter, their technology can efficiently detect vehicles (Ren et al., 2013). In the same year, Li et al. developed an advanced driver assistance system to warn drivers of potential rear-end collision based on a frontal vehicle tail-light detector (Li et al., 2013).

There are several relevant smartphone apps already available on the market. One example is iOnRoad as shown in Figure 2-8. This app first identifies the user's driving lane based on its feature of lane detection using the video camera. Through this lane detection process, this app can not only warn drivers of lane departures, but also can focus on the situation of the user's driving lane only. Then, this app measures the distance between the user and the vehicle in front of the user. Based on that distance with vehicle's real-time speed, this app can perform the forward collision avoidance to reduce the risk of a collision. The alerts sensitivity in this app can also be adjusted in "settings" from "less sensitive" to "very sensitive" depending on user's purposes.

Based on some user comments of this app, the warning systems in this app are reliable, even at night and in the rain. However, the interface customizability of this app needs to be improved. This app once failed to detect the car in front of one user when the user deliberately tested this app at high speed. Considering the low speed of mobile operations, the capacity of cell phone operation system can be sufficient to analyze the traffic condition and warn the drivers in time. The cost of smartphone apps is very low, for example, $0.99 per iOnRoad (iOnRoad, 2012).

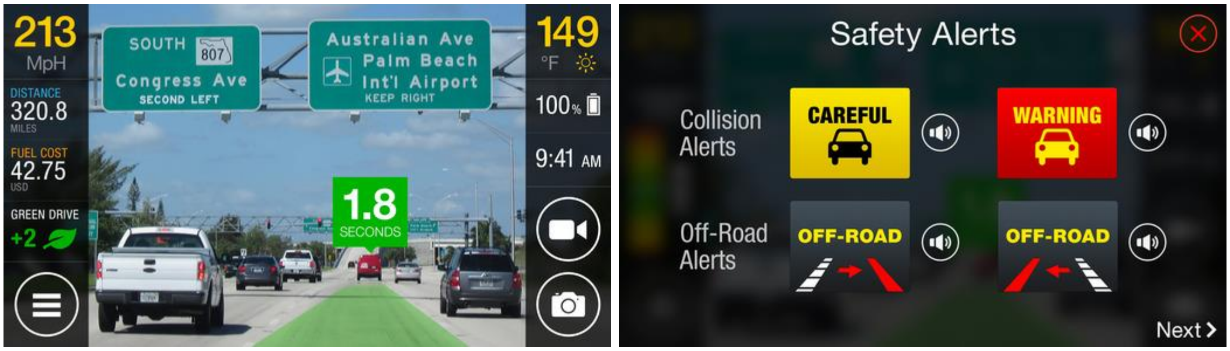

Figure 2-8 Interfaces of iOnRoad (iOnRoad, 2012)

2.3.2 Advanced Plans from Other State DOTs

In addition to using advanced devices, revising the TTC plan may also reduce the risk of rear-end collisions during mobile operations. This section extended the literature review to other state DOTs' TTC plans regarding mobile operations.

2.3.2.1 Appropriate spacing between shadow vehicle and work vehicle

Generally, many states (Colorado, Hawaii, Ohio, Oklahoma, Wisconsin, West Virginia, New Mexico, and Indiana) follow MUTCD to regulate the spacing between work vehicles (WVs) and shadow vehicles (SVs) during mobile operations. MUTCD states that (FHWA, 2009):

- For mobile operations on a two-lane road (6H-17): "The distance between the work and shadow vehicles may vary according to terrain, paint drying time, and other factors."
- For mobile operations on a multi-lane road (6H-35): "The spacing between the work vehicles and the shadow vehicles, and between each shadow vehicle should be minimized to deter road users from driving in between."

It is worth mentioning that MUTCD also considers the issue caused by public vehicles sneaking in and out between an SV and a WV, but does not specify a specific value for the spacing between them. Instead, MUTCD details the distance between signs used in a temporary traffic control (TTC) zone, as shown in Table 2-10. Many states also use this table to set the distance between WVs and SVs during mobile operations.

Table 2-10 Spacing between SV and WV Specified in MUTCD (6H-17 and 6H-35)

Road Type	Spacing between SV and WV (feet)
Urban (low speed)	100
Urban (high speed)	350
Rural	500
Expressway/Freeway	1000

Some state DOTs adjusted or specified the spacing between WVs and SVs, summarized as follows:

- Arizona roughly specifies that the spacing is 500 ft between WVs and SVs, and also 500 ft between SVs (AZDOT, 2010b).
- California requests that, not only on a multi-lane road (plans RSP-T15 and RSP-T16), but also on a two-lane road (plan RSP-T17), the spacing between vehicles (WVs and SVs) shall be minimized to deter road users from driving in between them (Caltrans, 2014).
- Pennsylvania sets the spacing between a WV and a nearest SV to be from 125 to 200 ft on either conventional highways (plan PATA 300) or freeways and expressways (plan PATA 603) (PennDOT, 2014).
- New York sets the spacing between a WV and a nearest SV to be 80 ft for low posted speeds (30-50 mph) on urban or rural highways, and 160 ft for high posted speeds on urban or rural highways or on freeways and expressways (NYDOT, 2008).
- Texas sets the spacing between a WV and a nearest SV to be from 120 to 200 ft on all types of roads (plans TCP3-1 through TCP3-5) (TxDOT, 2015).
- Wyoming shortens the distance between signs on interstates from 1000 to 750 ft, compared to the distances listed in Table 2-10 (WYDOT, 2011). Similarly, Oregon (ODOT, 2016) sets the distance between signs on interstates from 1000 to 700 ft.
- South Carolina sets the spacing between a WV and a nearest SV to be from 150 to 300 ft on all types of roads. To better protect the work vehicle on a two-lane road, one lead vehicle is added in front of the work vehicle at a distance of 100 to 500 ft to warn the oncoming vehicle (SCDOT, 2013).
- New Mexico (NMDOT, 2012) and Indiana (INDOT, 2013) specify the spacing between SVs and WVs during mobile operations according to the "roll-ahead buffer distance" varied by posted speeds, as shown in Table 2-11.

Table 2-11 Spacing between SV and WV Specified by NMDOT and INDOT

<table>
<tr><th rowspan="2">Posted Speed Limit</th><th>New Mexico</th><th>Indiana</th></tr>
<tr><th colspan="2">Spacing between SV and WV (moving)</th></tr>
<tr><td>20</td><td rowspan="5">100</td><td rowspan="6">150</td></tr>
<tr><td>25</td></tr>
<tr><td>30</td></tr>
<tr><td>35</td></tr>
<tr><td>40</td></tr>
<tr><td>45</td><td rowspan="3">175</td></tr>
<tr><td>50</td><td rowspan="2">200</td></tr>
<tr><td>55</td></tr>
<tr><td>60</td><td rowspan="3">225</td><td rowspan="2">275</td></tr>
<tr><td>65</td></tr>
<tr><td>70</td><td>325</td></tr>
</table>

Based on the above information, the maximum and minimum spacing between an SV and a WV regulated in some state DOTs is summarized in Figure 2-9. In the figure, Florida Option 1 applies to the scenario when an advanced warning vehicle is optional and is to be operated in the shoulder when feasible, while Florida Option 2 is used when an advanced warning vehicle is required and operated in the lane behind the SV. It can be seen that the minimum SV and WV spacing in Option 2 specified in the latest FDOT TTC plans (indices 607 and 619) is lower than that used by many other state DOTs. Meanwhile, the maximum SV and WV spacing specified by FDOT may still have room to be shortened.

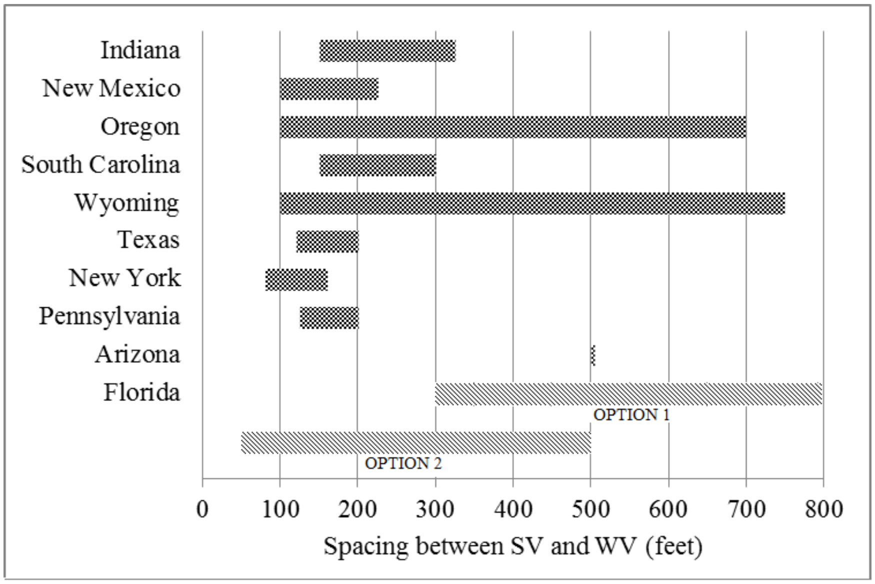

Figure 2-9 Maximum and minimum spacing between SV and WV regulated in state DOTs

2.3.2.2 Appropriate placement of shadow vehicle and work vehicle

During reviewing the guidelines of mobile operation from other state DOTs, it was found that some states adjust the placement of shadow vehicles (SVs) to protect the work vehicle (WV) under certain working conditions:

- When a WV is working in the center lane, PennDOT requires one more SV to run alongside the SV right behind the WV if workers are outside of the WV and positioned in the travel lane, as illustrated by shadow vehicles V5 and V2 in Figure 2-10(b). It is stated that "PATA 603" would have precedence over MUTCD TA-35 for a mobile operation on a multi-lane highway (PennDOT, 2014).
- ODOT requests that SVs should straddle the fog line or the skip line during mobile operations in center lanes, as shown in Figure 2-10(c). This adjustment of SV placement may provide a clearer view of the traffic coming up behind the WV (ODOT, 2016).
- On a two-lane road, head-on collision may occur between an oncoming vehicle and the WV. SCDOT adds one lead vehicle in front of the WV to warn the oncoming vehicle using a "KEEP RIGHT" sign, as shown in Figure 2-11(b) (SCDOT, 2013).

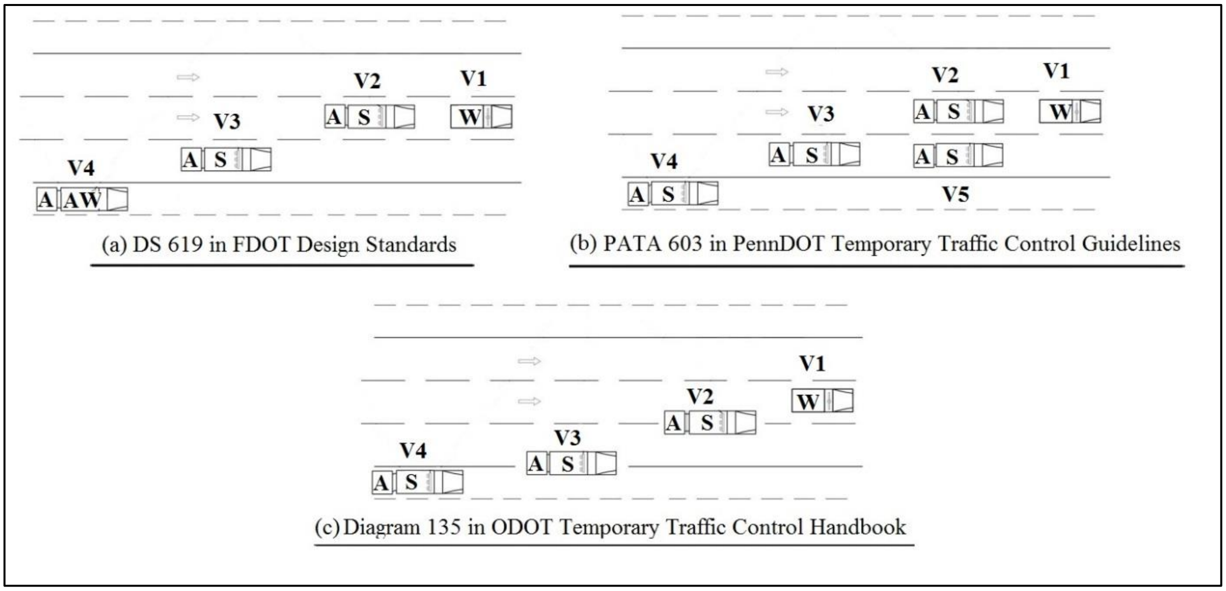

Figure 2-10 Placement of SVs and WV during mobile operations in center lanes

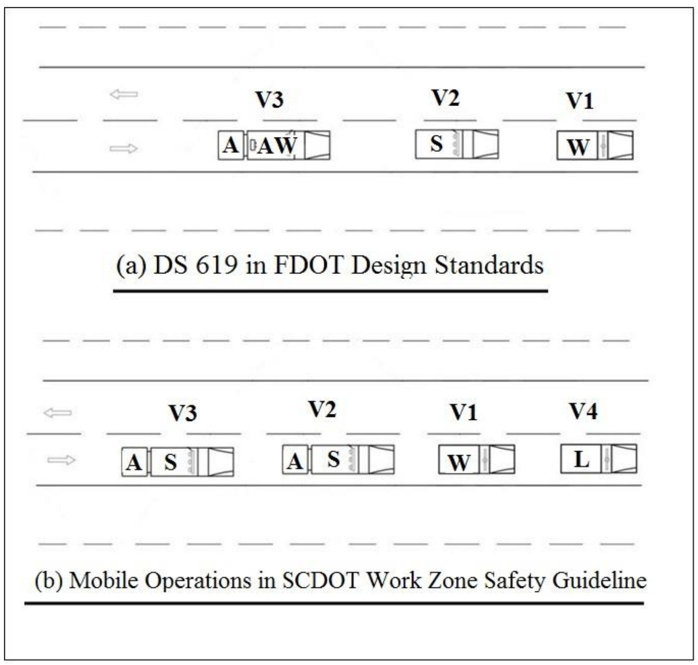

Figure 2-11 Placement of SVs and WV during mobile operations on a two-lane road

2.4 Advanced Safety Features for Field Testing with Full Lane Closure

One of the main causes of accidents or incidents at a pavement test site within an MOT operation or work zone is roadway motorist's failure to notice and identify the test site. This problem may be solved by maintaining proper signs and markings around the work zone so that drivers can easily identify it as a testing site and reduce their speed. Use of speed reduction devices upstream of a work zone may give a rather automatic solution as the drivers will spontaneously reduce their speed while crossing those devices.

2.4.1 Advanced Safety Devices

This section covers some advanced safety devices used in field testing with full lane closure. These devices are the key elements to compose the “smart work zone”. Different safety systems, as described in Section 2.4.2, may be built in work zones through properly combining some of these devices below.

2.4.1.1 Changeable message signs

A study carried out in 1995 shows that conventional advisory or regulatory speed control signs and markings gradually become less effective over time to catch drivers’ attention and at one point drivers do not even notice the sign let alone follow the instruction (Garber and Patel, 1995). Changeable message sign (CMS) can do a better job if used in place of advisory signs. The study showed that CMS with a radar unit could effectively reduce vehicle speed in a work zone. The radar unit detects vehicle speeds while the CMS displays specific messages corresponding to the detected speed condition. Results showed significant speed reduction at work zones over regulatory speed control sign systems (Garber and Patel, 1995).

2.4.1.2 Speed trailers as speed control measure

A comparative study was carried out to evaluate and compare speed reduction performance of speed trailer along with advisory speed sign versus radar drone with advisory speed sign (Carlson et al., 2000). A speed trailer is a portable setup with the following features: ability to measure and display the speed of an approaching vehicle, and to show the recommended speed limit for a temporary work zone; a camera setup that can take pictures of vehicles exceeding the speed limit. Results of that study showed that speed trailers can reduce speed more effectively than radar drone enforcement. Average speed reduction of trucks and passenger cars is 5 mph at rural high speed temporary work zones if a speed trailer is used whereas use of radar drone is expected to reduce speed by 2 to 3 mph (Carlson et al., 2000).

2.4.1.3 Portable plastic rumble strip (PPRS) as traffic control device

Another solution to speeding near work zones is the use of a portable plastic rumble strip (PPRS) as a traffic control device at upstream locations of a temporary work zone. This method has been found effective through a study performed in 2011 (Wang et al., 2011). The study showed that using PPRS as a speed reduction device at the upstream of testing sites can reduce car speed by 4.6 to 11.4 mph and truck speed by 5.0 to 11.7 mph from their usual speeds. The PPRS is easy to install and remove, and is completely reusable. Recommended practice is to use two sets of four rumble strips at 36-inch spacing in addition to existing traffic control devices in the temporary traffic control plan (Wang et al., 2011). This device has already been used by FDOT under the terminology of “Temporary Raised Rumble Strips” and outlined in Standard Index 603.

2.4.1.4 Speed-activated display

Using speed trailers to control speed may be expensive but provides good results. Using only stationary signs and markings is less costly but its effectiveness is also low. A speed-activated sign may provide a compromise between the two options. It can reduce speed more effectively than the stationary signs and markings, but is also more affordable than the speed trailer. In this system, each individual driver is targeted and warned while he/she exceeds the speed limit for the work zone. A warning message such as "YOU ARE SPEEDING IF FLASHING" is displayed, and the system triggers a flashing beacon when a predetermined speed threshold is exceeded. The system is able to reduce vehicle speed by an average of 3.3 mph (Mattox et al., 2015). The total setup cost is much lower than other high tech, activated sign systems.

A comparative study was carried out in 2001 to measure the performance of both rumble strips and speed activated signs as speed control devices on a low-speed rural highway. Both techniques were used to control traffic at the upstream of a temporary work zone (Fontaine and Carlson, 2001). Results showed that both measures performed similarly in controlling vehicle speed. However, the rumble strip was found to be more effective in controlling truck speed while the speed-activated sign reduced car speed more effectively (5.5 mph reduction on average). The rumble strip takes a longer time to install and it becomes unusable after one or a few times of use, while the speed-activated sign is easy to install and is completely reusable. The study recommended that it is more effective to use the speed-activated sign as a traffic control measure for temporary work zones on rural roads instead of the rumble strip (Fontaine and Carlson, 2001).

