Final Report

Prioritized Safety Consideration by Work Zone Types and Pilot Implementation

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Prepared for:

Florida Department of Transportation

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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric Conversion Chart

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
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

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16. Abstract

With the growing need for maintenance or reconstruction of existing infrastructure and the construction of new infrastructure, work zone (WZ) setup and management are important for the safe and efficient movement of road users and protection of construction workers and personnel. Applications of Smart Work Zone (SWZ) systems, which are efficient in traffic management and safe for traffic, workers, and pedestrians, have received significant attention in Florida and other states. This study conducted a pilot implementation of SWZs to evaluate the effectiveness of deploying Active Work Zone Awareness Devices (AWADs), connected vehicle technologies via iCone products, stationary police vehicles with flashing blue lights, and their combinations in improving WZ safety on arterials, considering three stationary WZ types: lane closure, lane shift, and work on shoulder or median. This research focused major efforts to evaluate the effectiveness of AWAD deployment and its combinations with other applications. AWADs employ radar combined with flashing Light-Emitting Diode (LED) signs that warn drivers of an upcoming active WZ for arterial roads. These devices indicate travel speed and display safety signage of "Active Work Zone When Flashing" and "Speeding Fines Doubled." In this project, vehicle speed data and driving behavior data were collected at seven study sites in Florida Department of Transportation (FDOT) District 7 that cover various WZ types, roadway classifications, and traffic conditions. Statistical analyses were applied to compare safety performance, including vehicle speeds, sudden deceleration behaviors, and sudden lane change behaviors between deployments of SWZs under different scenarios and their baseline conditions (without SWZ deployments). Significant results of the research at seven pilot implementation sites included decreasing speeds entering arterial WZs by 10%, increasing safe driving behavior by 44%, and reducing risky driving by 43% by deploying AWADs alone. By combining AWAD deployments with the presence of law enforcement, more reductions in vehicle speeds and risky behaviors were achieved. For iCone products using Connected Vehicle (CV) technology to communicate WZ conditions or warnings with road users, it is anticipated to have an impact on reducing vehicle speeds approaching a WZ if a WZ message can be displayed and/or broadcasted automatically via WAZE and other navigation systems in the future.

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Executive Summary

Background

With the growing need for maintenance or reconstruction of existing infrastructure and the construction of new infrastructure, work zone (WZ) setup and management are important for the safe and efficient movement of road users and protection of construction workers and personnel. With unexpected driving conditions, WZs or construction areas are likely to cause unexpected traffic delays and interrupt the expectation of drivers, resulting in erratic maneuvers that cause safety concerns for overall traffic and workers. With the increase in Intelligent Transportation Systems (ITS) applications in WZ management, many studies are identifying and implementing Smart Work Zone (SWZ) concepts that are efficient in traffic management and safer for traffic, workers, and pedestrians.

Previous SWZ projects were limited primarily to dedicated freeways and expressways. More WZ fatalities were found on state roads and arterials than those on interstates in Florida. As a result, it is needed and essential to build on previous research on freeways and expressways and expand it to cover WZs on state roadways, arterials, and local roads; study specific WZ types; further investigate SWZ applications; and find cost-effective and practical solutions to reduce arterial WZ and worker-related fatalities, injuries, and crashes.

Research Objectives

This study aimed to conduct a pilot implementation of SWZs to evaluate the effectiveness of selected SWZ applications in improving WZ safety on arterials. The pilot study focused on three stationary WZ types: lane closure, lane shift, and work on shoulder or median. With a proper understanding of the safety performance by WZ type under various combinations of SWZ applications and law enforcement (LE), different strategies, countermeasures, and technologies can be effectively implemented to reduce arterial WZ-related fatalities, injuries, and crashes by minimizing the risk associated with the severity of crashes.

The major focus of this research project was to deploy and evaluate SWZ applications and strategies to reduce vehicle speeds, speed variance, sudden decelerations, and sudden lane changes within WZ limits on arterials considering the following:

- AWAD
- Presence of LE via a stationary police vehicle with flashing blue lights
- Connected vehicle (CV) technologies (iCone products)
- Combinations of these technologies
- Methodology.

A before-after study method was used in this study to evaluate the effectiveness of AWAD deployment, presence of LE, CV technologies using iCone products, and their combinations in reducing vehicle speeds and risky behaviors on arterial WZs. The basic steps of the before-after study included close coordination with all involved agencies to implement SWZ applications, intensive data collection for various testing scenarios, qualitative and quantitative data analyses, and development of research findings, conclusions, and recommendations. Vehicle speed data and driving behavior data were collected at each study site under specific testing scenarios, and researchers conducted detailed statistical data analysis for each testing scenario at each study site and an overall analysis to evaluate the effectiveness of deployed WZ applications and develop research findings based on the analysis results.

Characteristics of Pilot Study Sites

Maintenance of Traffic (MOT) is the layout of cones, barrels, and other devices outlined in the FDOT Standard Plans Indix 102. Considering available arterial WZs, WZ MOT types, and MOT schedules, the research team consulted with the FDOT Project Manager (PM) to select seven study sites for pilot deployments of SWZ applications to cover different WZ types, roadway types, and traffic conditions, as shown below.

Pilot Study Site	Work Zone Type			Roadway Type	AADT (veh/day)	WZ/Posted* Speed Limit (mph)
	Lane Closure	*Median/ Shoulder*	*Lane Shift*			
US-98		✓	✓	Rural two-lane	7,500	25/45
SR-580 (E Busch Blvd)	✓			Multilane arterial	50,000	40/40
US-92 (E Hillsborough Ave)	✓			Multilane arterial	45,000	45/45
US-19 (N Hudson)	✓			Multilane arterial	50,500	44/55
N Dale Mabry	✓			Multilane arterial	51,000	55/55
US-301	✓	✓		Multilane arterial	52,000	45/50
Veterans Expressway	✓	✓		Freeway off-ramp	5,000	25/25

*Display of WZ posted speed limit and roadway posted speed limit.

For each pilot study site, the research team collected data at two positions: upstream of WZ activity zones (advance warning area) (P1) where SWZ applications were deployed and work activity areas (P2) with workers present during activation periods. Two devices (WaveTronix SmartSensors and GoPro Cameras) were used to collect data; WaveTronix SmartSensors measure vehicle speed on each lane, and GoPro cameras record traffic conditions, traffic signal status, and driving behaviors. The testing scenarios represent the combinations of various SWZ applications and the presence of LE, as shown below.

Testing Scenarios

The research team designed various testing scenarios, as shown in the following table. For each study site, researchers always collected "before" data (baseline) and strived to collect "after" data under different testing scenarios when a WZ MOT schedule allowed.

Scenario	Description
OFF (Baseline or Before Implementation)	• Traditional MOT • No SWZ application activation and/or LE present • Baseline for comparison with SWZ and LE scenarios
AWAD	• Only AWAD present • Activation during work zone activities
LE	• Only LE presence • Activation when MOT present
AWAD + LE	• Both AWAD and LE activated • Activation during work zone activities
iCone + AWAD	• Both AWAD and iCone activated • Display message to WAZE users when AWAD activated
iCone + Arrow Board	• Attached iCone connectivity box to Arrow Board • Display message to WAZE users when both iCone and Arrow Board activated
iCone + AWAD + LE	• Attached iCone connectivity box on AWAD • Activated LE at same time • Display message to WAZE users when both iCone and AWAD activated
iCone + Arrow Board + LE	• Attached iCone on arrow board • LE present at the same time • Display message to WAZE users when both iCone and Arrow Board activated
iCone + Arrow Board + AWAD	• Attached iCone on arrow board • Activated AWAD at the same time • Display message to WAZE users when both iCone and Arrow Board activated
iCone + Arrow Board + AWAD + LE	• Attached iCone on arrow board • Activated both AWAD and LE activated at the same time • Display message to WAZE users when both iCone and Arrow Board activated

Based on the collected data, the research team conducted a series of statistical comparisons between the baseline (OFF scenarios) and various SWZ and LE scenarios on vehicle speeds and driving behaviors (lane changing and deceleration). The improvement of these safety measures due to the implementation of SWZ applications and LE presence were qualified and quantified through the statistical analysis.

Major Findings

- Innovative SWZ applications and strategies identified for arterials to improve or enhance WZ safety include AWAD and iCone applications with combination with LE.
- Under low or moderate traffic conditions, deployment of AWAD or combined AWAD and LE applications is effective in reducing vehicle speeds and increasing safe driving behaviors for various testing scenarios considering different WZ types, posted speed limits, number of lanes, and urban and rural areas.

- Under heavy traffic or traffic congestions, deployment of AWAD does not impact vehicle speeds.
- Significant results for the seven pilot sites include decreased vehicle speeds entering arterial WZs by 10%, increased safe driving behavior by 44%, and reduced risky driving by 43% by deploying AWADs alone.
- Deploying combined AWAD + LE applications generally can further reduce vehicle speeds and increase safe driving behaviors than can AWAD alone.
- Deployment of AWAD applications can reduce vehicle speeds approaching a WZ up to 21%, with an average reduction of 10%; deployment of combined AWAD + LE applications can reduce vehicle speeds approaching a WZ up to 43%, with an average reduction of 19%.
- LE is always effective for speed management in WZs. With the presence of LE, the effectiveness of AWAD was observed as having a reduction in speed variance, which can be translated to smoothing the speed variation along the traffic stream near the work area.
- The combination of AWAD + LE is superior, especially for WZs on rural roads with high posted speed limits and a high reduction of posted speed limits from regular segments to WZ areas.
- The deployment of iCone + AWAD or Arrow Board showed little impact on reduction of vehicle speeds due to the need for drivers to use WAZE navigation systems and click on the iCone WZ message. If a WZ message can be displayed and/or broadcasted automatically via WAZE and other navigation systems, it is anticipated to have an impact on reducing vehicle speeds approaching a WZ.
- Results from field observation show that safe driving behaviors such as smooth lane change or slowdown increased up to 109% for deployment of AWAD from the baseline, with an average increase of 44%. Safe driving behaviors increased up to 136% for deployment of combined AWAD + LE from the baseline, with an average increase of 67%.
- Results from field observations show that risky driving behaviors such as sudden lane change or deceleration decreased up to 75% for deployment of AWAD from the baseline, with an average decrease of 43%. Risky driving behaviors decreased up to 100% for deployment of combined AWAD + LE from the baseline, with an average decrease of 54%.
- The deployment of AWAD or a combination of AWAD and LE is effective in reducing vehicle speeds and risky behaviors when entering an arterial WZ for all WZ types.
- Education campaigns via billboards with WZ safety messaging combined with WZ safety PSA radios broadcasted can achieve reduction of vehicle speeds by 4% to 11%.

- The percentage of WZ-related fatalities involving large trucks (commercial vehicles) was higher than that in non-WZ-related crashes in Florida with an average of 21%.
- The SWZ applications have more impacts on vehicle speed reduction in WZs on rural highways than those on urban or suburban arterials because slower speed limits are usually posted in rural, not in urban or suburban WZs.
- The SWZ applications have more impacts on vehicle speed reduction for a travel lane immediately adjacent to the WZ activity area than those for other lanes on urban or suburban arterials.
- It is important to collaborate with construction industries on their safety needs and concerns about WZs.

Conclusions

- This research project demonstrated successful use of advanced technologies to improve safety in arterial roadway WZs, demonstrably slowing down drivers and improving driver behavior.
- The deployment of AWADs alone can effectively reduce vehicle speeds approaching a WZ on arterials, increase safe driving behaviors, and reduce risky driving behaviors. Combining AWAD + LE at an arterial WZ can achieve a significant improvement of WZ and worker safety.
- The deployment of iCone + AWAD or Arrow Board showed little impact on reduction of vehicle speeds due to the need for drivers to use WAZE navigation systems and click on the iCone WZ button on the WAZE display. If a WZ message can be displayed and/or broadcasted automatically via WAZE and other navigation systems, it is anticipated to have an impact on reducing vehicle speeds approaching a WZ.

Recommendations

- AWAD implementation should be standardized and included in FDOT WZ MOT design so designers, contractors, PMs, and administrators can routinely use it on arterial and freeway WZs to improve WZ safety and protection of WZ workers.
- Implement AWADs in WZs on arterials with low or moderate traffic conditions to reduce approach speed, increase safe driving behaviors, and reduce risky driving behaviors.
- Implement combined AWAD + LE at WZs to achieve the maximum effectiveness in improving WZ safety, especially on rural roads with high posted speed limits.
- The capability of AWAD deployment to reduce vehicle speeds will gradually decrease with time. If LE cannot be always available to support AWAD deployment, an agency still can deploy LE periodically to help maintain the effectiveness of AWAD.

- Place an LE vehicle just upstream, not at a WZ activity area on arterials, to increase the visible presence of LE.
- Deploy AWAD application or combined AWAD + LE to any work type, including work on shoulder or median, lane closure, and lane shift.
- To prevent an incident of trailer battery stolen during a field data collection, it is important to secure trailers during the data collection.
- Although this SWZ pilot deployment focused on WZs on arterials, the recommended implementations can be applied to WZs on freeways.
- Conduct further study on the effectiveness of iCone devices or similar devices connected to AWAD or Arrow Boards to reduce vehicle speeds and risky behaviors when an iCone WZ message can be automatically displayed or broadcasted by WAZE and other navigation systems.

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List of Acronyms

AWAD	Active Work Zone Awareness Device
AVI	Automatic Vehicle Identification
AVL	Automatic Vehicle Location
CARS	Crash Analysis Reporting System
CHIPS	Computerized Highway Information Processing System
CCTV	Closed-Circuit Television
CMS	Changeable Message Sign
CTMC	Construction Traffic Management Center
DLM	Dynamic Lane Merge
DMS	Dynamic Message Sign
DSRC	Dedicated Short-Range Communication
DSD	Dynamic Speed Display
DSL	Dynamic Speed Limit
DOT	Department of Transportation
EDC	Every Day Counts
EEV	Entering/Exiting Vehicle
ESS	Environmental Sensor Station
FARS	Fatality Analysis Report System
FDOT	Florida Department of Transportation
FHWA	Federal Highway Admiration
HAR	Highway Advisory Radio
IDOT	Illinois DOT
ILCS	Intelligent Lane Control System
ITS	Intelligent Transportation System
KDOT	Kansas DOT
LED	Light-Emitting Diode
MAS	Motorist Awareness System
MDOT	Michigan DOT
MnDOT	Minnesota DOT
MOE	Measures of Effectiveness

MOT	Maintenance of Traffic
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
OBU	On Board Unit
PCMS	Portable Changeable Message Sign
PTMS	Portable Traffic Management System
QWS	Queue Warning System
RF	Radio Frequency
RFID	Radio Frequency Identification
RTMS	Radar Traffic Microwave Sensor
RTT	Real-Time Travel
RWIS	Road Weather Information Sensor
SDLMS	Simplified Dynamic Lane Merging System
SHSP	Strategic Highway Safety Plan
SSOGIS	State Safety Office Geographic Information System
SWZ	Smart Work Zone
TMC	Traffic Management Center
TMP	Transportation Management Plan
TTC	Temporary Traffic Control
TTCP	Temporary Traffic Control Plan
TPAR	Temporary Pedestrian Access Routes
WZ	Work Zone
WZITS	Work Zone Intelligent Transportation System
VASL	Variable Advisory Speed Limit
VSL	Variable Speed Limit
VMS	Variable Message Sign
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle

1. Introduction

1.1 Background

With the growing need for maintenance/reconstruction of existing infrastructure and the construction of new infrastructure, work zone (WZ) setup and management are important for the safe and efficient movement of road users and protection of construction workers and personnel. These WZs are configured and managed through the use of special traffic signs, standard channelizing devices, appropriate barriers, pavement markings, construction vehicles, and construction workers. The special conditions of roadways require some level of monitoring by state and local enforcement for safe and efficient traffic operation; as such, driving conditions inside WZs require more attention than normal driving conditions because of construction, maintenance, and utility work activities. Moreover, WZs also vary by duration and type of work not encountered on a normal roadway system. With these unexpected driving conditions, WZs or construction areas are likely to interrupt the expectation of drivers, resulting in unexpected traffic delays and erratic maneuvers that result in safety concerns for overall traffic and workers.

WZ geometries are different from typical roadway geometries. With unexpected driving conditions through different WZ types and associated configurations, drivers must pay special attention when driving. However, speeding, careless driving, lack of familiarity with WZs, impaired driving, roadway curvature, and visibility issues at night are commonly known to be major contributing factors to WZ-related crashes.

Florida has ranked #2 in the U.S. in traffic fatalities in WZ and worker fatalities since 2012; for WZ crashes, 30%–40% of fatalities involve workers and pedestrians. Construction workers and pedestrian safety concerns are important in WZ areas for multilane urban highways and at intersections (within WZ limits). Based on a review of WZ crashes, Hillsborough, Pinellas, Pasco, and Hernando counties in Florida Department of Transportation (FDOT) District 7 rank in the top 10 for WZ-related crashes in Florida for the following population categories:

- Population > 200,000 – Hillsborough #1, Pinellas #2, Pasco #8
- Population 50,001–200,000 – Hernando #2

By geometric configuration and WZ setup, WZs vary by type. There are four major WZ types: (1) lane closure, (2) lane shift or crossover, (3) work on shoulder or median, and (4) intermittent (i.e., mobile operations).

Initial assessment by the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) on WZ-related crash data suggests that crashes that occur in areas where work is being performed on shoulders or medians are 1.1–1.5 times more likely to result in severe injury (fatality or serious injury) compared to other WZ types. Moreover, the major functional classes of roadway (Freeway/Expressway, Principal Arterial, Collector, Local) crashes on local and collector systems for work performed on shoulders or medians are 1.3–4 times and

1.2–1.6 times more likely to occur, respectively. Because of low percentage of intermittent WZ crashes, it is important to investigate the causes, contributing factors, and effective countermeasures for three WZ types—lane closure, lane shift, and work on shoulder or median.

A review of locations of WZ-related crashes in FDOT District 7 shows that most (60% of more) WZ crashes occur on state and local roads, not on interstates and expressways. Initial assessment of WZ-related crash data also suggested following general contributing factors:

- Disregarding traffic signs for lane closures
- Exceeding posted speed limit
- Over-correcting for work on shoulders or medians

1.2 Smart Work Zone

With the increase in Intelligent Transportation Systems (ITS) applications in WZ management, many studies are identifying and implementing Smart Work Zone (SWZ) concepts that are efficient in traffic management and safe for traffic, workers, and pedestrians. Application of SWZ systems to improve safety and mobility has received significant attention in Florida and other states. SWZ systems may include temporary measures such as queue detection, speed monitoring, construction equipment alerts, travel time display, incident detection and surveillance, and temporary over-height vehicle warning.

Previous FDOT and other state WZ research has covered a variety of areas, including:

- Evaluation of safety and operational effectiveness of dynamic lane merge systems
- Analysis of freeway WZ capacity
- Human factors examination of driver response to specific WZ design using a driving simulator
- Integrated WZ safety management system and analysis tools
- Effectiveness of a Motorist Awareness System (MAS) in construction WZs
- Impact of lane closures on roadway capacity

These previous studies were limited primarily to dedicated freeways and expressways. This research expanded it to cover WZs on state roads, arterials, and local roads; studied specific WZ types; further investigated SWZ applications; and recommended cost-effective and practical solutions to reduce arterial WZ- and worker-related fatalities, injuries, and crashes.

1.3 Research Objectives

This study aimed to conduct a pilot implementation of SWZs to evaluate the effectiveness of selected SWZ applications in improving WZ safety on arterials. The pilot study focused on three stationary WZ types—lane closure, lane shift, and work on shoulder or median. With a proper understanding of the safety performance by WZ type under various combinations of SWZ applications and law enforcement (LE), different strategies, countermeasures, and technologies can be effectively implemented to reduce arterial WZ-related fatalities, injuries, and crashes by minimizing the risk associated with the severity of crashes.

The major focus of this research project was to deploy and evaluate SWZ applications and strategies to reduce vehicle speeds, speed variance, sudden decelerations, and sudden lane changes within WZ limits on arterials considering the following:

- Advanced Work Zone Awareness Device (AWAD)
- Presence of LE via stationary police vehicles with flashing blue lights
- Connected vehicle (CV) technologies (iCone products) and real-time information
- Combinations of these technologies

1.4 Report Organization

The report is organized as follows: Chapter 1 introduces the project background and research objectives, and Chapter 2 provides WZ facts, statistics, and historical crashes in Florida and presents a comprehensive review of best practices, guides, and resources on SWZ applications. Chapter 3 describes the data collection plan, methodology, and efforts at each pilot implementation site, including testing scenarios and data collected. Chapter 4 presents the data analysis methodology and results for each pilot implementation site, and Chapter 5 provides research findings, conclusions, and recommendations for implementing SWZ applications to improve WZ safety on arterials in Florida.

2. Literature Review

This task reviewed historical WZ crashes, quantified WZ crashes by WZ type, explored available Federal Highway Administration (FHWA) WZ safety resources, and identified potential and innovative SWZ applications for improving WZ safety by WZ type, especially on arterials. The task involved four key subtasks that examined major causes of WZ-related crashes by WZ type, helped to understand the distribution of WZ-related crashes by WZ types, identified FHWA WZ safety best practices and resources, and identified SWZ applications and success stories in Florida and other selected states, including the following:

- Review of historical WZ crash data for 2012–2019 in Florida and FHWA WZ facts and statistics to understand trends, characteristics, contributing factors, and major causes in each WZ type (lane closure, lane shift, and work on shoulder or median).
- Quantification of WZ-related crashes by WZ and roadway type to further understand the distribution of WZ-related crashes by WZ and roadway type.
- Review of WZ management programs, best practices, guidebooks, and other WZ-safety related resources.
- Review and summary of SWZ studies, technologies, applications, and project outcomes in Florida and other selected states to understand technologies, practices, benefits and success stories.

2.1 Work Zone Facts and Statistics

WZ-related crashes from the National Work Zone Safety Clearinghouse and the FDOT State Safety Office Geographic Information System (SSOGIS) were analyzed to understand the importance of WZ safety and compare national and Florida WZ crash patterns. On average, there were 724 fatalities annually in WZ-related crashes in the US for 2012–2019, which translates to approximately two fatalities daily. Figure 1 shows states with WZ fatalities in 2012–2019, which can be classified into five tiers based on their annual averages:

- Tier 1 – More than 60 Fatalities
- Tier 2 – 31–60 Fatalities (annual average)
- Tier 3 – 21–30 Fatalities
- Tier 4 – 11–20 Fatalities
- Tier 5 – Up to 10 Fatalities

Texas, Florida, and California ranked top three in the Tier 1, with more than 60 deaths. Considering the annual average for 2012–2019, Texas had the highest number of deaths (147), followed by Florida (70) and California (67). It is notable that WZ fatalities are higher in southern states, such as Georgia, Alabama, Tennessee, Arkansas, and Oklahoma. In the Midwest region, higher fatalities were observed in Illinois, Ohio, Indiana, Michigan, and Wisconsin. In the Northeast region, higher fatalities were observed in Pennsylvania and Virginia.

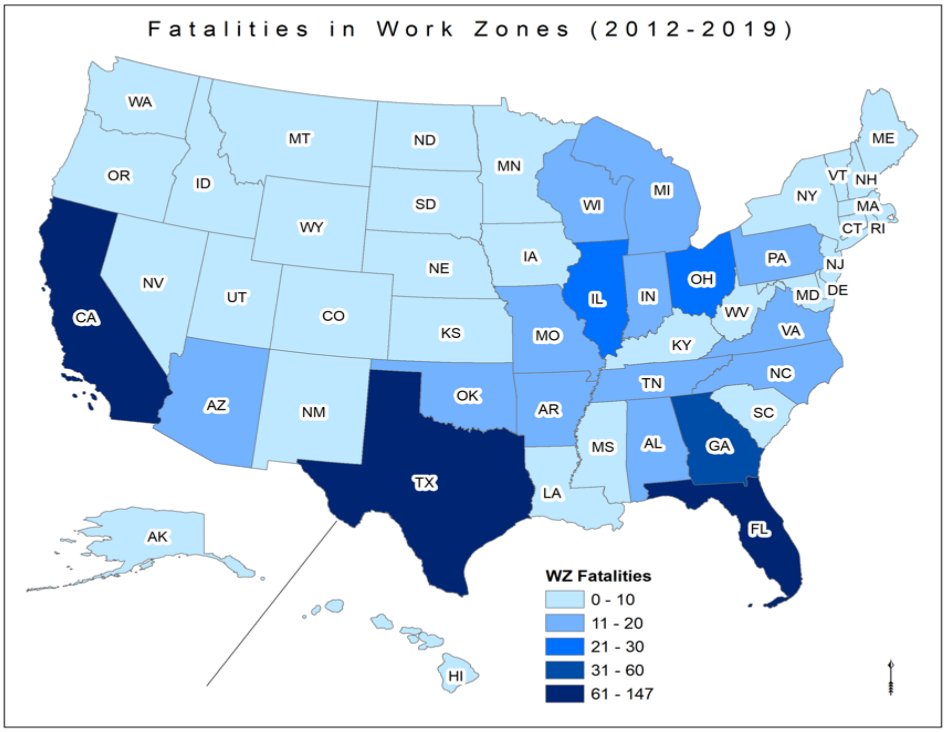


Figure 1. Average Number of WZ Fatalities per Year by State, 2012–2019
(Source: National Work Zone Safety Clearinghouse)

For 2012–2019, Florida experienced approximately 7,000 WZ-related crashes and 70 fatalities per year. Considering the magnitude of the problem in terms of frequency and severity of WZ-related crashes and fatalities of workers in Florida, WZs are given significant emphasis in the Florida Strategic Highway Safety Plan (SHSP). As such, appropriate traffic management is critical because it influences traffic delays, motorist and worker safety, completion of roadwork in a timely fashion, and maintenance of access to businesses and residents in the area.

As shown in Figure 2, in 2012–2019, there were, on average, 724 fatalities annually in WZ-related crashes in the US. The number of fatalities had little change between 2012 and 2013, began increasing in 2014, and reached the highest point in 2019, totaling 842 deaths. Between 2012 and 2019, the average number of WZ worker fatalities was 128 annually, with a peak of 143 fatalities in 2016; in 2019, the number reached 135.

In Florida, in 2012–2019, there were, on average, 70 fatalities in WZs annually. The highest numbers were in 2016 and 2018, with 80, which dropped to 68 in 2019. Between 2012 and 2019, the average number of worker fatalities was 11 annually. This number remained constant at 7 fatalities in 2012, 2013 and 2014. Worker fatalities reached the highest in 2018, with 21, but dropped to the lowest in 2019, with 5 (Figure 3).

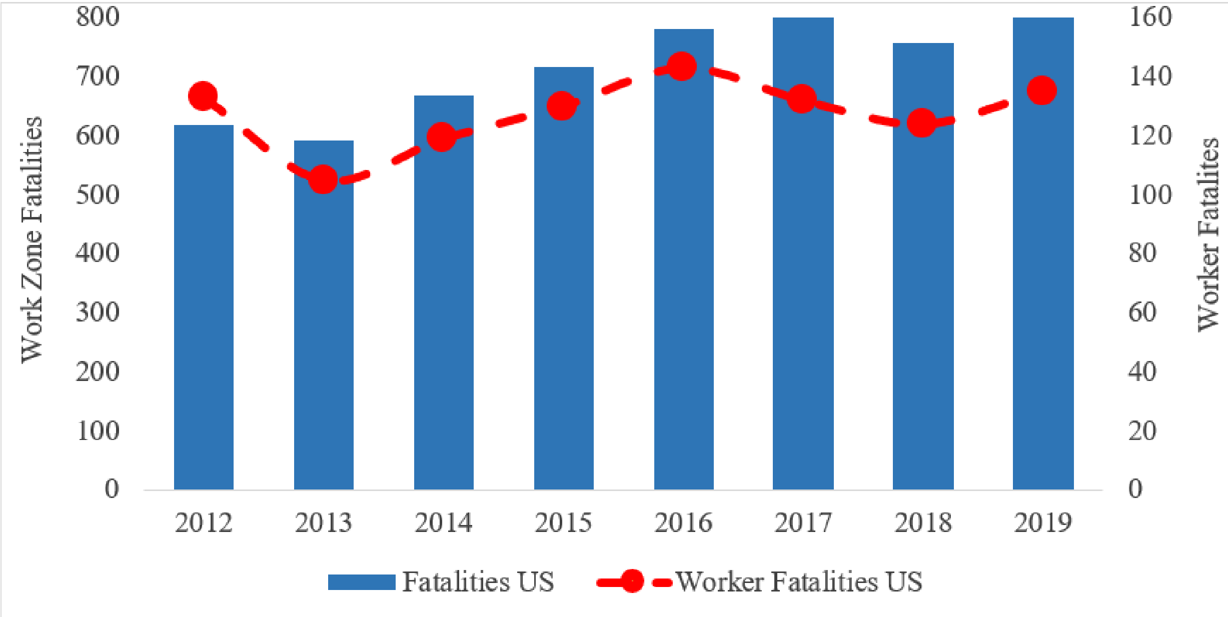


Figure 2. Fatalities in WZ and Worker Fatalities in the U.S., 2012–2019
(Source: National Work Zone Safety Clearinghouse)

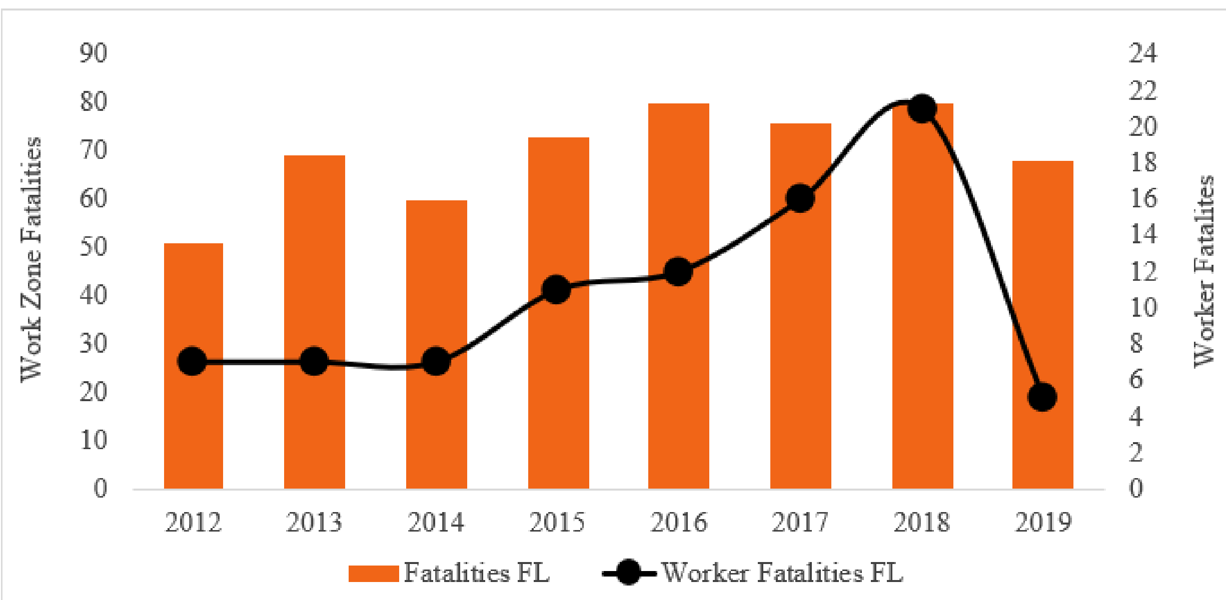


Figure 3. Fatalities in WZ and Worker Fatalities in Florida, 2012–2019
(Source: National Work Zone Safety Clearinghouse)

In 2012–2019, about 55% of WZ- related crashes in Florida occurred on arterial roads, followed by interstates (37%), collector roads (2%), and local roads (7%), as shown in Figure 4. The largest share of WZ fatal crashes in Florida occurred on arterial roads.

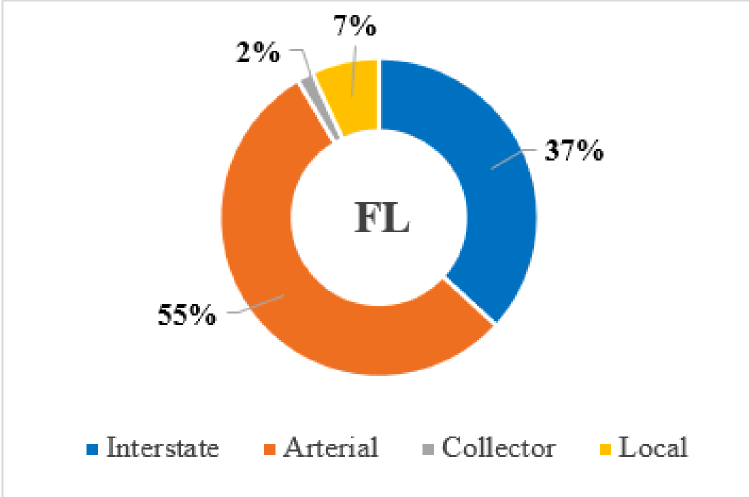


Figure 4. WZ Fatal Crashes by Functional Class of Roadways in Florida, 2012–2019
(Source: FDOT SSOGIS)

A summary of average annual WZ and worker fatalities and fatal crash distribution for interstates and arterials in Florida for 2012–2019 is provided in Table 1.

Table 1. Annual Fatalities and Fatal Crash Distribution in Florida Work Zones, 2012–2019

Fatalities and Fatal Crashes	Annual Average (2012–2019)
Fatalities*	
WZ Fatalities	70
WZ Workers Fatalities	11
Fatal Crashes on Functional Class of Roadways**	
Interstate	23 (37%)
Arterial	34 (55%)
Collector	1 (2%)
Local	4 (7%)

*Source: National Work Zone Clearinghouse Information
**FDOT SSOGIS

2.2 Historical Work Zone Crash Data in Florida, 2012–2019

This section summarizes the major trend of WZ-related crashes in Florida from 2012 to 2019 based on data obtained from the FDOT SSOGIS. During this time, there were, on average, 6,986 WZ-related crashes annually, as represented by a horizontal dotted black line in Figure 5. The highest number of WZ-related crashes occurred in 2016, totaling 8,335 crashes, which indicates that in Florida, in 2016, on average, 23 persons were involved in WZ-related crashes daily. The linear trend of WZ-related crashes in Florida has generally increased, as shown by the dotted black line in Figure 5; however, the number of WZ-related crashes started to decrease in 2016.

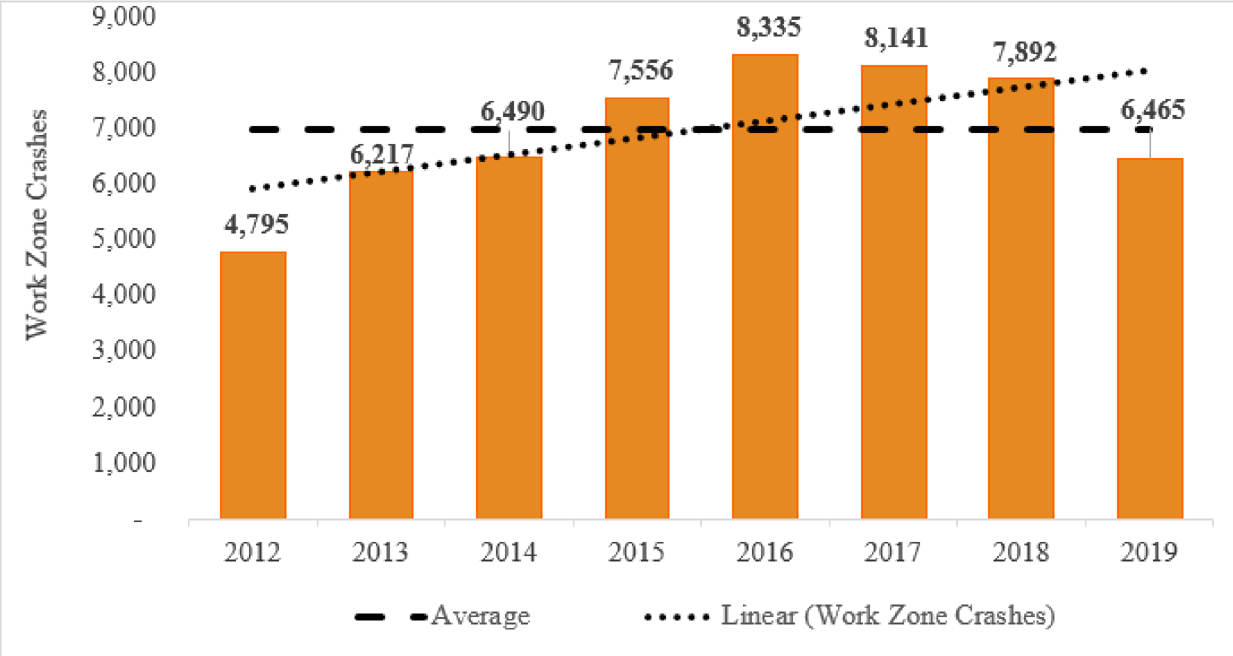


Figure 5. Total Number of WZ-related Crashes in Florida, 2012–2019
(Source: FDOT SSOGIS)

Figure 6 presents WZ-related crashes by WZ type. Analysis indicates that between 2012 and 2019, on average, 55% of WZ-related crashes occurred in the work on shoulder or median WZ type and 27% occurred in lane closure WZ type, followed by WZ crashes in lane shift WZ type (12%), and WZ crashes in intermittent WZ type (7%).