2.4.1.5 Radar-activated device

In 2001, Texas Transportation Institute (TTI) designed a radar-activated flagger paddle and a radar drone in a study sponsored by Texas Department of Transportation (TxDOT). When vehicles travel over a preset speed threshold, the LEDs in the sign face of the modified flashing flagger paddle will be activated. The design of the flagger paddle still needed improvement due to battery and wire issues (Fontaine and Hawkins, 2001). The radar drone emits a K-band radar signal, which can activate radar detectors once it detects vehicles in a range up to one mile away. Then, it can potentially decrease vehicle speeds as they approach the drone site (Fontaine and Hawkins, 2001).

2.4.1.6 Movable traffic barrier systems (MTBS)

A movable traffic barrier system (MTBS) is mentioned in several DOT manuals (MassDOT, 2006; MDOT, 2010; GDOT, 2008). In the MTBS, all barriers are pinned together to create a continuous barrier wall. Once a "road zipper machine" is driven through the roadway, barriers will be lifted by the machine one by one, and passed through a conveyor system inside the machine from one side to another side (Lindsay, 2015), as shown in Figure 2-12. This MTBS can quickly move the barriers within work zone in order to interrupt traffic less. The cost for the equipment and operation of the MTBS, however, is high.

Figure 2-12 MTBS working within work zone (Lindsay, 2015)

2.4.2 Advanced Safety Systems

Through assembling various safety devices into different systems, various smart work zones can be created for field testing with full lane closure.

2.4.2.1 Work zone intrusion warning system (WIWS)

MnDOT has noticed that some drivers do not adequately comply with warning signs while approaching a work zone. To provide sufficient reaction time to drivers, a work zone intrusion warning system (WIWS) was proposed by MnDOT, as shown in Figure 2-13. Warning signs at sufficient locations are first set to prevent the driver from entering a work zone area. If the driver is distracted and enters the work zone area, "STOP NOW" portable changeable message signs and siren (or horn alarm) will be triggered by a non-intrusive detection to warn both workers and the careless driver. A deceleration area then will give the driver enough time to safely exit the work zone. If the driver keeps ignoring work zone traffic control, the driver will be counteracted by a buffer area, and fined or punished in other ways later. The above concept of WIWS from driver's perspective is summarized in Figure 2-14. This WIWS will not only alert the careless driver, but also warn the workers in work space and notify the transportation management center that a driver activates the WIWS (MNDOT, 2015b). The selections of detection devices and warning devices in the WIWS can be specified based on MUTCD or certain traffic conditions.

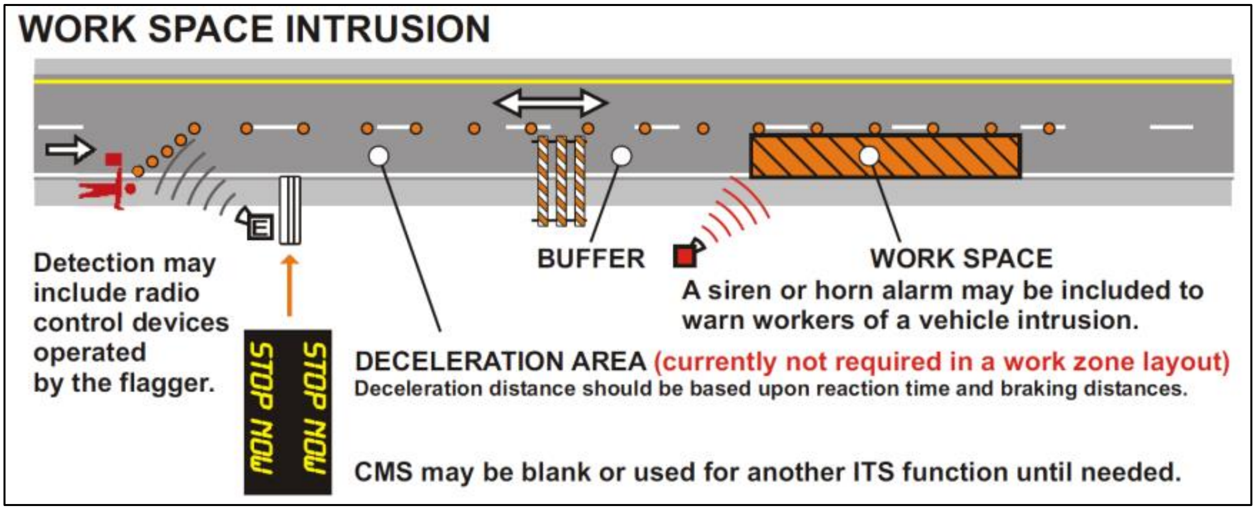

Figure 2-13 Typical work zone intrusion warning system (MNDOT, 2015b)

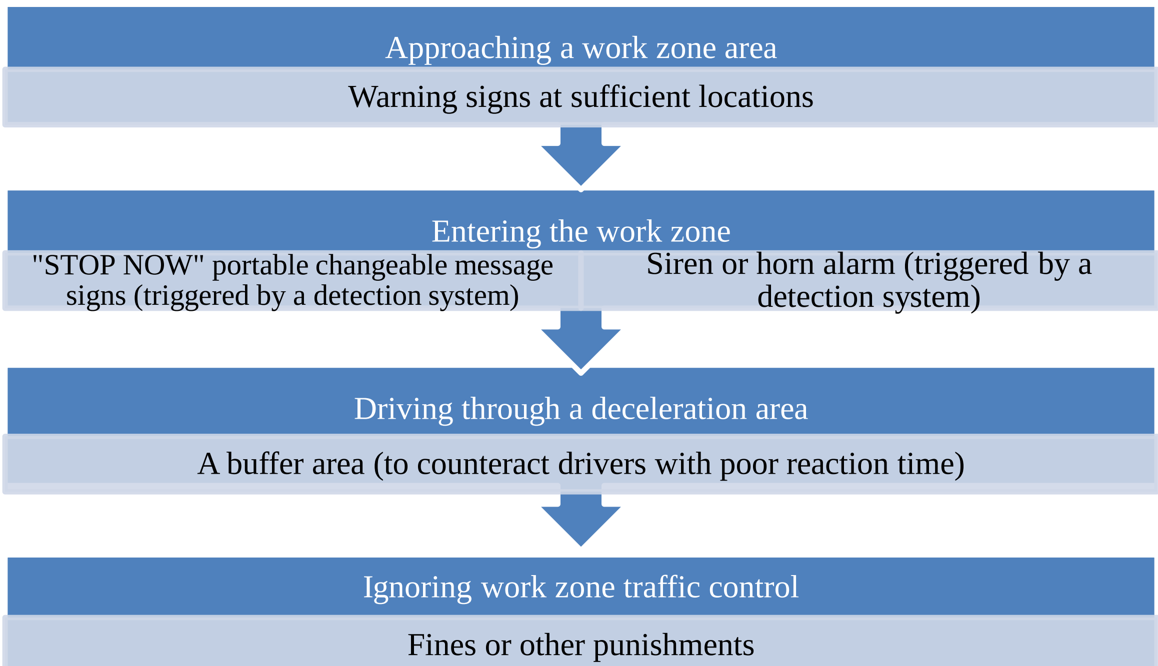

Figure 2-14 WIWS from driver's perspective

2.4.2.2 Queue warning system for work zone

A multiple queue warning system, portable and permanent changeable message signs (CMSs), and/or variable speed limits are usually used within a work zone to ensure the safety of workers and road users. However, crash history in MnDOT shows that the risk of end of queue crashes still needs to be mitigated by using additional safety systems (MNDOT, 2015b). MnDOT states that, properly setting a series of CMSs and non-intrusive detection devices in a work zone can better prevent road users from end of queue crashes. This safety improvement system, consisting of CMS signs and non-intrusive detection devices (NIDDs), is known as a queue warning system for work zones, as shown in Figure 2-15.

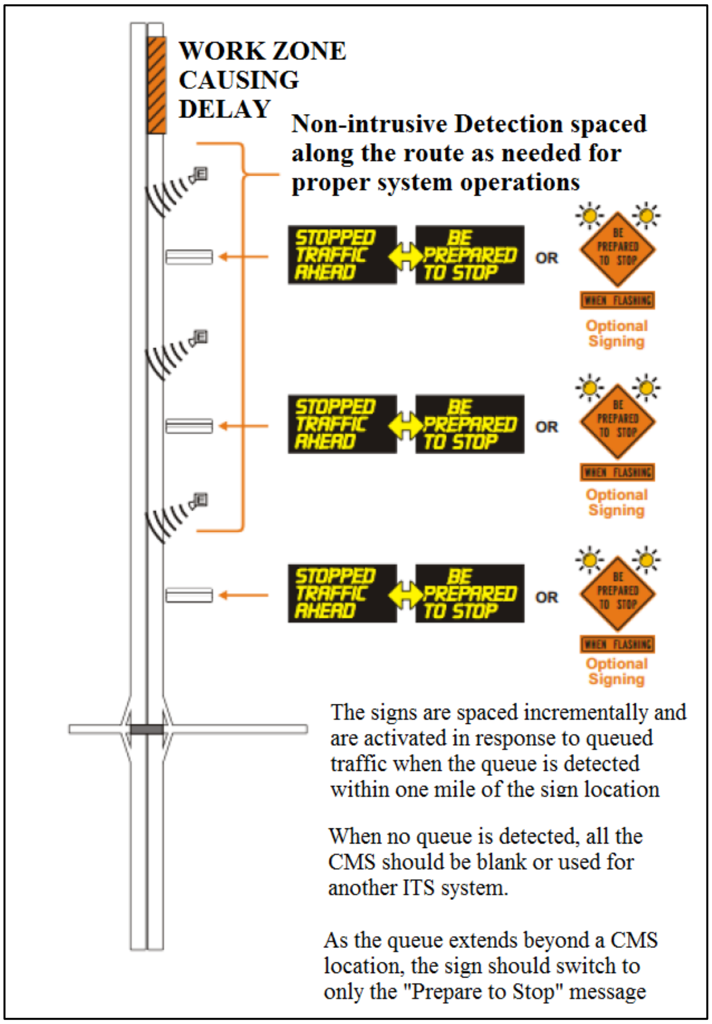

Figure 2-15 Example configuration of a queue warning system for work zone (MNDOT, 2015b)

NIDDs can detect the slowed or stopped traffic and queue locations. Based on the real-time work zone traffic condition from those NIDDs, CMS signs can properly display the travel delay information, speed advisory information, congestion advisory, and stopped traffic advisory information to inform road users (MNDOT, 2015b). In 2005, Sullivan et al. from the University of Michigan designed a smart drum containing an inexpensive speed sensor and a simple signaling system to inform drivers of impending hazard, as shown in Figure 2-16. In 2010, MnDOT developed an “iCone system” consisting of a series of smart drums and suggested that transportation agencies integrate the iCone into dynamic queue warning systems (MnDOT, 2010). A similar idea, named as “Intelligent Drum Line (IDL)”, was developed by Hourdos from the University of Minnesota in 2012. He built the IDL system by integrating five subsystems: sensor subsystem (e.g., active infrared, passive infrared, ultrasonic, magnetic, microwave, and video), communication subsystem, visual warning subsystem (e.g., emergency flashing lights), audible warning subsystem (e.g., piezo-electric horn and air horn), and center processing unit (CPU) subsystem (Hourdos, 2012).

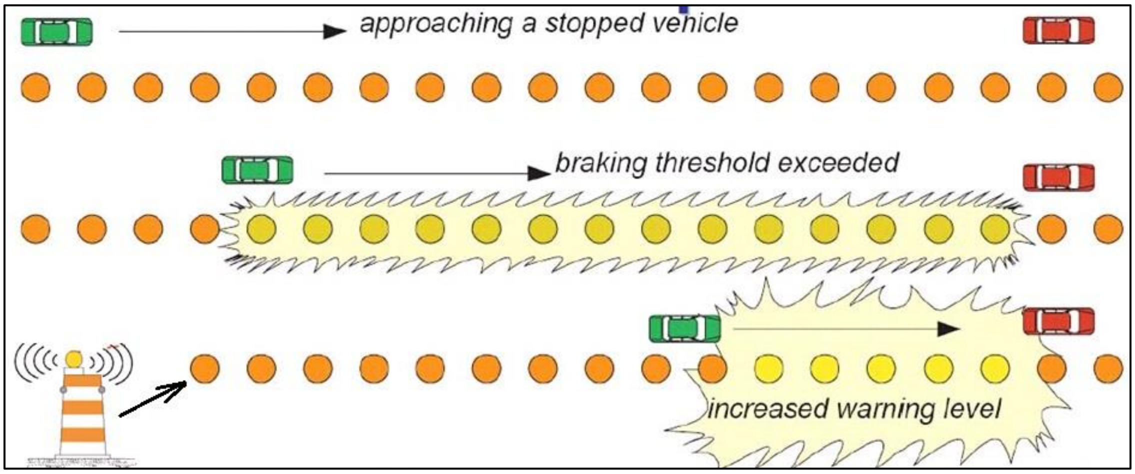

Figure 2-16 Smart drum operation (Sullivan et al., 2005)

2.4.2.3 Devices to alert distracted drivers approaching or within a work zone

Although a series of CMSs and NIDDs are set within the work zone area, the continued presence of distracted drivers in work zones is still difficult to eliminate. MnDOT suggested several methods to detect the distracted drivers, which can be supplemented by CMSs and NIDDs to improve the safety of workers in a work zone (MNDOT, 2015b):

- Adaptation of tunnel cameras is able to track constant movement, analyze vehicle drifting within the driving lane, and detect erratic lane changes.
- Radio frequency guns can be used to scan for radio frequency emanating from vehicles to detect any signals of texting and phone calls. This new type of detection device can prevent road users from using cell phones during driving.
- Some sensors are currently available to alert the drivers of lane drift, eyes off the road, or sleepiness. It can be further developed to cooperate with the utilities set in work zones to alert identified distracted drivers in the future.
- On the side of the driver, navigational phone apps can potentially notify drivers of changing traffic control.

2.4.2.4 Dynamic lane merge system

If traffic demand exceeds the capacity of a work zone under a single lane closure situation, the oncoming vehicles may have insufficient time to react to the queues expanding beyond the advance warning signs. A dynamic lane merge system (DLMS) can instruct motorists by the PCMSs to take turns merging, using either early or late lane merge strategy. The first DLMS was tested in the field by the Indiana Department of Transportation, as shown in Figure 2-17. The components in a typical DLMS are similar to those in other smart work zone systems (Radwan et al., 2009):

- Traffic detection stations, linked to central computer base station, to record vehicle speeds, volumes, and occupancies by sensors (e.g., remote traffic microwave sensor);
- One central computer base station, equipped with appropriate software, to dedicate wireless communications with traffic sensor stations and PCMS;

- Wireless communication links, equipped with radio modems, micro-processors, and antennae;
- PCMS to inform drivers of road conditions, such as the speed ahead information.

Since 1997, several studies have been conducted to test the effect of DLMS on the mobility and capacity in work zone areas. They are summarized as follows:

- For early merge strategy, a "before and after" study by Datta et al. showed that DLMS can generally mitigate the delay and decrease the number of aggressive driving maneuvers during peak hours (Datta et al., 2001). The effect of DLMS on the capacity in work zone areas, however, is not consistent based on the previous studies conducted by universities: it shows "positive" by the University of Nebraska (McCoy et al., 1999), "negative" by Purdue University (Tarko and Venugopal, 2001), and "no difference" by Wayne State University (Datta et al., 2001). Tarko et al. indicated that DLMS can decrease the rear-end accident rate, but meanwhile, can extend the travel time through work zone (Tarko et al., 1998).
- For late merge strategy, Taavola et al. observed shorter queue length after setting DLMS (Taavola et al., 2004).
- As a comparison between early and late merge strategies, Radwan et al. evaluated the safety and operational effectiveness of DLMS in Florida, and stated that the performance of dynamic early merge is better than that of dynamic late merge if the traffic volume ranges between 0 and 1000 veh/hr. However, as the traffic volume increases from 1000 veh/hr to 1500 veh/hr, the performance of dynamic late merge turns to be better than that of dynamic early merge (Radwan et al., 2009).

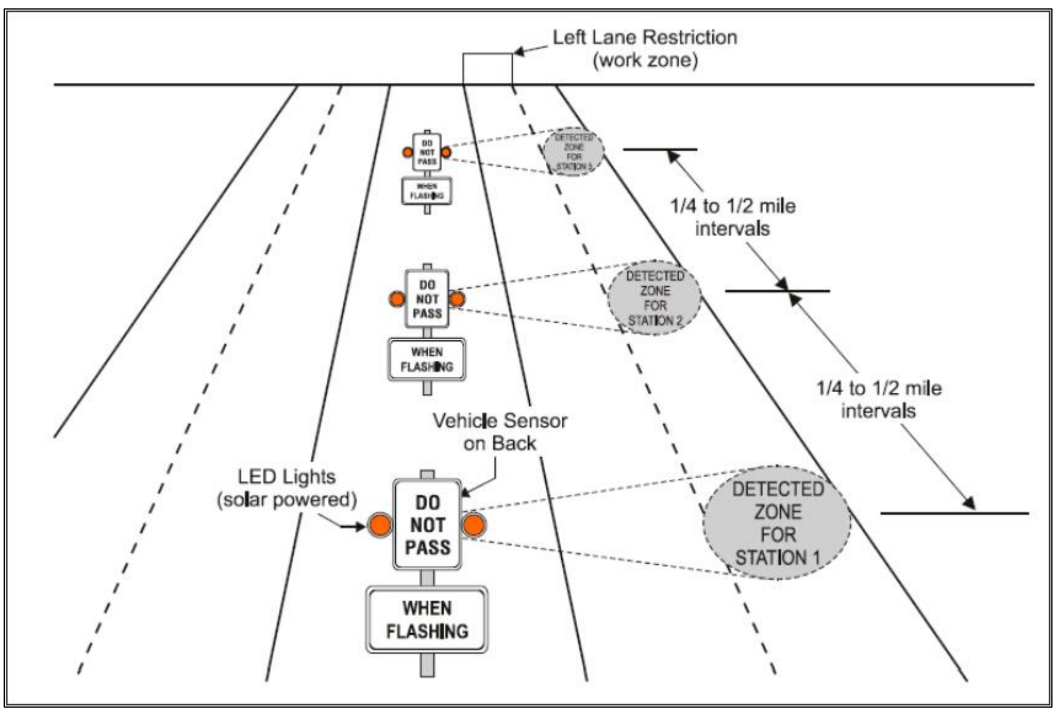

Figure 2-17 Indiana lane merge system (Beacher et al., 2004)

2.4.2.5 Variable speed limit system

Variable speed limit system (VSLS) can detect real-time traffic conditions in the work zone, and then calculate and display a proper speed limit on the sign regarding the safety of road users. For example, with using VSLS in work zones, the speed limit in a work zone area will drop from 65 mph to 45 mph if construction workers are present within work zone areas (FWHA, 2002). Some studies confirmed that adding VSL signs can reduce work zone accidents because of the reduction in average vehicle speeds and deviation in those speeds within work zone (Riffkin, 2008; Pesti, 2002).

Do advisory speed system and speed limit system have a similar effect on improving work zone safety? The answer is: "probably no." In 2012, Saito and Wilson evaluated the effectiveness of a variable advisory speed system (VASS) on queue mitigation in work zones in Utah. Their statistical conclusions showed that the VASS was effective to slow down traffic only on weekends during evening peak hours (Wilson and Saito, 2012).

2.5 Summary of Literature Review

Most safety related manuals implemented by state DOTs describe the safety measures during general testing or data collection processes, particularly for work zone safety. There are few manuals that provide specific safety strategies for pavement field testing at highway speeds or with mobile operations.

Based on the review of relevant state DOT safety manuals and plans, some key factors that may potentially affect the safety during pavement field testing include:

- Driver distraction by testing van or work zone
- Lane departure of testing vehicles or personnel
- Additional conflict points generated by the setup of temporary traffic control devices at intersections
- Potential hazard due to equipment handling in wrong way during pre or post testing process
- Impaired and aggressive drivers

As countermeasures, FDOT has included the following main strategies in its safety related manuals or handbooks (i.e., Florida Strategic Highway Safety Plan, Survey Safety Handbook, FDOT Loss Prevention Manual, Job Safety Analysis, and FDOT Design Standards):

- Educating and informing road users with timely and accurate information
- Training PTOs according to the process stated in the Safety Indoctrination document and make sure that all PTOs clearly understand the safety clauses in the FDOT Loss Prevention Manual and Florida Strategic Highway Safety Plan
- Implementing law enforcement to ensure safe operation such as speed reduction
- Planning proper road closures and activity areas for worker safety
- Complying with general safety rules and procedures such as always facing traffic, preventing sudden movements, and avoiding interruption of traffic

- Using traditional safety elements such as shadow vehicles, lighting, rumble strips, changeable message signs, hazard identification beacons, flags, and warning lights
- Developing advanced technologies, such as automated work zone information system, simplified dynamic lane merge systems, portable changeable message signs, and queue warning systems
- Trying other improvements including installing reflectors on barrier walls, spacing on curves, changing contractors penalties and fines for getting out of the roadway late, using crash cushions, and correcting pavement marking errors
- Properly complying with the safety steps delineated in the Job Safety Analysis documents before, during, and after each test run

After a thorough review of safety manuals used by other state DOTs, it is found that the number of PTOs required in different field tests varies from state to state, the severity of local PTO-related accidents, various local traffic conditions, and specific field test technologies. Most state DOTs suggest at least one safety person being involved in the field data collection or field tests. However, as suggested by Caltrans, a standard to assign the optimum number of personnel to accomplish a field test or survey safely is yet to be developed.

From a comprehensive review of research and practice reports from various states, it is observed that the use of more advanced and automated equipment may be more effective in improving safety for tests at highway speeds, while techniques towards more effective markings and signs and effective traffic control measures would be more effective for tests that require lane closure.

Specifically, for field tests at highway speeds, based on the literature review and communications with major vendors of pavement field testing vehicles or equipment, it is found that the vendors' effort to improve their system is mainly to increase data quality (e.g., accuracy, sampling rate, and resolution), while features that can directly improve safety during field testing are typically overlooked. However, several advanced equipment has been discovered in this report, including in-vehicle warning systems and voice recognition applications.

For safety of field tests within a TTC operation or work zone, in addition to signs and markings, various speed reduction devices have been developed or tested to provide a rather automatic solution. The devices covered in this review include changeable message sign, speed trailer, portable plastic rumble strip, speed activated sign, and radar-activated device. Through assembling above safety devices into different systems, various smart work zones (e.g., work zone intrusion warning system, queue warning system, dynamic lane merge system, variable speed limit system) may be created for field testing with full lane closure.

Based on concurrent practices by other states, recently updated technologies and safety related literatures, the following points may help further improve pavement testing safety for FDOT. It should be noted that these brief key points can be taken as potential ways to improve safety but need more detailed review through experimental application and validation before they are applied in actual testing processes.

- Some advanced features, such as forward collision and lane departure warning system, driver fatigue warning system, may be installed as a supplementary feature to current FDOT test vehicles.

- Rearview mirror cameras and turning lane camera may also be installed in test vehicles to reduce blind spots. These are already established and easy to install alternatives that can give results instantly.
- To make test vehicles operable by voice command, voice recognition software (e.g., Freesr and Dragon speech recognition software programs from Nuance, Braina, and Lilyspeech) can be installed in existing software interface as an easy solution.
- Updated and technically advanced test vehicles (e.g., the latest Mobile Retroreflectivity Unit) may replace backdated vehicles. This, however, is an expensive approach.
- Some advanced work zone safety techniques can be adopted and developed (i.e., work zone intrusion warning system, dynamic lane merge system, smart drum queue warning system) to increase safety of tests within work zones.
- Improved TTC plans may be considered to avoid critical safety issues. For example, variable spacing may be adopted between the work vehicle and shadow vehicles in the falling weight deflectometer (FWD) test based on posted speed limits to avoid vehicle sneaking in between the work vehicle and shadow vehicles.

CHAPTER 3 NATIONWIDE QUESTIONNAIRE SURVEY

3.1 Introduction

As a supplement to the literature review, which may not completely cover the safety related information in each state, a nationwide questionnaire survey was conducted to collect more information from state DOTs on their current practice and experience with safely collecting pavement condition and performance data, and ideas on potential safety improvement methods.

3.1.1 Survey Objective

This survey mainly aims to gather information on safety features implemented by state DOTs during pavement field testing.

3.1.2 Participants

The respondents who participated in the survey include construction directors, pavement management engineers, materials and tests engineers, state maintenance managers, and other personnel in state DOTs. To maximize the state DOT response rate, the questionnaire was distributed electronically to at least three contacts in each state DOT and re-sent a couple of times if no response had been received. The survey has collected a total of 34 responses from 32 state DOTs, as listed in Table 3-1.

Table 3-1 State DOTs with Responses

State	DOT Abbr.	State	DOT Abbr.	State	DOT Abbr.
Alabama	ALDOT	Louisiana	LaDOTD	Pennsylvania	PennDOT
Alaska	AKDOT	Maine	MaineDOT	Rhode Island	RIDOT
Arizona	AZDOT	Maryland	MDOT	South Carolina	SCDOT
Arkansas	AHTD	Michigan	MiDOT	South Dakota	SDDOT
California	Caltrans	Minnesota	MnDOT	Tennessee	TDOT
Colorado	CDOT	Mississippi	MissDOT	Texas	TxDOT
Hawaii	HDOT	Missouri	MoDOT	Utah	UDOT
Indiana	INDOT	Montana	MDT	Vermont	VTrans
Iowa	IowaDOT	Nevada	NDOT	Washington	WSDOT
Kansas	KSDOT	New Hampshire	NHDOT	Wisconsin	WisDOT
Kentucky	KYTC	New Jersey	NJDOT		

3.1.3 Questionnaire Design

The following four questions are included in the questionnaire:

- Is there a need in your state to improve the safety of pavement testing operators (PTOs) during field pavement condition survey or performance test?

- What safety features have been adopted or developed in your state to improve PTO safety?
- To your knowledge, does your sate have any unique practice feature that improves the PTO safety during field testing (compared to other states)?
- Do you have any suggestions or comments on the PTOs' safety during pavement field testing, in terms of equipment design, operation procedures, TTC practices etc.?

Survey participants were asked to answer each of the four questions under three scenarios:

A. Testing performed while operating a full-sized survey vehicle at highway speeds
B. Testing performed with mobile operations
C. Testing performed within temporary traffic control (TTC) or work zone

3.2 Results

The detailed responses from the survey participants are provided in Appendix A. The rest of this section provides an analysis and summary of the responses.

3.2.1 Needs in States to Improve PTOs' Safety during Pavement Field Testing

The answers, concerning the necessity of developing methods to improve PTOs' safety, can be divided into three categories: 1) positive answer "Yes"; 2) being satisfied with the status quo but feeling "There is always a need"; 3) negative answer "No". For each of the three testing scenarios, the distribution of the three answers is shown in Figure 3-1. It can be seen from Figure 3-1 that

- There is more need of safety improvement for tests performed within TTC or work zone (Scenario 3) than tests performed at highway speeds (Scenario 1).
- For Scenario 2 (mobile operations), the percentage of answer "No" is the lowest among the three scenarios (note that in some states Scenario 2 is not a typical pavement field test condition so no responses were provided). In other words, Scenario 2 seems to be the most dangerous test condition for PTOs.

3.2.2 Common Safety Features Adopted or Developed by State DOTs

3.2.2.1 Scenario A: tests performed at highway speeds

<u>3.2.2.1.1 Adding safety features to pavement test vehicles</u>

The most common safety measure mentioned in the responses is flashing light. Some of responses specified the flashing lights in details, such as the light bars on the rear of a vehicle (IowaDOT, MnDOT, ALDOT, PennDOT, VTrans, SDDOT) and 360-degree visible amber lights (MaineDOT, IowaDOT, NDOT, MDOT).

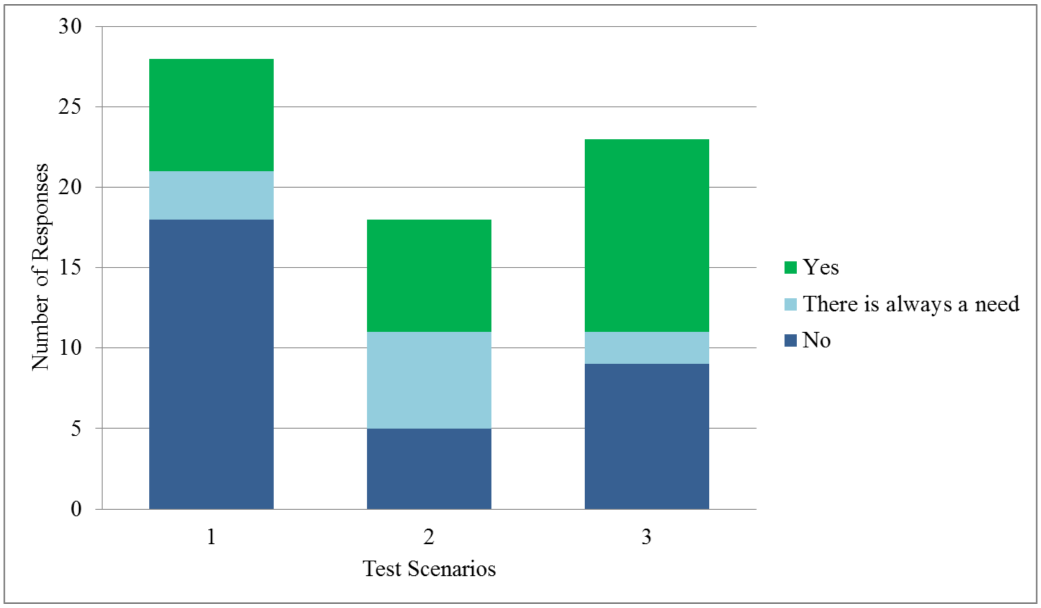

Figure 3-1 Responses to Question "Is there a need in your state to improve the safety of PTOs during field test?"

To raise the awareness of other drivers, one similar safety measure cooperating with flashing lights is the reflective tape or sign (MDOT, PennDOT, WisDOT, SDDOT), which can significantly increase the visibility of test vehicles during data collection and decrease the chance of people running into the back of a test vehicle. Advance warning signs can also be set in some applicable places (NDOT).

As one of the impressive ideas, the survey vans in Caltrans are outfitted with large high-visibility magnetic placards on the rear door panels stating: "Pavement survey in progress. Pass with care". Similarly, MaineDOT labels "test vehicle" on their pavement test vehicles. The placard can even be full back, as shown in Figure 3-2.

Figure 3-2 High-visibility, full back magnetic placard (Top Notch Signs, 2016).

3.2.2.1.2 Optimizing the plan of pavement field tests

One of the most challenging aspects in pavement field testing at highway speeds is to maintain a proper testing speed while driving in traffic streams. Real-time traffic condition may affect the test vehicle's data collection quality. Thus, an appropriate plan of pavement field tests is very important. This is mentioned by respondents in different ways, such as avoiding high traffic area at peak hours (ALDOT, AZDOT, TDOT), limiting left turns and U-turns (MDOT), improving skid testing at a higher speed (TDOT), and so forth.

3.2.2.1.3 Performing appropriate traffic control

Since one of the advantages of performing field tests at highway speeds is to minimize the need of traffic control, very few DOTs mentioned traffic control in their responses. AZDOT stated that they shadow the test vehicle with an impact attenuator.

3.2.2.1.4 Others

On the operator's side, WisDOT switches driver and operator on a 2-hour interval.

KYTC and TxDOT use two employees to conduct pavement field tests. One person drives and the other person operates all equipment.

NHDOT emphasizes the necessity of driver safety training, safety policy, and their job hazard analysis manual.

3.2.2.2 Scenario B: tests performed with mobile operations

3.2.2.2.1 Adding safety features to pavement test vehicles

Similar to the field test at highway speeds, different lighting patterns are adopted for increased visibility to raise other drivers' awareness under this test scenario, such as light bars on trucks and trailers (ALDOT, AZDOT, IowaDOT, LaDOTD, MDT, PennDOT, WisDOT), lighted arrow boards (AKDOT, AZDOT, INDOT, IowaDOT), and dual-rotator amber lights (IowaDOT). PennDOT also sets message boards on vans that perform mobile operations along road shoulders.

3.2.2.2.2 Optimizing the plan of pavement field test

Given the potential traffic disruption under this test scenario, some states strictly limit the duration of a total lane closure (IowaDOT, MoDOT). MoDOT requires that the activity be limited to a maximum of 15 minutes at a specific location prior to moving to a different location. Field tests performed with mobile operations shall also avoid high traffic areas at peak hours (ALDOT), or at night (MDT).

3.2.2.2.3 Performing appropriate traffic control

Compared to the field tests at highway speeds, field tests performed with mobile operations (also termed as "rolling closure" in AZDOT and MaineDOT) require more traffic control actions. As stated by AZDOT, the typical testing rolling closure for a low volume road requires a test vehicle, an impact attenuator, and a truck-mounted message board. Flaggers are also used to control traffic around the rolling closure (IowaDOT, LaDOTD, MoDOT). For most state DOTs (ALDOT, AZDOT, IowaDOT, INDOT, KYTC, MDOT, MDT, MoDOT, NJDOT, PennDOT, WisDOT), a protective vehicle with a truck-mounted attenuator is the most basic safety measure. ALDOT also stated that they usually enlist the help of a state trooper at the district's discretion.

3.2.2.3 Scenario C: tests performed within TTC or work zone

3.2.2.3.1 Adding safety features of pavement test vehicles

Under this test scenario, several options of lighting patterns and signs are also mentioned in this survey by respondents from several state DOTs (i.e., AZDOT, IowaDOT, LaDOTD, WisDOT, MDOT, VTrans, Caltrans), such as light arrow boards on the large maintenance vehicle (AKDOT, AZDOT, INDOT, IowaDOT), a flashing warning light (LaDOTD, WisDOT), variable message signs (MDOT), temporary portable rumble strip (Caltrans), Caltrans Balsi beam (Caltrans), and other sign packages (VTrans, LaDOTD). Since operators may walk outside of a test van during this type of field testing, high visibility vests and hard hats are required to be worn by their crews (PennDOT). TDOT also arranges queue trucks to give advance warning to traffic.

3.2.2.3.2 Optimizing the plan of pavement field test

As mentioned by TDOT, relatively shorter duration of lane closure and limited traffic disruptions are always desired during pavement field testing. MoDOT also stated that "when working in a specific location for greater than 15 minutes, a full lane drop with temporary traffic control (TTC) is required." Peak hour shall also be avoided when performing these types of pavement field tests (TDOT).

3.2.2.3.3 Performing appropriate traffic control

Considering the longest test duration under this scenario, high quality traffic control plays a key role in PTOs' safety (ALDOT, KSDOT, IowaDOT, PennDOT, AZDOT, CDOT), which is specified by different lane closure conditions, such as single-direction lane closure (ALDOT) and full closures (CDOT). As mentioned by AZDOT, "the typical TTC will consist of the test vehicle, impact attenuator, and the associated vehicles required for the traffic control setup/breakdown." The impact attenuator also seems to be the most basic safety measure under this test scenario (AZDOT, INDOT, IowaDOT, KSDOT, MDOT, PennDOT, TDOT). Enhanced traffic enforcement with highway patrol, especially for speeding, is mentioned in the responses from Caltrans, KSDOT, and SCDOT. Flaggers are also required under this test scenario in WisDOT, with a required handbook to follow. LaDOTD also sets up big orange barrels, and sometimes, concrete barriers to block off the area along with barricades. For profiler control sites, marking sections is required in ALDOT and KSDOT to make traffic control schemes safer in general, which shall also be annually re-marked.

3.2.2.4 Summary

Based on the inputs from respondents in state DOTs, the safety features to protect PTOs during field tests can be generally categorized into three aspects: 1) improving safety features of pavement test vehicles; 2) optimizing the plan of pavement field test; 3) performing appropriate traffic control. The details of those common safety measures are summarized in Table 3-2.