Analysis results of WZ-related crashes by injury severity indicate that between 2012 and 2019, on average, 5% of WZ-related crashes resulted in severe injury, 33% in minor injury, and 62% in no injury. On average, 65% of WZ-related crashes that resulted in severe injury occurred in work on shoulder or median WZ type, 21% in lane closure WZ type, 8% in lane shift WZ type, and 6% in intermittent WZ type. On average, 58% of WZ-related crashes that resulted in minor injury occurred in shoulder or median WZ type, 26% in lane closure WZ type, 10% in lane shift WZ type, and 6% in intermittent WZ type. On average, 55% of WZ-related crashes that resulted in no-injuries occurred in work on shoulder or median WZ type, 28% in lane closure WZ type, 12% in lane shift WZ type, and 5% in intermittent WZ type. Distribution of WZ-related crashes based on the type of injury is presented in Figure 7.

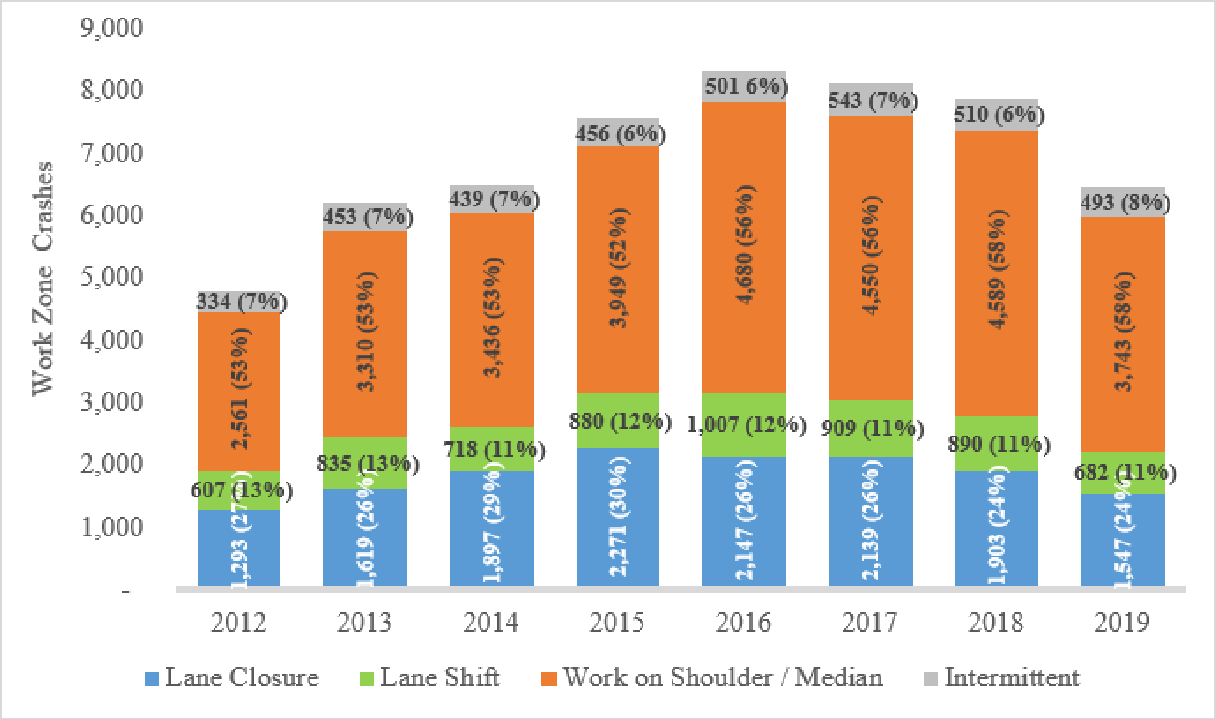


Figure 6. WZ-related Crashes in Florida by WZ Type, 2012–2019
(Source: FDOT SSOGIS)

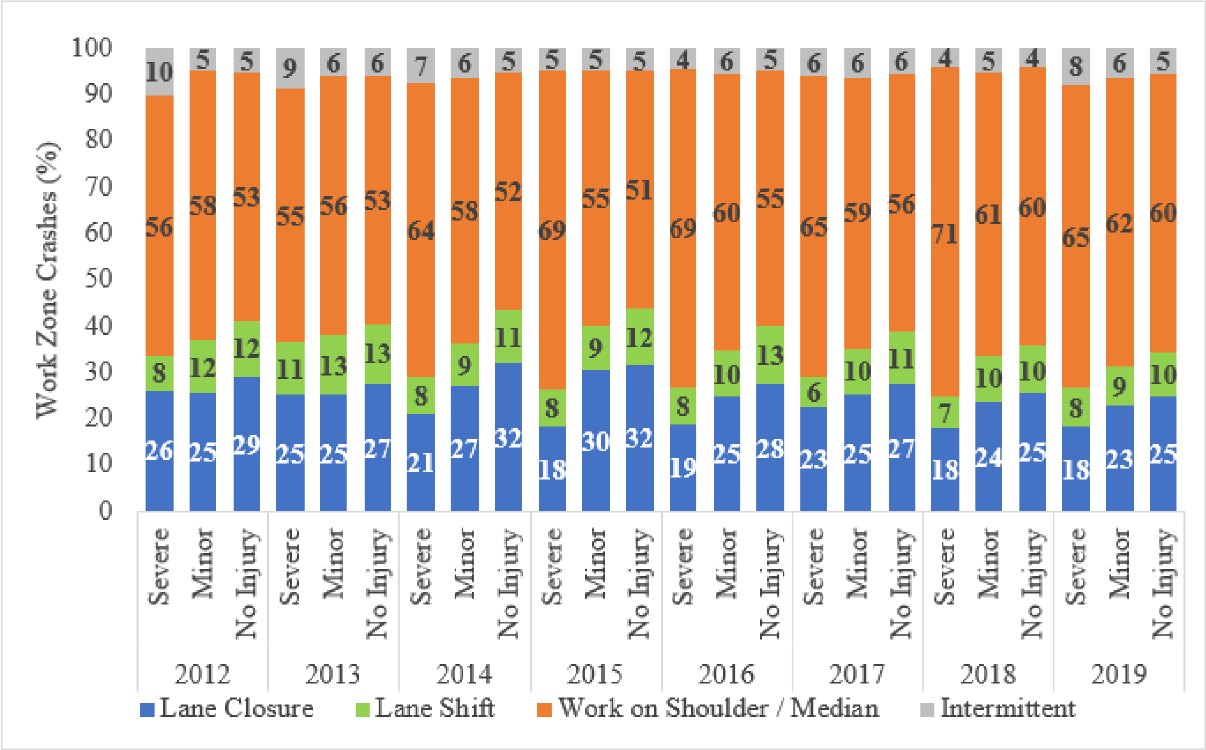


Figure 7. WZ-related Crashes in Florida by Injury Severity and WZ Type, 2012–2019
(Source: FDOT SSOGIS)

WZ-related crashes were analyzed by time of occurrence. Considering AM peak, PM peak, midday peak, off-peak periods and nighttime periods, the time intervals were not kept uniform for the data collection and analysis due to different duration for each period. Results of WZ-related crashes by time of occurrence analysis revealed that, on average, 16% of WZ-related crashes occurred 9:00 am–12:00 pm, 15% 6:00–9:00 am, 13% 2:00–4:00 pm, and 12% 12:00–2:00 pm. Every year from 2012 to 2019, the peak in WZ-related crashes occurred between 9:00 am and 12:00 pm. The number of WZ-related crashes and time of day are shown in Figure 8.

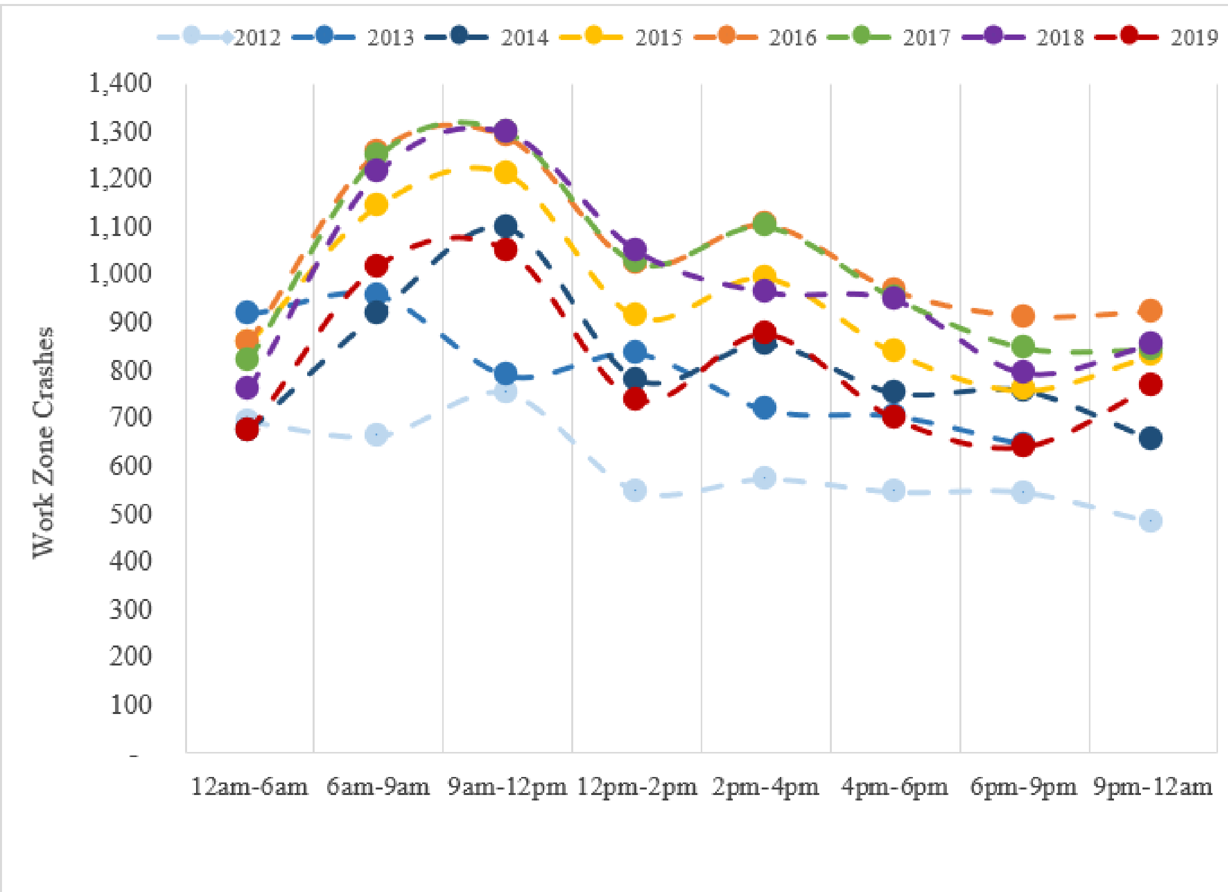


Figure 8. WZ-related Crashes in Florida by Time, 2012–2019
(Source: FDOT SSOGIS)

The results of WZ-related crashes by time of day and WZ type analysis are presented in Figure 9. Based on the Florida WZ crash data for 2012–2019, more WZ-related crashes occurred on shoulder or median than any other WZ type, on average accounting for 69% of WZ-related crashes for 6:00–9:00 am and 66% for 4:00–6:00 pm. In general, the average share of WZ-related crashes in work on shoulder or median WZ type was the smallest between 9:00 pm and 12:00 am (35%); during this time, the average share of WZ crashes was the highest in lane closure WZ type (50%).

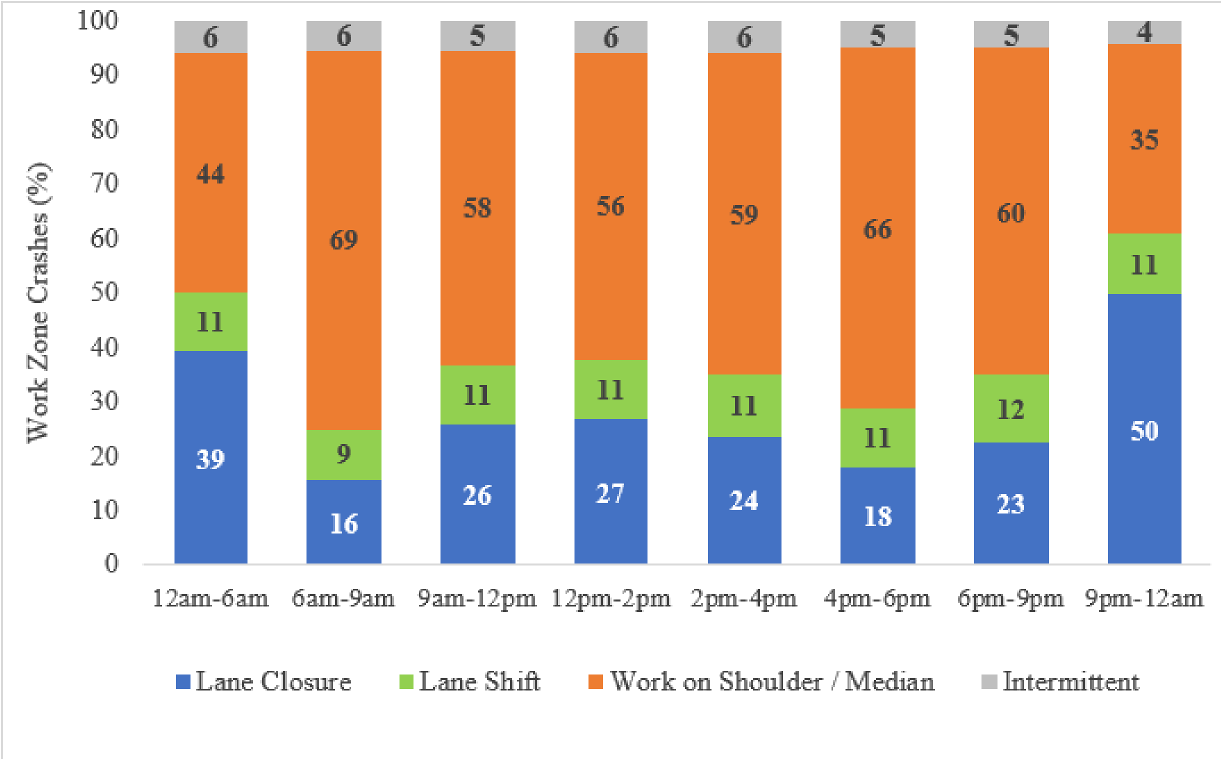


Figure 9. WZ-related Crashes in Florida by Time and WZ Type, 2012–2019
(Source: FDOT SSOGIS)

The results of WZ-related crashes by location within a WZ are presented in Figure 10 and indicate that for 2012–2019, on average, 67% of crashes occurred within an activity area, 17% in a transition area, 9% in an advanced warning area, 5% before the first WZ warning sign area, and 2% in a termination area. About 84% of WZ crashes occurred in the transition to an activity area of road construction.

The results of WZ-related crashes between 2012 and 2019 by location within a WZ and WZ type analysis are presented in Figure 11. For each WZ type, the same trend was observed—the highest share of the crashes occurred in an activity zone, followed by a transition zone and an advanced warning zone. The percentage of WZ-related crashes in an activity zone was 77% for work on shoulder or median, 72% for intermittent, 56% for lane shift, and 50% for lane closure.

For the common lane closure WZ type, 26% of WZ-related crashes occurred at a transition area, followed by 13% at an advanced warning area. For work on shoulder or median, only 12% of WZ-related crashes occurred at a transition area, followed by 7% at an advanced warning area.

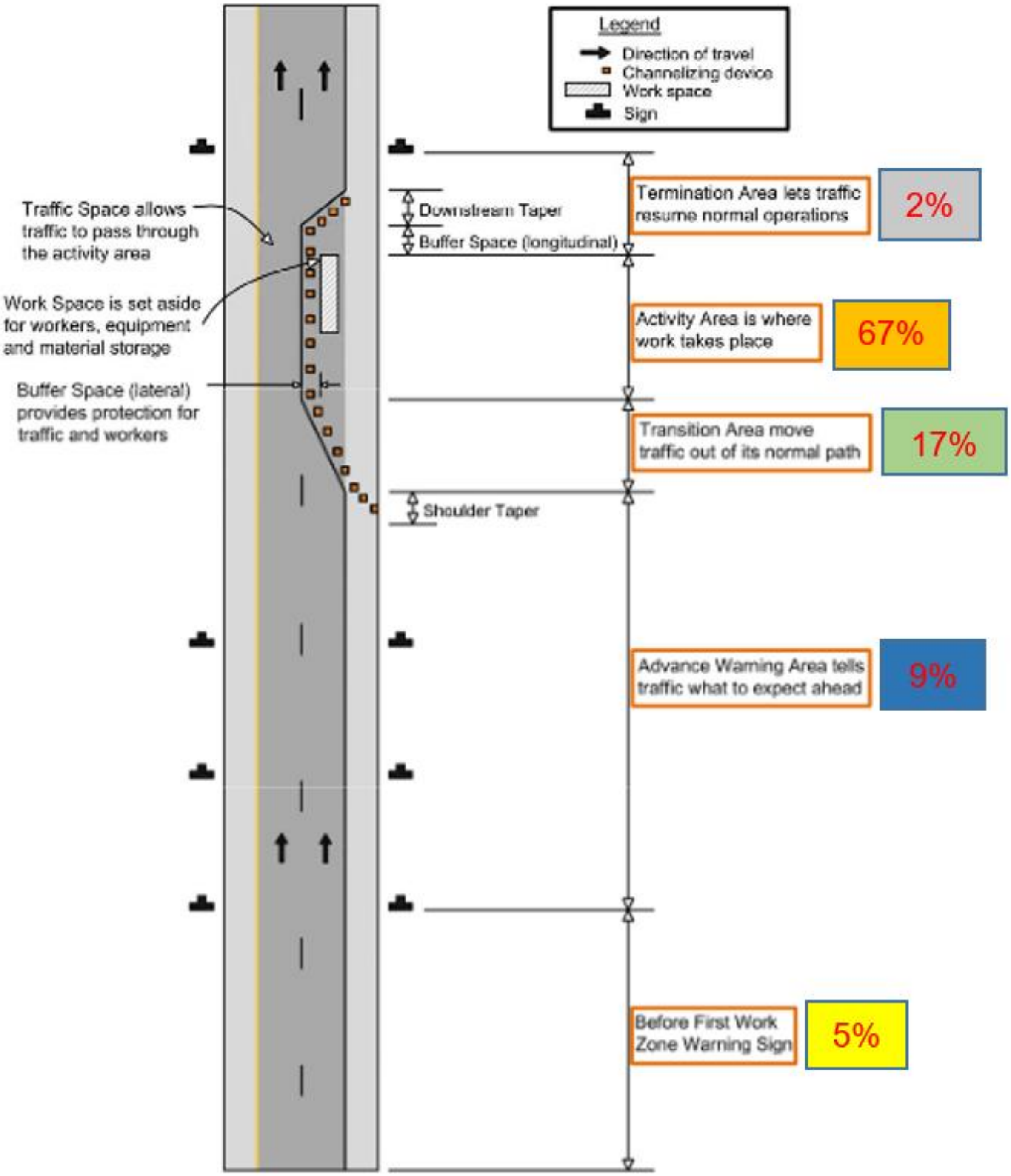


Figure 10. WZ-related Crashes in Florida by Location within WZ, 2012–2019
(Source: FDOT SSOGIS)

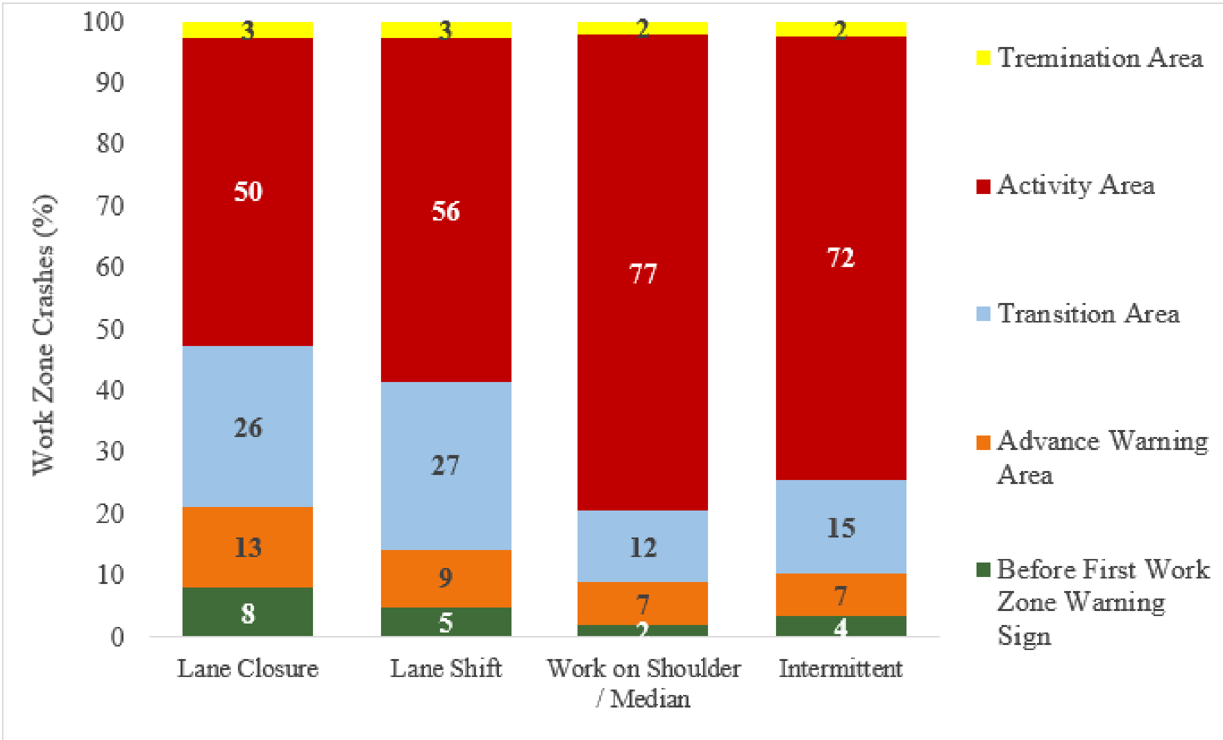


Figure 11. WZ-related Crashes in Florida by WZ Type and Location within WZ, 2012–2019
(Source: FDOT SSOGIS)

Results of WZ-related crashes by road contributing factors and WZ type analysis are presented in Figure 12 and indicate that between 2012 and 2019, the highest share of WZ-related crashes, about 71%, had non-roadway geometry-related factors in road contributing factors (in Figure 12, "None" indicates non-roadway geometry-related factors, such as human or other factors that may have contributed to a WZ-related crash), followed by WZ contributing factors (28%) and road surface conditions (3%). The remaining types of contributing factors played a less significant role, at 0.5% or less. The highest share of a WZ as a contributing factor was in lane shift WZ type (35%), lane change WZ type (34%), and intermittent WZ type (25%), followed by work on shoulder or median WZ type (16%). It is necessary to note that "none" category or any category that is not the "work zone" category contributed to a WZ-related crash was still influenced by the work zone.

The results of WZ crashes by environment contributing factors and WZ type analysis are presented in Figure 13 and indicate that between 2012 and 2019, the highest share (93%) of WZ crashes had no environment-related attributes; only 5% of crashes listed weather as a factor, and the remaining environmental factors were listed only for 1% and less crashes. It is necessary to note that "none" category or any category that is not the "work zone" category contributed to a WZ-related crash was still influenced by the work zone.

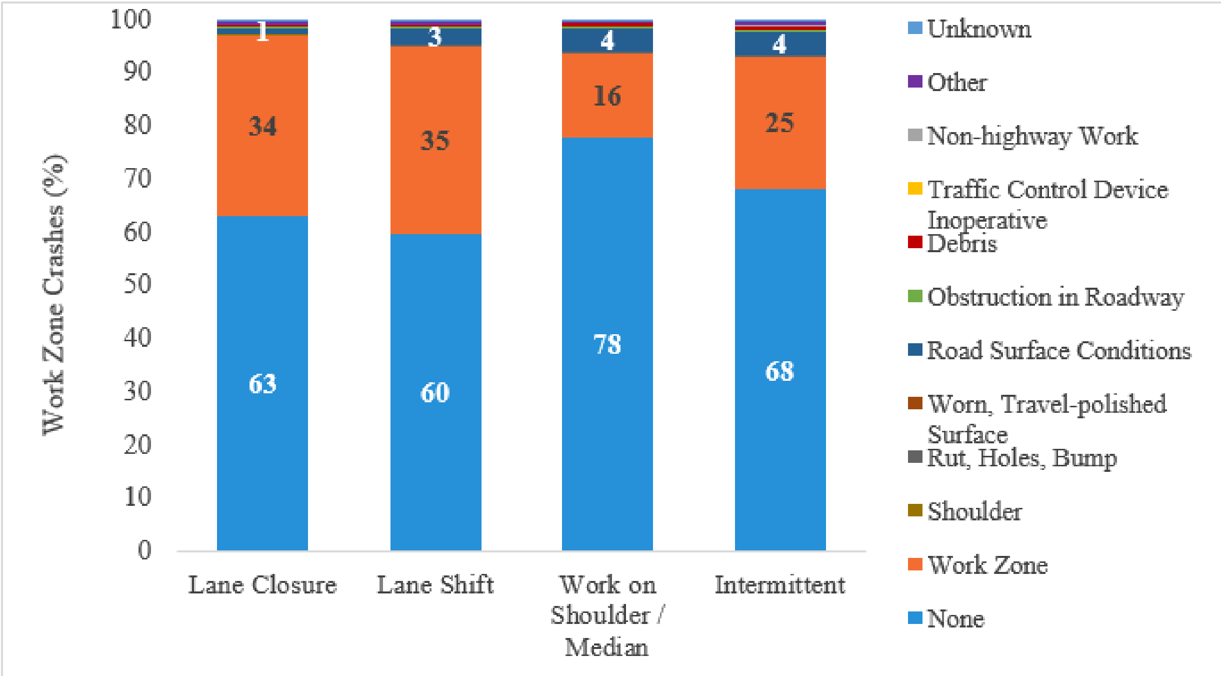


Figure 12. WZ Crashes in Florida by Contributing Factors: Road, 2012–2019
(Source: FDOT SSOGIS)

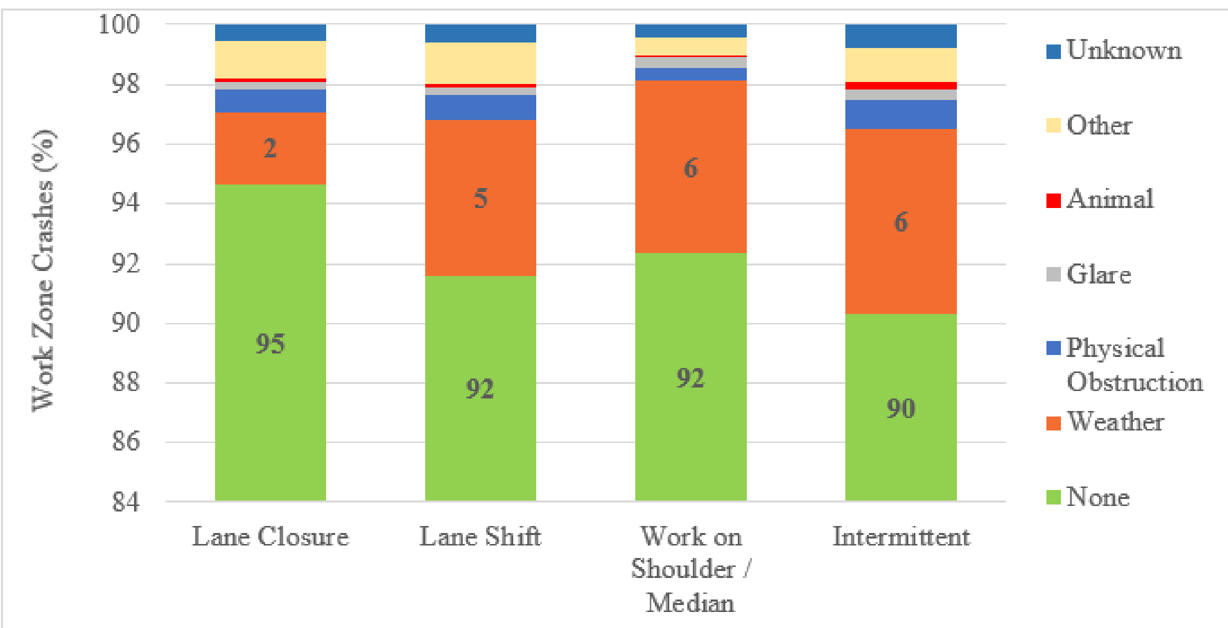


Figure 13. WZ-related Crashes in Florida by Contributing Factors: Environment, 2012–2019
(Source: FDOT SSOGIS)

Major findings from the analysis of WZ-related crash in Florida for 2012–2019 are summarized as follows:

- On average, 6,986 WZ crashes, 70 WZ fatalities, and 11 worker fatalities occurred annually in Florida.
- In total, 55% of WZ-related crashes occurred in a work on shoulder or median WZ type. On average, 65% of WZ-related crashes resulting in severe injuries occurred in a work on shoulder or median WZ type.
- On average, 31% of WZ-related crashes occurred between 6:00 am and 12:00 pm. Work on shoulder or median WZ type accounted for 69% of WZ-related crashes between 6:00 and 9:00 am and 66% between 4:00 and 6:00 pm.
- On average, 67% of WZ-related crashes occurred in an activity zone area, and about 84% of WZ-related crashes occurred within a transition zone and an activity area.
- The percentage of WZ-related crashes in an activity zone was 77% for work on shoulder or median, 72% for intermittent, 56% for lane shift, and 50% for lane closure type.
- About 70% of WZ-related crashes were likely attributed to human behaviors (i.e., non-road geometry-related), about 25% to WZ and road surface conditions, and about 5% to environmental factors.

*2.2.1 **WZ Crash by Roadway Functional Class***

Analyzing WZ-related crashes in Florida by nature of construction in major roadway types is important to enhance understanding. Analysis results of WZ crashes by functional class of roadway suggests that between 2012 and 2019, on average, 61.2% of WZ-related crashes occurred on arterial roads, 38.5% on interstates, 0.3% on collector roads, and 0.1% on local roads. On average, 58.9% of WZ-related crashes occurred related to a shoulder/or median WZ type; 25.6% to lane closure WZ type, 10.5% to lane shift, and 5.0% to intermittent WZ type. The share of WZ-related crashes by WZ type and functional class of roadway is shown in Figure 14.

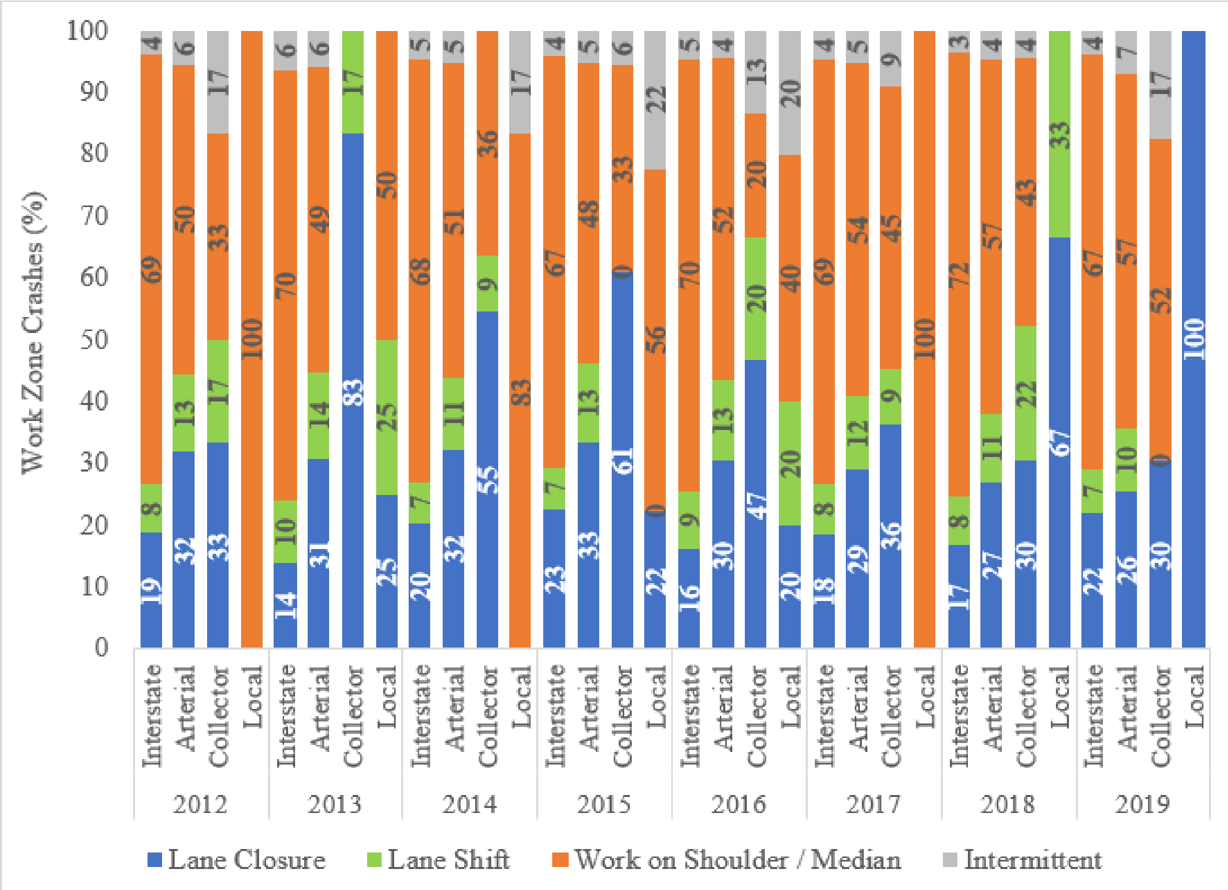


Figure 14. WZ-related Crashes in Florida by WZ Type and Functional Class of Roadway, 2012–2019
(Source: FDOT SSOGIS)

On interstates, on average, 69% of WZ-related crashes occurred related to a shoulder/or median WZ type; 19% to lane closure WZ type, 12% to lane shift, and 5% to intermittent. On arterial roads, on average, 53% of WZ-related crashes occurred related to shoulder or median, 30% to lane closure, and 12% to lane shift; the smallest share of WZ crashes occurred in the intermittent WZ type (5%). On collector roads, on average, 43% of WZ-related crashes occurred related to lane closure, 37% to shoulder or median, 11% to lane shift, and 9% to intermittent WZ type. On local roads, on average, 53% of WZ-related crashes occurred related to shoulder or median WZ type, 24% to lane closure, 12% to intermittent, and 12% to lane shift.

2.2.2 WZ Fatalities with Large Truck Involvement

Fatality Analysis Reporting System (FARS) data in Florida suggest that the percentage of WZ-related fatalities involving large trucks (commercial vehicles) was higher than that in non-WZ-related crashes. Figure 15 shows the percentages of WZ truck-involved fatal crashes in Florida from 2012 to 2019 with an average of 21% based on information from the National Work Zone Safety Clearinghouse. Historical crash data analysis suggests that WZ-related factors in Florida were important factors, followed by wet road surfaces and road design, for large truck-involved crashes with non-fixed objects in WZs.