Table 3-2 General Safety Measures Adopted by State DOTs for PTOs

Scenario 1: testing performed at highway speeds		
Safety feature of test vehicle	Plan of pavement field test	Traffic control
Light bars on the rear of vehicle; 360-degree visible amber light; Reflective tape or sign; Labels or placards stating "test vehicle"	Avoid high traffic area; Limit left turns and U-turns; Adjust test driving speed	Impact attenuator
Scenario 2: testing performed with mobile operations		
Safety feature of test vehicle	Plan of pavement field test	Traffic control
Light bars on the rear of vehicle; Light arrow boards; Message boards; Dual-rotator amber light	Limit the duration of lane closure; Avoid high traffic area	Impact attenuator; Flaggers; State trooper presence; Message boards
Scenario 3: testing performed within TTC or work zone		
Safety feature of test vehicle	Plan of pavement field test	Traffic control
Light arrow boards; Variable message signs; Flashing warning light; Queue trucks	Limit the duration of lane closure; Avoid high traffic area	Impact attenuator; Enhanced traffic enforcement; Marking sections; Big orange barrels; Flaggers

3.2.3 Unique Practice Features Adopted or Developed

3.2.3.1 Blue lights

The most popular method, which is developed and implemented by some state DOTs (IowaDOT, NDOT, AHTD, SCDOT), is to utilize blue lights with other flashing lights to reduce the speed of the traffic. In Iowa, during performing all types of pavement field tests in the winter, "snow removal operations have approval to utilize blue lights and white lights in unison with the amber lights on snow removal vehicles." In Arkansas, blue lights are currently reserved for law enforcement vehicles. "Law enforcement vehicles with blue lights on are used in specific types of construction projects and have shown that traffic slows down significantly when law enforcement is present within the project limits." In Florida, blue lights are reserved for law enforcement vehicles only.

3.2.3.2 Better preparation for field tests

MoDOT states that they will have pre-activity meetings before performing the field tests. There are weekly conference calls regarding work zone impacts on MoDOT's heavy interstate routes, which provide a means of sharing work zone impacts potentially across the state. "There is also a spreadsheet that is filled out every week that corresponds with these weekly conference calls. The information provided in the spreadsheets is for the next week's work zones/impacts. This information is included on MoDOT's traveler's information map, which is on MoDOT's web page for public viewing."

On another side, for flagging operations, MoDOT will not only train the flaggers but everyone, in order to know what to look for and the correct methods are being used. During the pavement field testing, additional cones are also used to stop vehicles at the flagger's position.

3.2.3.3 Paint on the road

In Alabama, for the field tests under scenario 3, "diagram using letters indicating sign placement has been developed to be compatible with the MUTCD. When the sites are chosen, the location of the letters (and the signs) is painted on the road. This speeds setup and breakdown of the traffic control such that impacts to the traveling public are minimized (as is the time spent by field personnel in the travel way)", as ALDOT responded.

3.2.3.4 Rear view mirror cameras and turning lane cameras

KYTC equips the survey vans with rear view mirror cameras and turning lane cameras. Those cameras can help with blind spots and create a bigger viewing area during pavement field testing at highway speeds.

3.2.3.5 Breakaway barricades

NJDOT standards use breakaway barricades for taper. MUTCD adopted by most states uses cones or drums for taper.

3.2.4 Suggestions or Comments

This survey collected suggestions or comments from respondents in state DOTs. Most safety measures have already been covered in Sections 2.2 and 2.3. Additional valuable points in the responses to Question 4 for the three test scenarios are listed below:

- Caltrans suggested that driver's sole responsibility is to focus on driving and only passengers should accomplish the operation of computers and components (Scenario 1).
- KYTC recommended scaling down the size of the test equipment. They use a passenger van that is boxy and has reduced turning radius. Meanwhile, a once a year safety training class should be required as part of driver certification (Scenario 1).

- MDOT requires personnel to have not only driver safety training, but also defensive driver training (Scenario 1).
- NJDOT suggested increasing the number of attenuator trucks if necessary (Scenario 2).
- UDOT emphasized the importance of developing more automation technologies to benefit PTO safety (Scenario 1 and Scenario 2).
- UDOT and WisDOT both suggested hands-free communication equipment installed in the test vehicle. Meanwhile, Caltrans stated "our pavement evaluators have seen a significant increase in the past few years of motorists violating the State's "Hands Free" law, especially regarding texting while driving. Stricter enforcement of this law is desired." (Scenario 1)
- WisDOT noticed that equipment problems are a distraction. Equipment with excessive age shall be avoided (Scenario 1).
- AZDOT suggested using local or state law enforcement as part of the rolling closure whenever possible to slow traffic down (Scenario 2 and Scenario 3).
- KSDOT felt that a lot of time and effort go into the traffic control. It would be great if it could be done with less signs, cones, etc. and still be safe (Scenario 3).
- PennDOT mentioned to develop an automatic radar ticketing system for work zones. MoDOT mentioned a similar idea: "the presence of law enforcement and video radar detection could be implemented in longer-term work zones." (Scenario 3)
- MnDOT suggested performing a short duration lane closure and limiting traffic disruptions. They prefer some standards for marking the locations of cores when a road is partially open to traffic. They often have inspectors dodging traffic to layout many things (striping) rather than close the road. Moreover, cutting cores is a semi-mobile operation that creates some open discretion when interpreting the MUTCD (Scenario 3).

3.3 Summary of Nationwide Survey

To gather safety features implemented by state DOTs to protect PTOs during pavement field testing, this survey collected a total of 34 responses from relevant personnel in 32 state DOTs. Based on their responses, most respondents suggest paying more attentions to the tests within TTC or work zone, compared to the tests at highway speeds.

Regarding the common safety measures adopted in states, the safety features to protect PTOs during field tests can be generally categorized into three aspects: 1) improving safety features of pavement test vehicles; 2) optimizing the plan of pavement field test; 3) performing appropriate traffic control. The details are displayed in Table 3-2.

Some state DOTs also share their unique safety measures for PTOs in this survey. One example is to utilize blue lights with other flashing lights to reduce the speed of the traffic. IowaDOT and AHTD have approval to utilize blue lights within specific project limits. This option, however, is currently infeasible in Florida since blue lights are reserved for law enforcement vehicles only.

Many state DOTs also provided several valuable suggestions for improving PTOs' safety. Most of them focus on advanced devices, including some automation technologies, radar detection system, and hands-free communication equipment. Others are about adjusting the standards or process of pavement field tests, such as adding more operators and more training, using more local or state law enforcement, and shortening the duration of lane closure by several ways.

CHAPTER 4 RECOMMENDATIONS

4.1 General Recommendations

Based on the findings from the literature review and survey, general recommendations for safety improvement during pavement field testing are given in this section, mainly from the perspectives of equipment improvement and safety system development.

Following recommendations are made for pavement field testing at highway speeds:

- In-vehicle warning systems, such as forward collision warning system (Save Drive Systems), lane departure warning system (Save Drive Systems), and driver fatigue and distraction warning system (MR 688 by Care Drive), are recommended to be evaluated and, if applicable, installed in FDOT test vehicles.
- Several voice recognition applications, such as Freesr, Dragon speech recognition, Braina, Lilyspeech, are available on the current market. All above products have free trial version, which can be installed in one of the FDOT vehicle data acquisition software for evaluation. However, among these applications, Freesr is recommended. Others may be considered as backup. If Freesr fails to fulfill FDOT needs then others may be tried.
- The most comfortable position of the computer screen in a survey vehicle is the one being closest to the steering wheel. For the FDOT test vehicles in which the computer position is at a distance from the driver seat and the PTO is uncomfortable with, a new mount system may be considered as a probable safety enhancement after a detailed review.
- The option to use blue lights with other flashing lights with other flashing lights is currently prohibited by Florida statues. Experience from some other state DOTs, however, showed its effectiveness in increasing survey safety. An initiative to change the Florida statues for allowing the use of blue lights for field testing may be proposed.

Following recommendations are made for pavement field testing with mobile operations:

- Considering the low speed of mobile operations and the improving capacity of cell phone operation system, the feasibility of using some cell phone applications (e.g., iOnRoad) to analyze the traffic condition and warn the drivers in time deserves further exploration in the next step of this project.
- Most states double the fine for speeding in a work zone. Doubling fines may also be implemented during pavement field testing. Adding a speed detector with a dynamic warning message on test vehicles, which turns each test vehicle into a "moving speeding detector", may help further reduce the speed of surrounding vehicles. Apparently, this strategy needs to get legislature approval before it can be implemented.

Following recommendations are made for pavement field testing with full lane closure:

- Various detection devices (e.g., non-intrusive detection devices, radio frequency guns, cameras) and warning devices (e.g., siren, portable changeable message sign, iCone system) can be explored and assembled to build several smart work zone systems (e.g., work zone intrusion warning system, queue warning system, dynamic lane merge system, variable speed limit system).

- For the dynamic lane merge system, early and late merge strategies shall be properly selected based on the traffic volume. Literature shows that as the traffic volume increases from 1000 vehicles/hour to 1500 vehicles/hour, the performance of dynamic late merge turns to be better than that of dynamic early merge. Otherwise, dynamic early merge strategy is prior.

A moveable traffic barrier system (MTBS) is mentioned in several state DOT manuals, but not in the relevant FDOT manuals. Since the MTBS can quickly move the barriers within work zone, traffic will be less interrupted. This option, however, is expensive (e.g., the California Golden Gate MTBS costs about $2200 per foot) and may only be considered for certain special areas with heavy traffic.

4.2 Recommendations for Potential Implementation

Some of the general recommendations may need a heavy investment or a long term for implementation. For immediate implementation at low costs, the following recommendations are provided.

4.2.1 Recommendations for Pavement Field Testing at Highway Speeds

4.2.1.1 Upgrading Data Acquisition Software with Voice Recognition Application

Making pavement test vehicles' data acquisition software voice enabled can help reduce PTO distraction during testing at highway speeds. There are two approaches to upgrade a pavement test vehicle to voice recognition: hardware upgrade or software upgrade. After much exploration and comparison, software upgrade is recommended due to its availability, low cost, ease of installation, and good adaptability. Specifically, the speech recognition software, Freesr, is recommended among several similar software products available on the current market. The reasons behind this choice are: (1) only Freesr was developed specifically to make other software voice enabled, whereas other voice recognition software products on the market are mainly used to help control typing software (e.g., Microsoft Word) through voice dictation; (2) the usable version of Freesr can be downloaded for free from its developer's website for trial with a very simple interface, as shown in Figure 4-1. A description on how the Freesr software works and how it can be operated to make other software voice enabled is provided in Appendix B. This description was written based upon the research team's experience with using Freesr to operate Google Chrome browser. Some simple actions such as opening new tab (needs Ctrl+t command in the keyboard), closing a tab, going to a webpage (i.e. youtube.com) were performed by uttering voice commands set by the team using the Freesr software.

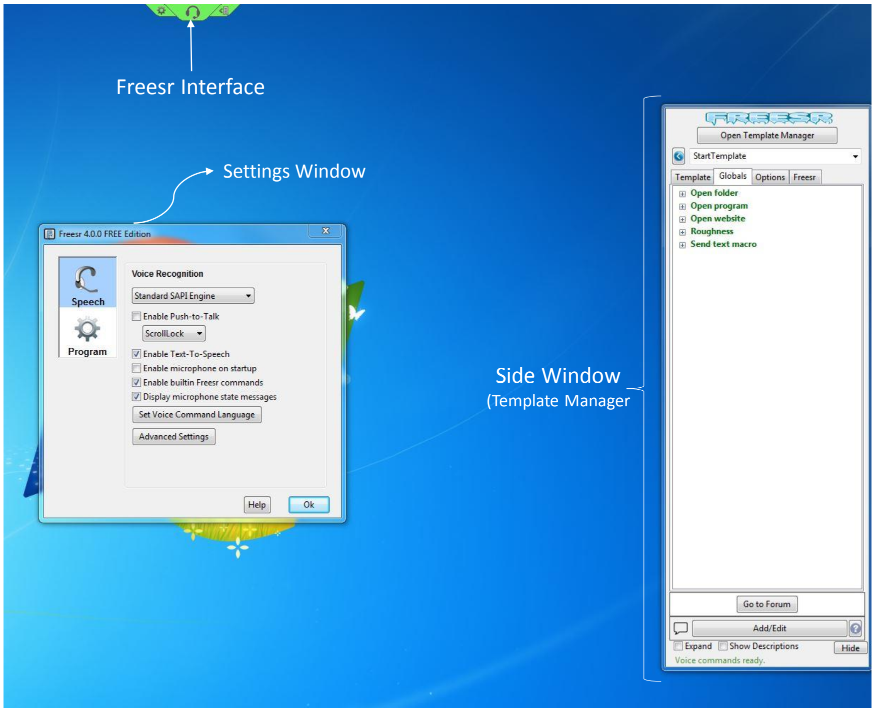

Figure 4-1 Simple user interface of Freesr speech recognition software

4.2.1.2 Adding Advanced Driving Assistance Systems

In section 2.1.1, in-vehicle warning systems, including forward collision and lane-departure warning system and driver fatigue and distraction monitoring and warning system, were introduced as one primary tool for safety improvement in pavement testing at highway speeds. Detailed information and comparison in terms of cost and features among various available models of those advanced driving assistance systems have been summarized in Table 2-8 and Table 2-9. Those driving assistance systems can be divided into two categories: radar-based detection system and camera-based detection system. The quality of camera-based detection system can be interfered by some unexpected weather conditions, such as heavy rain and heavy fog. This downside of using camera-based detection system leads to lower price, compared to that of radar-based detection system.

For forward collision and lane-departure warning system, upon contacting, one of the vendors (Safe Drive System) that manufactures Safe Drive System RD 140 informed that they are open to negotiations for deals that require installation of their product in multiple vehicle units. Price variation among other systems is due to the variation of some minor features (e.g., size of memory card provided, HD video recording availability, and other additional features). However, only the Safe Drive System provides the opportunity of having the system installed in a customer’s vehicle by their skilled personnel, whereas others require the users to install the system by themselves.

For driver fatigue and distraction monitoring and warning system, both the MR 688 Driver Fatigue Monitoring System and the Vuemate Driver Fatigue System are marketed by the Rear View Safety Company in the U.S. Though there is no difference between the basic features of these two products, their prices are different. The marketer reported that the MR 688 model is sturdier than the other one. That is why the price of the MR 688 model is higher than the other one. The third model is manufactured and marketed by a Chinese company and has to be shipped from overseas if purchased.

If FDOT considers the associated prices reasonable and acceptable, it is recommended to buy several of these models and test the systems in different vehicles (one for each model) to get the real feel and then pursue the best one based on users' (PTOs') feedback.

4.2.2 Recommendations for Pavement Field Testing with Mobile Operations

4.2.2.1 Refining the Spacing Standards between Shadow Vehicle and Work Vehicle

To set a proper spacing between a shadow vehicle (SV) and a work vehicle (WV) under a specific circumstance, "roll-ahead distance" has been introduced into many other state DOT standards (MDOT, 2004; NMDOT, 2012; INDOT, 2013; NYDOT, 2015). Roll-ahead distance is defined as the longitudinal displacement of the shadow vehicle when impacted by an errant vehicle.

In 1991, Humphreys and Sullivan developed guidelines for the use of truck-mounted attenuators and regulated specific roll-ahead distances for protective vehicles during mobile operations (e.g., SV weight, prevailing speed, weight of impacting vehicle, and mobile or stationary operation), as shown in Table 4-1 (Humphreys and Sullivan, 1991). This table has been referred to in some state DOT standards (NYDOT, 2015; MDOT, 2004) to set the safe distance between a SV and a WV. Some state DOTs simplify and slightly modify the table of roll-ahead distance (between the WV and the nearest SV) based on the particular weights of their protective vehicles, as shown in Table 2-11.

As described in section 2.1.5 in this report, two options are provided in FDOT Design Standards indices 607 and 619 for the arrangement and spacing of protective vehicles behind a WV in the travel way. In Option 1, an advanced warning vehicle (AWV) behind a SV is optional, and the spacing between the SV and the WV is in the range of 500 ft to 800 ft for rural areas and 300 ft to 500 ft for urban areas. In Option 2, an AWV is required and must be operated in the lane behind the SV, and the spacing between the SV and the WV is reduced to the range of 100 ft to 500 ft for rural areas and 50 ft to 300 ft for urban areas.

By comparing the FDOT SV and WV spacing standards with the roll-ahead distances listed in Table 4-1, it can be seen that the minimum lower bound (50 ft) of the spacing between a SV and a WV specified in the FDOT Design Standards is reasonable (corresponding to the scenario of a 15,000-lb SV and a prevailing speed of 45 mph or less, or the scenario of a 24,000-lb SV and a prevailing speed of 55 mph or less) but cannot be further reduced. The upper bounds of the FDOT SV and WV spacing (300 ft or 500 ft for urban areas, 500 ft or 800 ft for rural areas) also seems reasonable but still has room to be refined.

As one recommendation in this report, the FDOT spacing standards between a SV and a WV, particularly for Option 2 (an AWV following the SV in urban areas), may be refined by specifying different spacing values for different prevailing speeds. Since it is difficult to control precise spacing during mobile operations by PTOs and 50 ft spacing sometimes is not safe for heavy vehicle impact at high speed, it is better to regulate the range of spacing for different levels of posted speed limits instead of a specific spacing value. The recommended spacing may be varied based on field conditions (e.g., turning lanes, intersections, ramps, lane transitions) in order to avoid conflicts or improve site specific traffic controls. Based on literature review and analysis, the spacing values shown in Table 4-2 are recommended for the Option 2, urban area scenario of the FDOT Design Standards indices 607 and 619.

Table 4-1 Computed Roll-Ahead Distances for Protective Vehicles during Mobile Operations (Humphreys and Sullivan, 1991)

Shadow or Barrier Vehicle Weight (lb)	Prevailing Speed (mph)	Weight of Impacting Vehicle to Be Contained			
		4,500 lb	10,000 lb	15,000 lb	24,000 lb
10,000	60-65	100 Ft.	175 Ft.	225 Ft.	275 Ft.
	50-55	100 Ft.	150 Ft.	175 Ft.	200 Ft.
	45 or less	75 Ft.	100 Ft.	125 Ft.	150 Ft.
15,000	60-65	75 Ft.	150 Ft.	175 Ft.	225 Ft.
	50-55	75 Ft.	125 Ft.	150 Ft.	175 Ft.
	45 or less	50 Ft.	100 Ft.	100 Ft.	100 Ft.
24,000	60-65	75 Ft.	100 Ft.	150 Ft.	175 Ft.
	50-55	50 Ft.	75 Ft.	100 Ft.	150 Ft.
	45 or less	50 Ft.	75 Ft.	75 Ft.	100 Ft.

Table 4-2 Spacing between Protective Vehicles Suggested to FDOT for Urban Areas

Posted Speed Limit (mph)	Spacing (Ft.)
20-45	50-100
50-55	75-175
60-65	150-275
70 or more	300

4.2.3 Recommendations for Pavement Field Testing with Full Lane Closure

4.2.3.1 Exploring Devices for Smart Work Zone Systems

The concepts of several smart work zone systems (e.g., work zone intrusion warning system, queue warning system, and dynamic lane merge system) were reviewed in the first deliverable report "Deliverable 1: Literature Review". However, no such systems have been completely developed and implemented by state DOTs. In the long run, FDOT may consider implementing or adopting these systems when they become available. In the short term, some safety devices as elements of the smart work zone systems are available and may be used in pavement field testing with full lane closure.

One such device recommended for use is the radio frequency gun currently being developed by ComSonics (ComSonics, 2016) (Figure 4-2). It is designed to help police detect texting drivers while driving. Since the radio frequencies used for phone calls, texting, and data transfers are different, this gun can identify whether the radio signal is from phone call, texting, or browsing websites. However, one critical shortcoming of this product is that it cannot tell whether the driver or the passenger is texting. This disadvantage can be compensated by setting an extra camera to cooperate with the radio gun. The radio gun is currently under development and no price has been announced yet.

Figure 4-2 Radio frequency gun to detect texting drivers

As a potential application of this radio frequency gun within a work zone area, once a texting driver is detected, a high quality camera may be triggered to monitor the driver and a siren or horn alarm can be activated to warn workers. A dynamic message sign may also be used to display "NO TEXT" to warn the texting driver, as illustrated in Figure 4-3.

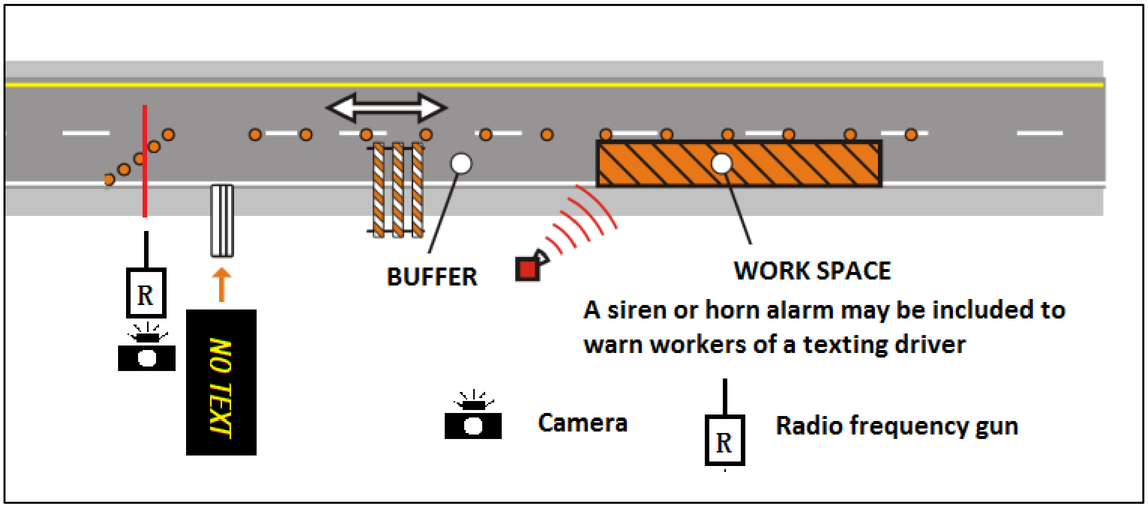

Figure 4-3 Application of radio frequency gun within work zone area

4.2.3.2 Developing a Mobile Work Zone Barrier System

During the nationwide questionnaire survey, responses from California Department of Transportation (Caltrans) mentioned that they use a high mobile barrier system, called the Balsi

Beam, to protect workers in a work zone during pavement testing. Figure 4-4 illustrates the application of the Balsi Beam in the field (Caltrans, 2004).

Recently, the Ontario Ministry of Transportation (MTO) in Canada tested an innovative work zone barrier system, MBT-1, on a four-lane highway in 2011 (Graham et al., 2011), as shown in Figure 4-5. Two crash attenuation components inside this system are connected by reversible axles which allow it to be easily reconfigured for use in either right lane or left lane, as shown in Figure 4-6(a) and Figure 4-6(c). If the work zone is in a middle lane, an additional attenuator truck can be assigned to cooperate with this system to protect PTOs' safety, as shown in Figure 4-6(b). Moreover, the mobile barrier in this system can be expanded from 42 to 101 feet to suit specific job sites (Graham et al., 2011). To better improve PTOs' safety, other safety devices (e.g., portable variable message sign, speed detection device, portable generator, lighting, and rear wheel steerable axle) can be added to further customize this barrier system (Graham et al., 2011). Compared to Caltrans Balsi Beam, MBT-1 is larger and more flexible in its configurations. Test results of the MBT-1 showed its excellent performance in improving PTOs' safety within work zones, and its good resistance to crashing impacts (Leon, 2008).

It is recommended that a mobile work zone barrier system similar to the MBT-1 may be developed and used for pavement field testing with full lane closure.

Figure 4-4 Using Balsi Beam mobile work zone barrier in the field (Caltrans, 2004)

Figure 4-5 Using MBT-1 mobile work zone barrier in the field (Graham et al., 2011)

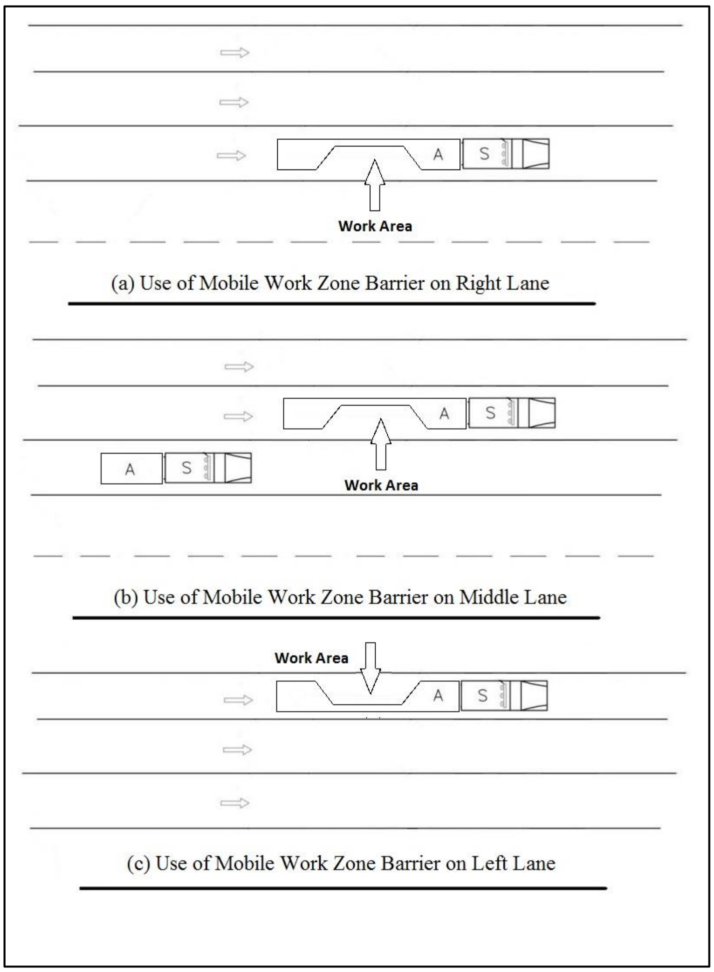

Figure 4-6 Use of mobile work zone barrier on (a) right lane, (b) middle lane, and (c) left lane

4.2.3.3 Improving Visibility of PTOs at Night

PTOs sometimes are required to work at night and occasionally need to leave their vehicles. It is recommended that reflective clothing or hat with LED light may be used by PTOs to increase their safety during pavement field testing at night with full lane closure.

Reflective clothing used in work zones has been standardized as in American National Standard for High-Visibility Public Safety Vests, ANSI/ISEA 107-2015. Type R garment, which is especially designed for roadway and temporary traffic control (Figure 4-7), is recommended.

Figure 4-7 Type R high-visibility public safety vest

For the hat with LED light, there is no standard to regulate its design. Similar to the use of LED light on test vehicles, LED light may be attached to the back or the front of a hard hat, as shown in Figure 4-8, or around a hard hat as shown in Figure 4-9. Considering the possibility of distracting public drivers by a ring of LED light, the research team recommends attaching LED light to the back of a hard hat during pavement field testing with full lane closure.

Figure 4-8 LED light bar behind or on the front of a hard hat

Figure 4-9 360-degree ring of LED light on a hard hat (Illumagear, 2017)

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APPENDIX A RESPONSES FROM VARIOUS STATE DOTS

Question 1: Is there a need in your state to improve the safety of pavement testing operators (PTOs) during field pavement condition survey or performance test, when

a) Testing is performed while operating a full-sized survey vehicle at highway speeds (hereinafter referred to as "Scenario 1")?

Responses:

Alabama DOT: *we have been lucky with regard to the limited number of incidents that have occurred while collecting data with our locked wheel friction tester and our inertial profiler. To my knowledge the vendor that collects our network level pavement distress data has never had an incident in Alabama.*

We have two types of these, a high-speed profiler, which does move at highway speeds, and a locked-wheel friction tester, which collects at 40mph. We have to keep that speed because a) our historical data is collected at that speed and there has been no correlation study done (if one is even truly possible), and b) 40mph provides a unique opportunity to examine the combined effect of both micro- and macrotexture as it relates to the frictional properties of a particular pavement. I wish there was something additional that we could do that was practical because of the closing rate between other vehicles and the friction tester. Fortunately, the largest speed differentials occur on multilane, controlled access facilities.

Alaska DOT: *No, we use equipment outfitted with warning lights and use arrow sign truck when test vehicle stops.*

Arizona DOT: *No, we use all appropriate safety measures when testing Interstates, US Highways and State Routes. We shadow the Profile test vehicle with an impact attenuator when testing urban areas due to high traffic volumes.*

Arkansas DOT: *No – Flashing lights are used to alert traffic while moving at highway speeds.*

California DOT: *Yes. Our pavement evaluators have seen a significant increase in the past few years of motorists violating the State's "Hands Free" law, especially regarding texting while driving. Stricter enforcement of this law is desired.*

Colorado DOT: *No - we do this via contract with data collection company annually.*

Hawaii DOT: *We do not operate a pavement testing machine to perform pavement condition surveys.*

Iowa DOT: *No, highway speed testing is fine.*

I believe there is always a need to improve if better processes are out there. At this time, our specifications are adequate for what we are trying to accomplish.

Kansas DOT: *We do a lot of this and we feel that it is done reasonably safely by our trained staff.*

Louisiana DOT: *No.*

Maine DOT: *We believe this process is safe.*

Maryland DOT: *Currently, we feel our safety practices are adequate for our testing purposes; methodology and standards are always under review and consideration for improvement. We strongly believe it is always important to create and ensure awareness and responsibility for safety. All personnel are responsible for safe operation of pavement testing vehicles and applying safety principles. All personnel responsible for using and implementing maintenance of traffic (MOT) practices are required to attend safety training and/or certification for traffic control. This scenario is our safest method of operation and requires the least amount of MOT.*

Michigan DOT: *A consultant collects our data so I do not believe this survey is applicable to our operations.*

Minnesota DOT: *No.*

Mississippi DOT: *No.*

Missouri DOT: *Scenario 1 is limited to MoDOT's Automated Roadway Analyzer (ARAN) and High Speed Profilograph. Both equipment operate at highway speeds; therefore there is no traffic control features except the vehicles are equipped with safety lights if needed. Although there is always a need to look for safety improvements, these operations would be considered a low priority.*

Montana DOT: *No.*

Nevada DOT: *No present need to change current operation.*

New Hampshire DOT: *No*

New Jersey DOT: *For highway speed, there is no specific safety concerns as long as the vehicle has warning lights and operators operate the vehicle safely (avoiding pulling in and out of travel lanes abruptly, etc.)*

Pennsylvania DOT: *As a DOT we feel there is always room for improvement. In this scenario, anything that can minimize the chance of or reduce the damage from rear impacts.*

Rhode Island DOT: *Any improvements in the safety procedures that can be identified for this type of operation should be considered.*

South Carolina DOT: *Yes; difficultly at times collecting pavement evaluation data on Video, PQI, IRI, Friction testing, etc. Also maintaining correct testing speed for collecting data can be a challenge with the flow of traffic.*

South Dakota DOT: *We run a pavement condition vehicle at near highway speed (55 to 60) MPH. Safety is a concern, so we have an light bars for when turning or running at lower speeds and have reflective tape on the back of the vehicle to decrease the chance of people running into the back of the vehicle.*

Tennessee DOT: *We have some concerns about the relatively slower speed of our testing vehicles on high speed roadways.*

Texas DOT: *No.*

Utah DOT: *Safety is the highest priority for our pavement data collection operators and we take it seriously and routinely emphasize it to our PTOs . We are doing what is in our control to make sure our PTOs are operating safely and not sure what else is needed at this time. Our equipment is fairly brand new and in its best operational condition. But, I think more PTO safety related training, webinars, etc. will always add more value and be very helpful.*

Vermont DOT: *Possibly.*

Washington DOT: *No need to improve safety for full-sized survey vehicle.*

Wisconsin DOT: *Scenario 1 is how WisDOT's Pavement Data Unit (PDU) does business. Our safety procedures are sufficient.*

b) Testing is performed with slow-moving lane closure (hereinafter referred to as "Scenario 2")?

Responses:

Alabama DOT: *we have been lucky with regard to the limited number of incidents that have occurred while collecting data with our FWD's. Our filed offices supply the traffic control and we do prefer that they always have an impact attenuator with us while testing is being performed.*

FWD testing is performed using a slow-moving lane closure. Our only times to exit the vehicle during testing are generally to take readings from temperature holes filled with mineral oil. These are located on the right shoulder, minimizing exposure to traffic. Overall, the support we get from our Districts (ALDOT's smallest geographic management area…unlike, say, in Florida) has been adequate, but we have been known to refuse to test without at least a minimum of personnel and vehicles dedicated to traffic control.

Alaska DOT: *not sure we would need to improve; we have not experienced difficulties that I am aware of…we use arrow sign truck or temporary traffic control personnel depending on extent of work and duration.*

Arizona DOT: *No, we use all appropriate rolling closure safety measures when testing Interstates, US Highways and State Routes. The typical FWD testing rolling closure for a low volume road is the test vehicle , impact attenuator, truck mounted message board (#2) and truck mounted message board (#1). Flaggers are used to control traffic around the rolling closure. The typical FWD testing rolling closure for a high volume road can have as many as 12 vehicles to slowly move traffic out of the lane.*

Arkansas DOT: *Yes – Slow-moving vehicles always present a potential for an incident on the highway and we are always in search of ways to increase the safety of those conducting the testing operations.*

California DOT: *This scenario is rarely, if ever, used for the purposes described.*

Colorado DOT: *No - this method rarely used by CDOT. Scenario 3 typically utilized except for rural highway FWD testing. No concerns apparent.*

Iowa DOT: *We utilize flag/arrow trucks following the testing operations. In higher volume traffic areas, we'll often utilize a crash-attenuator truck behind the testing operation as well. While we are always looking to improve safety within these work areas, short of a total lane closure I don't know what else we can ask for. Ideally we'd like traffic to slow down and increase awareness while in the area of our operations.*

Kansas DOT: *We are not allowed to do this in our state. Even our "slow-moving lane closures" require traffic control by our state rules.*

Louisiana DOT: *Yes.*

Maine DOT: *Maybe – we have a process, but improvements are always welcome.*

Maryland DOT: *Our safety practices are adequate for our testing purposes; methodology and standards are always under review and consideration for any further improvement.*

Minnesota DOT: *Sometimes in high volume areas.*

Mississippi DOT: *No.*

Missouri DOT: *Scenario 2 is the most common type of pavement testing that MoDOT performs; where the activity is limited to a maximum of 15 minutes within a specific location prior to moving to a different location. Yes, there is a need to improve safety for Scenario 2.*

Montana DOT: *No.*

New Jersey DOT: *Attenuator trucks with arrow boards need to follow the testing vehicle. The number of attenuator trucks depends on the number of lanes and the speed limit per MUTCD.*

However, we suggest going above the minimum number of trucks in MUTCD to give more advanced warning and time to motorists.

Pennsylvania DOT: *In this scenario, anything that can minimize the chance of or reduce the damage from rear impacts.*

South Dakota DOT: *There is always a need to improve safety when performing PTOs on our pavements. We operate two, two person crews that drive the shoulders of the road (where there are shoulder) at speeds not more than 15 mph. Visibility of our crews is of utmost importance when performing this operation*

Tennessee DOT: *We typically do not use mobile lane closures for pavement testing*

Texas DOT: *We do not use slow-moving lane closures for full-sized survey vehicle at highway speeds. We use full lane closures when doing project level FWD testing*

Utah DOT: *Safety is the highest priority for our pavement data collection operators and we take it seriously and routinely emphasize it to our PTOs. We have done what is in our control to make sure our PTOs are operating safely and not sure what else is needed at this time. Our equipment is fairly brand new (2016) and in best operational condition. But, I think more PTO safety related training, webinars, etc. will always add more value and be very helpful.*

Vermont DOT: *Not typically used.*

Wisconsin DOT: *Scenario 2 is used by WisDOT Subsurface Exploration Unit. We follow MUTCD guidelines. There is always room for improvement with regard to traffic control.*

c) When working within a Maintenance of Traffic (MOT) / Temporary Traffic Control (TTC) or Work Zone (hereinafter referred to as "Scenario 3")?

Responses:

Alabama DOT: *we have been extremely lucky that there have been no incidents while collecting pavement management data under scenario 3.*

We use work zones for quality control of pavement condition data collected by a vendor. This is typically only 10 sites a year or so, and each site is 0.3 mi in length. I feel we do a reasonable job given the personnel we have, even when we have to do single-direction lane closures. We also use work zones when marking sections for profiler control sites. There are 20 of these throughout the state, and they are re-marked yearly. All are on 4-lane routes, which make traffic control schemes safer in general.