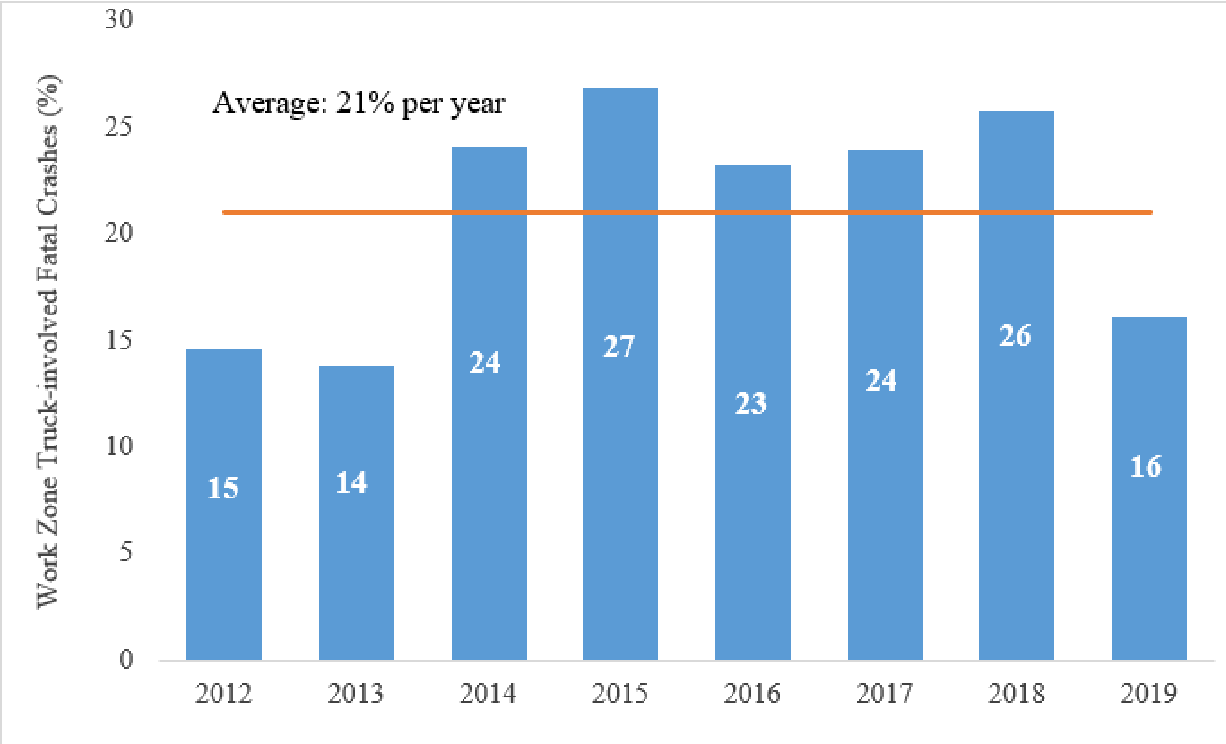


Figure 15. Work Zone Truck-involved Fatal Crashes in Florida, 2012–2019
(Source: National Work Zone Safety Clearinghouse)

Appendix A presents statistics on WZs for 2012–2019 based on FDOT SSOGIS data and statistics for the state average and FDOT District-wide share for different factors of WZ crashes based on Crash Analysis Reporting System (CARS) data for 2011–2017. Although this data analysis was performed earlier, it provides value for FDOT District-wide WZ crash information.

2.3 WZ Programs, Best Practice, Guidebook, and Resources

This section highlights WZ programs with best practices recognized by FHWA. According to the *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) (FHWA, 2012), a WZ is defined as "an area of highway with construction, maintenance, or utility work activities." It consists of four main components—an advance warning area, a transition area (known as a taper), an activity area, and a termination area. In an advance-warning area, road users are informed of the upcoming WZ area. In a transition area, road users are directed out of their normal path using tapering. Actual roadwork takes place in the activity area, which is divided into three spaces—work space, traffic space, and buffer space. The termination area allows road users to return to their normal driving path; this area extends from the downstream end of the WZ area to the last temporary traffic control (TTC) device, such as an "End Road Work" sign. Locations of each component within a typical WZ are illustrated in Figure 16.

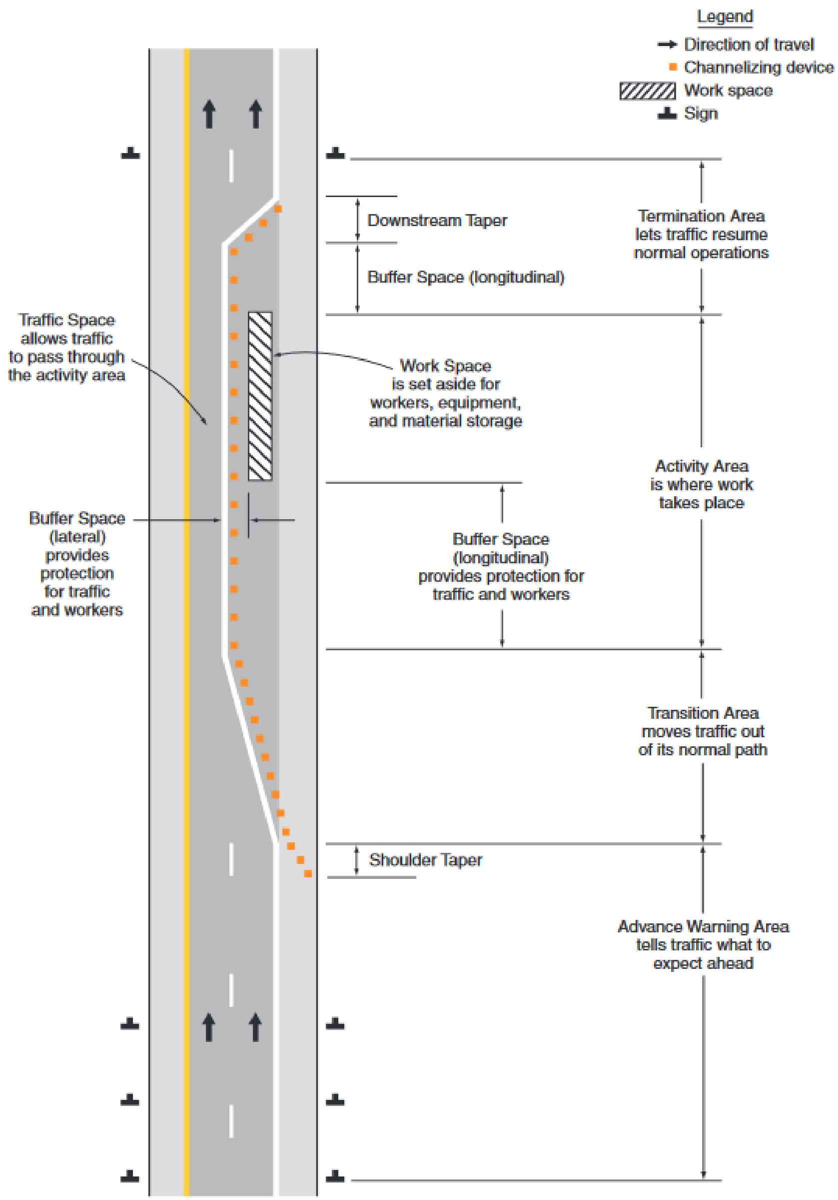


Figure 16. Components of a Work Zone
(Source: MUTCD for Streets and Highways; FHWA, 2012)

WZs are marked by signs, channelizing devices barriers, and/or work vehicles. Use of TTC devices allows proper traffic flow and safety within and around WZs. WZs may involve lane closures, detours, and moving equipment. They are set up according to the type of road and the work to be done on the road and vary by duration and WZ type. The four major WZ types are shown in Figure 17 for lane closure and lane shift, and Figure 18 for work on median or shoulder, and intermittent.

During maintenance/reconstruction of existing infrastructure and construction of a new infrastructure, designated construction zones or WZs are important for the safety and efficient movement of road users and workers. These WZs are specially configured and managed by special traffic signs, standard channelizing devices, appropriate barriers, pavement markings, construction vehicles, and construction workers. The type of WZ and its geometric configuration is based on the type of reconstruction or improvement work being done on a particular segment of the roadway in rural and urban settings. Based on the recommended TTC plan on the MUTCD (FHWA, 2012), construction work continues with a specific target time to deliver the project by opening the corridor to normal traffic operation. Safe and efficient WZ operation and management are important to the safety and mobility of all road users and construction workers.

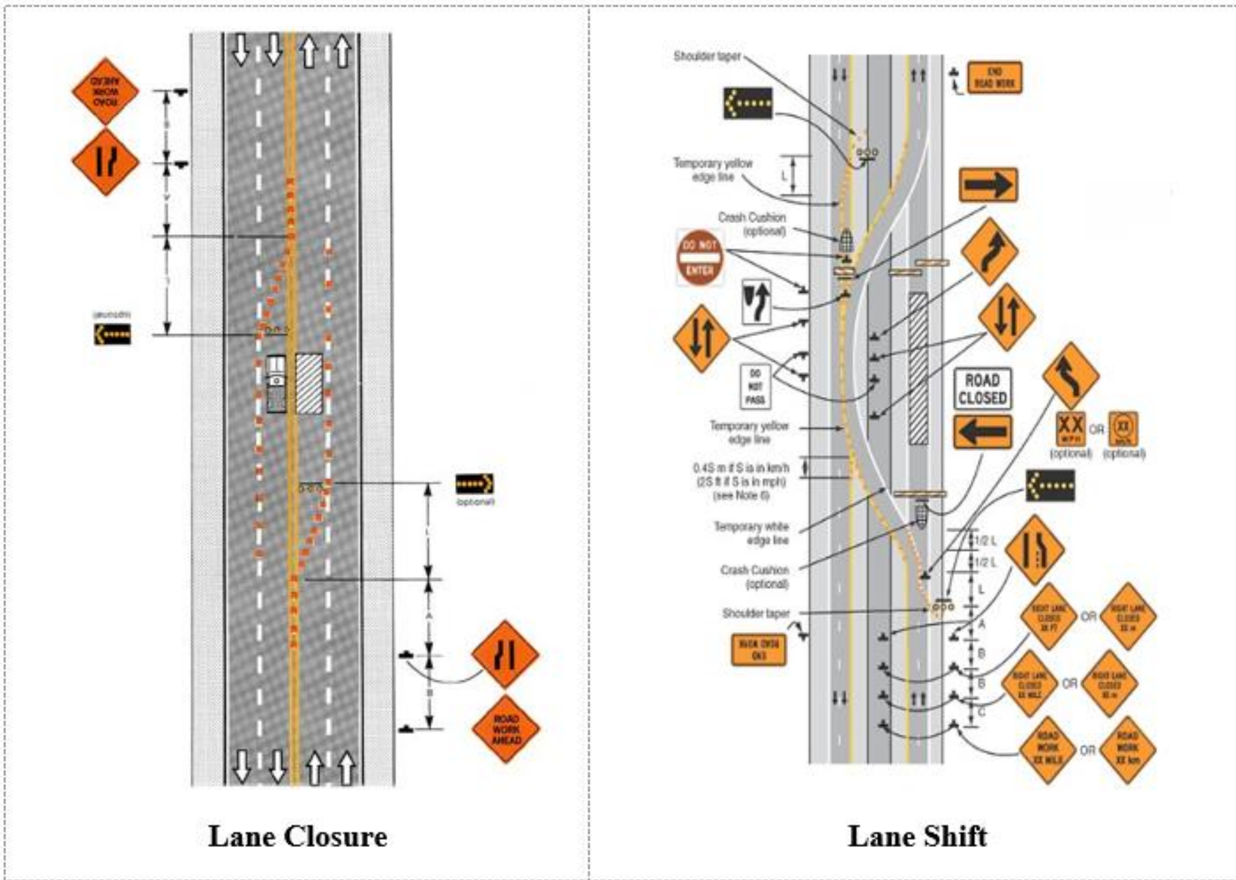


Figure 17. WZ Types of Lane Closure and Lane Shift
(Source: mutcd2009r1r2edition.pdf (dot.gov))

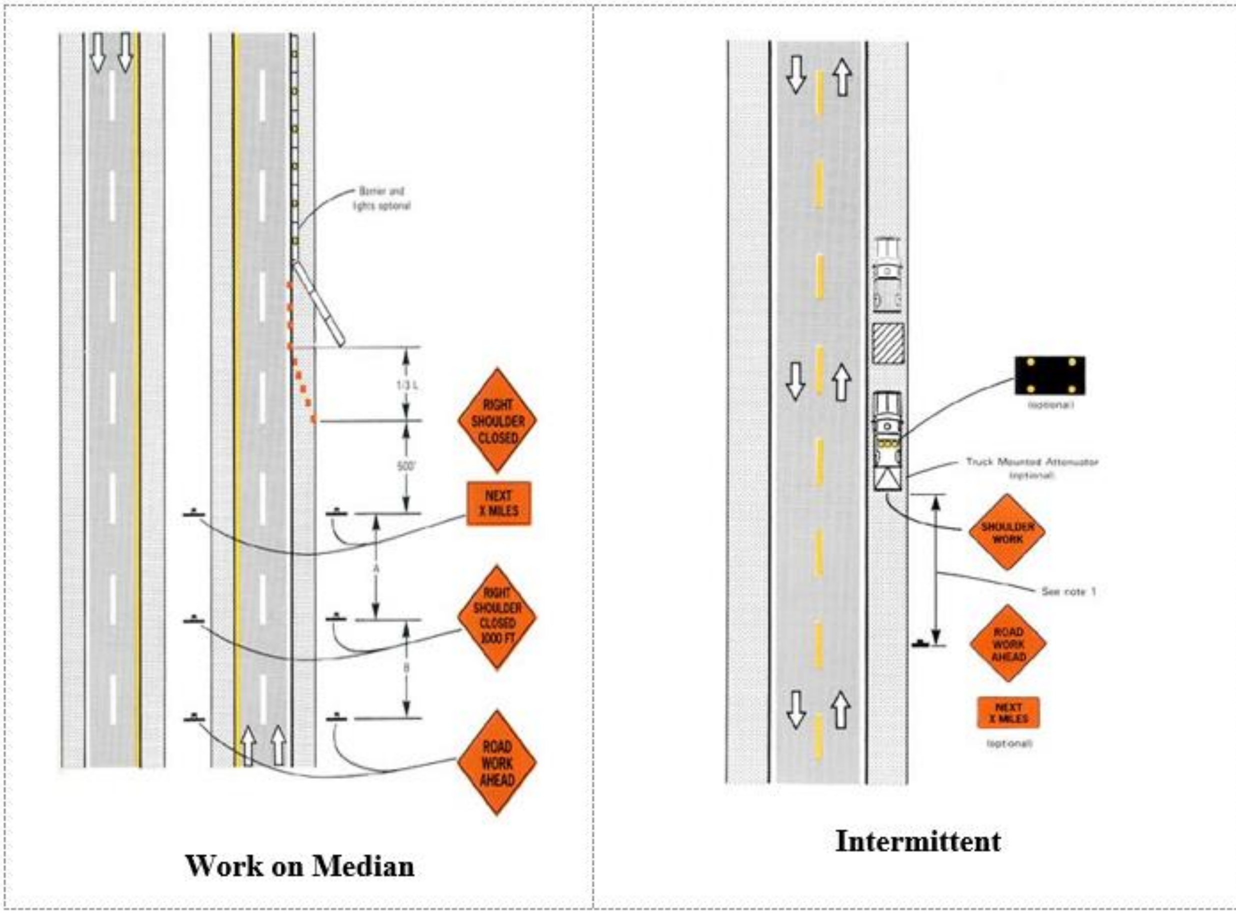


Figure 18. WZ Types of Work on Median and Intermittent
(Source: [mutcd2009r1r2edition.pdf (dot.gov)](mutcd2009r1r2edition.pdf))

2.4 FHWA Work Zone Management Program

FHWA created a repository for publications and studies related to best WZ management programs in the National Cooperative Highway Research Program (NCHRP) under the FHWA Work Zone Safety Grant program (FHWA 2019b). This WZ management program helps to provide high-quality products, tools, and information for all transportation practitioners. Information helps researchers, contractors, and all other transportation practitioners to design, plan, and implement safer, more efficient, and less congested WZs. The program's website serves as a central location for all WZ-related resources with updated information and resources and includes resources on SWZs, WZ safety and mobility rules, peer-to-peer programs related to WZs, a best practices guidebook, WZ training courses, publications and studies related to WZs, and WZ-related latest news (FHWA, 2019a). The latest studies in the Best Practices section include reports from 2017 discussing a variety of devices, such as longitudinal channelizing devices and automated flagger assistance devices. Mobile barrier systems, the Work Zone Automated Speed Enforcement Program, and Work Zone Intrusion Reporting Research Synthesis and Internal Traffic Control Plans for Work Zones are also discussed.

2.5 Work Zone Best Practices Guidebook

FHWA provides an accessible compilation of WZ operations best practices and polices used across states and localities in its *Work Zone Operations Best Practices Guidebook* (FHWA 2013). This descriptive document assists practitioners and researchers with updated new approaches, technologies, and practices for effectively managing WZs, thus helping to reduce their impacts on mobility and safety.

In total, 50 WZ topics and subtopics are discussed in this document. Best practices are grouped into 11 major categories with reference by State/FHWA, project life cycle, nature of work, traffic conditions, geographic and demographic characteristics, and roadway characteristics. Discussed in the guidelines are policy and procedure; public relations, education, and outreach; modeling and impact analysis; planning and programming; project development and design; contracting and bidding procedures, construction and maintenance materials, practices and specifications; traveler and traffic information; enforcement; ITS and innovation technology; and evaluation and feedback. Table 2 through Table 12 relate to the subcategories.

Policy and Procedures: This section focuses on customer-driven comprehensive WZ transportation management policies, as described in Table 2; reducing exposure and impacts to the road user is a focal point. Design, construction, and maintenance operation policies and practices are included.

Table 2. FHWA Best Practices on WZ Policy and Procedures

<table>
<tr><th colspan="2">Subcategory</th><th>Policy and Procedures</th></tr>
<tr><td rowspan="9">1.</td><td rowspan="9">Lane/Ramp/ Road Closure Policy</td><td>Road Closure Program</td></tr>
<tr><td>Street Restriction Program</td></tr>
<tr><td>Maintain Existing Number of Travel Lanes</td></tr>
<tr><td>Limited Length of Lane Closure</td></tr>
<tr><td>Ramp Closures During Reconstruction</td></tr>
<tr><td>Total Closures to Accelerate Work and Minimize Delay</td></tr>
<tr><td>Lane Closure Policy/Map</td></tr>
<tr><td>Lane Closure Coordinator</td></tr>
<tr><td>Narrowing Lanes and/or Reinforcing Shoulders to Maintain Existing Number of Lanes</td></tr>
<tr><td rowspan="4">2.</td><td rowspan="4">Collaboration</td><td>Mayor’s Transportation Management Task Force</td></tr>
<tr><td>Public-Private Partnership Incentives for Early Completion</td></tr>
<tr><td>“Design for Safety” Partnership</td></tr>
<tr><td>Consolidated Traffic Control Logbook</td></tr>
<tr><td>3.</td><td>Organizational Strategy</td><td>Full-Time WZ Traffic Control Engineer</td></tr>
<tr><td rowspan="2">4.</td><td rowspan="2">Performance Goals and Measures</td><td>WZ Performance Goal – Maximum Delay Specification</td></tr>
<tr><td>WZ Designed at the Posted Speed</td></tr>
</table>

Table 2. FHWA Best Practices on WZ Policy and Procedures, Continued

Subcategory		Policy and Procedures
5.	Technical Guidance	Guide to Establishing Speed Limits in Highway Work Zones
		WZ Speed Limit Reduction and Speeding Fine Program
		Long Life Pavement Rehabilitation Program for Urban Freeways
		Minimum Geometric Standards for Work Zones
		Additional Shoulder Thickness
6.	Traffic Management Planning	Travel Time Systems in WZ
		WZ Traffic Incident Management Plans
		"Compendium of Options" (Construction Traffic Maintenance Strategies)
		Policy/Standards for Slow Moving or Mobile Maintenance Operations
		Traffic Management in WZs
		Temporary Pedestrian Access Routes (TPAR)
		Commuter Incentives to Minimize Congestion in WZs

Public Relations, Education, and Outreach: This section focuses on program-level outreach efforts described in Table 3 to help agencies to raise general awareness about motorist and worker safety and mobility issues while driving in a WZ without gearing towards any specific projects. These outreach practices help to keep the general public, road users, elected officials, and others informed about WZ safety needs.

Table 3. FHWA Best Practices on Public Relations, Education, and Outreach

Subcategory		Public Relations and Outreach
1.	Drivers	Motor Carrier Initiative to Prevent WZ Crashes
		Multi-Faceted Approaches to Providing Construction Information to Truckers
		Partnership with Motor Truck Association
2.	General Public	WZ Awareness Week
		Outreach Program for Construction and Maintenance WZs
		Regional Coalition for Disseminating Road Construction Information
		Public Outreach to Increase Use of Transportation Management Plan (TMP) Strategies
		Traffic Safety Information Center
3.	Media	Develop Media Partnerships
4.	State/ Contractors/ Workers	Circuit Rider Program
		WZ Safety Round Tables
		"What's Wrong with This Work Zone" – Training Video
		WZ Traffic Control Training Requirements
		Regional WZ Workshops
		"Build a Better Mousetrap" Competition

Modeling and Impact Analysis: This section includes details on mathematical equations, software, and analysis used to predict the impact of WZs before and during implementation. These best practices, as described in Table 4, provide feedback to design and construction teams on how a WZ affects traffic and determines how to mitigate incidents related to a WZ to increase safety in the WZ.

Table 4. FHWA Best Practices on Modeling and Impact Analysis

Subcategory		Modeling and Impact Analysis
1.	Lane Closure and Capacity Analysis	Lane Closure Analysis
		Using Software to Predict Congestion and Associated User Costs
		Traffic Impact Analysis
2.	Impact Identification and Mitigation	Traffic Impact Reports
		Road Construction Safety Audit

Planning and Programming: This section discusses best practices emphasizing a corridor approach to evaluate, plan, and program, as described in Table 5, to minimize WZ impacts on road users. Planning and programming include defining issues and opportunities, assessing alternatives solutions, and other decisions within existing budgetary constraints.

Table 5. FHWA Best Practices on Planning and Programming

Subcategory		Planning and Programming
1.	Corridor Planning	Multi-Level TMPs
		Corridor Planning to Minimize Delays and Enhance Safety in WZs
		Corridor Planning
		Partnering with the Local Community on Project Planning
		Corridor Modeling for Construction Closure and Restriction Alternatives
2.	Organizational Strategy	High Impact Project Task Forces
		Coordination of State Department of Transportation (DOT), Local Government, and Utility Construction and Maintenance Work to Minimize Motorist Delays
		Partnering to Improve WZ Design and Traffic Control
		Use of a Computerized Planning System for Road Work and Lane Closures
3.	Traffic Management Planning	Transportation Management Plan
		Transportation Management Plan Development Tools
		Widening Bridges to Accommodate Future Construction
		Multi-Disciplinary Teams to Develop TMPs

Project Development and Design: This section provides details on best practices in project development and design, as described in Table 6, in a WZ-related area to encourage assessing motorist delay, road user and worker safety, and impacts on adjacent communities on all significant urban and other corridors with high-volume traffic.

Table 6. Best Practices on Project Development and Design

Subcategory		Project Development and Design
1.	Constructability Review Process	Constructability Reviews to Minimize Construction Contract Time and User Delays
		Constructability Practices for Reducing the Impact on Motorists and Businesses
		Formal Constructability Review Process
		Constructability Reviews by Construction Industry Representatives During Project Design
		Contractor Participation in Constructability Reviews
		Constructability Reviews on High Visibility Projects in Design Phase
		North Carolina Contractor's Association Participation in Constructability Reviews
		Employ a Contractor to Assist Designers and to Perform Constructability Reviews
2.	Design and Scheduling Decisions	Value Engineering Performed on All Projects Over $5 Million
		Comparison of the Estimated Construction Time Required to Maintain Traffic Versus Diverting Traffic
		Value Engineering Studies Conducted on Major Projects
		Evaluating Staging Approaches to Assess Tradeoffs between Traffic Flow and Construction Efficiency
		Critical Path Method (CPM) Scheduling to Set Contract Time
		Consideration of Nighttime Construction during Project Development
		Life−Cycle Costing to Select Longer Lasting Materials and Products
3.	Project Specific Traffic Management Planning	Construction WZ Traffic Control Strategy
		Comprehensive Traffic Management Plan
		Access/Egress Practices in WZs
		Using a TMP Peer Review Process
4.	Community Involvement and Coordination	Traffic System Management Committees
		Involvement of Affected Communities and Businesses in the Project Development Process
		Using Video to Enhance Public Involvement
		Community Advisory Councils

Contracting and Bidding Procedure: This section discusses the application of contracting and bidding procedures related to WZ projects as describe in Table 7 to reward contractors for quality work, innovation, and enhancing the safety of road users and workers.

Table 7. FHWA Best Practices on WZ Contracting and Bidding Procedures

Subcategory		Contracting and Bidding Procedures Best Practices
1.	Contracting Techniques	Alternative Contracting Practices
		A+B Bidding with Incentive/Disincentive Clauses
		A+B and Incentive/Disincentive Clauses
		Lane Rental
2.	Contractor Qualifications	Pre-Qualifying Contractors
3.	Flexible Timing	Flexible Start Times
		Narrow Window for On-Site Construction

Construction abd Maintenance Materials, Methods, Practices, and Specifications: This section discuss best practices related to construction techniques, innovation in materials and specifications, and other practices to increase the level of service and safety in a WZ, as described in Table 8.

Table 8. FHWA Best Practices on Specifications and Construction Materials Methods

Subcategory		Construction and Maintenance Materials, Methods, Practices, and Specifications
1.	Construction Methods	Incident Management in WZs
		Use of Pull-Off Areas in WZs
		Hoosier Helper
2.	Oversight/ Coordination	Requiring a Traffic Control Supervisor
		“Safety Program” Specification
		Traffic Control Coordinator
		Project Coordination Teams
3.	Traffic Control	Delay Damage Specification for Failure to Remove Lane Closures
		Quick Change Moveable Barrier™
		Coordination of Detours for Over-Sized Vehicles During Construction
		Performance-Based Lane Closures
		Standard Specification that Requires the Contractor to Correct Deficient Traffic Control
		Reduced Speed When Flashing
		Closure of Entrance Ramps During Construction
		Drone Radar on Changeable Message Signs
		Zipper Merge
		Halogen Stop/Slow Paddle
		Pocket-sized “Guidelines for Temporary Traffic Control”
		Traffic Pacing Design
		Water Filled Barrier in Work Zones
		Use of 42” Flexible Cones (a.k.a. “Grabber Cones”)
4.	Worker Safety/ Productivity	Flagger Certification Program
		WZ Safety Checklist Form
		High Visibility Reflective Apparel
		Nighttime Lighting Specification
		Improved Warning Lights on Vehicles

Traveler and Traffic Information: This section provides up-to-date information related to WZs for road users to help them make informed travel decisions, as described in Table 9. Practices discussed in this section emphasize strategies to provide detailed project information to the public, include planned duration, type of work being done, and expected delay to strategy to avoid delay.

Table 9. FHWA Best Practices for Work Zone Traveler and Traffic

Subcategory		Traveler and Traffic Information
1.	Project Public Outreach Techniques	Project Public Information/Public Relations Program
		Public Outreach for Travel Demand Management
		Public Relation Campaigns and the Use of Public Relation Firms
		Targeting Public Outreach to Key Stakeholders
		Signing for Businesses Affected by Construction
2.	Traffic Information Management	Bid Item in the Construction Contract for Public Relations
		District WZ Traffic Management Coordinator
		Construction Database and Website
		Contractor Involvement in Disseminating Project and Lane Closure Information
3.	Traveler Information Delivery	New Technologies to Communicate Project Information
		Using a Communications Center to Provide Real-Time Traffic Information to the Public
		Dissemination of WZ Project Information
		Use of Traffic Management Centers to Advise Motorists of WZ Delays
		Single Source for Construction Project Information in a Metro Area
		Website for Traffic Information, Advisories, and Alerts
		Media Campaign for Major Projects – Real-Time Traffic Information to Public
		Disseminating Information on Current WZs to Motor Carriers
		Highway Condition Reporting System
		"Wizard" CB Radio Transmissions Providing WZ Safety Messages to Truckers

Enforcement: This section provides detailed project information to the public about the activities undertaken by law officers to enforce laws and encourage safe conditions in WZ areas, as described in Table 10.

Table 10. Best Practices on Work Zone Law Enforcement

Subcategory		Enforcement
1.	Organizational Strategy	Interagency Agreement for Police Presence in WZs
		Police Officer Training Program for WZ Duty
		Full-Time State Police Positions Assigned to Safety and Construction Issues
		Helping All WZs Keep Safe (HAWKS) Program
2.	Speed Management	Active Law Enforcement to Manage Speed in WZs
		Drone Radar in WZs

ITS and Innovation Technology: This section discusses the best practices using ITS, as described in Table 11, to provide accurate real-time information automatically to motorists and construction teams, enforce speed, and provide the necessary information for road users to safely navigate a WZ.

Table 11. FHWA Best Practices on Work Zone ITS and Innovation Technology

Subcategory		ITS and Innovative Technology
1.	Traffic Monitoring and Management	Queue Length Detector
		Mobile Surveillance/Ramp Metering
		Portable ITS Technology for WZ Traffic Management
		Dynamic Lane Merge
2.	Traveler Information Delivery	Indiana Expert System for Advanced Traveler Information
		Providing Real-Time Traffic Information via Changeable Message Signs
		WZ ITS for Traveler Information
3.	Other Technology Tools	Automated Machine for Cone Placement and Retrieval
		Toolbox for Work Zone ITS

Evaluation and Feedback: This section emphasizes methods to collect and evaluate work data and feedback from road users and others. Electronic collection of WZ data, surveys, meetings, and project hotlines, and many other best practices are discussed here.

Table 12. FHWA Best Practices on Work Zone Evaluation and Feedback

Subcategory		Evaluation and Feedback Best Practices
1.	Data Collection/ Analysis	WZ Crash Data Analysis
		Analysis of WZ Crash Data
		Analysis of WZ Crash Trends
2.	Driver Surveys K	WZ Report Card
		Project Specific Customer Surveys on Major Interstate Reconstruction Projects
3.	Project Review and Use of Findings	WZ Review Team
		Statewide WZ Inspection Program
		Maintenance of Traffic (MOT)* Committee
		WZ Safety Task Force
		WZ Safety Award Program

* MOT is the layout of cones, barrels, and other devices outlined in the FDOT Standard Plans Indix 102.

2.6 Work Zone Intelligent Transportation System Implementation Guide

Different types of WZ ITS are implemented by different states with different objectives in their roadway construction projects. A research study by Fontaine (2003) summarizes the field test experience of Maryland, Iowa, Kentucky, Nebraska, Illinois, and Ohio. Table 13 provides a summary and information of past operational test results (Fontaine, 2003). Past research studies provide the following guidelines to determine if a WZ intelligent transportation system (WZITS) would be beneficial at a WZ or not:

- Install WZ ITS only if congestion present in a WZ at least some part of the day. If congestion is not occurring at the site, the WZITS would not have an impact, as it would not be able to display any messages.
- Use WZITS only on long-term construction or maintenance projects, as it may be difficult to justify the use of WZITS until the cost and portability of the existing technologies improve in a short-term project.

- Use Variable Advisory Speed Limit (VASL) signs only when vehicle density exceeds 40 vehicles per mile, thereby suggesting placing them in advance of locations where the density increases above this value. Use an alternative-route message to significantly improve driver travel time only if there are potential alternative routes in the area.

Table 13. Field Tests in U.S. States

Features	Maryland	Iowa	Kentucky	Nebraska	Illinois	Ohio
Type of message displayed	Speed	Delay	Speed, delay, alternate route	Speed, delay, alternative route	Travel time	Travel time
Sensor type	Optical sensors, radar	Radar, video cameras	Radar	Radar	Radar	Radar
Information dissemination devices	CMSs*	CMSs*, HAR	CMSs*	CMSs*	CMSs*	CMSs*
Accuracy of information	Messages not in real-time	Messages not in real-time	Poor delay estimates	Good	Good	Delay estimates worsened during congested conditions
Impact on safety	No data available	No data available	No data available	No detectable change	No data available	No data available
Impact on speeds	No data available	No data available	No data available	Messages effective when density > 40 vpm	No data available	No data available

* CMS is a abbreviation of changeable message sign.

The Maryland State Highway Administration, in its report "Use of Portable Changeable Message Signs with Speed Display in Work Zones," provides the following deployment guidelines for portable changeable message signs (PCMS) (Maryland State Highway Administration, 2005):

- PCMS with speed display should be placed in advance of the WZ location.
- PCMS should be placed on the same side of the roadway when multiple PCMS are used to avoid driver distraction.
- Periodic law enforcement should be arranged if PCMS are to be used for more than four weeks to maintain the effectiveness of the signs.
- PCMS should be installed only where shoulder space allows sufficient room for setup outside of the travel way, especially if the PCMS has a large display panel.
- To ensure accuracy each time a PCMS is set up, radar should be checked and adjusted.

- To measure speeds of vehicles traveling in the fastest-moving lane, radar should be aimed at no more than 10 seconds of distance upstream of the radar location.
- On high-speed facilities (i.e., roadways where the posted speed limit is 50 mph or greater), speeds of vehicles traveling more than 25 mph over the speed limit should not be displayed to discourage drivers from seeing how fast they can get the speed display trailer to read.
- Although PCMS with speed display may be used on all types of highways and WZs, irrespective of rural or urban environments, PCMS deployment is recommended particularly for rural and urban multilane divided high-speed roadways.
- PCMS with speed display may be used anytime of the day (day or night) and under inclement weather conditions.

From the Minnesota Intelligent WZ Toolbox, operational guidelines for dynamic speed display (DSD) deployment in WZ sites suggests having blank DSD signs when no traffic is detected. When traffic is detected over the speed limit, the sign should blink at a 50–60 cycles/minute.

The following section discusses SWZ studies that highlight technologies and applications and presents selected project experiences.

2.7 SWZ Studies, Technologies, Applications, and Project Outcomes

*2.7.1 **Overview***

National and state agencies have conducted research and documented progress on SWZ applications. A literature review was conducted to summarize SWZ studies, technologies, and applications as well as project outcomes in Florida and other selected states to understand technologies, practices, benefits, and success stories.

SWZ systems have been around for more than 20 years, but within the last 10 years the systems have become more robust and accessible. These systems are portable and automated, with temporary components that obtain and analyze traffic flow data in real time, providing frequently-updated information to motorists (Bledsoe, Raghunathan & Ullman, 2014).

SWZ systems use advanced technologies deployed within a roadway WZ to provide real-time traffic information on delays, expected speed, and predicted travel time. The benefits of using SWZ systems include enhancing safety in WZs for motorists and workers, reducing congestion caused by WZs, and increasing the quality of the information received by residents about WZs in their communities. SWZ systems can be implemented for any WZ that is expected to have a significant impact on the roadway network.

An SWZ should have the following general characteristics:

- Real-time – obtain and analyze traffic data in real-time, providing frequently updated information to motorists
- Portable – system being portable
- Automated – operate in an automated manner with minimal human supervision
- Reliable – provide accurate and reliable information on the situation in a WZ

SWZ uses a variety of communication-based information and electronic technologies, such as sensors, communication systems, software, and electronic equipment. Sensors collect traffic information in the field; the collected data may include traffic volumes, speed, and video recordings of traffic flow. Communication systems transmit the data for processing and distribution; communication links might be wired or wireless. Software processes and analyzes the data, preparing information that can be used by other components of the SWZ. Electronic equipment circulates the information to end-users such as motorists and transportation agencies. SWZ components are presented in Table 14.