Alaska DOT: *Not sure we would need to improve; we have not experienced difficulties that I am aware of…we use arrow sign truck or temporary traffic control personnel depending on extent of work and duration.*

Arizona DOT: *No, we use all appropriate safety measures when FWD testing Interstates, US Highways and State Routes. The typical MOT/TTC for FWD testing will consist of the test vehicle, impact attenuator and the associated vehicles required to the traffic control setup/breakdown.*

Arkansas DOT: *Construction zones are maintained by the contractor and strict adherence to the MUTCD is required. These areas are typically safer than if the testing operation were not in a construction zone, but we are continually in search of methods that make construction zones safer for all those working in them.*

California DOT: *There is always a continued need to enhance safety for those performing work in the work zone, especially in temporary traffic control situations.*

Colorado DOT: *No, safety concerns not apparent. Full closures with traffic supervisor-created Method of Handling Traffic are utilized successfully.*

Iowa DOT: *No, not with our operations themselves. If we could improve the public's reaction to the work zone and slow them down that would improve safety for everyone.*

Kansas DOT: *We do a lot of these too. Mostly for Falling Weight Deflectometer testing. We would like to do these more efficiently and still be safe. Because of all the rules, the majority of our effort is on traffic control in order to get the little bit of data we need.*

Louisiana DOT: *Yes.*

Maine DOT: *Yes – this could always be improved.*

Maryland DOT: *Our safety practices are adequate for our testing purposes; methodology and standards are always under review and consideration for any further improvement. This scenario has received the most attention due to its extended presence of equipment and personnel being on the roadway in the work zone. As being the most disruptive to normal driving patterns, this scenario requires the most attention for coordinated MOT.*

Minnesota DOT: *Yes*

Mississippi DOT: *Yes*

Missouri DOT: *When working in a specific location for greater than 15 minutes, a full lane drop with TTC is required. Yes, there is always a need to improve safety for our work zone operations.*

Montana DOT: *No.*

New Jersey DOT: *We follow MUTCD and NJDOT standards and believe they are adequate.*

Pennsylvania DOT: *We do some work with walking profilographs under temporary lane closures. We are always looking for ways to improve the safety of our work crews.*

South Carolina DOT: *Yes; issues with moving equipment such as coring trucks-rigs, QC staff work vehicles that carry nuclear density gauges can be a challenge. Working during nighttime hours adds more risks to employees due to more fatigued drivers and workers, and difficultly making visual observations on the job. Difficult for our specialized staff to work from centralized area in the state and have to drive back from the work zone 2-3 hours very early in the morning in order to return equipment, etc.*

South Dakota DOT: *We do FWD testing in a Work Zone, so we have our maintenance unit completely close the lane with MUTCD approved methods and products.*

Tennessee DOT: *We would be interested in finding a way to improve the safety of our worker in a practical manner that accommodates a short duration lane closure and limits traffic disruptions.*

Texas DOT: *No.*

Vermont DOT: *Possibly*

Wisconsin DOT: *Scenario 3 is used by WisDOT Subsurface Exploration Unit. We follow MUTCD guidelines. There is always room for improvement with regard to traffic control.*

Question 2: What safety features have been adopted or developed in your state to improve PTO safety?

a) Scenario 1

Responses:

Alabama DOT: *collection vehicles are required to have flashing lights.*

We use light bars on trucks and additional lights on the friction testing trailers. We attempt to avoid high traffic areas at peak hours.

Alaska DOT: *vehicle has appropriate warning light system installed and regularly use temp traffic control if deemed appropriate*.

Arizona DOT: *in urban areas and areas with high traffic volumes we Profile test at night when traffic volumes are decreased and we shadow the test vehicle (Profiler) with an impact attenuator.*

Arkansas DOT: *Flashing lights on the equipment.*

California DOT: *Our survey vans are outfitted with large high-visibility magnetic placards on the rear door panels stating: "Pavement survey in progress. Pass with care".*

Iowa DOT: *360-degree visible amber lights. Amber strobes/light bars on the rear of the vehicle.*

For our own state vehicles we have started looking at LED light bars and different colored lights for survey and plow trucks instead of the old "A" (amber) lights. We have also tried some different lighting patterns to make vehicles more visible in snow/rain storms or fog. As far as your questions below we have improved sheeting requirements on signs and other requirements as outlined in the MUTCD when required.

Kansas DOT: *Since we are moving in traffic at traffic speeds, we don't really have any special safety requirements in this data collection mode.*

Kentucky DOT: *a) We test with two employees. One person drives and the other person operates all equipment. The passenger also provides another set of eyes for driver safety. b) Our vans are equipment with a wide array of strobe lights and rear view cameras.*

Maine DOT: *We use strobe lights and "Test Vehicle" labeling on vehicles.*

Maryland DOT: *We require high intensity reflective tape and strobe lights on our testing vehicles for increased visibility. We also have safety protocols to try to limit making left turns across traffic and avoid making U-turns when possible. Our personnel are required to complete an online driver safety training program and satisfactorily pass a test.*

Minnesota DOT: *Vehicle is marked*

Mississippi DOT: *Our Maintenance forces provide traffic control per MUTCD.*

Missouri DOT: *Safety lights required for all test vehicles; which is considered sufficient for these operations.*

Montana DOT: *We utilize high intensity flashing yellow lights on our vehicles. We have frequent safety meetings to discuss safety on the roadway.*

Nevada DOT: *High Intensity Strobe lights, advance warning signs where applicable.*

New Hampshire DOT: *Driver Safety Training, Safety Policy and Job Hazard Analysis Manual*

New Jersey DOT: *None. Regular traffic laws are followed. To ensure proper collection of data, speed is limited to 45-60 mph or the posted speed limit (whichever is lower)*

Pennsylvania DOT: *LED light bars and reflective chevron patterns on the rear of vehicles.*

Rhode Island DOT: *Vendors with vehicles that collect pavement condition data must submit a plan for maintenance and protection of traffic. This includes the lights and signs that are to be used while performing data collection.*

South Dakota DOT*: Safety: First, last and always. The implementation of LED flashing lights mounted at the highest points of our vans have greatly improved visibility. Training is important. It allows us to tell drivers what to look for and how to avoid precarious situations. Hands on training in "real-world" situations is a must. When visibility is low (during rain or fog) operations are suspended. As with any other operation, seat belts are required to be worn in any state vehicle in use.*

Tennessee DOT: *TDOT is currently looking into skid testing at a higher speed while testing on interstates. This will improve safety by lessening the speed differential between our vehicle and traffic; off peak hours; skid trucks are equipped with warning lights*

Texas DOT: *we require two persons a driver and an operator.*

Utah DOT: *Mandatory seat belt usage at all times during data collection operation. No dialing or writing, talking on the phone while driving and collecting data. Following department's policy while operating state vehicle. Equipment inspection prior to data collection operation. Proper safety vests, boots while in the field. Signage/proper messaging, and lighting on the data collection equipment. Data collection operation in outside or slow lane, and for some busy and high volume roads during selected hours. Processing of the data in a safe environment off the road and after the collection. Annual department-wide driver safety related training, etc.*

Vermont DOT: *Lightbar on vehicle*

Washington DOT: *Daily safety check, monitoring of fire extinguishers, first-aid kits, safety flares, etc.*

Wisconsin DOT: *Reflective tape and reflective signs; LED flashing lights – fore, aft, and top; Maximize vehicle spacing in traffic; Never exceed speed limits or vehicle data collection speed constraints; Frequent maintenance and frequent mechanical safety checks; Review safety PowerPoint designed for PDU; Relieve drivers on 2-hr interval; Obey all driving laws*

b) Scenario 2

Responses:

Alabama DOT: *traffic control is performed as per the MUTCD.*

We use light bars on trucks and additional lights on the FWD trailers. We attempt to avoid high traffic areas at peak hours. A District maintenance crew provides traffic control. On occasion, we enlist the help of a state trooper (usually at the District's discretion). Many of our projects in urban areas are done at night such that traffic is lighter.

Alaska DOT: *arrow truck, signage, and/or use of traffic control personnel*

Arkansas DOT: *Flashing lights/light bars mounted on the back of the vehicle or trailer or lighted arrow boards and truck mounted crash attenuators. (depending on the type of testing and highway conditions)*

Indiana DOT: *For slow-moving lane closures, we use a series of trucks with arrow boards and impact attenuators.*

Iowa DOT: *Addition of crash-attenuator truck when the testing operators want it. Arrow/sign boards and dual-rotator amber lights on all vehicles.*

Kentucky DOT: *Crash cushion trucks are used to protect employees as they lay down cones, and crash cushion trucks protect any testing performed in the closed lane. Lane closure signs are also places every 500 feet up to 1500 feet away notify lane closure ahead. (This is performed once a year for driver certification.)*

Louisiana DOT: *Use LADOTD Standard Traffic procedures like most state DOTD setup for a slow-moving lane closure which uses vehicles with flashing warning lights at the beginning and end of moving lane closure as well as flaggers at the beginning and end of lane closure to make sure traffic does not enter in between flashing vehicles in to lane closed.*

Maine DOT: *We have developed a "rolling work zone" for this work (e.g., Falling weight deflectometer).*

Maryland DOT: *We implement more frequent use of vehicle-mounted attenuators for safety of workers and motorists. We consider this our most dangerous scenario and implement additional MOT requirements/standards taught in MOT Training and Certification classes. Maryland DOT has a Temporary Traffic Control Manager's Training Course and a Flagger's Training Certification Course that personnel are required to have certification for using traffic control. We have traffic control standards and typical applications for various roadway scenarios, traffic volumes, traffic speeds, and weather conditions.*

Minnesota DOT: *Nothing beyond standard moving lane closure use as per MUTCD*

Mississippi DOT: *Work done in this scenario that is done with MDOT forces is performed per MUTCD manual with Maintenance Division.*

Missouri DOT: *Traffic control guidance that follow MUTDC standards are followed for moving operations. The set-up will vary based upon the traffic and roadway type and will require the use of a protective vehicle with a Truck Mounted Attenuator (TMA). For two-lane roadways, the appropriate flagging set-up will be required followed. These required traffic control set-ups are provided in MoDOT's Engineering Policy Guide (EPG) at the following link: http://epg.modot.org/index.php?title=616.8_Typical_Applications_%28MUTCD_6H%29*

Montana DOT: *Again, we utilize high intensity flashing yellow lights on our vehicles. We feel we are doing a stellar job with our slow-moving lane closure. Again, frequent safety meetings are held to discuss the safety on the roadway.*

New Jersey DOT: *For a slow-moving operation, the maximum time we spend at any given location is typically less than 30 mins. Apart from the usual signs informing other users that road work is in progress, we have an attenuator truck about 500 ft. from the PTO and another attenuator truck right behind the PTO.*

Pennsylvania DOT: *Message boards on vans that performs slow-moving testing along the road shoulder and LED light bars and chevrons for increased visibility. Crash trucks with scorpion impact attenuators are used in rare cases.*

Tennessee DOT: *We typically do not use mobile lane closures for pavement testing.*

Texas DOT: *For project level, FWD testing full lane closures is required.*

Utah DOT: *Mandatory seat belt usage at all times during data collection operation. No dialing or writing, talking on the phone while driving and collecting data. Following department's policy while operating state vehicle. Equipment inspection prior to data collection operation. Hands-free communication equipment installed in the vehicle, Proper safety vests, boots while in the field. Signage/proper messaging, and lighting on the data collection equipment. Data collection operation in outside or slow lane, and for some busy and high volume roads during selected hours. Processing of the data in a safe environment off the road and after the collection. Annual department-wide driver safety related training, etc.*

Wisconsin DOT: *We request assistance from local county forces to provide crash attenuators; Follow the MUTCD; All employees are required to take annual mandatory field safety training; LED flashing lights*

c) Scenario 3

Responses:

Alabama DOT: *traffic control is performed as per the MUTCD.*

We have the flexibility of choosing the sites where we do lane closures. There are more constraints on the vendor QA sites, as we must have distress present, etc. Profiler control sties are chosen such that they are distributed throughout the state and represent a range of values, but otherwise can be optimized for sight distance.

Alaska DOT: *arrow truck, signage, and/or use of traffic control personnel*

Arkansas DOT: *Lighted arrow boards and truck mounted crash attenuators*

California DOT: *Often use enhanced traffic enforcement with our Highway Patrol to provide an increased presence in the work zone. Typically have increased fines for speeding in construction work zones along with additional signage. Recent law requiring public slow or move over when an emergency vehicle is occupying the shoulder. Increased usage of temporary portable rumble strips to alert drivers of upcoming roadwork in certain instances. Use of the Caltrans Balsi beam in certain conditions.*

Colorado DOT: *None, standard MHT utilized at present.*

Indiana DOT: *For slow-moving lane closures, we use a series of trucks with arrow boards and impact attenuators.*

Iowa DOT: *Large maintenance vehicles provide the arrow/signage. Crash attenuator vehicle when in higher traffic volumes.*

Due to our traffic volumes we require (like some states) the reduction or lane closure miles at certain traffic times and volumes

Kansas DOT: *Data collection in this mode is treated just like a maintenance lane closure. We have signing standards that largely follow MUTCD but were developed and approved through our signing and traffic safety experts. We use pilot cars to move traffic through our work zone and provide training to all of the employees who perform the traffic control or data collection. We also use crash attenuators behind our data collection equipment.*

Louisiana DOT: *Use LADOTD Standard Traffic procedures like most state DOTD setup for Maintenance of Traffic (MOT) / Temporary Traffic Control (TTC) or Work Zone vehicles with flashing warning lights at the beginning and end of zone. Signs warning of lane closer about to beginning at the beginning along with signs informing end of Work Zone at end. Big Orange Barrels and sometimes concrete barriers blocking off area along with barricades for Work Zone and end of lane closure to make sure traffic does not enter in between flashing vehicles in to lane closed for Work Zone.*

Maine DOT: *Standard work zone as in MUTCD.*

Maryland DOT: *We have an extensive number of traffic control standards and typical applications that are utilized for varying conditions. More frequent use of variable message signs (VMS) can help with driver attention. We also implement more frequent use of vehicle-mounted attenuators for safety of workers and motorists.*

Minnesota DOT: *MUTCD*

Mississippi DOT: *Traffic control is left up to the contractor when testing is done within Scenario 3. It is sometimes an afterthought since the testing to be done is delayed by 24 hours after placement in the original lane closures.*

Missouri DOT: *The required traffic control set-ups are also provided in MoDOT's EPG (same link) for full lane closers as described by Scenario 3. Each traffic control scenario is listed which describe all the safety features that are required depending on the situation and roadway type.*

Montana DOT: *Here, we feel quite safe due to the equipment our maintenance folks have at their disposal to assist us in those rare occasions where we use their services.*

New Jersey DOT: *Similar to Scenario 2, we have typical road signs informing the road users about the work area. We also have an arrow board at the start of the work area to direct the traffic in the appropriate lanes and an attenuator truck behind the PTO.*

Pennsylvania DOT: *A traffic spotter is used in temporary lane closures when walking profilograph is used. High visibility vests and hard hats are worn by our crews. A crash truck with impact attenuator follows our falling weight deflectometer test vehicle.*

South Carolina DOT: *Pilot vehicles can aid in moving vehicles around barriers and workers and it is helpful in keeping speed at or below the posted work safety zone speed limit. This may reduce number of work zone crashes, damage claims, and unnecessary repairs to new asphalt and concrete pavements. Highway Patrol (SIT Team) is often called to monitor and work within the work zones to promote work zone safety.*

South Dakota DOT: *No, not that I am aware of. South Dakota is kind of unique in its methods for collection of crack data. Driving along the shoulder of the road (where there are shoulders) at no more than 15 mph in a continuous survey manner is not widely used.*

Tennessee DOT: *Lane closures per MUTCD are performed by personnel experienced in traffic control from TDOT's Operations Division. Operations staff is from the local county office for greatest familiarity of area. Testing is performed during off peak hours to limit traffic exposure.*

Vermont DOT: *Sign package and TTC for FWD testing*

Wisconsin DOT: *We use flaggers for this situation; All employees are required to take annual mandatory field safety training; A flaggers handbook is provided and required to be followed; Follow the MUTCD; LED flashing lights*

Question 3: To your knowledge, does your sate have any unique practice feature that improves the PTO safety during field testing (compared to other states)?

a) Scenario 1

Responses:

Iowa DOT: *Snow removal operations have approval to utilize Blue lights and White lights in unison with the Amber lights on snow removal vehicles.*

Kentucky DOT: *Rear view mirror cameras and turning lane cameras. This helps with blind spots and creates a bigger viewing area.*

Missouri DOT: *Low priority on any safety improvements.*

b) Scenario 2

Responses:

Iowa DOT: *Snow removal operations have approval to utilize Blue lights and White lights in unison with the Amber lights on snow removal vehicles.*

Maine DOT: *We have developed a "rolling work zone" for this work (e.g., Falling weight deflectometer).*

Missouri DOT: *When needed; two protective vehicles with TMA's are used with additional signing. Pre-activity meetings*

Montana DOT: *Not sure how other states do it, but we do high ADT route testing at night.*

New Jersey DOT: *Number of attenuator trucks recommended exceeds MUTCD.*

Pennsylvania DOT: *LED message boards and chevron patterns for improved visibility.*

South Dakota DOT: *Stay highly visible with lights. Maintain vigilance and escape paths. Train, train, train. Continue to develop a method to collect this data, in an automated fashion, in a high speed van. Getting the manual crews off the road will greatly reduce risk.*

c) Scenario 3

Responses:

Alabama DOT: *For the vendor QA sites, a diagram using letters indicating sign placement has been developed to be compatible with the MUTCD. When the sites are chosen, the location of the letters (and the signs) are painted on the road. This speeds setup and breakdown of the traffic control such that impacts to the traveling public are minimized (as is the time spent by field personnel in the travelway).*

Iowa DOT: *Snow removal operations have approval to utilize Blue lights and White lights in unison with the Amber lights on snow removal vehicles.*

Missouri DOT: *MoDOT has worked on flagging operations and methods. Not only are the flaggers being trained; but everyone is required to take flagging training in order to know what to look for and the correct methods are being used. Additional cones are being used to stop vehicles at the flagger's position as illustrated below. Portable rumble strips are being investigated to slow down drivers prior to reaching the work zone. There are weekly conference* *calls regarding work zone impacts on MoDOT's heavy interstate routes I-70 and I-44. These weekly conference calls provide a means of sharing work zone impacts (potential impacts) across the state. There is also a spreadsheet that is filled out every week that corresponds with these weekly conference calls. The information provided in the spreadsheets is for the next week's work zones/impacts. This information is included on MoDOT's Traveler's Information Map which is on MoDOT's web page for public viewing. There are weekly conference calls regarding work zone impacts on MoDOT's heavy interstate routes I-70 and I-44. These weekly conference calls provide a means of sharing work zone impacts (potential impacts) across the state. There is also a spreadsheet that is filled out every week that corresponds with these weekly conference calls. The information provided in the spreadsheets is for the next week's work zones/impacts. This information is included on MoDOT's Traveler's Information Map which is on MoDOT's web page for public viewing.*

New Jersey DOT: *NJDOT standards use breakaway barricades for taper. MUTCD adopted by most state use cones or drums for taper.*

Tennessee DOT: *TDOT has for several years emphasized queue protection/advance warning.*

Question 4: Do you have any suggestions or comments on the PTO's safety during pavement field testing, in terms of equipment design, operation procedures, MOT practices, etc.?

a) Scenario 1

Responses:

Arizona DOT: *shadow the profile test vehicle when an impact attenuator when need.*

California DOT: *Vehicle design should be so that the driver's sole responsibility is to focus on driving. Operation of computers and components should be accomplished by passengers only.*

Kentucky DOT: *I would recommend scaling down the size of the test equipment. We use a passenger van that is boxy and reduced turning radius. A once a year safety training class should be required as part of driver certification.*

Maryland DOT: *Require personnel to have some type of driver safety training or defensive driver training. Establish safety protocols.*

Montana DOT: *Use state of the art high intensity flashing lights, have frequent safety meetings so the crew is reminded and aware of the issues of the roadway.*

Nevada DOT: *Non Flashing High Intensity Blue lights, vehicle-mounted message/ arrow board.*

Tennessee DOT: *minimize speed differential*

Utah DOT: *I think more PTO safety related webinars or NHI courses, best practices from other States and retrofit of the testing equipment by manufactures/vendors with more automation and safety related features and technologies will always benefit PTO safety.*

Wisconsin DOT: *Hands-free phones (Bluetooth) or pull-over to talk/call out; Try to avoid equipment with excessive age. Equipment problems are a distraction; Park vehicle in safe location to address equipment problems.*

b) Scenario 2

Responses:

Arizona DOT: *use local or state law enforcement as part of the rolling closure whenever possible to slow traffic down.*

Arkansas DOT: *The addition of blue lights on testing vehicles may reduce the speed of the traffic. Currently in Arkansas blue lights are reserved for law enforcement vehicles. Law enforcement vehicles with blue lights on are used on specific types of construction projects and has shown that traffic slows down significantly when law enforcement is present within the project limits.*

Iowa DOT: *Light bars on rear of testing vehicles have improved public awareness and reactions.*

Kentucky DOT: *Our state as a whole has very good safety track records.*

Montana DOT: *Again, use state of the art high intensity flashing lights, use one or 2 shadow vehicles appropriately spaced behind the testing vehicle. These shadow vehicles should have high intensity LED lit Variable Message Boards with well-trained operators to pick the appropriate message at the appropriate time. Another thing, perform your high ADT route testing at night.*

New Jersey DOT: *Increase the number of attenuator trucks and use state troopers.*

Pennsylvania DOT: *Our slow-moving testing equipment does not have a crash truck following the operation under most scenarios. Development of a smaller scorpion type impact attenuator for minivan/SUV sized vehicles would improve protection from rear impacts.*

Utah DOT: *I think would be nice to have PTO safety related webinars or NHI courses. Publication on best practices from other States and retrofit of the testing equipment by manufactures/vendors with more automation up to date or latest safety features and technologies will always add values.*

c) Scenario 3

Responses:

Arizona DOT: *use local or state law enforcement as part of the rolling closure whenever possible to slow traffic down.*

Iowa DOT: *Maintenance assistance for traffic control on closed lane operations is ideal.*

Kansas DOT: *We would like to continue to provide safe work zones while we collect data, but it seems like a lot of time and effort go into the traffic control. It would be great if it could be done with less signs, cones, etc. and still be safe.*

Minnesota DOT: *We could use some standards for marking the locations of cores when a road is partially open to traffic. We often have inspectors dodging traffic to layout many things (striping) rather than close the road. Cutting cores is a semi-mobile operation that creates some open discretion when interpreting the MUTCD. On very low volume roads, things may not always be done to standard.*

Missouri DOT: The presence of law enforcement and video radar detection could be implemented in longer-term work zones.

Montana DOT: *Use them when you can – these are the Cadillac situations in our opinion, when you can use a temporary traffic zone.*

New Jersey DOT: *Require Work Zone Safety certification from the consultants and contractors.*

Pennsylvania DOT: *Develop an automatic radar ticketing system for work zones.*

South Carolina DOT: *More funding and availability for the highway patrol to monitor traffic flow and use blue lights to slow the public down when driving through work zones.*

Tennessee DOT: *Advance warning for traffic, utilize MUTCD design for closures performed by professional staff with local knowledge of traffic, minimize exposure by working in off-peak times.*

APPENDIX B BRIEF TUTORIAL ON THE USE OF FREESR

Freesr speech recognition software works with other software programs (e.g., FDOT vehicle data collection software) through defined voice commands within specific templates specially set for individual software programs. Freesr templates can be categorized into two broader types: global template and specific software templates. Global template includes voice command that can be executed in any interface if Freesr is activated, but template defined for specific software contains voice commands that will be executed only if that software is opened and within its interface. Specific template determines which voice command will be executed to operate which software. For example, same voice command can be defined to execute different commands within two different software programs, but when the template for specific software is activated the operation defined for that software only will be executed. In Freesr, once a software program is opened the corresponding template for that application is also activated automatically without taking further steps. Thus, only the voice commands set for that software within its template will be executed once it is opened. Voice commands set in the global template will be executed all the time if Freesr is activated. The following sections describe how voice commands can be defined to execute an operation in both global and specific templates. The procedures of creating and working with templates will also be included in the discussion. At the end, a typical application example will be presented to illustrate how Freesr executes defined operations through voice activated commands.

Creating templates

To create a template and assign that template to a specific software program, as shown in Figure B-1, the following steps may be followed:

1. Left click on “Open Template Manager” (a window will pop up where creating, editing, deleting and importing template may be performed).
2. Left click on “New”.
3. In the next window the template name and description should be written. Then left click on ‘Next’.
4. In the prompted window the template should be linked to an application for which commands within this template will run. To link up left click on “Add” and then browse to the application location. Another way to do this is to open the application and press F5 key when a red box with cross mark appears on the program window and then the program file path will be automatically taken.
5. Check program file name and left click on “OK”.
6. Then left click on “Next”.
7. Finish creating template by left clicking on “Finish” button.
8. Left click on “Exit Edit Mode” and now Freesr is ready to put the change into action.

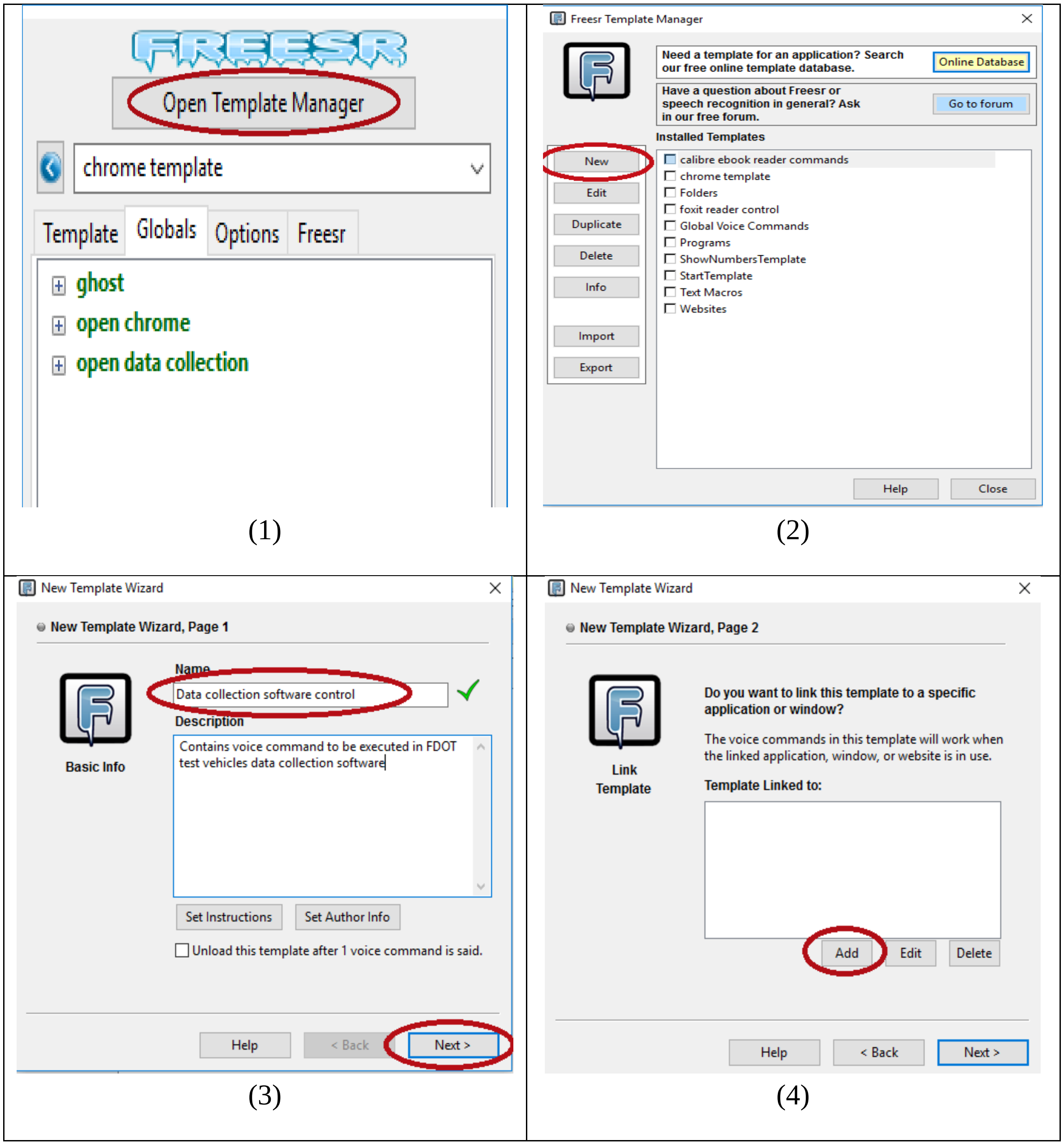


Figure B-1 Steps to follow to create template in Freesr and link it to the software program

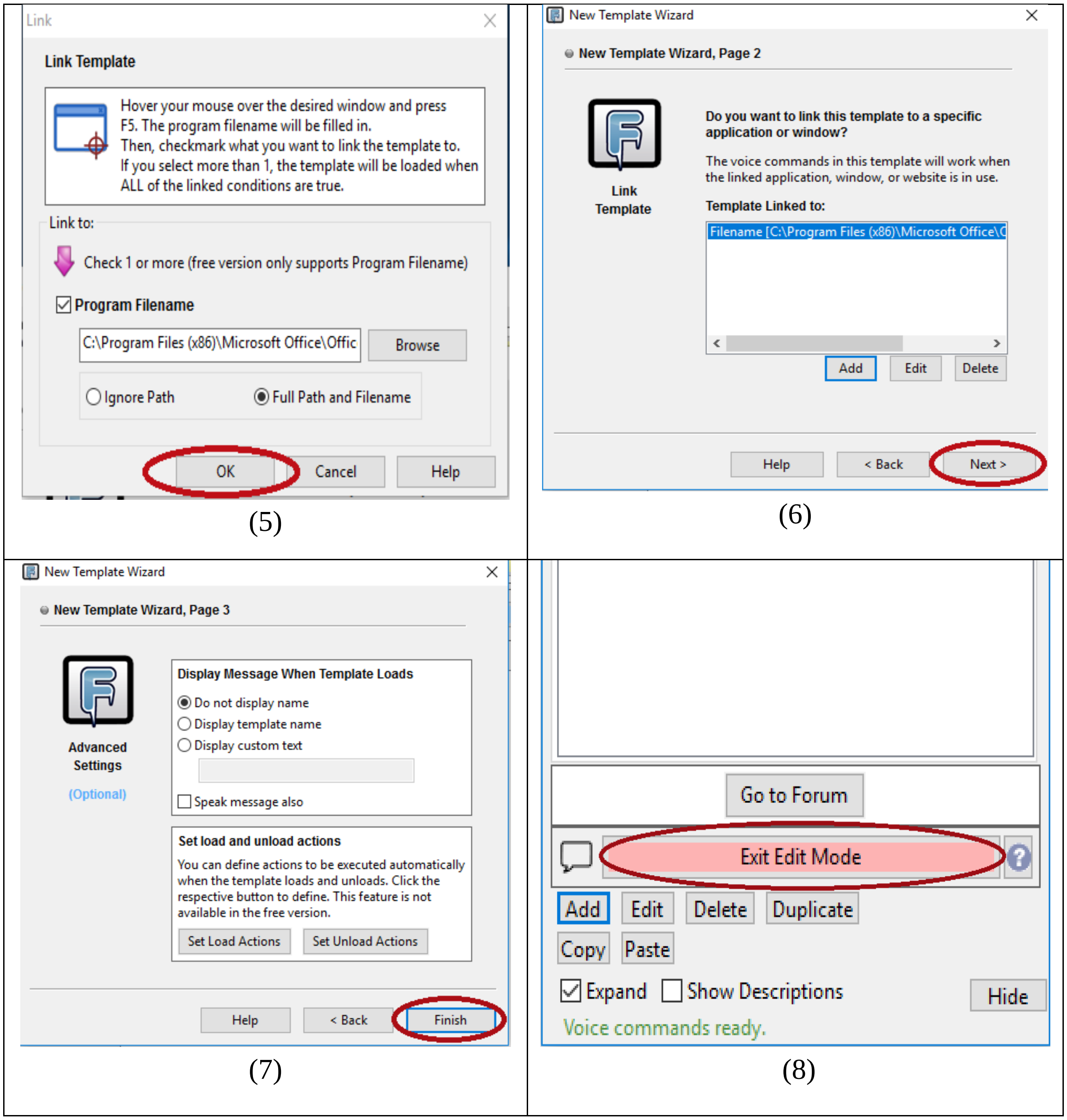


Figure B-1 Steps to follow to create template in Freesr and link it to the software program (Cont'd)

Defining voice command within created template for specific action

A specific voice command defined within a template means that the action corresponding to that command will only be executed when the software program linked to that template is opened. For demonstration purpose, this section shows how to set up a voice command that will execute an operation (which is done by pressing F8 key in the keyboard in usual software interface) by a defined voice dictation, for example 'roughness'. This means after this setup the Freesr will do the job of pressing "F8" key in the linked software interface when the operator gives voice command “roughness” through her/his microphone. Following steps, as shown in Figure B-2, describe how to set this up:

1. Left click on the drop down menu bar at the top of Freesr side window and select desired software template. This can be done by opening that software as when opened the corresponding template is automatically selected in Freesr.
2. Left click on “Add/Edit” button at the bottom of the side window. This will bring the options for adding, editing, and deleting commands.
3. Left click on “Add”.
4. In the popped up window while ‘voice command’ option is checked left click “OK”.
5. Write a convenient voice command for the desired operation; in this case write “Roughness”. So when “roughness” is uttered the desired operation will be executed. When finished writing, left click on “Next”.
6. After completing the previous step a new window will open. From this window required action can be chosen from a diverse set of actions for the voice command set in the previous step. For FDOT survey vehicles operations, only the action of sending a key press is needed. So “Send Key” action from this box should be selected. Left click on “Send key” and then click “Add”.
7. The prompted window will ask which key press needs to be sent. For this demonstration, assuming the “F3” function key needs to be pressed when the word “roughness” is spoken, “{F3}” is typed in the box. Left click on “OK”.
8. Left click on “Finish”. Now the voice command is added to the application template.
9. Left click on “Exit Edit Mode” to let Freesr be ready to execute the command.