Table 14. Available ITS Components for SWZ

ITS Component	Types
Sensors (to collect data on traffic conditions)	• Sensors: Spot speed/volume/occupancy, point-to-point travel time • Cameras (manual visual monitoring and automated video detection) • Sensors (automated vehicle identification (AVI); radio frequency identification (RFID); automatic vehicle location (AVL); Bluetooth; cellular telephone tracking) • Emissions sensors • Road Weather Information Sensor (RWIS) • Environmental Sensor Station (ESS) • Vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) • Doppler Radar • Microwave Radar
Communications Systems (to transfer the data)	• Cellular • Wireless (Wi-Fi), private or public • Satellite communications • Dedicated short-range communications (DSRC)
Software (to process/analyze data storage)	• JamLogic • StreetSmart • Jobber • WorkWave Service
Electronic Equipment (to disseminate information to end users)	• PCMS • Dynamic Signs • Specialized signs (e.g., variable speed limit operations) • Highway Advisory Radio (HAR) • Websites • Smartphone/tablet applications • Alerts (e-mail/text, social media)

Adapted from: Bledsoe et al. (2014); Ullman (2017a); Ullman, Schroeder & Gopalakrishna (2014)

2.7.2 SWZ Applications

To make travel safer and more efficient through and around a WZ, many transportation agencies use SWZ applications. SWZ involves the use of electronics, computers, and communication equipment to automatically collect and analyze traffic flows upstream from, within, and downstream from a WZ. Examples of SWZ applications include the following:

- **Queue Length Detectors** (Queue Warning Systems) – Infrared beams monitor how long it takes a vehicle to cross through the infrared beams. If the time taken by a vehicle to cross the beam exceeds a certain pre-set time, then traffic has stopped or slowed, and an alert will be sent that helps to remedy the problem and to take action to increase traffic flow. This device can be applied in any WZ where queues form.
- **Mobile Surveillance/Ramp Metering** – Self-powered surveillance trailer with wireless communication and video image processing that provides images and traffic data such as speed, volume, and occupancy to the Traffic Management Center (TMC) from locations that do not have permanent surveillance infrastructure. This method of collecting data can be used on city streets and freeways and in urban areas and rural areas in any condition of construction activity.
- **Variable Message Signs (VMS)** – Technology used to provide messages to motorists about traffic conditions. Usually, a VMS is integrated with queue length detectors where these detectors collect data such as lane occupancy and traffic speed and send them to a computer that processes the data and determines the appropriate message to be displayed. This technology helps keep motorists advised of real-time conditions and smooth traffic flow and gives drivers earlier notice when incidents occur and advance warning to avoid rear-end crashes. This technology can be applied both in urban and rural areas where high volume is experienced.
- **Dynamic Lane Merge (DLM)** – System that varies merging behavior based on traffic conditions. Implementation involves the deployment of both static and changeable message signs in conjunction with ITS technology, encouraging drivers to either merge early or late depending on traffic volume as they approach a lane closure. DLM technology has a positive effect on aggressive driving, queue lengths, crashes, travel time, and speed differentials between lanes, resulting in safer and improved mobility. It is more appropriate to implement where congestion is expected due to lane closures both in urban and rural environments.
- **Real-Time Traveler Information** – Traffic-responsive systems used in WZs to monitor real-time traffic conditions continuously and respond with appropriate and dynamic messages automatically. Messages such as delay time information, alternate route information, stopped traffic warnings, dynamic speed, lane merge, and other motorist instructions are provided. The system can run 24 hours per day, 7 days per week, keeping

motorists informed of all traffic conditions. The most applicable location for this system is any WZ exposed to traffic and is most useful in areas with limited sight distance and the high volume of traffic.

- **Dynamic Speed Limit (DSL)** – Systems that take account of real-time traffic, road, and weather conditions and are increasingly applied worldwide, usually on motorways. A main objective of DSL is to improve traffic safety through a reduction in speed variation within and across lanes and between downstream and upstream. This system can be applied in WZs with high-speed traffic both in rural and urban areas.

Examples of SWZ applications are provided in Table 15. Criteria to justify the SWZ application with feasibility assessment is provided in Appendix A.

Table 15. Examples of SWZ Applications

SWZ Application	Description	Addressed Issues
Dynamic Speed Limit	Warns traffic of slow or stopped traffic ahead	• Safety • Speed Management
Queue Warning System (QWS)	Detects congestion in WZs and warns drivers of slow or stopped traffic ahead	• Safety (especially rear-end crashes)
Real-Time Travel (RTT) Information	Provides drivers with current travel conditions within and before WZ. May consist of information on WZ ahead or alternative routes, incidence information, or site-specific construction information to divert traffic away from WZ during congestion	• Reduced congestion and delay • Improved safety • Enhanced driver awareness • Improved communication with drivers
Entering/Exiting Vehicle (EEV) Notification	Informs drivers of slow-moving construction vehicles that might enter/exit roadways	• Enhanced safety of construction workers and drivers
Dynamic Lane Merge	Encourages drivers to merge at a specific point based on current operating conditions	• Delay • Aggressive driving behavior • Safety • Queue length
Traffic Data Collection	Can include traffic volumes, speed, travel time, and vehicle classification	• Evaluation • Performance

Adapted from: Ullman et al., (2014)

SWZs are designed to provide benefits to road users, WZ workers, and agencies. The main benefits of SWZs include increased safety (fewer and less severe crashes), reduced travel mobility impacts, reduced customer dissatisfaction/complaints, and reduced impact to WZ worker productivity. Table 16 presents the primary and secondary benefits for different types of SWZ applications.

Table 16. SWZ Applications and Benefits

SWZ Application	Benefits	
	Primary	***Secondary***
Queue Warning System	• Fewer crashes • Less severe crashes	• Reduced delays • Reduced impact on contractor productivity
Travel Time Information	• Reduced customer dissatisfaction • Reduced delay	• Fewer crashes • Reduced impact on contractor productivity
Variable Speed Limit (VSL)/Speed Limit Harmonization	• Fewer crashes • Less severe crashes • Reduced delay	• Reduced impact om contractor productivity
Dynamic Late Merge ("Zipper Merge")	• Reduced customer dissatisfaction • Fewer crashes	• Reduced delay • Reduced impact on contractor productivity
Construction Access Point Warning	• Fewer crashes	• Reduced delay • Reduced impact on contractor productivity
Maintenance/Enhancement of Traffic Surveillance and Incident Management Functions	• Fewer crashes • Less severe crashes • Reduced delays • Reduced customer dissatisfaction	• Reduced impact on contractor productivity

Source: (Ullman, 2017b)

Based on preliminary findings on general contributing factors from the previously-noted WZ crash data assessment, the major focus of this project is to deploy SWZ applications and strategies to reduce vehicle speeds, speed variance, sudden decelerations, and sudden lane changes within WZ limits considering the following:

- Dynamic speed limit sign (SWZ concept)
- Queue warning message (SWZ concept)
- Combination of posted speed limit and speed feedback sign
- Stationary police vehicles with blue lights
- Blue lights on static equipment or signs
- Adequate lighting setup and configuration in WZ at night

Table 17 shows some of the widely-used SWZ applications and links with WZ types based on work characteristics considered in the FHWA implementation guide (Ullman et al., 2014).

Table 17. SWZ Applications and WZ Types

SWZ Applications	Lane Closure	Lane Shift	Work on Shoulder or Median
Queue Warning	✓	✓	✓
Real-time Traveler Information	✓	✓	✓
Incident Management		✓	✓
Dynamic Lane Merge	✓		
Variable Speed Limit	✓		✓
Automated Enforcement			✓
Construction Vehicle Entrance/Exit Warning			✓
Temporary Ramp Metering*	✓	✓	

* Applicable to freeway section or interchange area connected with arterials (local roads).

Given the research objectives and SWZ application and their applicable scenarios based on WZ types, posted speed limit and speed feedback signs could be used for all three WZ types. In this regard, an AWAD highly recommended by the Florida Work Zone Safety Coalition was considered and selected as a major SWZ application for this project. An AWAD employs radar combined with flashing LED signs that warn drivers of an upcoming active WZ for arterial roads. This device indicates travel speed and displays safety signage that says “Active WZ When Flashing” and “Speeding Fines Doubled.” A detailed discussion on AWADs as part of a low-cost and novel approach of SWZ application is provided in Appendix A with field data deployed on a section of I-4 freeway section in Florida. Implementation of AWAD provides a promising direction to deploy the same application on arterial roadway sections considering lane closure or work on shoulder or median. An AWAD is shown in Figure 19.

Figure 19. Photos of AWAD

FHWA developed a WZITS tool for use in assessing whether an SWZ application is beneficial to an agency at WZ sites. Based on certain criteria (as explained in Appendix A), the tool assesses if the score assigned for those criteria and the input from agency professionals leads to a decision for the agency on deployment of SWZ application:

- If the total score is greater than or equal to 30, ITS is likely to provide significant benefits relative to costs for procurement.
- If the total score is between 10 and 30, ITS may provide some benefits and should be considered as a treatment to mitigate impacts.
- If the total score is below 10, ITS may not provide enough benefits as a treatment to justify the associated costs.

In addition, CUTR reviewed important ITS application systems from the vendor standpoint, which could be considered for SWZs in Florida (see detailed summary in Appendix A).

2.8 Work Zone Experiences in Florida

Per the Florida State Safety Office, Florida had the second-highest number of fatal crashes in WZs in 2016, with workers present in 35% of fatal crashes and 44% of injury-related severe crashes. WZs also are causes of traffic congestion and non-recurring freeway delays, so it is essential to maintain and upgrade highway systems in WZ areas. Application of innovative construction WZ management solutions based on WZ types should be explored, tested, and evaluated on their effectiveness to inform drivers, deter unsafe driving, and improve WZ visibility at night to protect drivers, pedestrians, and construction workers.

Traffic safety and efficiency of roadway WZs is a major concern of FDOT, which has integrated ITS-based lane management such as DLM, PCMS, and traffic sensors in its existing MOT plans for movable WZs. Simplified Dynamic Lane Merging Systems (SDLMS) also have been used to address lane merging problems in WZ places

2.8.1 ***Lane Closure***

Every WZ has frequent lane closures, which reduces roadway capacity, resulting in vehicle queuing. As a safety hazard, queuing makes it difficult for drivers to safely merge into slower-moving traffic queues in the WZ; this also results in rear-end collision crashes.

A study by the University of Florida (UF) found that data collected on-site helped to evaluate a simulations-based model for freeway during lane closure. UF researchers developed a new planning and operation models for estimating WZ capacity using simulation data with the addition of field data collected in a freeway WZ in Jacksonville. Using TMC cameras to collect data at the WZ site during each lane closure for 15 days, different levels of traffic congestion were found on each day when lane closures occurred. Using these collected data for the WZ site, a new operation model was developed that can predict traffic flow with less than 1% error and was more accurate than FDOT's traditional model. Through this research, it was observed that real data would help in estimating flow capacity with more accuracy (Washburn, Hiles & Heaslip, 2008).

USF researchers evaluated the use of DLM systems in WZ areas. These systems are used to calm traffic and prevent collisions within WZ areas; they efficiently manage traffic approaching lane closures when demand exceeds capacity. Using CORSIM, a simulation model was developed to simulate a real freeway WZ and operation of a DLM. Data collection was performed by computing and reading the Measures of Effectiveness (MOEs) and running them in CORSIM. Through analysis, it was found that DLM had a positive effect on traffic operations and safety on a range of traffic conditions, especially reducing the number of lane changes at a merge area when only one lane is open. Researchers expressed concerns that operational performance was not improved after implementation of the DLM system due to WZ capacity reduction in the WZ (Lu, Wang & Wang, 2008).

*2.8.2 **Lane Shift***

FDOT deployed and tested an SDLMS at two levels (early and late) on a WZ to address lane-merging problems caused by lane closures. The SDLMS used by FDOT consisted of one set of traffic detection stations, one central computer base station, wireless communication links, and PCMS. SDLMS uses DOT-compliant PCMS to convey real-time traffic conditions and can operate 24 hours per day, 7 days per week. These systems also are password-protected with an independent, stand-alone unit and provisions for future integration with other traffic control/maintenances systems. All data acquired from SDLMS are archived in a log file that is date and time-stamped, and the system can operate in all weather conditions. It was found that simplified early and late merging did not affect travel time through a WZ. The number and percentage of lane changes were found highest for the early SDLMS and lowest for the late SDLMS, indicating that drivers were complying with the message displayed by the PCMS (Radwan, Harb & Ramasamy, 2009).

A study by the University of Central Florida (UCF) integrated SDLMS and VSL systems to check performance concerning traffic mobility with existing individual controls. UCF researchers, using VISSIM, configured a WZ with a two-lane to one-lane closure to represent an actual geometry of the WZ using a series of links, connectors, routing, decisions, and lane closures. Later, logics for a VSL sign and its integration with SDLMS were done in VISSIM and tested through various simulations runs. Through analysis, it was found that for higher traffic volume levels, SDLMS with and without VSL produced higher mean throughputs. From this research, it can be inferred that the integration of SDLMS and VSL systems would have better performance in traffic mobility and showed that this integration has more potential than each individual existing control system (Radwan, Zaidi & Harb, 2011).

It is imperative to have a lane with a proper taper length for vehicles in a WZ to safely shift from one lane to another, especially during lane closures. A previous study to determine whether reducing the standard length noted in Design Standard #613 would have any impact on vehicles traveling in a WZ with the presence of a visually-occluding lead vehicle considered as a key-moderating factor influencing WZ safety. Duley et al. (2007) conducted simulations at two different levels; in the first experiment, the taper length and lead vehicle were considered as two primary factors, and simulation was performed. In the second experiment with the replication of first experiment factors, additional vehicles were added, and simulation was performed. Results suggested that reduction of a WZ taper paired with a WZ occlusion increased accident risk. Additionally, the authors also suggest considering driver behavior in the WZ as a moderating factor to better understand the context of WZ operation. This research study helps to understand the importance of human factors in and around WZs, the impact of visual occlusion, and the elimination of uneven speed patterns to increase the efficiency of a roadway WZ and its safety (Barnabe & Esea, 2010).

*2.8.3 **Work on Shoulder or Median***

FDOT developed a new MOT system for WZ traffic control, called the MAS, which uses PCMS, radar display units, and regulatory speed limit signs to make a WZ safer. An effort to determine the effectiveness of the new system MAS was made in a construction WZ by Reddy et al. (2008) and in two segments of I-95 and I-10 in Florida by collecting speed data with MAS and without MAS at various times of the day and week. A comparison of MAS was also made at three different levels to determine the effect of MAS on travel speed in a WZ via a standard MOT, MAS with police enforcement, and MAS without police enforcement. After several statistical tests, the authors found that MAS had a positive impact on reducing the speed of vehicles traveling in the WZs and with police enforcement resulted in additional speed reduction. Overall, MAS can be used as a countermeasure to reduce vehicular speed through a WZ, especially during scenarios in which construction work takes place on a median or shoulder where vehicles tend to speed, as they do not see any presence of workers in their travel lane.

2.9 Work Zone Experiences in Other States

Multiple reports and articles published on the FHWA website provide concepts, overviews, guidance, and benefits of SWZs and introduce the need to provide drivers with real-time information within a WZ and describe the characteristics of SWZ systems. In 2015, FHWA launched the SWZ initiative, promoted by Every Day Counts (EDC). The goal was to help agencies better design, plan, coordinate, and operate WZs. There are two main strategies to implement SWZ successfully—project coordination to harmonize construction projects to reduce WZ impacts and technology applications (for example, queue management and speed management systems) to control traffic in and around WZs dynamically. By the end of 2016, 9 states had institutionalized project coordination practices; 18 had incorporated strategies and software tools into their processes for planning, design, operations, and maintenance; 11 had mainstreamed technology tools and strategies; and 28 had incorporated applications into their agency practices. The EDC SWZ final report is available online at www.fhwa.dot.gov/innovation/everydaycounts/reports/edc3_final. Other resources, related publications, case studies, tools, demonstration site visits, and webinars are available from FHWA's SWZ website at www.workzonesafety.org/swz (Paracha & Ostroff, 2018).

2.9.1 Lane Closure

In 2002, FHWA examined SWZ applications at four locations in Michigan, Illinois, New Mexico, and Arkansas (FHWA 2002). The case study in Michigan included a total closure of I-496 in downtown Lansing; full closure of the affected miles required that all traffic be diverted from the freeway at those points and that additional traffic management and traveler information be provided. The Michigan Department of Transportation (MDOT) used its mobile traffic monitoring and management system as a virtual TMC, with a system that included 17 cameras, 12 dynamic messign signs (DMSs), 6 queue detectors, and National Sign and Signal's ITSworkzone™ software to gather and process data on current conditions and display advance traveler information to the public. In this SWZ application, the Telemetered Traffic Monitoring Sites (TTMS) consisted of data collection devices electronically linked via wireless radio frequency (RF) communications equipment to a server at the Construction Traffic Management Center (CTMC). The ITSworkzone™ software processed data collected by system sensors and then informed TMC operators of problem areas where queues were building. The software automatically updated the signs depending on the time of day and the current stage of construction. MDOT staff had the ability to update the messages displayed manually. The software had a bank of pre-determined messages that could be posted on each DMS, and operators also had the option of creating a new message for use. Real-time traffic condition information was conveyed to motorists via the system's DMSs. In addition, the system displayed a map with color-coded average roadway speeds on the website. MDOT staff had not used a similar system in the past. However, MDOT was motivated to seek more aggressive solutions to WZ traffic congestion because the I-496 project was much larger in scope than other WZs deployed in the area.

The case study in New Mexico (FHWA 2002) included a frequent change of closed lanes, so traffic flow patterns changed regularly. The main goals of the SWZ application were to provide traffic management capabilities and traveler information on traffic routing, detours, and significant incidents, minimize capacity restrictions due to incidents by more quickly identifying incidents and determining an appropriate and effective response to clear the roadway, and enhance traveler safety. The system included eight fixed Closed-Circuit Television (CCTV) cameras, eight modular (expandable) DMSs, four dynamic arrow signs, four all light-emitting diode (LED) portable DMS trailers, four ADDCO, Inc. Smart Zone® portable traffic management systems that integrate CCTV cameras, dynamic message signs on one fully-portable traffic management system, and four HAR units. The cameras and DMSs were linked electronically to base station computers in a TMC using an internet platform with both wireline and wireless communications. In addition to the DMSs and HAR, information on traffic conditions was distributed via websites and use of media outlets such as radio, newspaper, and television (FHWA, 2002).

A case study in Arkansas (FHWA, 2002) included a reconstruction project of three miles of concrete pavement on 1-40. The main goals of the automated WZ information system (AWIS) were to provide traveler information and enhance traveler mobility and safety for motorists approaching and traveling through the WZ area. The West Memphis AWIS was deployed in October 2000 that detected traffic conditions approaching the WZ and used that information to determine what messages to transmit to travelers in real-time via DMSs and highway advisory radio. West Memphis used the Computerized Highway Information Processing System (CHIPS) developed by ASTI Transportation Systems, which consisted of sensors, a wireless communications network, a control center with a computer, and an interface for processing the sensor data, and output devices. The system included 12 queue detectors, 5 remotely-controlled DMSs linked to a central base station server using wireless communications, 3 highway advisory radio units, 5 pagers, and an e-mail alert system. The detectors were spread over a seven-mile stretch extending before and after the WZ on each side, and the message boards were spread over about nine miles approaching the WZ from both sides. The range of the HARs was approximately 23 miles.

Another project in Arkansas reported the deployment of SWZ technology. AWIS can provide queue detection that can aid in reducing rear-end collisions and provide real-time information for motorists about potential backups caused due to lane closures. AWIS included two system CHIPS and automated data acquisition and processing traffic information in real-time (ADAPTIR), which consisted of two highway advisory radio systems (HDR), five radar traffic microwave sensors (RTMS), five changeable message signs (CMS), and two speed stations per lane closure. It was found that RTMS had difficulties in calibrating and operating due to a high percentage of trucks on the interstate, which was resolved by replacing the RTMS with Doppler radar. CMS was designed such that if the traffic sensors exceeded 10 mph, the upstream CMS would display “Reduce Speed YY mph” followed by “XX Minute Delay,” but if the speed limit was below the threshold value, CMS would display delay information only. HRS broadcast had three different phases—an introductory message providing general project information, details about lane closure plans, and a recorded message that would fit the scenario in effect of the lane closure. From this research, it was found that implementing AWIS had a positive impact on WZ safety in Arkansas. Fatal and rear-end crash analysis revealed a reduction in fatal crashes and that the system helped in enhancing congestion management, especially in urban areas (Tudor, Meadors & Plant, 2003).

The Kansas Department of Transportation (KDOT) used SWZ technology during the construction of a diverging diamond interchange at the intersection of I-35 and Homestead Lane in Johnson County. KDOT implemented SWZ applications that incorporated dynamic lane merge with a queue warning system. Travel times were provided for drivers on changeable message signs prior to the WZ, and eight CCTV cameras were installed to monitor traffic operations throughout the WZ. KDOT noted that drivers appeared to be courteous, which may have been promoted by the large public outreach about the SWZ late merge application.

Additionally, there were many discussions on what data should be retained from the WZ. The data became quite large and was too big for the temporary unit to store. The speeds and volumes were retained. Based on a before-after comparison, it appeared that about 10% of the traffic was diverted away from the WZ during the peak periods (Bledsoe et al., 2014).

Gambatese et al. (2019) investigated the effectiveness of flashing blue lights mounted on construction equipment during mainline paving operations at night on high-speed roadways in Oregon. Researchers analyzed three case studies that revealed that vehicle speed was affected by the presence of flashing blue lights. In general, with the blue lights flashing, the mean vehicle speed was lower compared to when they were off. Closer to, immediately adjacent to, and downstream of the paver, the reduction in mean speed was sometimes less or none at all with the blue lights on; at some locations, the mean speeds were higher with the blue lights on. In case study 1, the mean speed was 28.8–49.3 mph with the blue lights off and 24.6–40.0 mph with the blue lights on. In case study 2, the mean speed was 37.0–45.1 mph with the blue lights off and 36.0–44.0 mph with the blue lights on. In case study 3, mean speed was 41.6–47.3 mph with the blue lights off and 31.5–45.3 mph with the blue lights on.

The Minnesota Department of Transportation (MnDOT), working with the University of Minnesota (UMN), developed and evaluated a new speed warning system that alerts drivers nearing freeway WZs. In this system, speed detection sensors were installed on poles every half mile through a new highway construction WZ. Using a type of portable Intelligent Lane Control System (ILCS), the new system collects traffic speed data throughout the WZ, runs it through an algorithm, and generates a real-time message for drivers on a VMS such as “35 mph 1 Mile Ahead” or “Stopped Traffic Ahead.” The system was deployed at a large, multistage highway WZ on I-94 east of downtown St. Paul during work replacing and repairing the roadway (Frost, 2019).

2.9.2 ***Lane Shift***

In 2002, FHWA examined SWZ applications at four locations in Michigan, Illinois, New Mexico, and Arkansas. The case study in Illinois included reconstruction of the Lake Springfield bridges and involved closing the southbound bridge and diverting southbound traffic onto the northbound bridge. During construction, traffic on the bridge was separated by a barrier wall, requiring motorists to reduce speeds to 55 mph or 45 mph depending on whether or not workers were in the area. Once the new southbound bridge was complete, the process was reversed. The SWZ application provided travelers with information on traffic conditions in the WZ while providing Illinois DOT (IDOT) and contractors with real-time information regarding these conditions. Additionally, SWZ offered potential savings to Illinois taxpayers through automation by eliminating the need to have full-time IDOT staff or state employees constantly monitoring conditions. The Real-Time Traffic Control System included 17 remotely-controlled portable DMSs, 8 portable traffic sensors electronically linked to a central base station server, and 4 portable CCTV cameras electronically linked to a central base station using wireless communications. The system consisted of data collection devices electronically linked via wireless communications to a central base station server. The base station server processed data collected by system sensors and then disseminated appropriate information to travelers and IDOT staff. IDOT staff were automatically updated via e-mail based on pre-defined parameters established by the agency. For example, the system would contact higher-level IDOT staff as longer queue lengths were detected. Real-time traffic condition information was conveyed to motorists via the system's DMSs and websites. The SWZ application was selected because IDOT staff had favorable experiences with similar systems in other areas of the state that required the provision of traveler information due to traffic congestion, especially in the Chicago area.

Through an SWZ deployment initiative, researchers from the University of Kansas evaluated early merge static WZ signage in Oklahoma to examine the safety and operational benefits of having traffic merge early into an open lane before a WZ merge area. A static sign stating "State Law Merge Now" was placed approximately a half mile upstream from the freeway merge area in four WZ areas of Oklahoma. As the sign was implemented in the middle of the construction season, it helped in providing an opportunity to compare the before-and-after the impact of early merge signage in an actual WZ. Field data were collected over 15 days using video trailers; these video trailers had two cameras: one focusing on the WZ merge area, and the other view towards traffic prior to drivers viewing the "State Law Merge Now" sign. The measure of effectiveness included the number of conflicts that occurred in the merge area and the percentage of traffic that remained in the closed lane. It was found that early merge signs did not have any effect on reducing the rate of vehicles that remained in the closed lane, but it appeared that the signage was able to reduce the number of conflicts at the merge area. Based on this research, early merge signs had no impact in making vehicles merge early but helped in encouraging drivers to consider how early they could make their merge maneuver (Shrock, 2008).

Tooley et al. (2004) evaluated automated WZ information systems in which an AWIS was implemented at a WZ in a rural area in Arkansas on I-40, notifying motorists of changing traffic conditions (slowdown or backups). Field observations of backups were collected using video cameras, which recorded vehicular movements in both lanes, and speed data were collected by a lidar or radar gun adjacent to the video camera and aimed at approaching traffic. The distance of the vehicle was calculated using the speed data. Through CMS, backup sensed by AWIS was identified. Later, AWIS was compared with field observations for two traffic speeds, 30 and 50 mph. It was observed that AWIS concurred with the field observation 92% of the time for a 30-mph speed, and for 50 mph speed, the system indicated a backup 88% of the time. Based on this research, it was concluded that backups formed at short-term flow rates as low as 800–900 passenger car equivalents per hour, which was lower than the capacities of earlier reported literature (1,100–2,000 vehicle per hour) (Chu, Kim, Chung & Recker, 2005).

2.9.3 *Work on Shoulder or Median*

A Portable Traffic Management System (PTMS) was used to collect speed data in an operational test in Minnesota on I-94. The system included a portable vision camera placed at a strategic location. Evaluation of the PTMS system was made by collecting data before system information was made available to motorists and comparing these data to data collected after system information was made available. The results showed the traffic volume decreased in the WZ when the PTMS was in operation. A decrease in traffic volume was also observed, which might be due to increased driver confidence in traveling through the WZ because of the real-traffic information provided by PTMS. Also, it was observed that the PTMS helped in decreasing the average speed for the traffic approaching the WZ by 9 mph, which suggests that it is an improvement in safety, as vehicles approaching the WZ slowed down sooner (SRF Consulting Group, 1997).

To reduce traffic conflicts in a WZ, a practical approach was used on an I-494 WZ in Twin Cities, Minnesota, for a three-week period in 2006. The proposed project was determined with a two-stage reduction scheme using VASL. Five sets of radar sensors (to measure speed and volume), three VASL with lighting emitting diode panel (for variable speed display), three sets of Doppler radar sensors (for speed measurement at the advisory speed sign location), and one set of web-based wireless communication system (for data collection, processing, and speed determination) were used in the study. It was determined to vary the VASL every 1 minute in 5-mph increments; the data collected included lane-by-lane speed and volume for every 30 seconds at 5 locations. Driver compliance was also calculated by comparing the three speeds values (speed at approaching the sign, speed near posted advisory speed limit sign, speed at downstream). After a three-week testing period under the shadow operation mode, data collected before and after indicated a 25%–35% reduction of the average one-minute speed difference along the WZ area during morning peak hours after the system was implemented. Driver compliance level showed 20%–60% speed reductions even though the posted speed values were advisory. Based on this research study, a variable advisory speed limit system can be used as a regular tool for WZ management. The research also noted that a requirement of a study was on the long-term effect of VSL control on driver compliance levels for a better understanding of driver behavior in WZs (Kwon et al. 2007).

2.10 Summary

Results of the project’s four major tasks are summarized below and include major highlights.

2.10.1 *WZ Facts and Statistics*

- In the US, between 2012 and 2019, 724 fatalities occurred in WZ crashes; on average, 128 worker fatalities occurred in WZ-related crashes annually.
- In Florida, between 2012 and 2019, 70 fatalities occurred in WZ crashes; on average, 11 fatalities occurred in WZ-related crashes annually.

- In Florida, between 2012 and 2019, 55% of WZ fatal crashes occurred on arterial roads and 37% on interstates.
- On average, 6,986 WZ-related crashes occurred annually in Florida, with a peak in 2016 of 8,335 crashes. In 2016, 23 persons were involved in WZ-related crashes daily. The number of WZ-related crashes started to decrease from 2016.
- In total, 55% of WZ-related crashes occurred in the work on shoulder or median WZ type. On average, 65% of WZ-related crashes resulting in severe injuries occurred in the work on shoulder or median WZ type.
- On average, 31% of WZ-related crashes occurred between 6:00 am and 12:00 pm. Crashes for the work on shoulder or median WZ type accounted for 69% of WZ-related crashes between 6:00 and 9:00 am and 66% between 4:00 and 6:00 pm.
- On average, 67% of crashes occurred within an activity zone area, and about 84% work occurred within a transition zone and an activity area.
- The percentage of WZ-related crashes in an activity zone was 77% for WZ type of work on shoulder or median, 72% for intermittent WZ type, 56% for lane shift and 50% for lane closure type.
- The percentage of WZ-related fatalities involving large trucks (commercial vehicles) was higher than that in non-WZ-related crashes in Florida with an average of 21%.
- About 70% of WZ-related crashes were likely attributed to human behaviors (i.e., non-road geometry-related), about 25% attributed to WZ and road surface conditions, and about 5% to environmental factors.

2.10.2 ***WZ Crash by Roadway Functional Class***

- In 2012–2019, about 55% WZ- related crashes in Florida occurred on arterial roads, followed by interstates (37%), collector roads (2%), and local roads (7%).
- On average, 65% of WZ-related crashes that resulted in severe injuries occurred in work on shoulder or median WZ type.
- On interstates, on average, 69% of WZ-related crashes occurred related to a shoulder/or median WZ type; 19% to lane closure WZ type, 12% to lane shift, and 5% to intermittent WZ type.
- On arterial roads, on average, 53% of WZ-related crashes occurred related to shoulder or median, followed by 30% to lane closure, 12% to lane shift, and the smallest share of WZ crashes occurred in the intermittent WZ type (5%).
- On collector roads, on average, 43% of WZ-related crashes occurred related to lane closure, followed by 37% to shoulder or median, 11% to lane shift, and 9% to the intermittent WZ type.

- On local roads, on average, 53% of WZ-related crashes occurred in shoulder or median WZ type, 24% in lane closure, 12% in intermittent, and 12% in lane shift.

2.10.3 ***WZ Experiences in Florida and Other States***

- Real-time data help to estimate flow capacity in WZs.
- DLM application produced higher mean throughputs through WZs.
- Real-time traffic information notifies motorists about potential backups caused due to lane closures.
- Real-time traffic information in WZs is associated with reduction of fatal crashes and congestion reduction.
- Use of blue lights in WZs is associated with speed reduction.
- Use of SWZ offers potential savings, as no employees are required in the field to operate the application.
- Displaying speed data on a portable traffic management board helps decrease average speed through a WZ.

2.10.4 ***SWZ Applications and Implementation Guidelines***

- Locations that do not have permanent surveillance infrastructure should use mobile surveillance trailers to collect traffic data.
- To measure the speeds of vehicles traveling in the fastest-moving lane, radar should be aimed at no more than 10 seconds of distance upstream of the radar location.
- To capture WZ speed and volume data, portable ITS technologies should be used that can provide real-time roadside travel and traffic management information.
- There is no benefit to installing WZITS if a WZ has no congestion; WZITS would not have any impacts if congestion is not occurring at the site, as it does not display messages.
- An AWIS can provide queue detection, which can aid in reducing rear-end collisions and provide real-time information for motorists about potential backups caused due to lane closures.
- A Portable ILCS collects traffic speed data throughout a WZ, runs it through an algorithm, and generates a real-time message for drivers on a VMS.
- FDOT deployed an SDLMS at a WZ to address lane-merging problems caused due to lane closures, which was found to have no effect on travel time through the WZ.
- A PTMS integrated with a portable camera to collect speed data helps in decreasing traffic volume in a WZ.
- A VASL system can be used as a regular tool for WZ management.

- Providing travel time details for drivers on a CMS prior to a WZ helps drivers to make decisions on using an alternate route, which eventually reduces congestion at a WZ site.
- PCMS should be placed on the same side of the roadway when multiple PCMS are used to avoid driver distraction.

Considering the major highlights of these tasks from the literature review, CUTR, in coordination with FDOT, developed a work plan for site selection, data collection, data evaluation, and analysis for pilot testing. With the existing knowledge on SWZ applications gathered from best practices and FDOT experiences, CUTR deployed a low-cost but novel approach with SWZ application that can satisfy the traffic conditions and scenarios of WZ sites in FDOT District 7.

Florida is expected to grow economically in terms of road infrastructure, and the number of WZs is likely to increase across the state, with continued exposure to crash risks and injury severity. Given the importance of WZ safety in Florida and the US, appropriate strategies and countermeasures were developed via this research project to reduce the frequency of WZ crashes especially on arterials, and minimize the associated injury severity for all motorists and workers.

3. Work Zone Data Collection at Pilot Implementation Sites

This chapter describes the data collection plan, methodology for data collection, and detailed data collection efforts at each pilot implementation site, including testing scenarios and data collected. It first presents a procedure for SWZ application deployment and data collection followed by study site selection, SWZ applications and testing scenarios, efforts on SWZ implementations and coordinations, performance measures, and data collection methodology. Finally, a detailed before-after data collection effort at each study site and the data collected are described.

3.1 Data Collection Plan

A data collection plan was developed to guide the data collection tasks in this study. The data collection plan included:

- Identification of SWZ applications for a pilot study based on literature review
- Selection of WZ projects covering three WZ types
- Development of implementation plan and testing scenarios
- Determination of performance data and data collection methodologies

The pilot study adopted the before-after method to compare various safety performance measures before and after the implementation of SWZ applications. The pilot involved coordination among the research team, FDOT District 7, construction managers, and construction contractors. The following procedure defines the workflow of the before-after study:

- *Planning* – The research team coordinated with FDOT District 7 and WZ site managers to understand project types, duration, existing MOT, and available resources. Based on the information, the research team determined SWZ applications for implementation, including application types and combinations, implementation duration (starting and ending dates), implementation positions, and application operations.
- *Before Study* – At the beginning of a WZ project, construction contractors applied traditional MOT. The research team set up data collection devices on the roadside to collect necessary data. "Before" data, which represent safety performance without SWZ applications, were used as the evaluation baseline.
- *After Study* – Once the "before" data collection was completed, construction contractors implemented SWZ applications in WZ areas. Based on different testing scenarios that may involve combinations of different SWZ applications, the implementation was split into several stages. In each stage, the research team collected safety performance data in the field after contractors installed the selected SWZ applications. The "after" data collection was repeated for each testing scenario.
- *Evaluation* – The research team assembled the safety performance data collected in the "before" and "after" stages. Statistical comparisons of selected safety performance

measures between these scenarios were conducted to assess if the risk of traffic crashes could be reduced due to the implementation of SWZ applications. The comparison also helped assessment on SWZ application combinations by WZ type.

3.1.1 Procedure for SWZ Application Deployment and Data Collection

The procedure for implementing SMZ applications and data collection is shown in Figure 20.

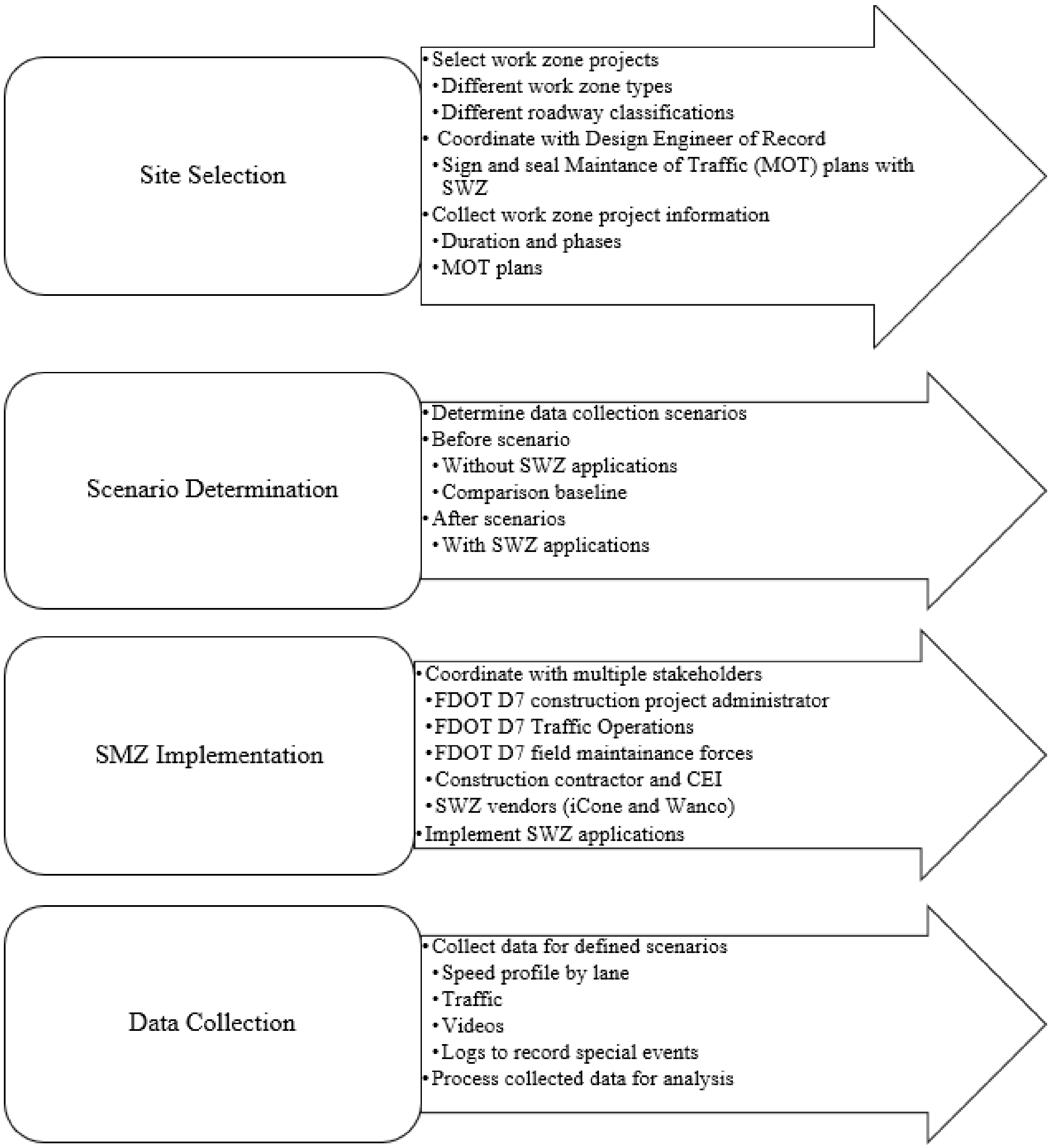


Figure 20. Procedure for SWZ Application Deployments and Data Collection

3.1.2 Study Site Selection

The FDOT Project Manager (PM) provided construction projects that were planned for construction in FDOT District 7 from 2020 to 2021 as candidate study sites. The CUTR team worked with the FDOT PM to select sites for the pilot study from the candidates based on the following criteria:

- Selected construction projects should cover different work zone types (lane shift, work on median/shoulder, and lane closure).
- Selected construction projects should cover different roadway function classifications (rural roads and urban arterials).
- SWZ applications should be available at selected work zones.
- Selected construction projects should be in active construction within the timeline of the research project.

Upon approval from the FDOT PM, the research team selected seven study sites throughout the project data collection period, as shown in Table 18.

Table 18. Study Sites for Pilot Study

Site	Work Zone Type			Roadway Type	Period
	Lane Closure	*Median/ Shoulder*	*Lane Shift*		
US-98		✓	✓	Rural two-lane	May–Sep 2020
SR-580 (E Busch Blvd)	✓			Multilane arterial	Sep–Oct 2020
US-92 (E Hillsborough Ave)	✓			Multilane arterial	Jan 2021
US-19 (N Hudson)	✓			Multilane arterial	Jan 2021
N Dale Mabry	✓			Multilane arterial	Mar 2021
US-301	✓	✓		Multilane arterial	Feb–Mar 2021
SR-580 (W Hillsborough Ave)	✓			Multilane arterial	Dec 2020
Veteran's Expressway	✓			Expressway two-lane	June 2021

3.1.3 SWZ Applications and Testing Scenarios

The research team tested three SWZ applications and law enforcement on pilot study sites:

- *AWAD* – A SWZ device that consists of a radar device with LED signs (speed feedback signs) mounted to a trailer that continuously displays the speed of approaching vehicles on an LED message board as shown in Figure 21. A static sign with the message:

“Active Work Zone When Flashing Speeding Fines Doubled” is mounted on the device. AWADs also have flashing beacons that are activated when work zone activities are present. The speed feedback signs can be deployed anywhere that excessive vehicle speeds are a concern. Florida Work Zone Safety Coalition with core members in construction industries is a pioneer for developing and implementing AWADs in an I-4 construction project to protect their workers. It is important to collaborate with construction industries on their safety needs and concerns about WZs.

Figure 21. Example of AWAD

- *Law Enforcement (LE)* – A law enforcement officer in a vehicle with lights flashing is positioned in the work zone to increase driver attention and encourage compliance with the speed limit. (Gan et al., 2018) as shown in Figure 22. The enforcement vehicle and officer serve a traffic-calming and attention-getting function to reduce the likelihood of high-speed rear-end crashes at the upstream end of the queue.

Law enforcement during nighttime

Law enforcement during daytime

Figure 22. Example of Law Enforcement

- *iCone + AWAD connection and iCone + Arrow Board connection (two SWZ applications)* – An iCone Connectivity Box connects to flashing beacons on the AWAD or Arrow Board trailers. When a work zone is active and the beacons are activated, the box broadcasts a customized message that is eventually displayed on navigational apps like WAZE. An illustration of WZ message displayed on WAZE app via iCone application on Arrow Board is shown in Figure 23. Examples of messages displayed on WAZE app for AWAD and Arrow Board are shown in Figure 24.

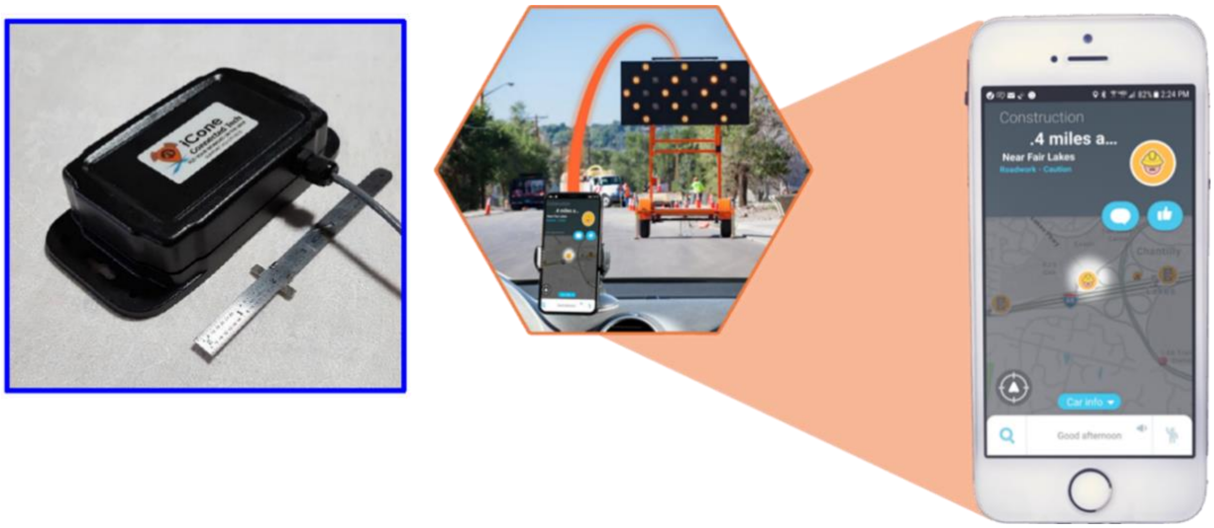
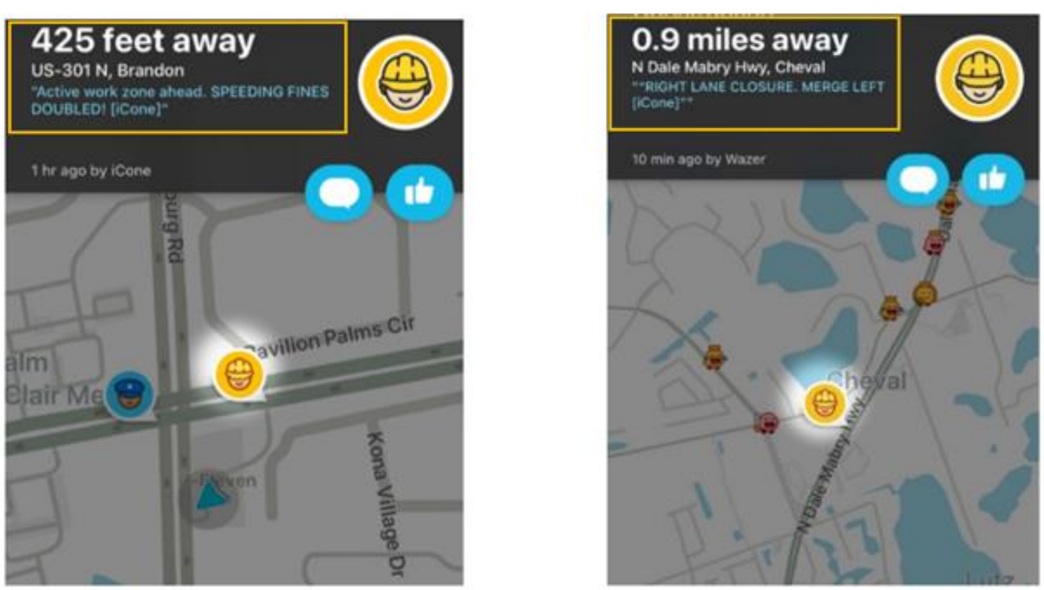


Figure 23. WZ Message Display on WAZE via iCone application on Arrow Board



(a) Message displayed on WAZE app for AWAD (b) Message displayed on WAZE app for arrow board

Figure 24. Messages on WAZE Apps

Based on the available SWZ applications and law enforcement, the research team developed a data collection plan with various scenarios. To assess the joint effects of different SWZ applications with and LE, the data collection scenarios also included a combination of various SWZ applications and LE. The data collection scenarios are presented in Table 19. Due to several factors affecting the deployments at pilot study sites, some scenarios may not be carried out at the study sites.

Table 19. Testing Scenarios

Scenario	Description
OFF (Baseline or Before Implementation)	• Traditional MOT • No SWZ application activation and/or LE present • Baseline for comparison with SWZ and LE scenarios
AWAD	• Only AWAD present • Activation during work zone activities
LE	• Only LE presence • Activation when MOT present
AWAD + LE	• Both AWAD and LE activated • Activation during work zone activities
iCone + AWAD	• Both AWAD and iCone activated • Display message to WAZE users when AWAD activated
iCone + Arrow Board	• Attached iCone connectivity box to Arrow Board • Display message to WAZE users when both iCone and Arrow Board activated
iCone + AWAD + LE	• Attached iCone connectivity box on AWAD • Activated LE at same time • Display message to WAZE users when both iCone and AWAD activated
iCone + Arrow Board + LE	• Attached iCone on arrow board • LE present at the same time • Display message to WAZE users when both iCone and Arrow Board activated
iCone + Arrow Board + AWAD	• Attached iCone on arrow board • Activated AWAD at the same time • Display message to WAZE users when both iCone and Arrow Board activated
iCone + Arrow Board + AWAD + LE	• Attached iCone on arrow board • Activated both AWAD and LE activated at the same time • Display message to WAZE users when both iCone and Arrow Board activated

3.1.4 Implementation and Coordination

Based on the developed data collection scenarios, FDOT District 7 and CUTR implemented the SWZ applications and activated the applications according to schedule. The pilot study involved intensive coordination efforts among the agencies, as shown in Figure 25. Coordination activities started 3–4 weeks in advance of the construction projects and continued during the data collection timeframe to ensure synchronization among CUTR, FDOT District 7, construction contractors, design EORs for the contract plans, law enforcement agencies, and/or the iCone vendor. Coordination helped identify and address any needs and unexpected issues. The FDOT PM conducted overall coordination among the research team, construction PMs, and FDOT

Tampa field maintenance forces, including providing project information, communicating among different groups, reviewing testing scenarios and data collection plans, and supporting data collection. The CUTR team (led by Dr. Pei-Sung Lin) communicated with the PM and construction administrators, construction contractors, and SWZ vendors to synchronize the data collection activities. Dr. Mouyid Islam contributed major coordination efforts with other agencies, and Dr. Zhenyu Wang took responsibility in the field. Frequent communications, such as emails, meetings, and phone calls, were conducted among the PM, the CUTR research team, and stakeholders to ensure the success of scenario implementation and data collection.

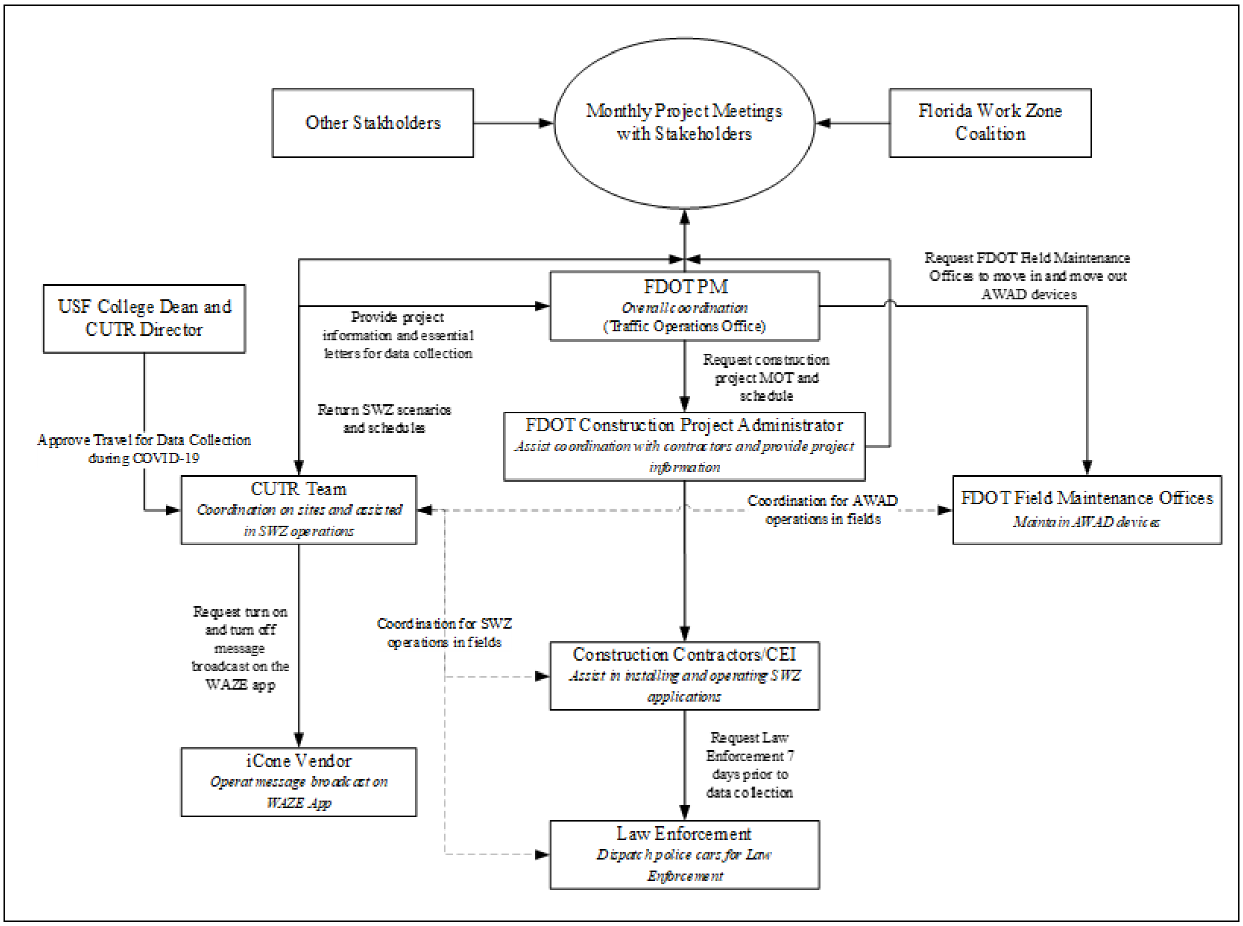


Figure 25. Coordination for SWZ Pilot Studies

Led by the FDOT PM, stakeholder meetings were conducted monthly via monthly project meetings during the pilot study period including FDOT PM, FDOT Construction Administrators, CUTR team, external experts (Florida Work Zone Safety Coalition), and other invited stakeholders. The meetings reviewed pilot implementation procedures, reported data collection and analysis results, examined issues faced in the pilot studies, and discussed resolutions.

3.1.5 Data Collection Methodology

Data collection was conducted during the COVID-19 pandemic. Per USF policies, special approval for data collection travel was obtained from the Dean of College of Engineering and the CUTR Director based on an essential letter provided by the FDOT PM. With approval, data collectors followed USF guidance to wear face masks and social distance (≥ 6 ft) during data collection.

With the implementation of the SWZ applications and/or presence of law enforcement, the CUTR team conducted data collection at the seven study sites for one or two days for each scenario to ensure a sufficient sample size. On each day, data collection duration varied over sites but covered different traffic conditions (peak, non-peak). It is worth noting that data collection did not cover nighttime, as MOT devices were removed after finishing daily WZ activities at these sites.

The CUTR team set up data collection devices at two positions as shown in Figure 26:

- Upstream of WZ activity zones (advance warning area) (P1) where SWZ applications were deployed. With low and moderate traffic demands, speeding/high-speed events may occur in this area. The sensor and camera were installed upstram of the SWZ applicaton depending on the availability of right of way and the safety of placing the devices.
- Work activity area (P2), with workers present during activation periods. High-speed/speeding behaviors tend to increase the risk of collisions and injury to both drivers and workers.

Two major data collection devices were installed on the roadside at the two points to collect safety-related data as shown in Figure 27:

- *WaveTronix SmartSensor* – a microwave radar to measure vehicle speed on each lane at a given section that can also identify vehicle classification and count vehicles by lane. The device was powered by a gasoline-powered inverter generator, and an RS-485 cable was used to connect it to a laptop for configuring and monitoring the data collected through the SmartSensor Manager software.
- *GoPro camera* – mounted on a tripod near the Wavetronix SmartSensor to record traffic conditions and traffic signal status. Researchers could validate speed data using the videos and retrieve special events from the videos, such as traffic congestion, unsafe behaviors, etc.

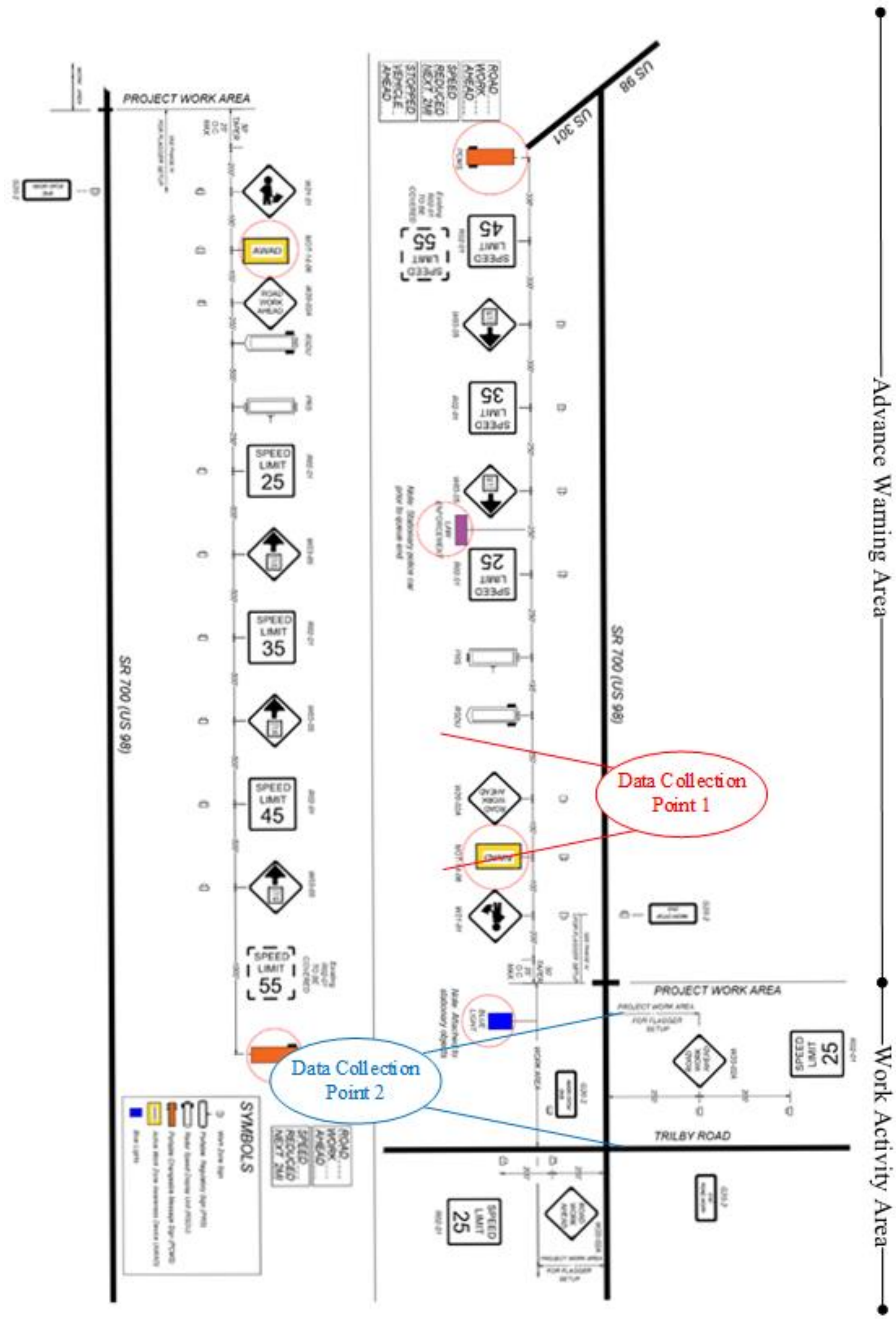


Figure 26. Layout of Data Collection Position Shown in MOT

WaveTronix SmartSensor ***GoPro Camera***

Figure 27. Installation of Data Collection Devices

The two devices were used to collect data for specified scenarios at each site. Raw data collected are summarized in Table 20. The data were processed to generate the dataset for analysis.

Table 20. Collected Raw Data

Raw Data	Description	Collection Method
Spot speed	• Individual vehicle speed by lane • Measured at two points (P1 and P2)	WaveTronix SmartSensor
Vehicle classification	• Individual vehicle classification by lane • Measured at two points (P1 and P2)	
Vehicle count	• Number of vehicles by lane • Measured at two points	
Video	• Traffic operations at two data collection points • Reviewed by researchers in lab	GoPro
Log	• Written by data collectors • Record data collection information • Starting and ending data collection time • SWZ scenarios • MOT plans • Special events (crash, congestion, device malfunction, etc.)	Data collector

1	13-Aug-20	1010415AB0019551	HD Legacy ITS Radar	Unknown	North		
2	LANE	LENGTH	Speed (MPH)	CLASS	RANGE	YYYY-MM-DD HH:MM:SS.sss	
3	LANE_01	18	38.8	2	38	14:38.9	
4	LANE_01	18	42.5	2	38	14:40.6	
5	LANE_02	19	43.8	2	50	14:57.1	
6	LANE_01	19	33.1	2	36	15:09.2	
7	LANE_02	15	37.7	2	51	15:09.4	
8	LANE_02	80	39.4	5	49	15:16.3	
9	LANE_02	41	36.2	3	51	15:22.4	
10	LANE_02	25	38.9	3	50	15:24.6	
11	LANE_02	17	38.5	2	50	15:26.1	
12	LANE_01	38	26.9	3	38	15:28.5	
13	LANE_02	17	34.8	2	44	15:28.6	
14	LANE_01	18	26.2	2	37	15:30.5	
15	LANE_02	23	42.1	2	51	15:40.5	
16	LANE_01	16	26.6	2	38	15:46.0	
17	LANE_01	15	26.6	2	38	15:48.4	
18	LANE_02	20	36.6	2	50	15:52.8	
19	LANE_02	18	31.9	2	50	15:55.9	
20	LANE_02	20	39.8	2	50	16:10.0	

Figure 28. Example of Speed and Vehicle Data Collected by WaveTronix SmartSensors

The Per Vehicle Data screen displays the following information about each vehicle detected:

- *Lane* – States lane in which vehicle detected
- *Timestamp* – Displays time at which vehicle detected
- *Range* – Class bins allow classification of vehicles by ranges of lengths

4 Classification Bins	
Lengths	Scheme F
0–10	1
10–19	2, 3
19–35	4, 5, 6
35–256	7-13

6 Classification Bins	
Lengths	Scheme F
0–10	1
10–19	2
19–24	3
24–54	4, 5, 6, 7
54–109	8, 9, 10
109–256	11, 12, 13

Figure 29. Scheme F Vehicle Classification
(Source: SmartSensor HD User Guide)

- *Speed* – shows the speed of the vehicle in miles per hour (mph). A negative number will be reported for speed in the following cases: (1) lane configured to left or right and Direction Protection on, but traffic traveling against configured direction, indicating that direction of lane has switched; useful in hurricane evacuation scenarios; (2) lane configured to left or right and Direction Protection off, but more vehicles detected traveling against configured direction than detected traveling with configured direction for given data interval; and (3) lane configured as bidirectional and lane traveling to left (vehicles traveling to right have positive per vehicle speeds in bidirectional lanes).

- *Length* – displays length of vehicle in ft.

3.2 Site 1: US-98

US-98 in Dade City is a rural two-lane road. FDOT constructed a roundabout to replace a signalized intersection (US-98 and Trilby Rd), as shown in Figure 30, from March to September 2020. This construction project consisted of multiple phases—I, IIA, IIB, IIIA, IIIB, IVA, IVB1, IVB2, and V.

Figure 30. Construction Plan at US-98 and Trilby Rd

During construction, the existing posted speeds of 55 mph on US-98 were reduced to 25 mph prior to the beginning of construction. Full road closures with detours were implemented in Phase IVB1 for reconstruction of Trilby Rd. This project utilized Portable Changeable Message Signs (PCMS) that alert motorists of upcoming work and changes in traffic patterns. The existing MOT plan during construction (without SWZ applications) at Site 1 is shown in Figure 31.

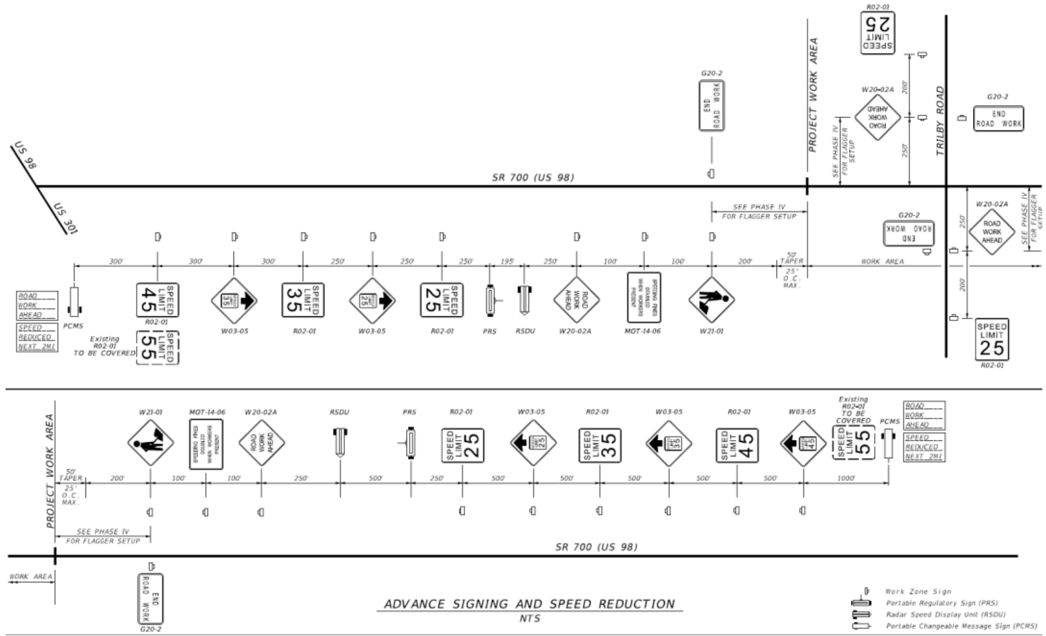


Figure 31. Existing Temporary Traffic Control Plan at US-98 and Trilby Rd

3.2.1 Testing Scenarios

The research team selected five phases for testing SWZ applications to cover different WZ types. The testing scenarios and data collection are summarized in Table 21.

Table 21. Data Collection Timeline for Site 1 (US-98 and Trilby Rd)

Phase	Deployment Stage	Scenario	Date	Type
2A	Before	OFF	5/14/2020 & 5/19/2020, 11 AM–10 PM	Work on Shoulder
	After I	AWAD + DSFS[1]	6/2/2020, 11 AM–9 PM	
		AWAD	6/3/2020, 11 AM–5 PM	
	After II	AWAD + LE	6/9/2020, 11 AM–5 PM	
		LE + DSFS[1]	6/9/2020, 7 PM–9PM	
		LE	6/10/2020, 12 AM–9 PM	
3B	Before	OFF	7/2/2020, 11 AM–10 PM	Work on Shoulder
	After 1	AWAD	7/22/2020, 12 PM–1 PM[2] 7/23/2020, 8 AM–10 AM[2]	
	After 2	AWAD + LE	7/15/2020, 12 PM–4 PM	
		LE + DSFS[1]	7/7/2020, 7 PM–9 PM	
		LE	7/7/2020, 1 PM–5 PM	
4B1	Before	OFF	8/5/2020, 11 AM–5 PM	Lane Shift with Flag Operation
	After 1	AWAD	8/6/2020, 12 PM–5 PM	
4B2	Before	OFF	8/12/2020, 12 PM–1 PM	Work on Median (roundabout)
	After 1	AWAD	8/11/2020, 10:45 AM–5:15 PM	
	After 2	AWAD + LE	8/13/2020, 12 PM–5 PM	

[1] DSFS – Dynamic Speed Feedback Sign; [2] Rain interrupted data collection

3.2.2 ***Phase 2A***

The construction activities in Phase 2 occurred on the shoulder on the east side. Six scenarios were conducted in three stages for Phase 2A. No SWZ applications were activated during Stage 1 (Before). In the stage of After I, AWAD and AWAD + DSFS (located upstream of AWAD) were tested. In the stage of After II, LE was implemented with AWAD and DSFS for testing.

Data collection was conducted on NB of US-98. Two devices (WaveTronix SmartSensors and GoPro cameras) were installed at two measurement points to monitor spot speed, traffic, and special events on the NB lane at the two points. The layout of a construction zone for Phase 2A is shown in Figure 32. The data collection layout is presented in Figure 33 through Figure 36.

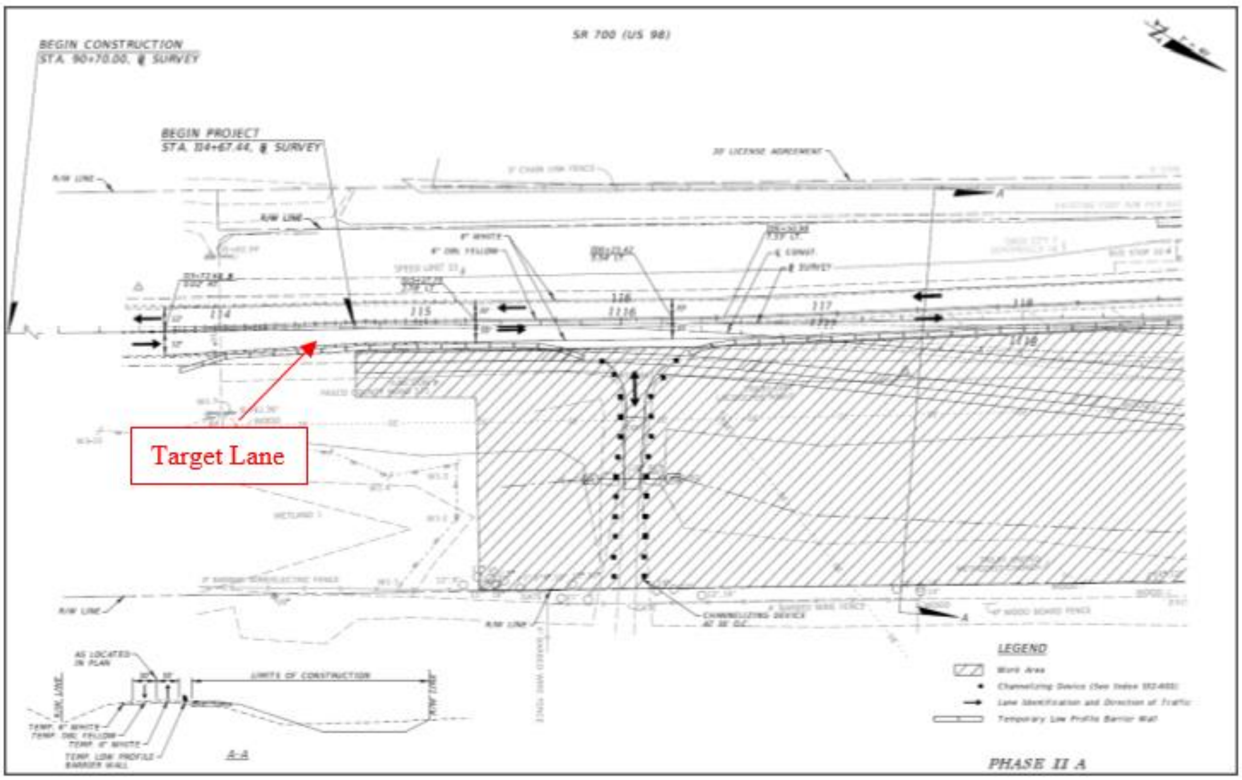


Figure 32. Layout of Construction Zone for Phase 2A at US-98 and Trilby Rd

Figure 33. Deployment Stage of "Before" for Phase 2A at US-98 and Trilby Rd

Figure 34. Deployment Stage of "After 1" for Phase 2A at US-98 and Trilby Rd

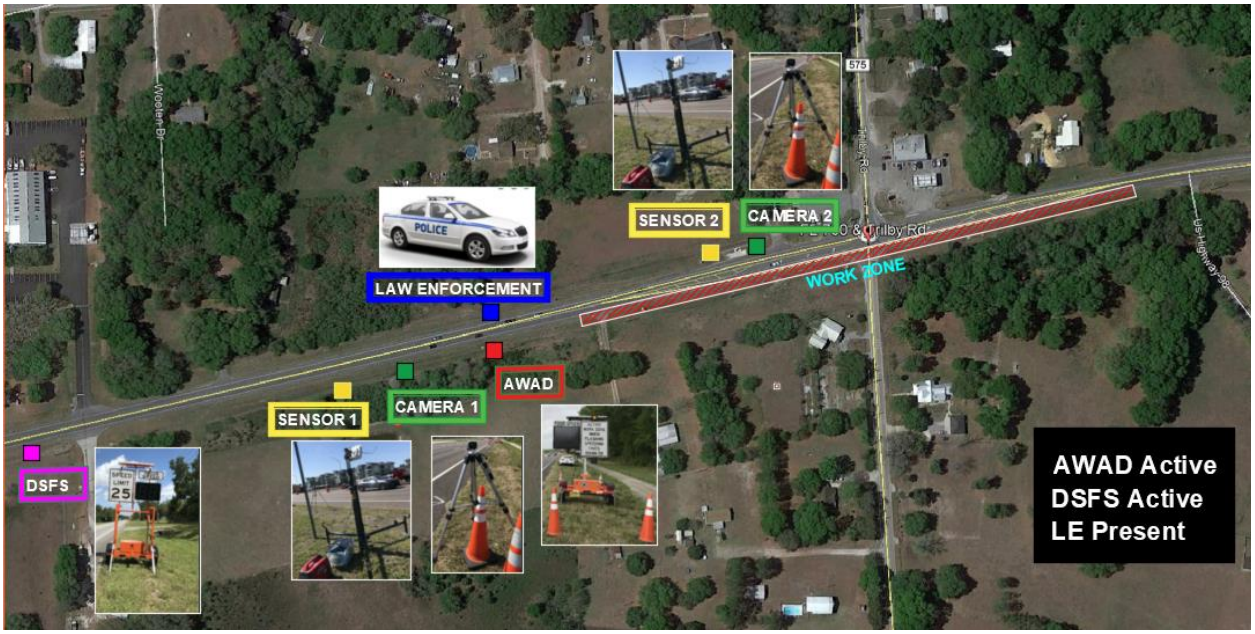


Figure 35. Deployment Stage of "After 2" for Phase 2A at US-98 and Trilby Rd

Figure 36. Field View for Phase 2A at US-98 and Trilby Rd

3.2.3 *Phase 3B*

Construction activities of Phase 3B occurred on the west shoulder. The CUTR team tested five scenarios in three stages, covering AWAD, LE, and DSFS. Data collection was conducted on NB. The layout of the construction zone for Phase 3B is shown in Figure 37, and the data collection layout is presented in Figure 38 through Figure 40.