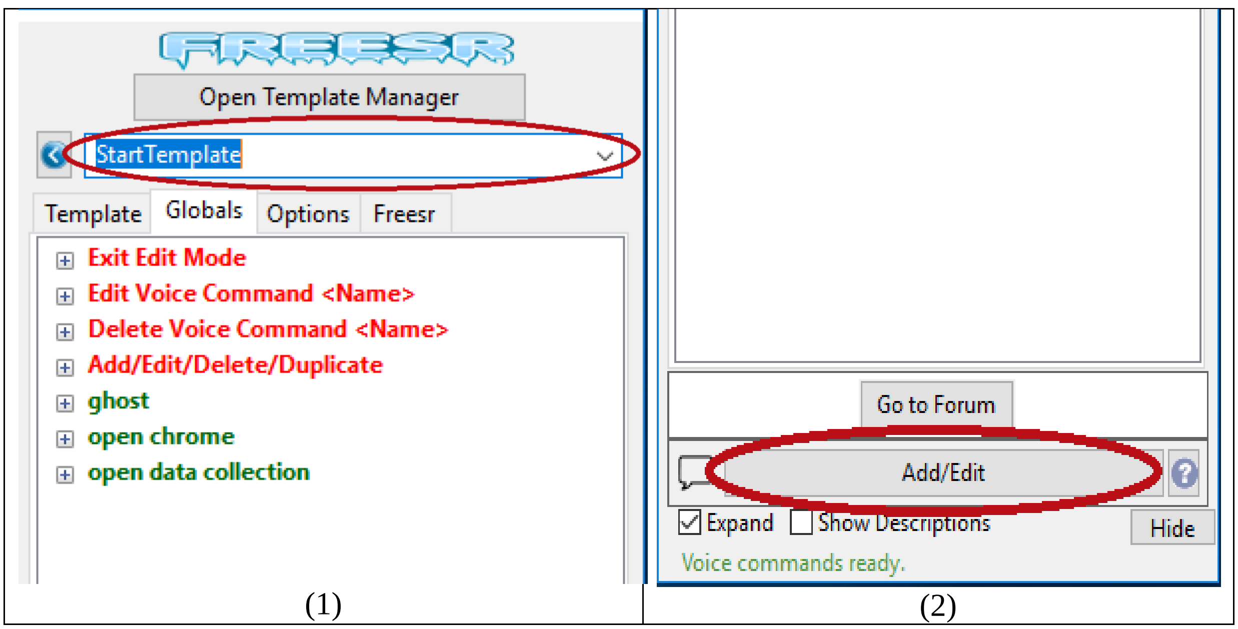


Figure B-2 Steps to define voice commands in template linked to software

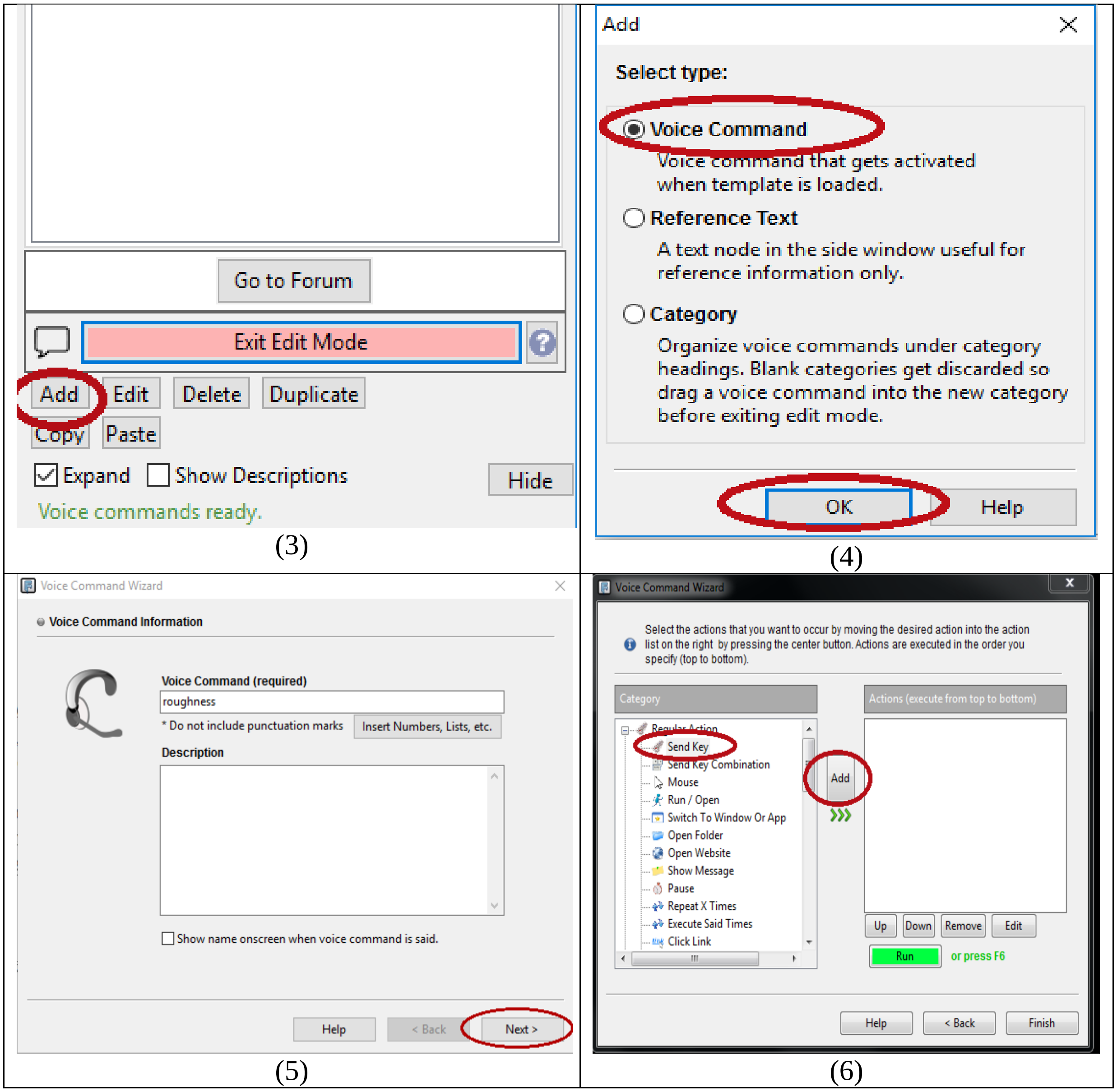
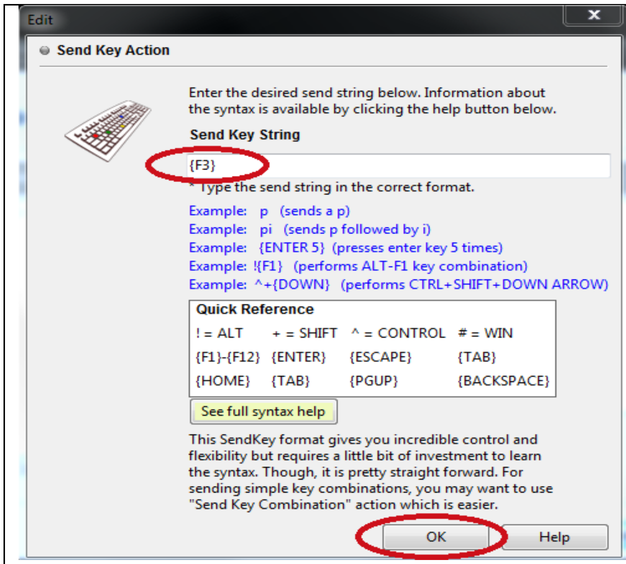
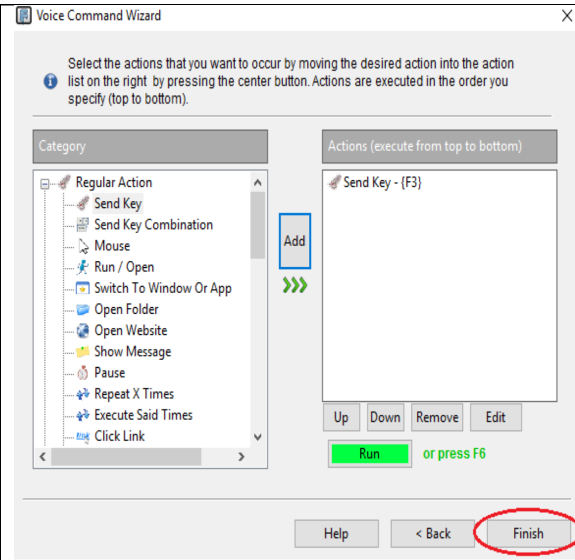


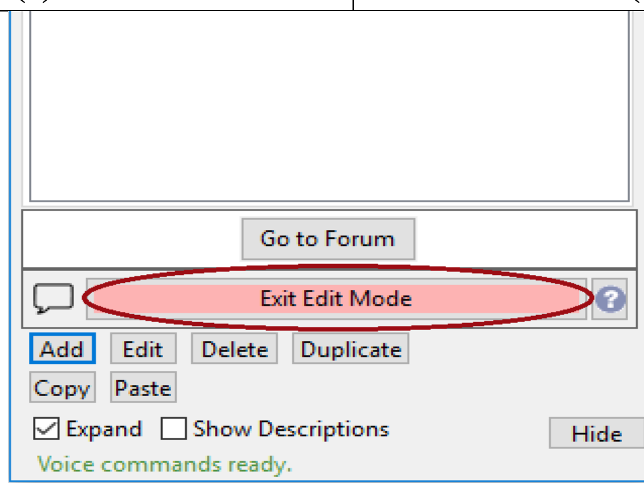
Figure B-2 Steps to define voice commands in template linked to software (Cont'd)



(7)



(8)



(9)

Figure B-2 Steps to define voice commands in template linked to software (Cont'd)

Defining voice commands in global template

Templates linked to specific software programs contain voice commands that can be executed if only those programs are open. On the other hand, global template contains voice commands that are executed in every situation when Freesr is active. Below are steps to define voice commands in global template, as shown in Figure B-3, using the command to open a data collection program as an example:

1. Select the "Globals" tab at the top section of Freesr side window. Then left click on "Add/Edit" at the bottom portion of the side window.
2. In the next window left click on "Add" to add a new command. Commands can be edited or deleted in the global template by selecting suitable box at the bottom of this window.
3. Left click on "OK" in the prompted window. Write down the voice command (e.g., "Open data collection") and then left click on "Next".

4. Now from this window select “Run/Open” by a left click and then click on “Add”.
5. Software program that needs to be opened by this voice command should be selected in this window. This can be done in two ways as described in the previous section. One way is to browse the software file location and select the application file of that software. Another way is to open that software and press the “F5” key on the keyboard when a red box with cross mark appears over the software window. When done it should be made sure that the proper file path is shown in the software path box. Then left click on “Ok”.
6. Finish the step by clicking on “Finish” in the next window.
7. Left click on “Exit Edit Mode”. Now Freesr is ready to execute the added or edited command.

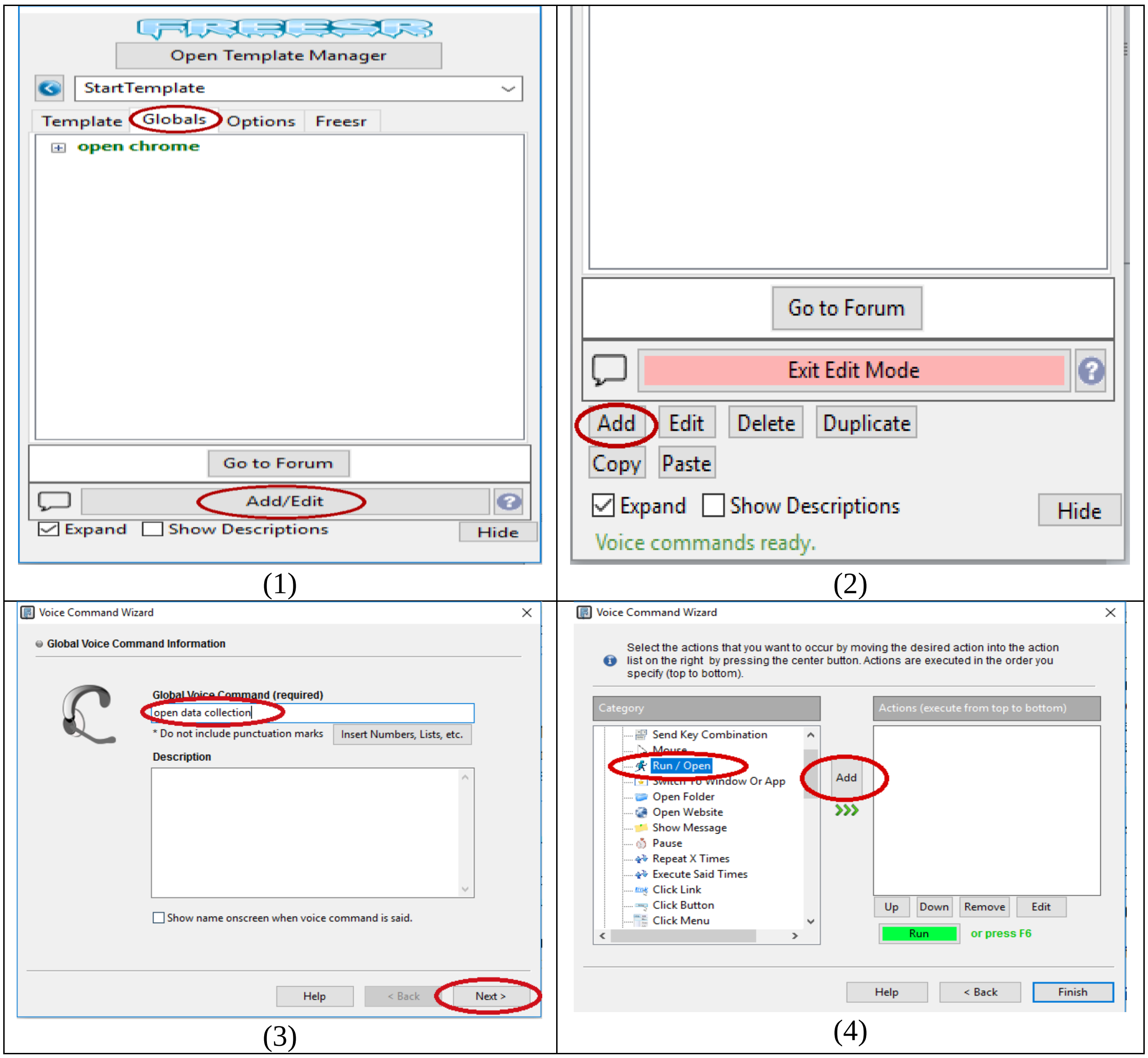


Figure B-3 Steps to follow to define voice commands in global template

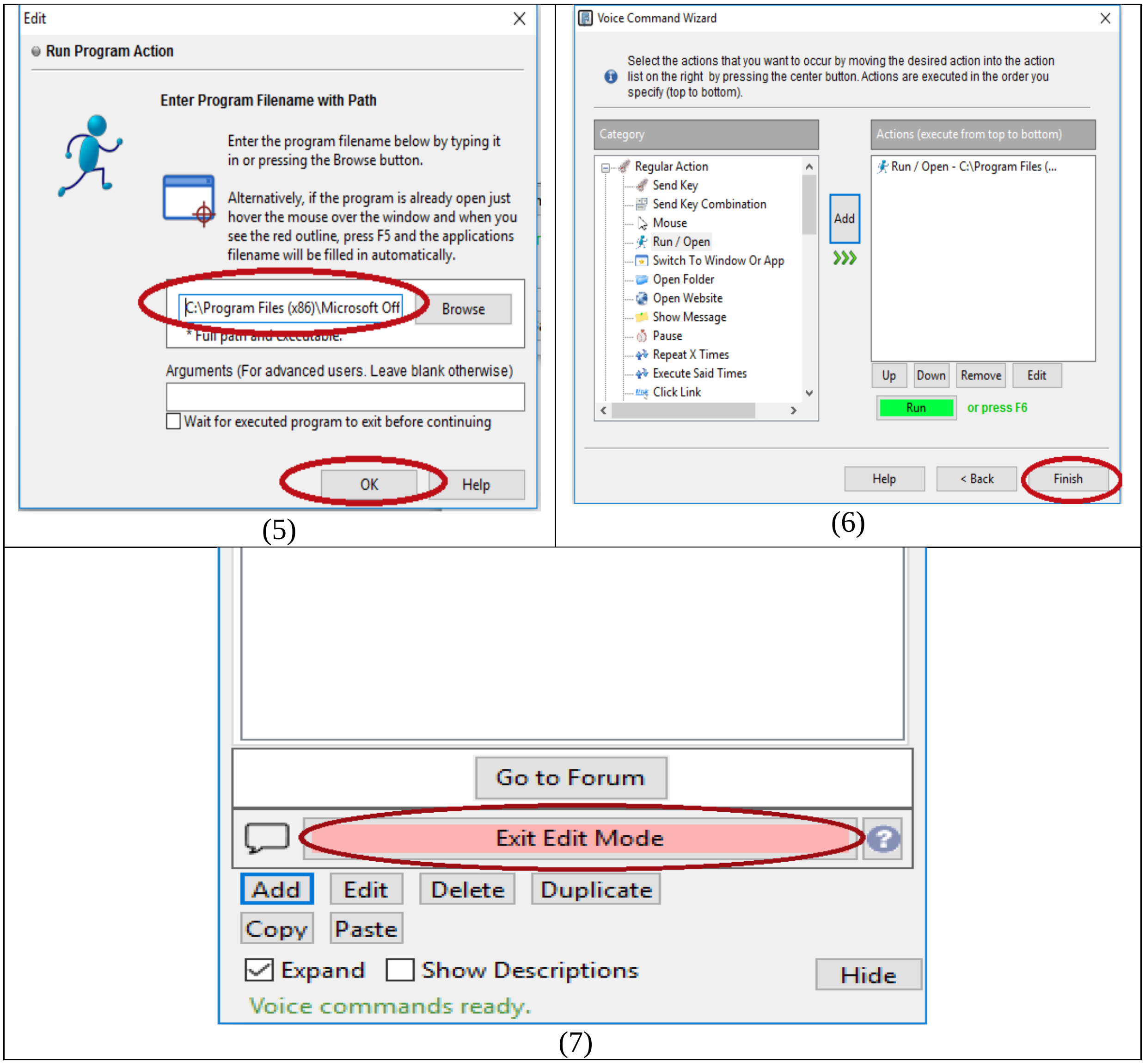


Figure B-3 Steps to follow to define voice commands in global template (Cont'd)

As it has been realized so far that the FDOT survey vehicles need to execute only a few operations using voice commands. So, instead of creating new templates, another option can be to define those commands in the global template. This option should be chosen if FDOT decides to use Freesr to control only one software program (e.g., data collection software) with voice activated commands. However, if multiple software programs need to be controlled using Freesr, it is recommended to create different templates and define voice commands in those templates.

Operating any software through voice commands using Freesr

Once template creation and voice command definitions are completed, the linked software programs may be operated using voice commands through Freesr. Following steps will help better understand the operation of Freesr while executing voice commands in linked software programs.

1. Open Freesr by double clicking on its desktop icon. Freesr interface is very simple. By default its interface is located in the top middle position of a computer screen. The interface has three components: settings menu on the left, audio activation control in the middle, and side window control on the right. The side window can be revealed or hidden by left clicking on the right most icon of the interface. As shown previously, the side window contains an interface where all the templates and associated voice commands can be created, edited, and deleted.
2. To activate the execution of voice commands through Freesr, its audio control should be activated. This can be done by just one click on the middle button of the interface resembling a headphone with a microphone. Once activated it will be highlighted by green background color which indicates that all Freesr voice commands can be executed and Freesr is ready to listen to voice commands. If clicked again Freesr audio control will be deactivated and the green highlight will be replaced with the usual grey color.

There are many other actions that can be performed using Freesr, but they are not included in this brief tutorial, since this document is only prepared for the operations of FDOT survey vehicles. It is expected that the operators will need some time to get accustomed with the operations and the idea of using a microphone while driving. Besides, it is recommended to use a microphone without headphone for inputting audio commands because a headphone may hinder the operator's listening capacity. Based on the experience of the investigators with Freesr, the software is very good at recognizing a user's voice and commands. But even if scarcely, sometimes it fails to realize the commands correctly specially at the beginning of use. However, this issue gets better as the software is used more and more over the time. For this reason, it is recommended to run Freesr with data collection software a few times before going to actual test sites, to make sure it works with high accuracy and the operator is comfortable with its use.