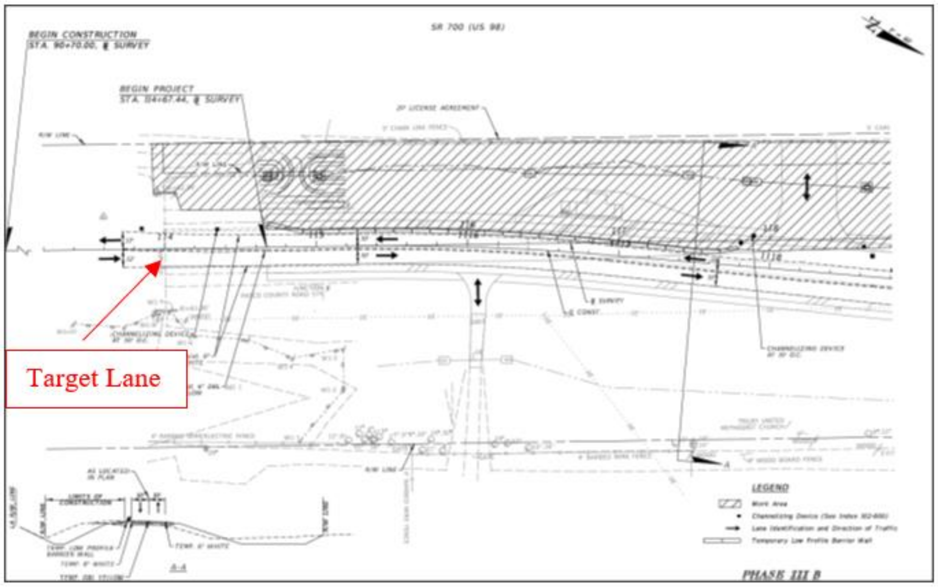


Figure 37. Layout of Construction Zone for Phase 3B at US-98 and Trilby Rd

Figure 38. Deployment Stage of "Before" for Phase 3B at US-98 and Trilby Rd

Figure 39. Deployment Stage of "After 1" for Phase 3B at US-98 and Trilby Rd

Figure 40. Deployment Stage of "After 2" for Phase 3B at US-98 and Trilby Rd

*3.2.4 **Phase 4B1***

Travel lanes were closed and detour lanes were provided for through traffic on US-98. Flagging operations were present at both entry points. Thus, queues formed when the flagging operations were in place. The CUTR team tested two scenarios in this phase: OFF and AWAD. Data collection was conducted on the northbound lane. The layout of the construction zone for Phase 4B1 is shown in Figure 41, and the data collection layout is presented in Figure 42 through Figure 44.

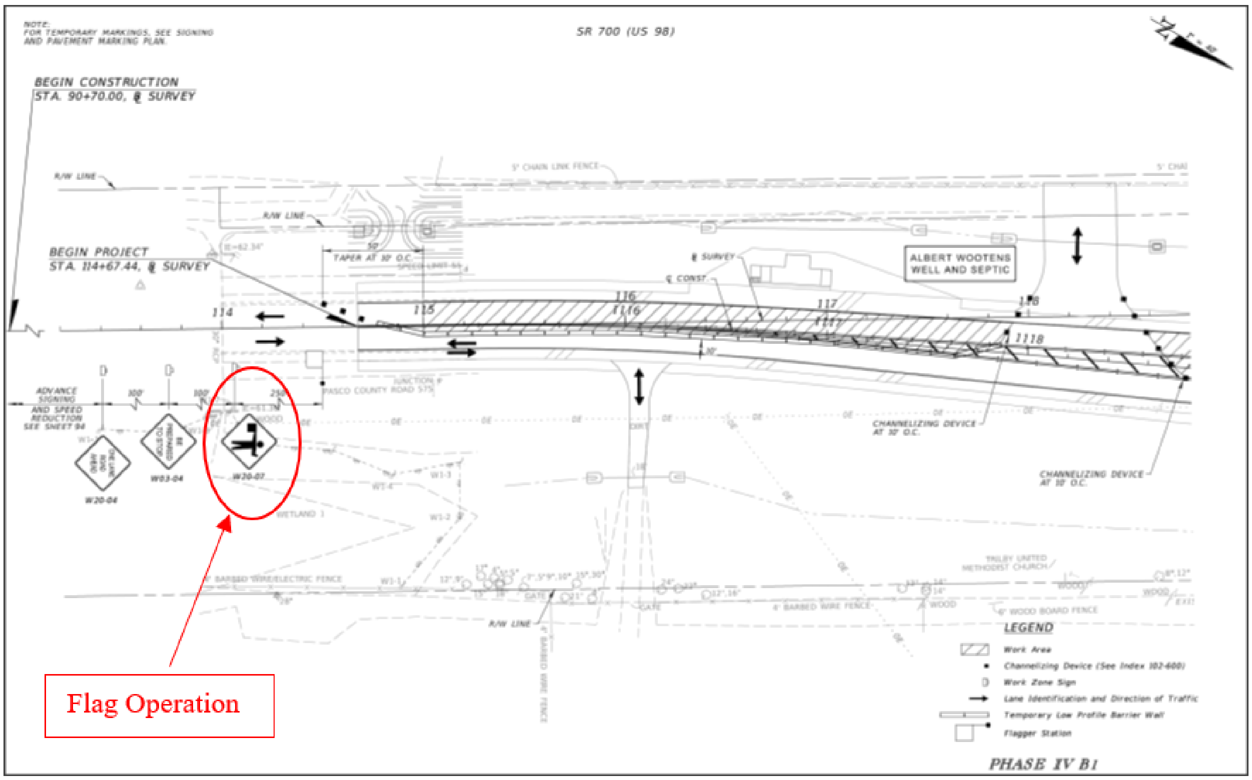


Figure 41. Layout of Construction Zone for Phase 4B1 at US-98 and Trilby Rd

Figure 42. Deployment Stage of "Before/OFF" for Phase 4B1 at US-98 and Trilby Rd

Figure 43. Deployment Stage of "After 1/AWAD" for Phase 4B1 at US-98 and Trilby Rd

Figure 44. Flag Operation and Queue Formed in Phase 4B1 at US-98 and Trilby Rd

*3.2.5 **Phase 4B2***

In this phase, the roundabout and both lanes were opened to traffic. There were still some construction activities on medians on each approach without flagging operations. The CUTR team tested three scenarios in this phase: OFF, AWAD, and AWAD + LE. Data collection was conducted on the northbound lane. The layout of the construction zone for Phase 4B2 is shown in Figure 45, and the data collection layout is presented in Figure 46 through Figure 49.

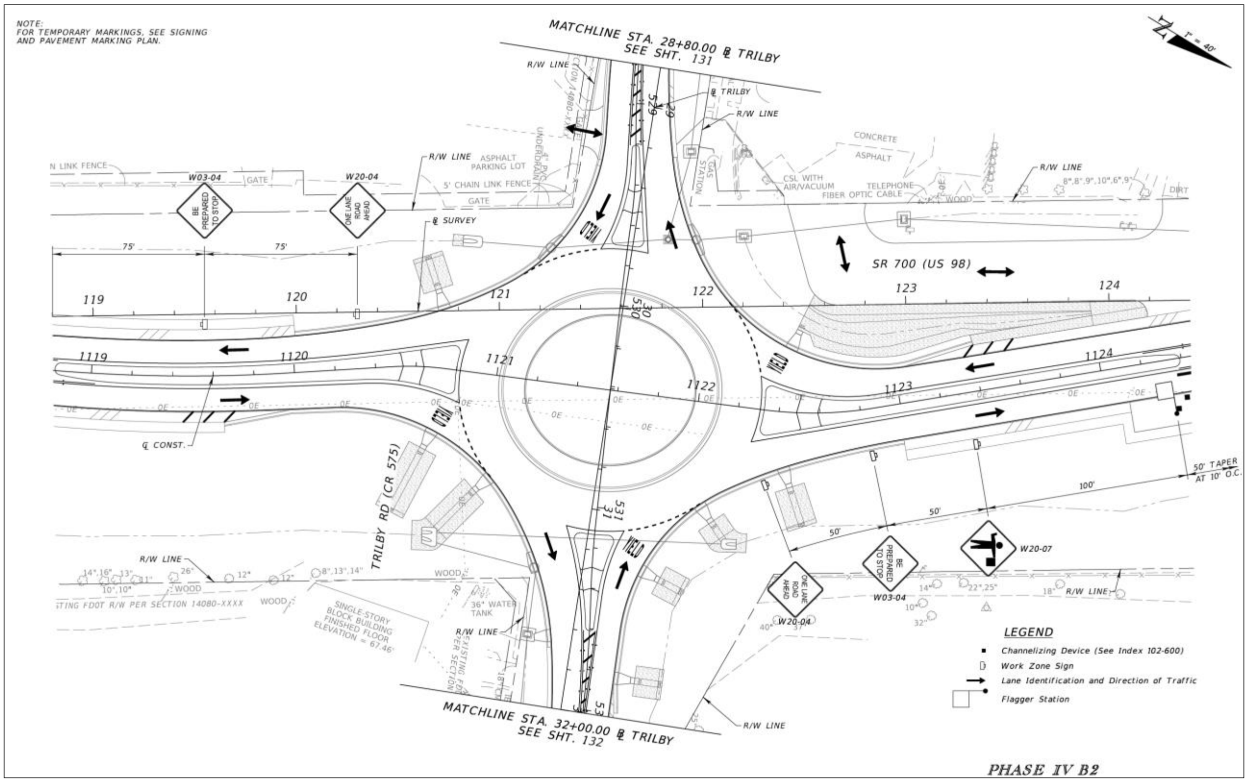


Figure 45. Layout of Construction Zone for Phase 4B2 at US-98 and Trilby Rd

Figure 46. Deployment Stage of "Before/OFF" for Phase 4B2 at US-98 and Trilby Rd

Figure 47. Deployment Stage of "After 1/AWAD" for Phase 4B2 at US-98 and Trilby Rd

Figure 48. Deployment of "After 2/AWAD+LE" for Phase 4B2 at US-98 and Trilby Rd

Figure 49. Field View of Phase 4B2 at US-98 and Trilby Rd

3.2.6 Collected Data

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis. In addition, evidence of unsafe behaviors was retrieved from videos for qualified analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 22. There was an incident of an AWAD trailer battery stolen during a field data collection at this site, so it is important to secure trailers during the data collection.

Table 22. Summary of Collected Data at US-98 and Trilby Rd

Speed	Collected
Video	Collected
Traffic condition	Low traffic demand Relatively high speed Queues observed only with flag operations Frequently-crossing pedestrians and workers observed
Traffic signal influence	No significant influence Measure point far from signal
Special event	One crash in Phase 4B1

3.3 Site 2: SR-580 (E Busch Blvd)

Busch Blvd is a multilane arterial (three lanes per direction) in urban areas. The posted speed limit is 40 mph along SR-580 at Brooks St (EB) and 45 mph at Brooks St (WB). FDOT installed HAWK beacons (High-intensity Activated crossWalK beacon, also named Pedestrian Hybrid Beacon [PHB]) along the corridor to improve pedestrian safety. The existing MOT plan for the construction project is shown in Figure 50. The posted speed limit (40 mph) did not change during construction.

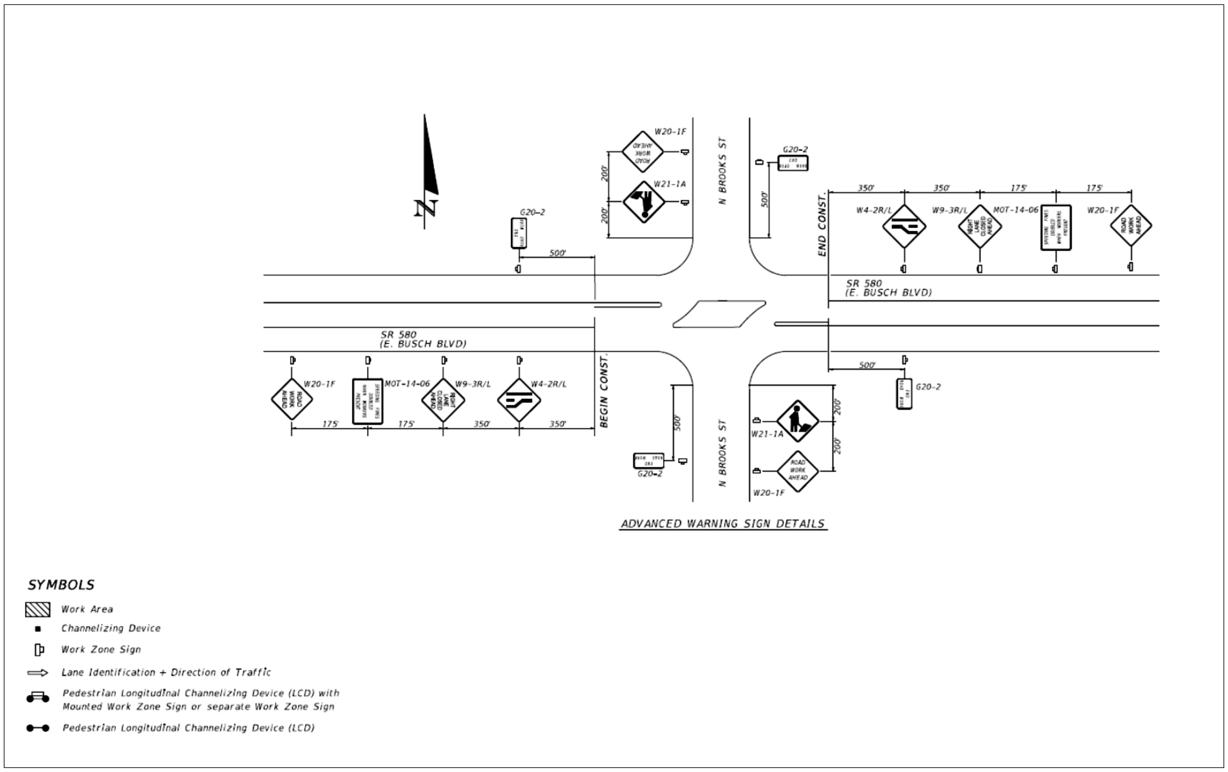


Figure 50. Existing MOT at Site 2: SR-580 (E Busch Blvd) and Brooks St

An education campaign was conducted during the construction period, with three billboards with WZ safety messaging installed on Busch Blvd and 60-second PSA radio spots and 30-second paid radio spots on local radio stations to remind drivers to go slow in WZs. Information from the education campaign is presented in Figure 51.

Figure 51. Education Campaign on Busch Blvd

3.3.1 *Testing Scenarios*

The research team collected data on Busch Blvd near Brooks St (unsignalized intersection) in two stages. In Stage 1, data were collected before and after the education campaign to assess its effectiveness on driving behaviors; no SWZ applications were implemented during this stage. In Stage 2, three SWZ scenarios were tested with outside lane closure. The testing scenarios and data collection timeline are summarized in Table 23. The data collection occurred at WB of Busch Blvd near Brooks St.

Table 23. Data Collection Timeline for Site 2 (Busch Blvd and Brooks St)

Stage	Scenario	Date	Type
1	Before Education (No SWZ)	7/14/2020, 12:00 PM–3:30 PM	Inside Lane Closure
	After Education (No SWZ)	10/8/2020, 12:40 PM–3:40 PM	Outside Lane Closure
2	OFF	9/23/2020, 1:45 PM–3:30 PM	Outside Lane Closure
	AWAD	10/09/2020, 12:00 PM–2:30 PM	
	AWAD + LE	10/21/2020, 10:30 AM–3:45 PM	

This construction project involved two MOT plans: inside lane closure and outside lane closure. The two MOT plans are presented in Figure 52 and Figure 53.

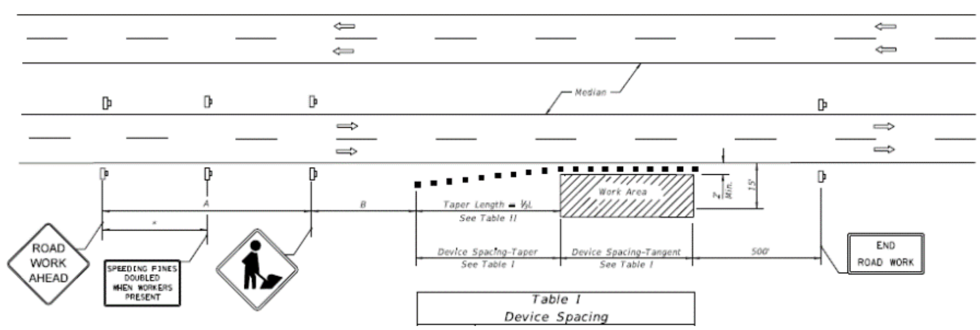


Figure 52. MOT Plan of Outside Lane Closure on Busch Blvd

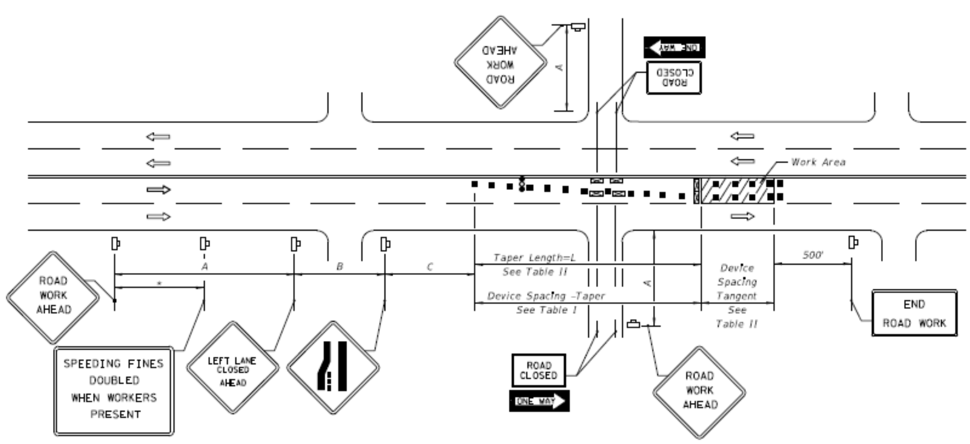


Figure 53. MOT Plan of Inside Lane Closure on Busch Blvd

3.3.2 Data Collection for Education Campaign

In the first stage, the research team collected speed and video data before and after the education campaign; field views of the two scenarios are presented in Figure 54 and Figure 55. Due to the construction schedule, the MOT plan was not consistent before and after the education campaign. The before condition had an inside lane closure and the after condition had an outside lane closure.

Figure 54. Field View for Data Collection before Education Campaign

Figure 55. Field View for Data Collection after Education Campaign

3.3.3 Data Collection for SWZ Applications

The CUTR team tested three scenarios in this stage—OFF, AWAD, and AWAD + LE. Data collection was conducted on WB of Busch Blvd near Brooks St. The existing MOT for SWZ scenarios was an outside lane closure (Figure 52), and the data collection layouts are presented in Figure 56 through Figure 58.

Figure 56. Data Collection Layout for OFF scenario on Busch Blvd

Figure 57. Data Collection Layout for AWAD Scenario on Busch Blvd

Figure 58. Data Collection Layout for AWAD + LE Scenario on Busch Blvd

Figure 59. Law Enforcement in Closed Lane (after AWAD) on Busch Blvd

3.3.4 Collected Data

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualified analysis. Traffic and environment conditions and special events were recorded in data collection logs for reference in analysis. The collected data are summarized in Table 24.

Table 24. Summary of Collected Data at Busch Blvd

Speed	Collected
Video	Collected
Traffic condition	Traffic demand lower than in past years Relatively high speed No queue and congestion with normal conditions Pedestrians and workers observed
Traffic signal influence	No significant influence Measure points far from signal
Special event	Significant pedestrian crossing volumes and jaywalking before HAWK/PHB installed Congestion observed due to disabled car during OFF scenario Law enforcement in closed lanes

3.4 Site 3: US-92 (E Hillsborough Ave)

Hillsborough Ave is a multi-lane arterial (three-lane per direction) in urban areas. The posted speed limit is 45 mph. FDOT installed a PHB at Hillsborough Ave and 50th St to improve pedestrian safety. For this purpose, a drilled shaft installation was conducted on the median at night with an inside lane closure. The existing MOT plan is shown in Figure 60, and the data collection layouts are presented in Figure 61 through Figure 63. The speed limit was not reduced in the work area.

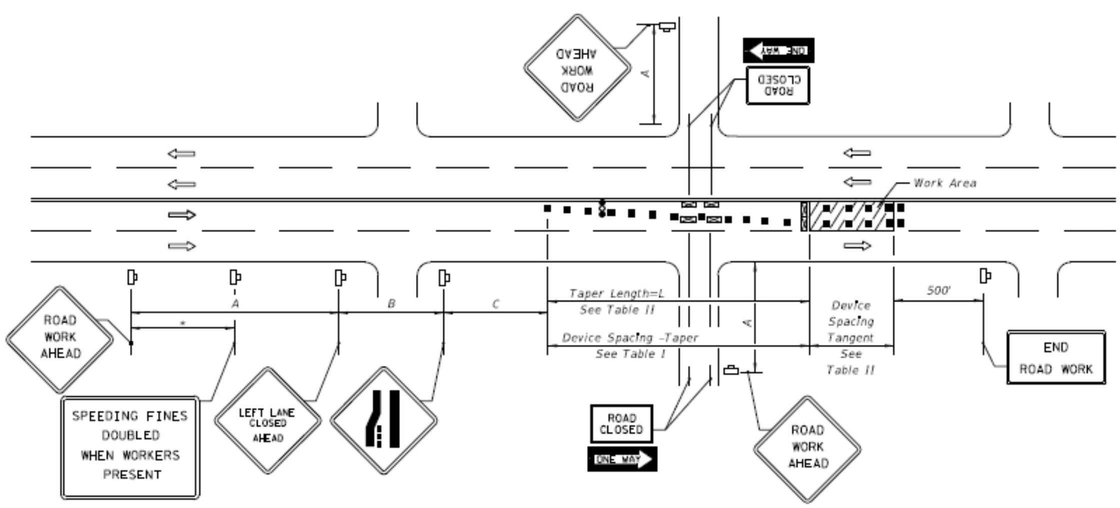


Figure 60. Existing MOT at Site 3: US-92 (E Hillsborough)

3.4.1 *Testing Scenarios*

The research team collected data on EB of E Hillsborough Ave near 50th St. The data collection occurred during nighttime. Three SWZ scenarios were tested with inside lane closure. The testing scenarios and data collection timeline are summarized in Table 25. As the drilled shaft installation was anticipated to be for one night, the evening hours of 1/12/21 was split for the three scenarios.

Table 25. Testing Scenarios for Site 3 (US-92)

Scenario	Duration (day)	Work Zone Type
OFF	01/12/21, 2:31 AM–4:00 AM	Inside Lane Closure
AWAD	01/12/21, 10:00 PM–12:00 AM	
AWAD + LE	01/12/21, 12:01 AM–2:30 AM	

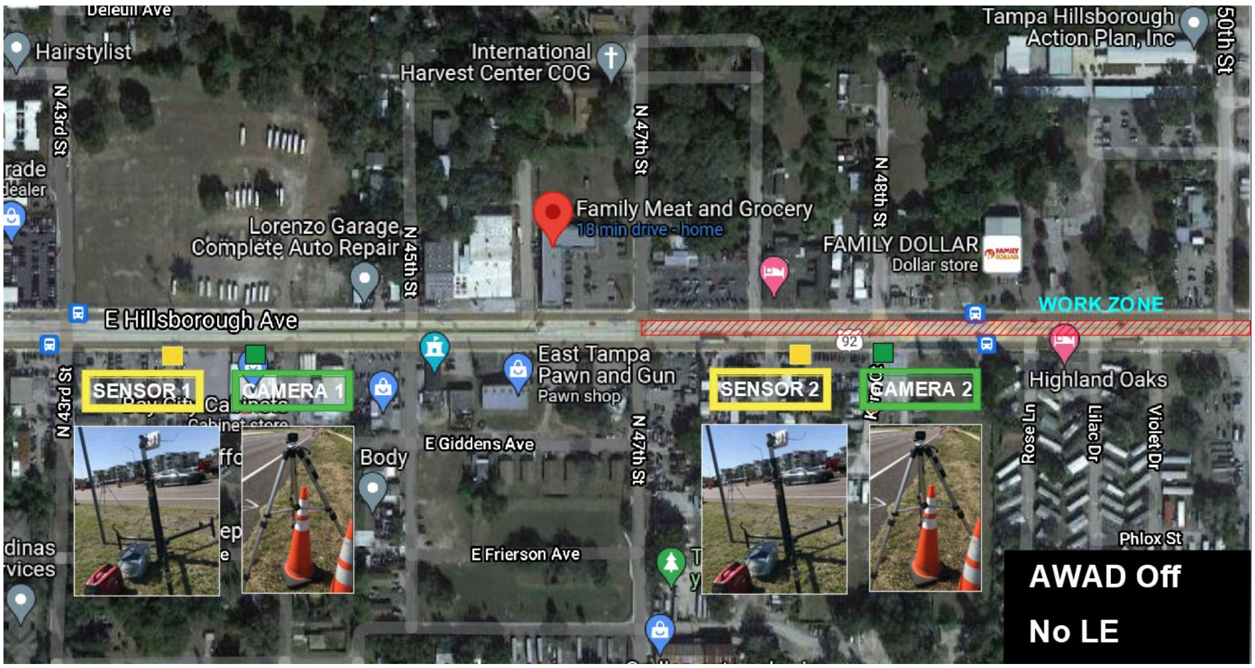


Figure 61. Layout of Data Collection for OFF Scenario on E Hillsborough Ave

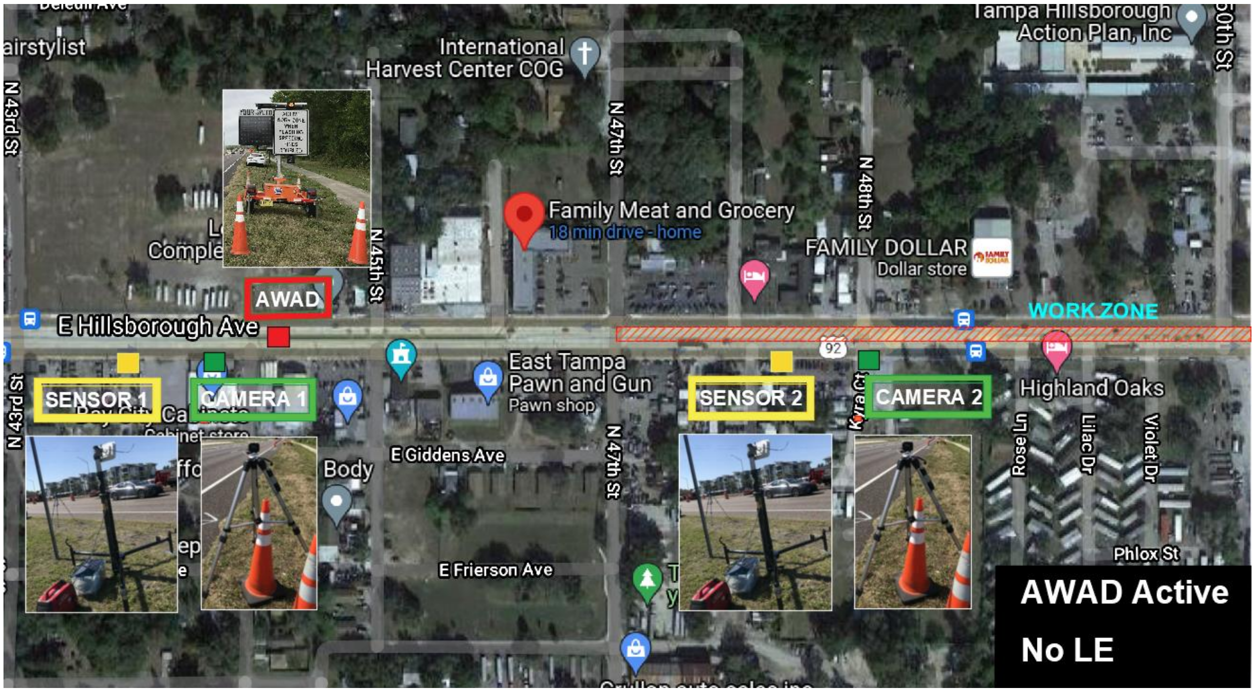


Figure 62. Layout of Data Collection for AWAD Scenario on E Hillsborough Ave

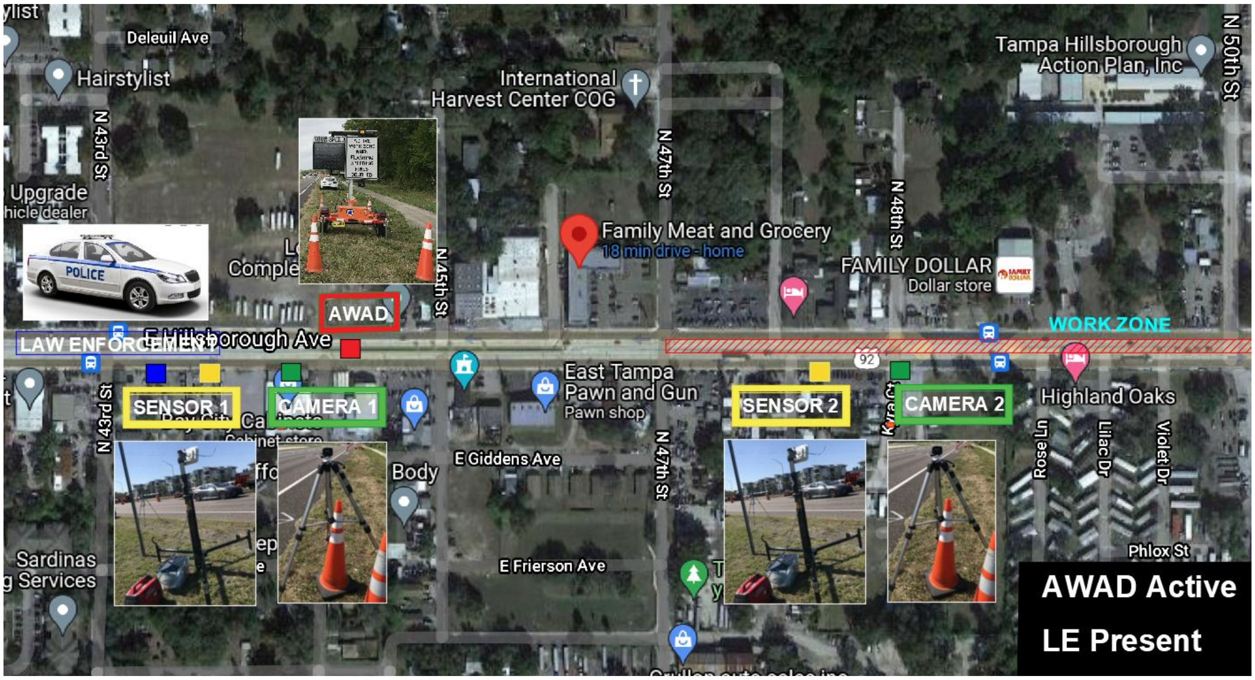


Figure 63. Layout of Data Collection for AWAD + LE on E Hillsborough Ave

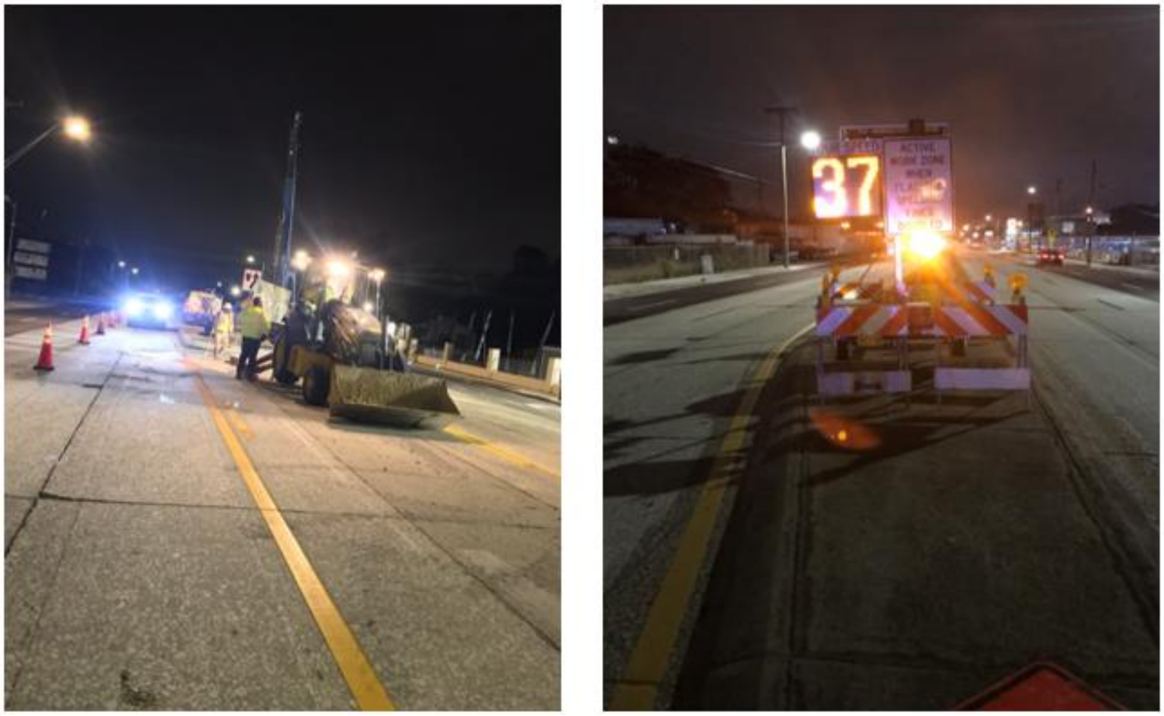


Figure 64. Field View of Construction Activities on E Hillsborough Ave

3.4.2 Collected Data

The research team collected spot speed, vehicle lassification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualified analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 26.

Table 26. Summary of Collected Data at Site 3

Speed	Collected
Video	Collected
Traffic condition	Less traffic demand at night Relatively high speed No congestion observed
Traffic signal influence	No significant influence Measure point far from signal
Special event	None

3.5 Site 4: US-19

US-19 is a multi-lane arterial (three though lanes with one right-turn lane in each direction) in an urban area. The posted speed limit is 45 mph. The construction project included widening and resurfacing the right-turn lane. The construction layout is shown in Figure 65.

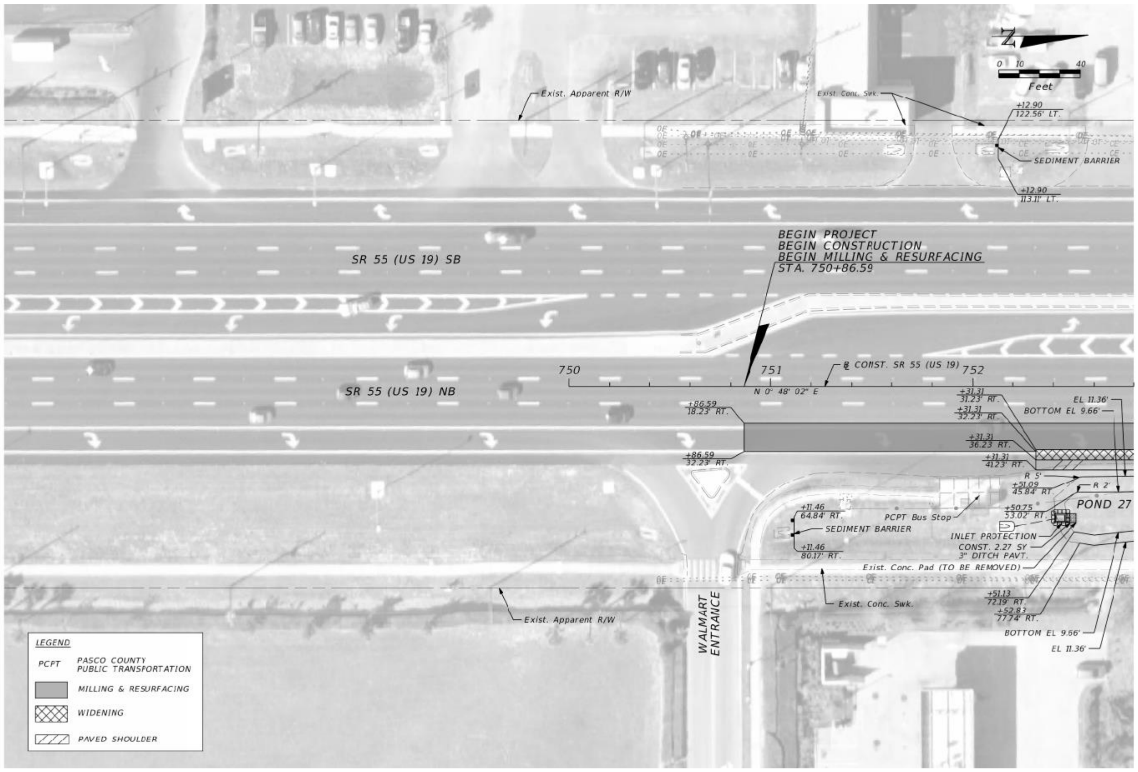


Figure 65. Construction Layout at Site 4: US-19

3.5.1 Testing Scenarios

The research team collected data on NB of US-19 (Beach Boulevard to Dipaola Drive). The right-turn lane was closed, and through lanes were kept open to traffic. The existing speed limit of 45 mph was maintained throughout construction. Three SWZ scenarios were tested with right-turn lane closures. The testing scenarios and data collection timeline are summarized in Table 27.

Table 27. Testing Scenarios for Site 4 (US-19)

Scenario	Date	Work Zone Type
OFF	01/25/21, 11:30 AM–5:00 PM	Right-Turn Lane Closure
AWAD	01/26/21, 10:15 AM–3:40 PM	
AWAD + LE	01/27/21, 11:00 AM–4:15 PM	

The existing MOT plan is shown in Figure 66, and the data collection layouts showing the positions of SWZ applications and data collection devices are shown in Figure 67 through Figure 69.

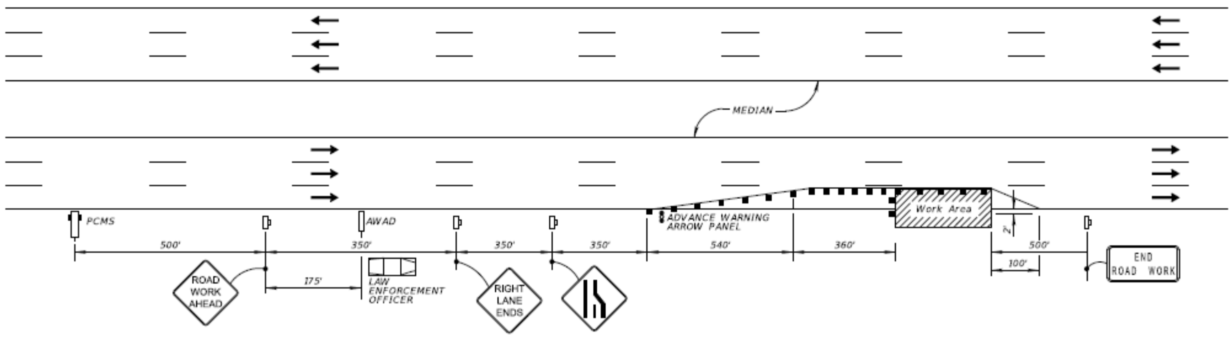


Figure 66. Existing MOT for Construction Project on US-19

Figure 67. Layout of Data Collection for OFF Scenario on US-19

Figure 68. Layout of Data Collection for AWAD Scenario on US-19

Figure 69. Layout of Data Collection for AWAD + LE on US-19

Figure 70. Field View of Construction Zone on US-19

3.5.2 Collected Data

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualitative analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 28.

Table 28. Summary of Collected Data at Site 4

Speed	Collected
Video	Collected
Traffic condition	High traffic Relatively high speed Congestion observed on-peak hours
Traffic signal influence	Significant influence Measure point close to signal
Special event	None

3.6 Site 5: N Dale Mabry Hwy

Dale Mabry Hwy is a multilane arterial (two through lanes per direction) with a 57-ft vegetated median in urban areas and a posted speed limit of 55 mph. FDOT conducted a multi-phase project at the section near Sunlake Blvd. The construction layout is shown in Figure 71.

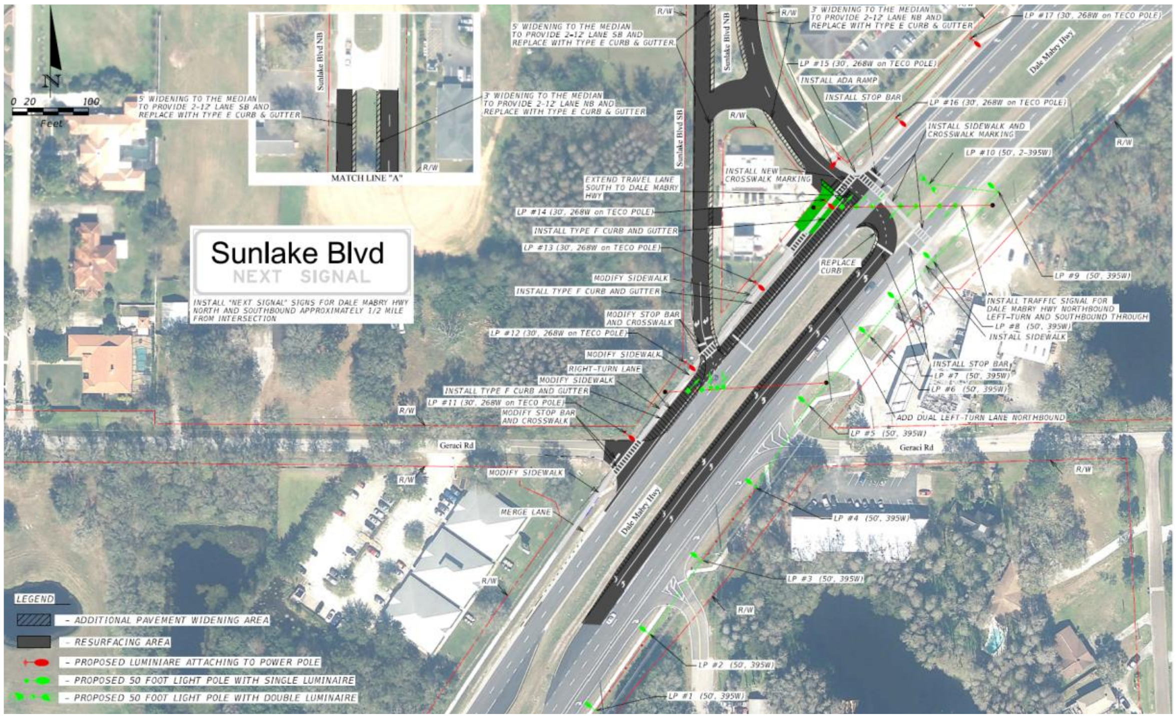


Figure 71. Construction Layout at Site 5: N Dale Mabry Hwy

3.6.1 Testing Scenarios

The research team collected data on SB of N Dale Mabry Hwy (near Sunlake Blvd) for Phase IIIA. The right-turn lane and the side through lane were closed; the inside through lane was kept open to traffic. The existing regulatory speed limit of 55 mph was maintained throughout construction. Four SWZ scenarios, including two iCone scenarios, were tested with outside lane closures. The testing scenarios and data collection timeline are summarized in Table 29.

Table 29. Testing Scenarios for Site 5 (N Dale Mabry Hwy)

Scenario	Date	Work Zone Type
OFF	03/17/21, 11:30 AM–2:45 PM	Outside Lane Closure (right-turn and outside through lane)
AWAD	03/18/21, 10:15 AM–2:45 PM	
AWAD + iCone	03/23/21, 12:30 AM–3:15 PM	
ARROW BOARD + iCone	03/24/21, 1:15 PM–2:30 PM	

The MOT plan is shown in Figure 72, and the data collection layouts indicating the positions of SWZ applications and data collection devices are shown in Figure 73 and Figure 76.

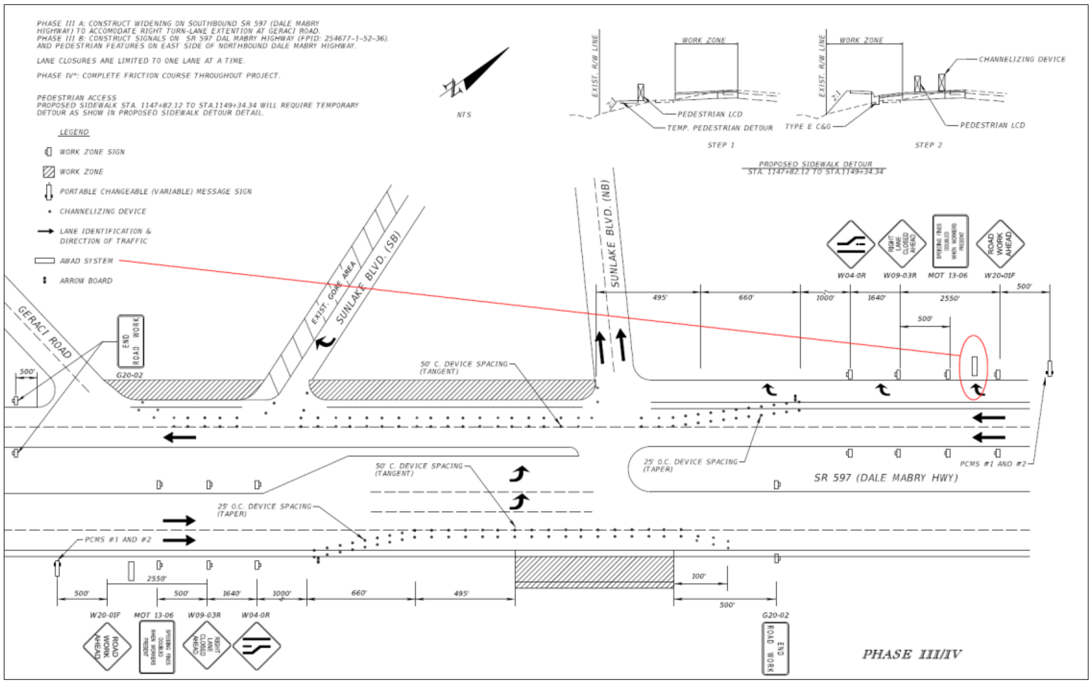


Figure 72. Existing MOT for Construction Project on N Dale Mabry Hwy

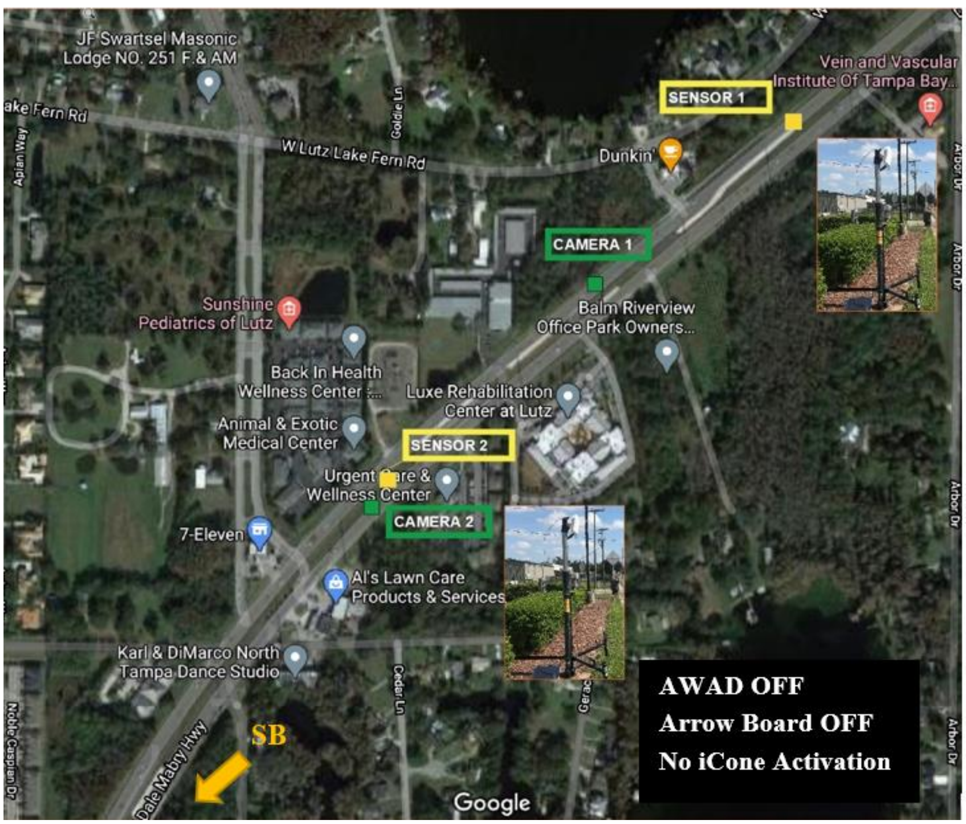


Figure 73. Layout of Data Collection for OFF Scenario on N Dale Mabry Hwy

Figure 74. Layout of Data Collection for AWAD Scenario on N Dale Mabry Hwy

Figure 75. Layout of Data Collection for AWAD + iCone on N Dale Mabry Hwy

Figure 76. Layout of Data Collection for Arrow Board + iCone on N Dale Mabry Hwy

Figure 77. Field View of Construction Zone on Dale Mabry Hwy

3.6.2 ***Collected Data***

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualitative analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 30.

Table 30. Summary of Collected Data at Site 5

Speed	Collected
Video	Collected
Traffic condition	High traffic with relatively high speed Congestion observed on-peak hours Crossing pedestrians and workers Drivers shifting lane when close to WZ
Traffic signal influence	Significant influence Measure point far from signal
Special event	None

3.7 Site 6: US-301

US-301 is a multilane principal arterial (three through lanes per direction) in urban areas with a posted speed limit of 50 mph. FDOT conducted median improvements at US-301 and Wes Kearney Way and Windermere Lake Dr. The construction layout is shown in Figure 78.

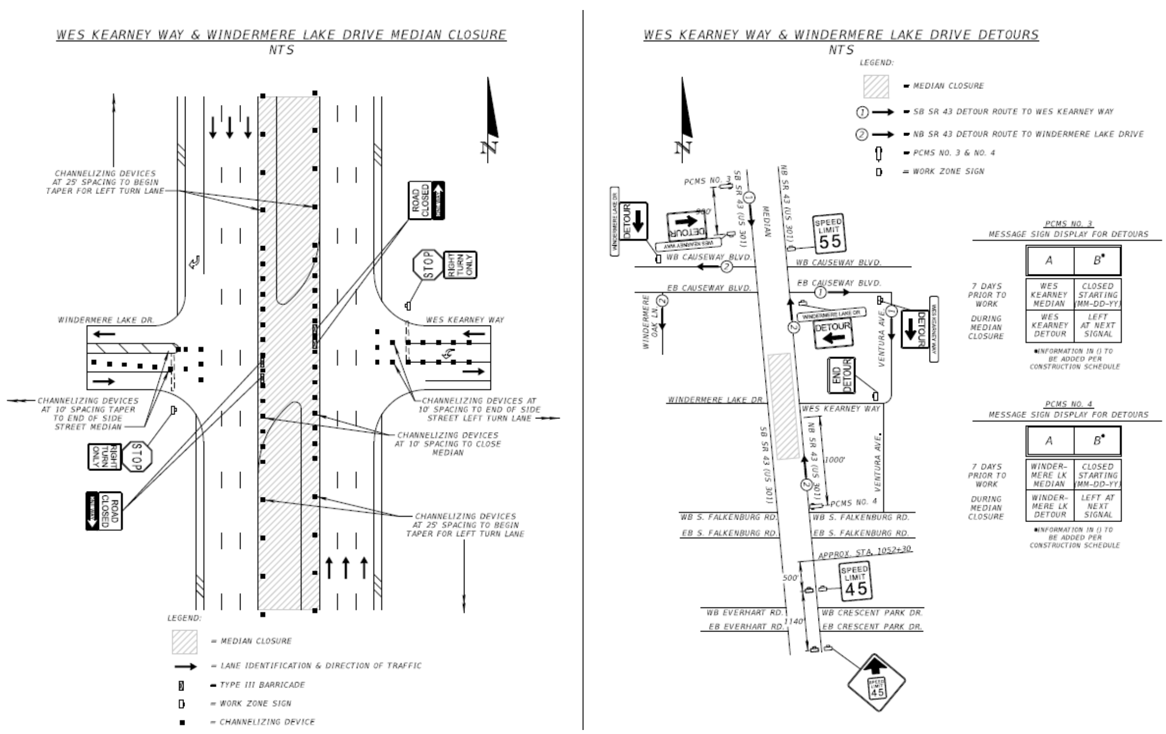


Figure 78. Construction Layout at Site 6: US-301

3.7.1 Testing Scenarios

The research team collected data on NB of US-301 (near Wes Kearney Blvd). The inside through lane (one lane) was closed; the outside two lanes were kept open to traffic. The existing regulatory speed limit of 50 mph was maintained throughout construction. Seven SWZ scenarios were tested with outside lane closures. The testing scenarios and data collection timeline are summarized in Table 31.

Table 31. Testing Scenarios for Site 6 (US-301)

Scenario	Date	Work Zone Type
OFF	02/22/21, 11:00 AM–4:00 PM	Inside Lane Closure (one through lane)
AWAD	02/23/21, 11:00 AM–4:00 PM	
AWAD + iCone	03/24/21, 11:00 AM–4:00 PM	
ARROW BOARD + iCone	03/02/21, 11:00 AM–4:00 PM	
AWAD + LE	03/30/21, 2:00 PM–3:30 PM	
AWAD + iCone + LE	03/30/21, 11:00 AM–12:30 PM	
ARROW BOARD + iCone + LE	03/30/21, 12:30 PM–2:00 PM	

This MOT plan is shown in Figure 79, and the data collection layouts indicating the positions of SWZ applications and data collection devices are shown in Figure 80 through Figure 85.

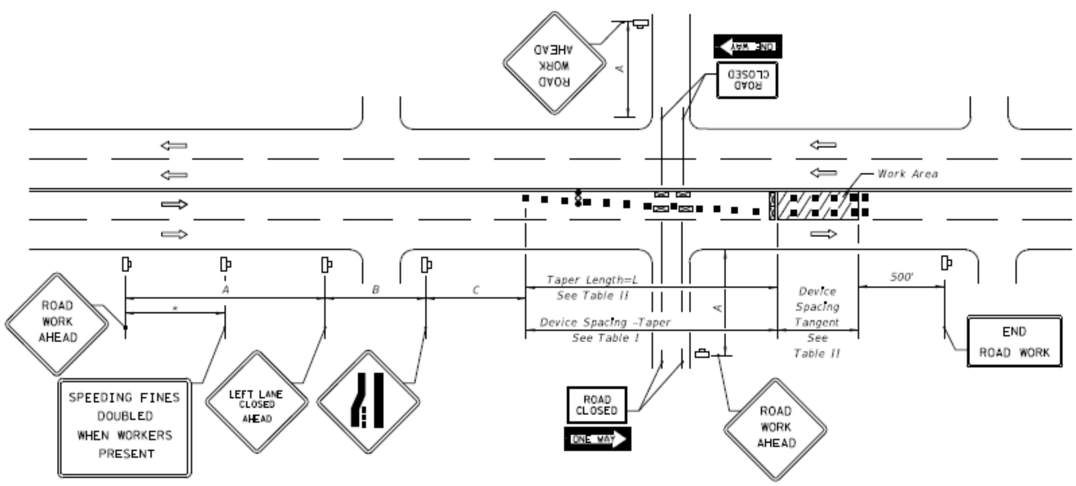


Figure 79. Existing MOT for Construction Project on US-301

Figure 80. Layout of Data Collection for OFF Scenario on US-301

Figure 81. Layout of Data Collection for AWAD Scenario on US-301

Figure 82. Layout of Data Collection for AWAD + iCone on US-301

Figure 83. Layout of Data Collection for Arrow Board + iCone on US-301

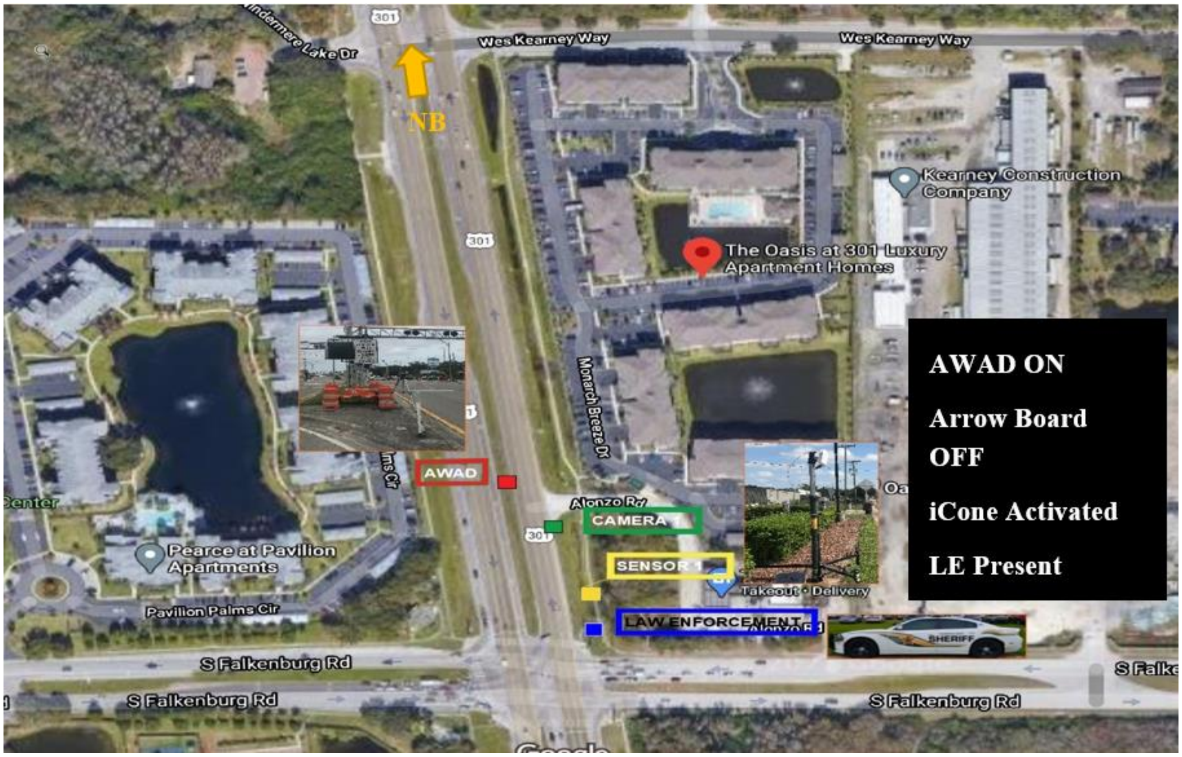


Figure 84. Layout of Data Collection for Arrow Board + iCone + LE on US-301

Figure 85. Layout of Data Collection for Arrow Board + iCone + LE on US-301

Figure 86. Field View of Construction Zone on US-301

3.7.2 Collected Data

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualitative analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 32.

Table 32. Summary of Collected Data at Site 6

Speed	Collected
Video	Collected
Traffic condition	High traffic Relatively high speed Congestion observed on-peak hours Drivers shifting lane when close to WZ
Traffic signal influence	Significant influence Measure point close to signal
Special event	None

3.8 Site 7: Veterans Expressway

Veterans Expressway is a double-lane toll expressway (two unidirectional lane) in urban areas with a posted speed limit of 25 mph. FDOT conducted a multi-phase project at the section near Veterans Expressway. The northbound off-ramp under construction is shown in Figure 87.

3.8.1 *Testing Scenarios*

The research team collected data on NB of Veterans Expressway (exit lane). The outside through lane (one lane) was closed; the inside lane was kept open to traffic, as shown in Figure 88. The existing regulatory speed limit of 25 mph was maintained throughout construction. Three SWZ scenarios were tested with outside lane closures, as shown in Figure 89 through Figure 91. The testing scenarios and data collection timeline are summarized in Table 33.

Table 33. Testing Scenarios for Site 8 (Veterans Expressway)

Scenario	Date	Work Zone Type
OFF	06/14/21, 9:00 PM–10:00 PM	Outside Lane Closure (One-lane)
AWAD	06/14/21, 10:15 PM–11:15 PM	
AWAD + LE	06/14/21, 11:15 AM–12:15 PM	

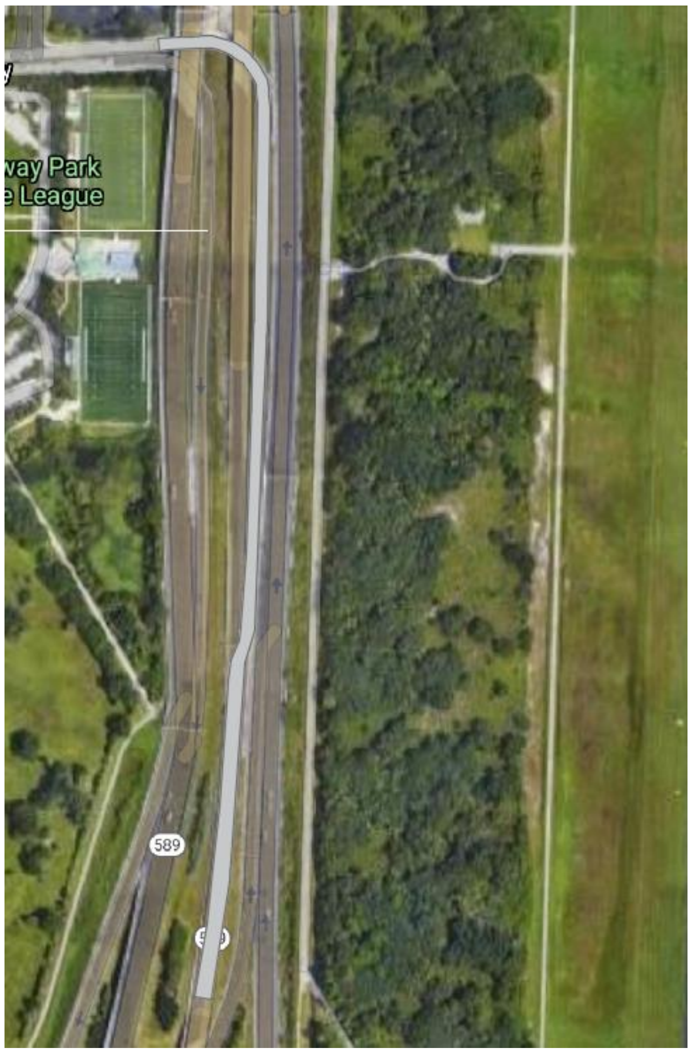


Figure 87. Northbound Off-ramp under Construction at Site 8: Veterans Expressway

Figure 88. Outside Lane Closure at Site 8: Veterans Expressway

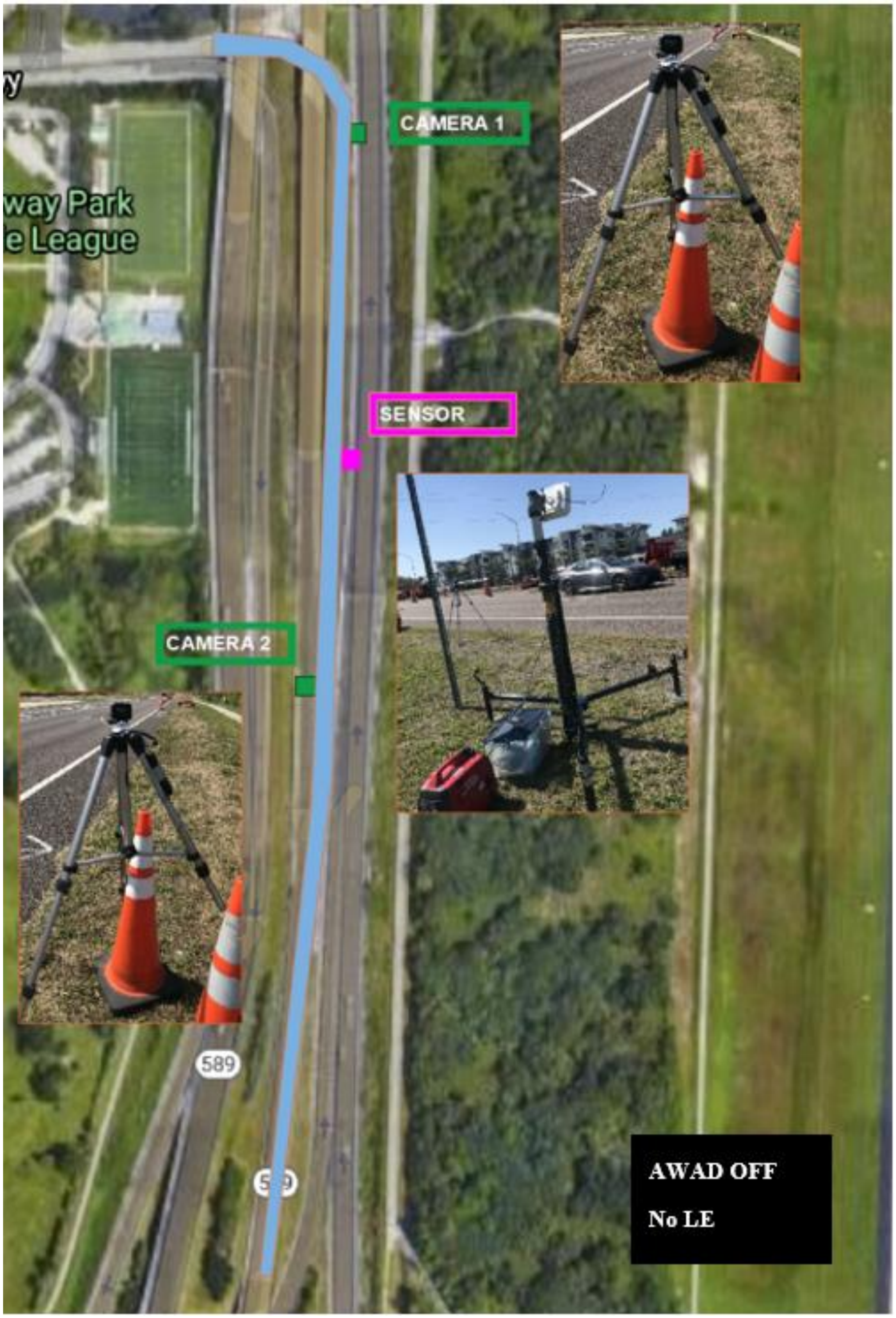


Figure 89. Layout of Data Collection for OFF Scenario on Veterans Expressway

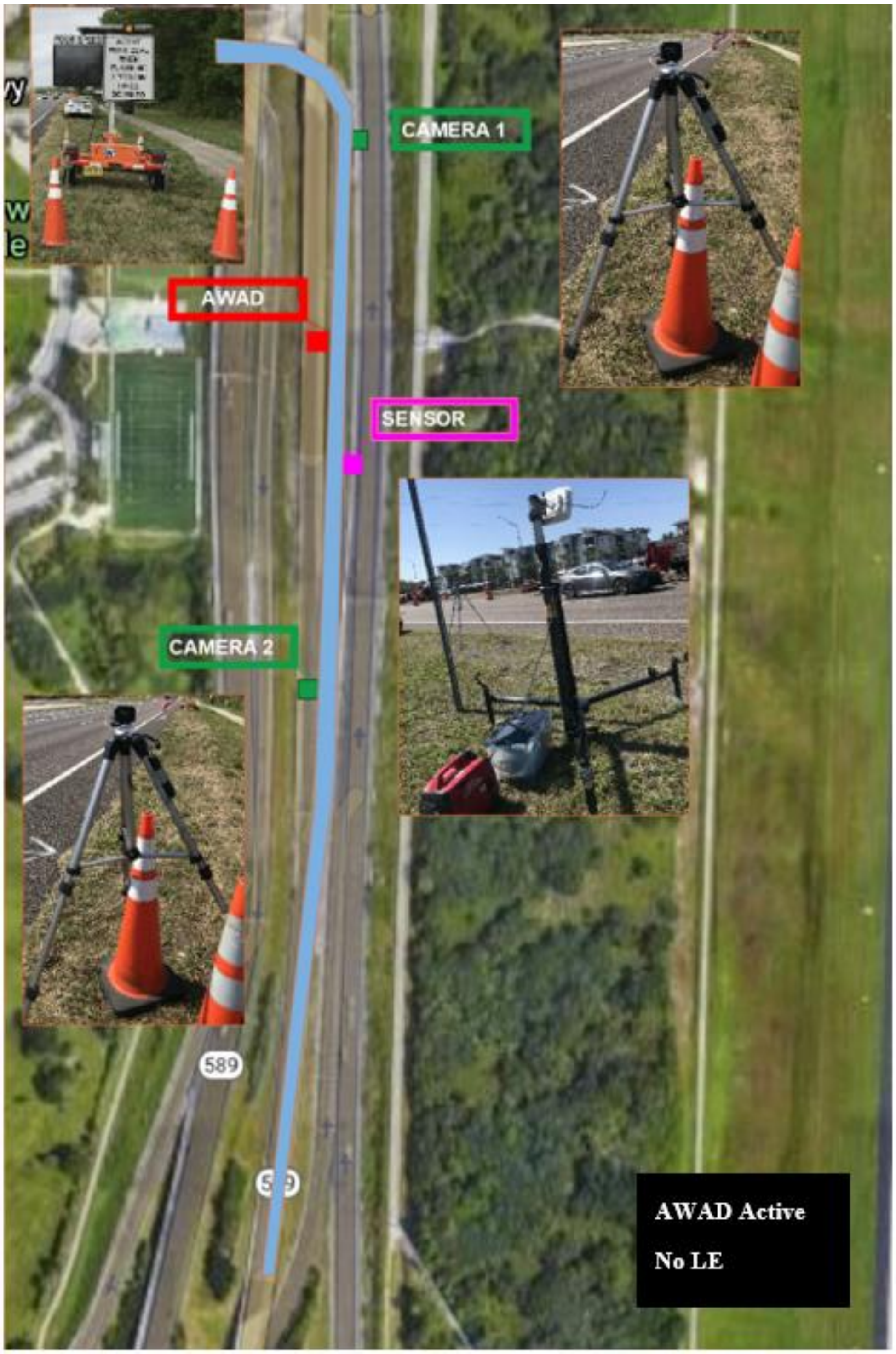


Figure 90. Layout of Data Collection for AWAD Scenario on Veterans Expressway

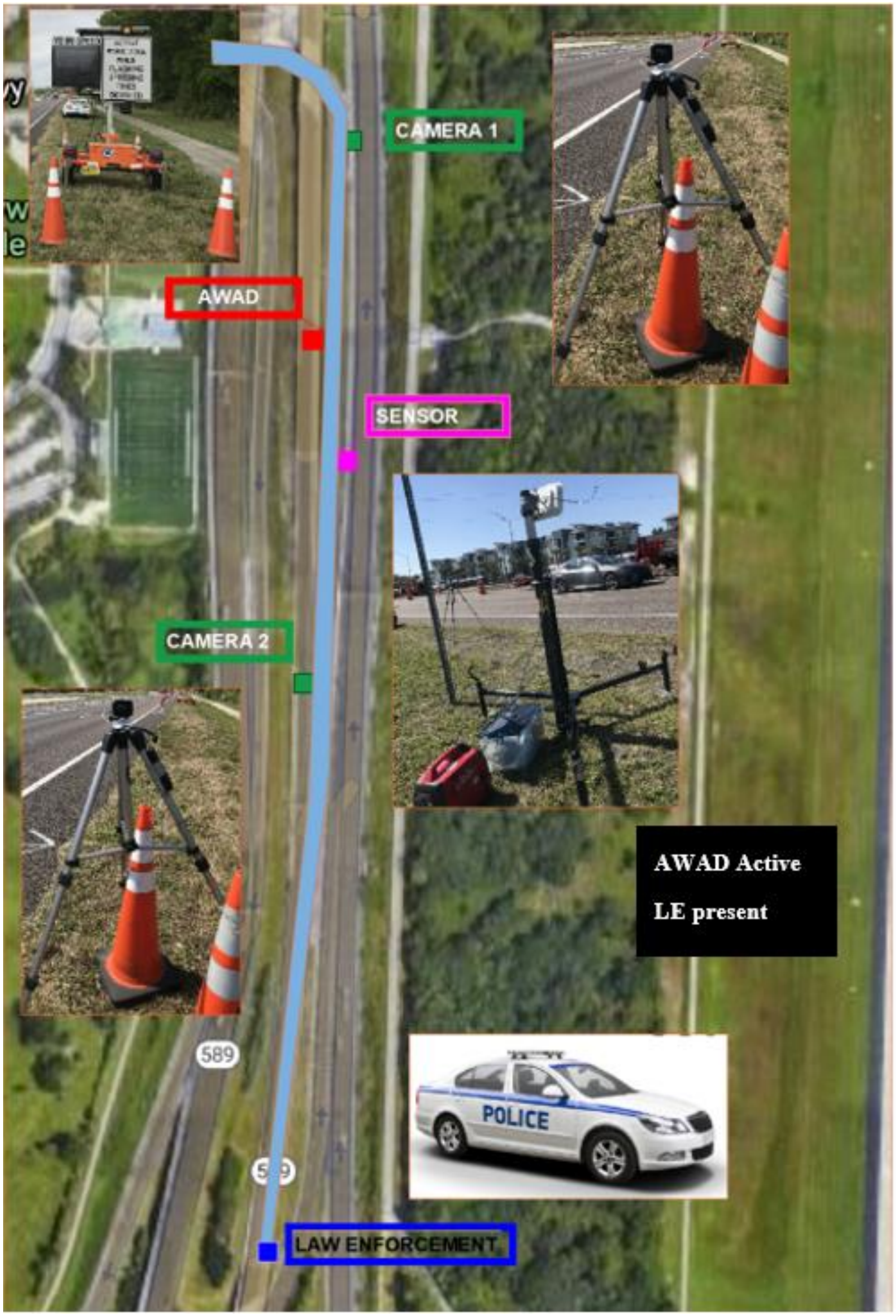


Figure 91. Layout of Data Collection for AWAD + LE Scenario on Veterans Expressway

3.8.2 Collected Data

The research team collected spot speed, vehicle classification, and traffic data with WaveTronix SmartSensors at two data collection points, near the AWAD and construction zone. The data were processed for quantitative analysis, and videos were recorded to identify behavior data for qualitative analysis. Traffic and environment conditions and special events were recorded in data collection logs for references in analysis. The collected data are summarized in Table 34.

Table 34. Summary of Collected Data at Site 8

Speed	Collected
Video	Collected
Traffic condition	Medium traffic Relatively high speed Congestion observed during WZ vehicle movements
Traffic signal influence	No traffic lights
Special event	None

3.9 Summary of Data Collection

With the full support and coordination from FDOT District 7, CUTR conducted the pilot study of SWZ applications from May 2020 to June 2021. The tested WZ application included AWAD, iCone, LE, and combinations thereof. Data were collected at seven sites that covered different WZ types and traffic conditions. Two WaveTronix SmartSensors were installed at two locations (upstream and work area) to collect speed, vehicle classification, and traffic counts by lane, and two GoPro cameras were installed at these locations to record video. The research team collected hundred hours of speed data and video data that were reviewed, compiled, and processed for quantitative (speed data) and qualitative (video data) analysis. The detailed data analyses are presented in Chapter 4.

4. Data Analysis Methodology and Results

4.1 Introduction

In the data analysis task, researchers analyzed, both quantitively and qualitatively, data collected from the seven pilot deployment sites. These analyses were performed based on before-after studies to evaluate the effectiveness of implemented SWZ applications and LE at different WZ types in terms of reduction of average vehicle speeds, sudden deceleration behaviors (i.e., braking), and sudden lane change behaviors (i.e., transition from a closing lane to a through lane). The pilot implementation sites for SWZ applications and LE included seven WZs on arterial roadways in the Tampa Bay area in FDOT District 7. The analysis results indicated that, in many test scenarios, vehicle speeds can be significantly reduced and driving behaviors can considerably be improved by deployment of SWZ applications and LE for different WZ types, MOT, characteristics of traffic, and geometric attributes of the arterial roadways.

The characteristics and WZ types of the pilot study sites are shown in Table 35. This research project covered three major WZ types—work on shoulder or median, lane closure, and lane shift. Some WZs of construction projects within the pilot study sites were for work on medians (US-301) and a right-turn lane (US-19). Due to the nature of construction and for the safety of vehicular movement in a WZ area, a through lane of US-301 adjacent to medians was closed, and, from the perspective of through lanes, work on a right-turn lane of US-19 was treated as work on shoulder; Therefore, for the studied work zone type, it is categorized as "work on median" for US-301, and "work on shoulder" for US-19; operationally, both MOTs refer to "lane closure." From the perspective of studied WZ type, this study included four sites with "work on shoulder or median" (US-98, US-19, US-301, Veterans Expressway), four sites with "lane closure" (SR-580, US-92, SR-597, Veterans Expressway), with one site—US-98—overlapping as "lane shift" and "work on shoulder or median."

Table 35. Summary of Work Zone Sites for SWZ and LE Applications for Test Scenarios

Study Sites	Work Zone Type	Improvement Project	SWZ and LE Applications	Studied Work Zone Type	Behavior Parameter
US-98	Lane shift, work on shoulder or median	Roundabout installation	AWAD, DSFS, LE	Lane shift, work on shoulder or median	
SR-580	Lane closure	Pedestrian safety	AWAD, LE	Lane closure	
US-92	Lane closure	Pedestrian safety	AWAD, LE	Lane closure	
US-19	Lane closure*	Pedestrian safety	AWAD, LE	Work on shoulder	Speed data and video observation
SR-597	Lane closure	Resurfacing	AWAD, iCone	Lane closure	
US-301	Lane closure**	Pedestrian safety	AWAD, iCone, LE	Work on median	
Veterans Expressway	Lane closure Work on shoulder	Road resurfacing	AWAD, LE	Lane closure Work on shoulder	

* Main work at shoulder and sidewalk but closed right-turn lane.
** Main work was on median but closed lane adjacent to median for safe traffic operation.
AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign

The following subsection presents the overall site characteristics of the WZs for which the research team evaluated the effectiveness of SWZ applications. These characteristics relate to operational aspects and MOT for WZ types as the focus of this research study.

4.1.1 Study Sites

With a well-planned coordination and data collection plan, vehicle speed and video data were captured from different sites with the approval of the FDOT PM, the FDOT Project Administrator, and contractors involved in the construction projects. Understanding of a temporary traffic control plan (TTCP) for each site provided more insight into setting up sensors and video cameras at two locations—one upstream and one in the main work activity area—for the construction projects.

An overall summary of these study sites in terms of WZ types and basic operational and geometric characteristics is shown in Table 36. Except for the Trilby Rd installation, the sites were high-volume arterials, ranging from 45,000–52,000 veh/day, with speeds of 40–55 mph. The research team followed the MOT index recommended by FDOT to understand WZ operation and developed a data collection and analysis methodology.

Table 36. Summary of Overall Site Characteristics for Pilot Study

Characteristics	US-98	SR-580	US-92	US-19	SR-597	US-301	Veterans Expressway
Roadway type	2-lane undivided roadway	6-lane divided roadway	6-lane divided roadway	6-lane divided roadway	4-lane divided roadway	6-lane divided roadway	2-lane exit ramp
Traffic volume (AADT)^ (vpd)	7,500	50,000	45,000	50,500	51,000	52,000	5,000
Work zone type	Lane shift and work on shoulder	Lane closure	Lane closure	Lane closure* (work on shoulder)	Lane closure	Lane closure** (work on median)	Lane closure
MOT index (FDOT)	102-601, 102-602, 102-603	102-613	102-616	102-613	102-613	102-616	102-613
Focus of travel direction	NB	WB	EB	NB	SB	NB	NB
Work zone speed limit (mph)	25	40	45	45	55	45	25
Posted speed limit (mph)	45	40	45	45	55	50	25

* Main work was on shoulder and sidewalk but closed right-turn lane, which was very similar to work on shoulder for safe traffic operation.
** Main work was on median but lane adjacent to median was closed for safe traffic operation.
^ AADT = Annual Average Daily Traffic; FDOT Online Traffic (2019), https://tdaappsprod.dot.state.fl.us/fto/.

4.2 Methodology

This section summarizes the data collection and analytical framework for evaluation of SWZ applications at the study sites. Figure 92 presents the methodology of the data collection and analytical framework; major milestones for this study were the following:

- Coordination with FDOT played a key role at the initial stage of the data collection planning and provided needed information for CUTR to design and plan the test scenarios for a study site. Communication was continuous among the CUTR team, the FDOT PM, FDOT site managers, contractors, the iCone vendor and technical team, and LE to finalize the data collection plan. The coordination and communication process resulted in a successful data collection plan.
- The CUTR data collection crew, including two graduate students and project Co-PIs who followed the data collection plan to perform data collection, set up speed sensors and video cameras at both upstream and at WZ activity area of a study site, collected “before” (baseline) data, worked with FDOT on SWZ and LE deployment, and collected “after” data based on test scenarios at each study site. This data collection process was closely coordinated with all involved entities.
- The analysis framework included “before” data analysis based on the baseline condition and “after” data analysis based on test scenarios. CUTR researchers focused on the quantitative data analysis using vehicle speed data and qualitative analysis using driving behavioral data collected at the immediate upstream location of a WZ, as this is a critical location for speed reduction and safe driving behaviors to ensure WZ safety. The speed data at a WZ activity area were analyzed when needed. The data analyses were designed to evaluate the effectiveness of deployment of SWZ applications and/or LE in a WZ area on speed reduction and driving behavior improvement.
- Results of the before-after study were used to understand how deployment of SWZ applications and LE influenced drivers to reduce their speed (quantitative) in a WZ area and changed their driving behaviors (qualitative). Evaluations were conducted by analyzing and comparing the results based on test scenarios with SWZ applications and LE implementation, with the result based on the baseline scenario for different WZ types and roadway geometries.

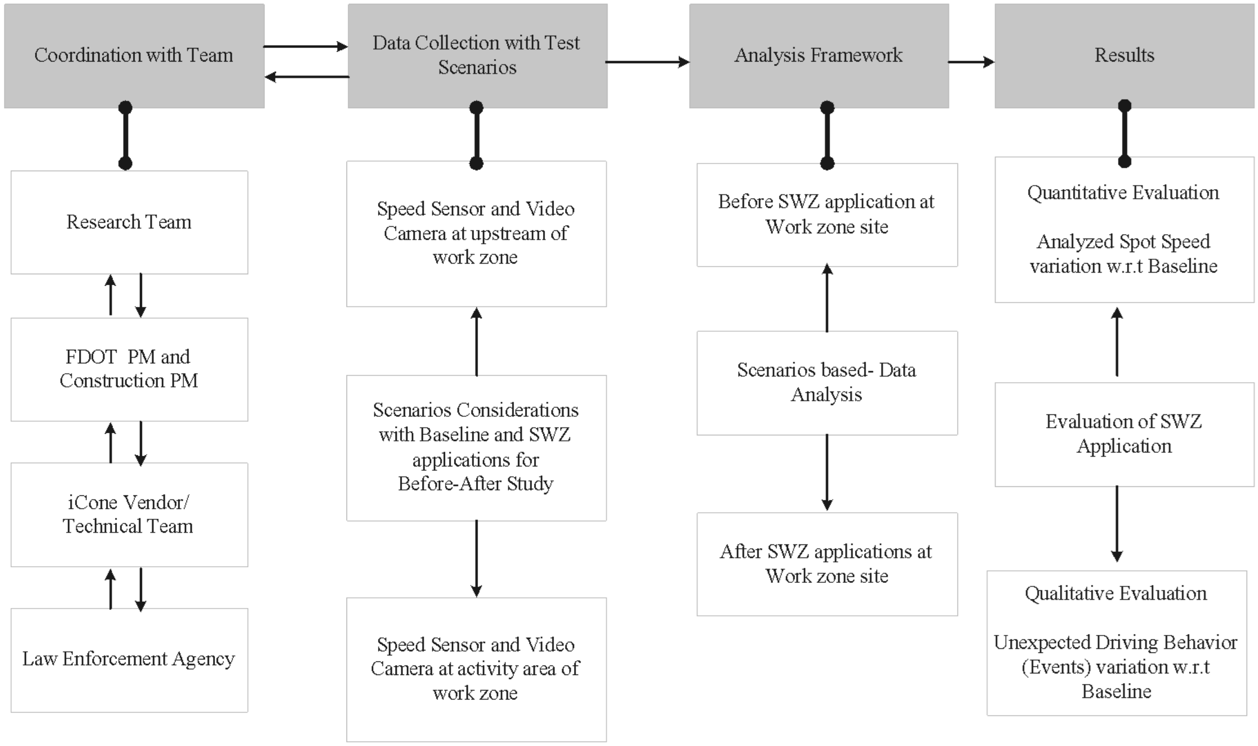


Figure 92. Methodology for Data Collection and Analytical Framework

4.2.1 Rationale

Good coordination among the FDOT project and construction PMs, MOT designers, and construction contractors was essential for the CUTR team to review MOTs for WZ areas and prepare for field data collection. Understanding of MOTs and their implementation schedule guided development of the data collection plan and design of the test scenarios for the selected sites. These test scenarios were evaluated by comparing “before” and “after” implementation of SWZ applications and their combinations with presence of LE. CUTR researchers analyzed vehicle spot speeds via sensor data and observed driving behaviors via video data. The before-after analysis based on sensor data resulted in effectiveness for speed reduction for different SWZ applications at selected WZ sites. Similarly, driver behavior during lane change or declaration based on video data extraction resulted in qualitative evaluation (i.e., safe, moderate, risky behaviors) of test scenarios.

4.2.2 MOT Review

Construction sites usually are managed with one or multiple MOT plans for efficient and safe movement of traffic in consideration of construction work. For the studied sites, FDOT recommended an index representing a WZ configuration that was reviewed and discussed. This MOT review played a key role in developing the data collection plan and designing the test scenarios. Some MOTs were used for several weeks, but some were used only for a couple of days. The duration and schedule of a MOT could affect the number of test scenarios that the CUTR research team can conduct for at a selected study site.

4.2.3 Before-After Analysis

For this project, the effectiveness of a SWZ application was determined primarily by its reduction of average spot speeds from the baseline condition. The effectiveness on speed reduction is computed as the percentage of difference of average spot speeds between baseline (no device)—traditionally considered "before"—and a test scenario—traditionally considered "after," as shown below:

$$Effectiveness\left(\%\right) = \frac{\left[\bar{X}_{Before} - \bar{X}_{After}\right]}{\bar{X}_{Before}} * 100\% \qquad [1]$$

where, $\bar{X}_{Before}$ = average spot speed before (mph) and $\bar{X}_{After}$ = average spot speed after (mph).

The positive value of percentage generally indicates that the implementation of an SWZ application or its combination with LE can reduce vehicle speeds at a WZ. A negative value generally indicates it cannot achieve that.

The research team also analyzed the statistical significance of average spot speed reduction in the test scenarios. The study hypothesis was to measure if average spot speed before (no device) was different from average spot speed after (with test scenario). Eq. 2 presents the null hypothesis of no difference and the alternative hypothesis of significant difference. Hypothesis testing was conducted based on the Z* statistic, as shown in Eq. 3 (Washington et al., 2020).

$$\begin{aligned} H_0 &: \mu_a - \mu_b = 0 \\ H_a &: \mu_a - \mu_b \neq 0 \end{aligned} \qquad [2]$$

$$Z^* = \frac{\left(\bar{X}_a - \bar{X}_b\right) - \left(\mu_a - \mu_b\right)}{\sqrt{\frac{s_a^2}{n_a} + \frac{s_b^2}{n_b}}} \qquad [3]$$

where,

$\bar{X}_a$ = average spot speed of sample (after)

$\bar{X}_b$ = average spot speed of sample (before)

μ_a = average spot speed of population (after)

μ_b = average sport speed of population (before)

s_a^2 = variance of spot speed of sample (after)

s_b^2 = variance of spot speed of sample (before)

n_a = sample size (after)

n_b = sample size (before)

The Z* statistic was computed for all scenarios, and it was found that test statistics were much larger than 1.96, the critical value for a two-tailed test at a 5% significance level. This led to the conclusion that average spot speeds, in the before and after periods, were equal and were rejected (accepting the alternative hypothesis). This meant that most spot speeds in the "after" scenarios were statistically lower than those under the baseline condition.

4.2.4 Behavior Analysis

The research team qualitatively investigated driving behavior—in particular, risky behavior in different types of WZs—by reviewing video data for all study sites. A scoring system assigned values for these driving behaviors qualitatively for a comparative picture of different behaviors for specific test scenarios—AWAD, DSFS, LE Only, and combinations. Table 37 describes two typical behavior types when a vehicle approaches a WZ—lane change for merging due to a lane closure and deceleration due to slow-down of a front vehicle or lower posted speed limit, both of which are relevant to this study. For each driving behavior type, CUTR researchers provided definitions and ratings for safe, moderate, and risky behaviors, as shown in Table 37.

Table 37. Qualitative Evaluation of Typical Driving Behavior with Scoring System

Typical Behavior	Definition	Rating
Lane changing	Smooth transition without risk to another vehicle	1
	Rough transition with indicator	2
	Risky transition without indicator	3
Deceleration	Smooth slowdown	1
	Moderate slowdown without risk to another vehicle	2
	Risky slowdown with sudden deceleration	3

Using the noted process for selecting a site, reviewing MOT, and conducting quantitative before-after analysis and qualitative behavioral analysis, the following sections present detailed analyses for all sites considered in this study.

4.3 Site 1: US-98

4.3.1 Construction Project

US-98 in Dade City is a rural two-lane road. FDOT constructed a roundabout to replace a signalized intersection (US-98 at Trilby Rd) from March to September 2020. The research team designed the test scenarios for this construction project, which consisted of multiple phases (II, IIIB, IVB1, and IVB2). The following subsection presents spot speed reduction information with the application of different test scenarios for the different phases of the US-98 WZ site.

4.3.2 ***Quantitative Analysis***

4.3.2.1 Phase II: Work on Shoulder on US-98 (NB)

Spot speed for different test scenarios with respect to the baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ even with work on the shoulder and with one through lane open in each direction. These spot speed readings were taken by a sensor (Sensor 1) at the upstream of the WZ area where the expected change in driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 38. In Phase II, the work was primarily on the right shoulder and an adjacent area, with a posted speed limit of 25 mph for the WZ.

In this phase, the effectiveness of the scenarios in vehicle speed reduction was AWAD + DSFS 17%, AWAD 16%, AWAD + LE 43%, LE + DSFS 25%, AWAD + LE and DSFS 18%, and LE Only 36% from a baseline speed of 44 mph.

Table 38. Effectiveness of Test Scenarios in Phase II Upstream on US-98 (NB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Baseline (no device)	44		25	Work on shoulder
AWAD + DSFS	37	17%		
AWAD	37	16%		
AWAD + LE	25	43%		
LE + DSFS	33	25%		
AWAD + LE + DSFS	27	18%		
LE Only	28	36%		

AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign; LE = Law Enforcement; computed values rounded to higher number.

4.3.2.2 Phase III: Work on Shoulder on US-98 (NB)

The spot speeds for different test scenarios with respect to baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ even with work on shoulder and one through lane open in each direction. These spot speed readings were taken by a sensor (Sensor 1) at the upstream of the WZ area where the expected change in driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 39. In Phase III, the work was primarily on the right shoulder and an adjacent area, with a posted speed limit of 25 mph.

In this phase, the effectiveness of the different scenarios in vehicle speed reduction was AWAD 10%, AWAD + LE 33%, LE + DSFS 26%, and LE Only 29%, a decrease from the baseline speed of 42 mph.

Table 39. Effectiveness of Test Scenarios in Phase IIIB at Upstream on US-98 (NB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Baseline (no device)	42		25	Work on shoulder
AWAD	38	10%		
AWAD + LE	28	33%		
LE + DSFS	31	26%		
LE only	30	29%		

AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign; LE = Law Enforcement; computed values rounded to higher number.

4.3.2.3 Phase IV: Lane Shift on US-98 (NB)

Spot speed for different test scenarios with respect to baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ even with lane shift having one lane open in both directions. These spot speed readings were taken by a sensor (Sensor 1) at the upstream of the WZ area where expected changes in driving behavior in the form of reduction of spot speed were observed and computed, as presented in Table 40. In Phase IV, lane shift was maintained in Phase IVB1, although the new road was open to traffic in Phase IVB2. The speed limit was 25 mph in this WZ.

In these phases, the effectiveness of the scenarios was AWAD (Phase IVB1) 3% (increase), AWAD 5%, and AWAD + LE (Phase IVB2) 33%, decreases from the baseline speeds of 32 and 39 mph.

Table 40. Effectiveness of Test Scenarios in Phase IVB1 and IVB2 at Upstream on US-98 (NB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type (Sub-phase)
Baseline (no device)	32		25	Lane shift (IVB1)
AWAD	33	-3%		
Baseline (no device)	39			New road (IVB2)
AWAD	37	5%		
AWAD + LE	26	33%		

AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign; LE = Law Enforcement; computed values rounded to higher number.

4.3.3 ***Qualitative Analysis***

4.3.3.1 Driving Behavior

During Phase II, video review of driving behavior indicates that slow braking increased from 35% in the baseline scenario to 39% in the AWAD scenario and 55% in the combined scenario of AWAD + LE. The trend for risky braking decreased from 20% in the baseline scenario to 15% in AWAD and 11% in AWAD + LE. Figure 93 presents the qualitative analysis in Phase II translated into ratings by video observers to understand the changes in smooth, moderate, and risky slowdown for baseline, AWAD, and AWAD + LE for the US-98 (Phase II) construction site.

During Phase III, video review for driving behavior indicates that slow braking increased from 35% in the baseline condition to 43% in the AWAD scenario and 50% in AWAD + LE. The trend for risky braking decreased from 20% in the baseline scenario to 10% in AWAD + LE. Figure 94 presents the qualitative analysis for Phase III translated from ratings by video observers to understand the changes in smooth, moderate, and risky slowdown for baseline, AWAD, and combined scenario of AWAD + LE for the US-98 (Phase III) construction site.

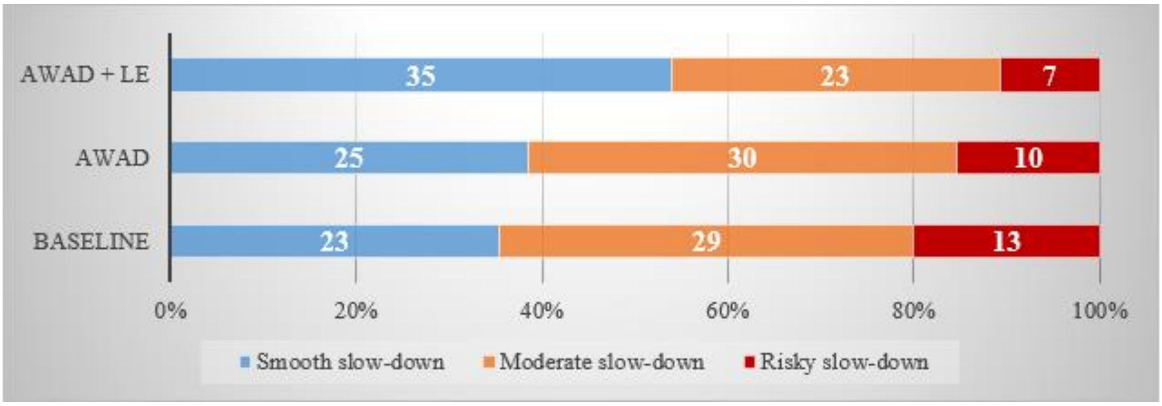


Figure 93. Driving Behavior for Phase II on US-98

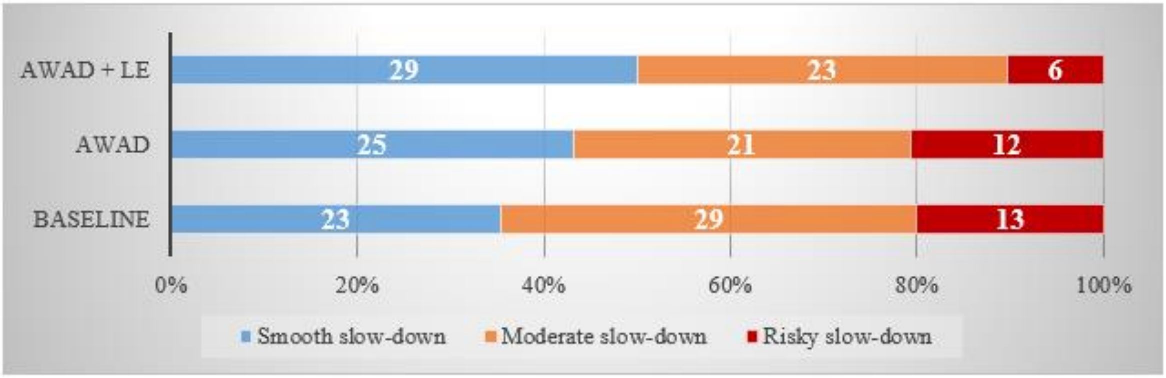


Figure 94. Driving Behavior for Phase III on US-98

4.3.4 Summary Results

The US-98 WZ site is two-way undivided rural highway with multiple phases of construction. As noted, Phases II, III, and IV were targeted with SWZ applications with speed observations on the NB direction. These applications suggested that driving behavior in terms of speed reduction while approaching the WZ had significant safety implications. Results for speed reductions (quantitative) and driving behavior (qualitative) are summarized below.

Table 41 presents the effectiveness of the SWZ applications at the US-98 construction site, where AWAD, AWAD + LE, LE + DSFS, and LE Only showed significant speed reductions in most scenarios except in Phase IVB1, which had human flaggers. These significant reductions have important implications for MOT design, where speed reductions along the roadway (NB) was gradual, from 45 mph to 25 mph. Even speeds under the AWAD scenario were over the speed limit of 25 mph in the WZ for US-98, and the reduction was significant. More important, speed and speed reduction with AWAD + LE led to expected driving behaviors when the speed limit was 25 mph.

Table 41. Comparison of Effectiveness of Test Scenarios in Phase IVB1 and IVB2 at Upstream on US-98 (NB)

	Baseline (No Device) (mph)	AWAD (mph)	AWAD + LE (mph)	LE + DSFS (mph)	LE (mph)
Phase II	44	37	25	33	28
Effectiveness in speed reduction		16%	43%	25%	36%
Phase IIIB	42	38	28	31	30
Effectiveness in speed reduction		10%	33%	26%	29%
Phase IVB1	32	33	-	-	-
Effectiveness in speed reduction		-3%	-	-	-
Phase IVB2	39	37	26	-	-
Effectiveness in speed reduction		5%	33%	-	-

AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenario and the baseline speed, the hypothesis noted in Eq. 2 was tested and indicated the null hypothesis with no difference in speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggest that the null hypothesis was rejected at a 95% confidence level for all scenarios and was above the critical Z-score. This indicates that speeds in the test scenarios were statistically and significantly different from the baseline speed. Table 42 presents the statistical test results on the differences between the baseline and test scenarios.

Table 42. Statistical Tests on Test Scenarios at Upstream on US-98 (NB)

Scenario Comparison		Z-statistics (Critical Z-score = 1.96)	Statistical Significance
Baseline	***Scenarios***		
No device	AWAD	25.7	Significant
	AWAD + LE	92.6	Significant
	AWAD + DSFS	29.5	Significant
	LE + DSFS	28.5	Significant
	LE Only	77.3	Significant

AWAD = Active Work Zone Awareness Device; DFSF = Dynamic Speed Feedback Sign; LE = Law Enforcement; computed values rounded to higher number.

The result of driving behavior in terms of qualitative rating scale for smooth, moderate, and risky slowdown suggested that drivers slowed down more smoothly with both AWAD and AWAD + LE scenarios at this site. The video review process was consistent for Phases II and III. As there was significant traffic operation by a human flagger, the video review process was not comparable with earlier phases in the same scale.

4.4 Site 2: SR-580 (E Busch Blvd)

4.4.1 Construction Project

SR-580 (Busch Blvd) is a multilane arterial road in urban areas with a posted speed of 40 mph along SR-580 WB and 45 mph EB. The installation of HAWKs by FDOT along the corridor was to improve pedestrian safety at Brook St and Busch Blvd. The posted speed limits of 40 mph along WB and 45 mph along EB near Brook St remained unchanged during construction.

4.4.2 Quantitative Analysis

4.4.2.1 Lane Closure on SR-580 (WB)

As described in Chapter 3, an education campaign was conducted at this site during the construction period, with three billboards with WZ safety messaging installed on Busch Blvd and 30 and 60-second WZ safety PSA radios broadcasted. A before-after data analysis showed that there were 11% reduction of vehicle speeds for eastbound traffic and 4% for westbound traffic.

Spot speeds for different test scenarios with respect to baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ even with the right-most lane (adjacent to right shoulder) closed. These spot speed readings were taken by sensors (Sensor 1 at upstream and Sensor 2 at work area) approaching the WZ area and at work areas where the expected change of driving behavior in the form of reduction of spot speeds was observed and computed, as presented in Table 43. On SR-580 (WB) near Brook St, work was primarily on the right-most lane, with a posted speed limit of 40 mph due to this WZ.

Table 43. Effectiveness of Test Scenarios at Upstream on SR-580 (WB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Right-most lane:			40	Lane closure
Baseline (no device)	42			
AWAD	34	19%		
AWAD + LE	43	-2%		
Inner lanes (middle and left-most lanes):				
Baseline (no device)	44			
AWAD	42	5%		
AWAD + LE	46	-5%		

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

At this site, with closure of right-most lane, the effectiveness of AWAD and AWAD + LE was 19% (reduction) and 2% (increase), respectively, from the baseline speed of 42 mph. However, for the inner lanes (middle and left-most lanes), the effectiveness for AWAD and AWAD + LE was 5% (reduction) and 5% (increase), respectively.

It was found that speed increased by 2% for AWAD + LE from the baseline. The speed reading was collected about two weeks after AWAD was first introduced at this site and suggests that drivers were already familiar with AWAD at the WZ site on Busch Blvd. Moreover, an enforcement vehicle was parked inside the WZ instead of upstream because of sight distance complicated by alignment and uphill sections for drivers traveling WB. This clearly suggests sensitivity of drivers on driving speed along the WZ in the presence of law enforcement and the position of the parked vehicle. This observation led the research team to investigate other important speed-related parameters, such as average spot speed and speed variance, to understand this unexpected phenomenon at the upstream of the WZ. These additional analyses are described in the following sub sections.

4.4.2.2 Additional Speed Analysis on SR-580 (WB)

Speed analysis for the activity area for inner lanes (middle and left-most lane combined, as the right-most lane was closed) was performed to compare average spot speed and speed variance for the scenario of AWAD + LE with baseline and AWAD. Table 44 shows the average speed (mph) and speed variance (mph^2) for the scenario AWAD + LE for 36 mph and 43 mph,[2] clearly indicating that speed variance reduced by 35% compared to the baseline.

Table 44. Effectiveness of Test Scenarios at Activity Area on SR-580 (WB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Speed Variance (mph^2)	Effectiveness in Reduction of Speed Variance
Baseline (no device)	36		66	
AWAD	37	-3%	47	29%
AWAD + LE	36	0%	43	35%

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

The statistical significance of this speed reduction as presented in Table 43 was tested for the scenario of AWAD at the upstream section for the right-most lane and inner lanes (middle and left-most lane combined) by using Z-statistics (Eq. 3). As shown in Table 45, the speed redcution for the scenario of AWAD compared to the baseline was statistically significant. Slight apeed increase for the right-most and inner lanes for AWAD + LE was also statistically significant compared to the baseline.

Table 45. Statistical Tests on Test Scenarios at Upstream Right-most Lane and Inner Lanes on SR-580 (WB)

Lane Configuration	Scenario Comparison		Z-statistics (Critical Z-score = 1.96 or -1.96)	Statistical Significance
	Baseline	Scenario		
Right-most lane	No device	AWAD	6.7	Significant
		AWAD + LE	-3.5	Significant
Inner lanes		AWAD	7.9	Significant
		AWAD + LE	-16.1	Significant

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

4.4.3 Qualitative Analysis

4.4.3.1 Driving Behavior

During construction on WB SR-580, video review for driving behavior indicates that smooth transition increased from 27% in the baseline scenario to 45% for AWAD and 51% for AWAD + LE. The trend for risky transition decreased from 22% in the baseline scenario to 15% for AWAD and 14% for AWAD + LE. Figure 95 presents the qualitative analysis translated from ratings of video observers to understand the changes in smooth, rough, and risky transition for the baseline, AWAD, and AWAD + LE scenarios at the SR-580 construction site.

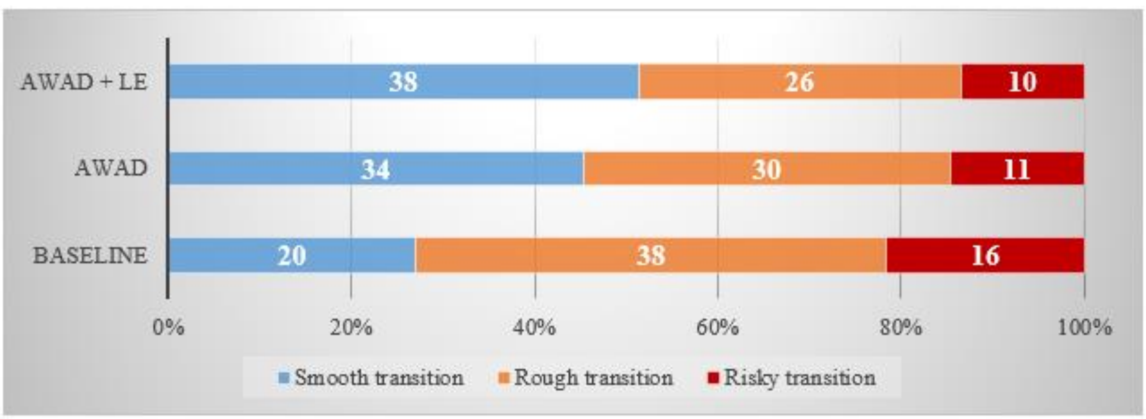


Figure 95. Driving Behavior on SR-580 (WB)

4.4.4 Summary Results

The SR-580 WZ site is a 6-lane divided urban arterial highway with HAWK construction at Brook St. As noted, a right-most lane closure was targeted with SWZ applications, with speed observations on the WB direction. These applications suggest that driving behavior in terms of speed reduction while approaching the WZ had significant safety implications. The results of speed reductions (quantitative) and driving behavior (qualitative) are summarized below.

Table 46 presents the effectiveness of the SWZ applications at the SR-580 construction site, where AWAD and AWAD + LE showed significant speed and speed variance reductions compared to the baseline. At the upstream of the Brook St, the effectiveness of AWAD and AWAD + LE was 19% (reduction) and -2% (increase), respectively, for the right-most lane. Similarly, the effectiveness of AWAD and AWAD + LE was 5% (reduction) and -5% (increase), respectively, for the inner lanes. Although an unexpected speed increase was observed for AWAD + LE compared to the baseline, the statistical significance test using Z-statistics suggested that the increase was not significant. Moreover, the speed variance decreased for AWAD + LE compared to the baseline.

Table 46. Comparison of Effectiveness of Test Scenarios at Upstream and Activity Area on SR-580 (WB)

	Baseline (No Device) (mph)	AWAD (mph)	AWAD + LE (mph)	Lane Configuration
Upstream	42	34	43	Right-most lane
Effectiveness in speed reduction		19%	-2%	
Upstream	44	42	46	Inner lanes
Effectiveness in speed reduction		5%	-5%	
Activity Area	36	37	36	Inner lanes
Effectiveness in speed reduction		-3%	0%	

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenarios and the baseline speed, the hypothesis noted in Eq. 2 was tested and indicates the null hypothesis with no difference in speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggest that the both null hypotheses were rejected at a 95% confidence level for the scenarios of AWAD and AWAD + LE, as the computed Z-statistics (Eq. 3) suggest that they are either above or below the critical Z-score. This concludes that the speed in the test scenarios was statistically and significantly different from the baseline speed. Table 47 presents the statistical test results on the differences between the baseline and test scenarios on the right-most lane under the outside lane closure WZ type.

Table 47. Statistical Tests on Test Scenarios at Upstream on SR-580 (WB)

Scenario Comparison		Z-statistics (Critical Z-score = 1.96 or -1.96)	Statistical Significance
Baseline	***Scenarios***		
No device	AWAD	6.7	Significant
	AWAD + LE	-3.5	Significant

The result of driving behavior in terms of qualitative rating scale for smooth, rough, and risky transition suggested that drivers transitioned smoothly with both AWAD and AWAD + LE scenarios at this site.

4.5 Site 3: US-92 (E Hillsborough Ave)

*4.5.1 **Construction Project***

US-92 (Hillsborough Ave) is a 6-lane divided arterial in urban areas with a posted speed limit of 45 mph. The installation of HAWK beacons by FDOT along the corridor was to improve pedestrian safety at 50th St and Hillsborough Ave. At this construction site, a drilled shaft installation was conducted on the median at night with the lane adjacent to the median closure. The speed limit near 50th St remained unchanged during the construction.

*4.5.2 **Quantitative Analysis***

4.5.2.1 Lane Closure on US-92 (EB)

Spot speeds for different test scenarios with respect to the baseline (no device) indicated that there were reductions of spot speed due to awareness of drivers traveling through the WZ even with the left-most lane (adjacent to the median) closed. These spot speed readings were taken by a sensor (Sensor 1 at upstream) at the approach to the WZ area, where the expected change of driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 48. On US-92 (EB) near 50th Street, the work was primarily on the left-most lane (adjacent to the median), with a posted speed limit of 45 mph due to this WZ during nighttime.

At this site with the closure of left-most lane, the effectiveness of AWAD and AWAD + LE was 2% and 9% (reduction), respectively, from the baseline speed of 48 mph. However, for the outer lanes (middle and right-most lanes combined), the effectiveness for AWAD and AWAD + LE was 2% (increase) and 7% (reduction), respectively. As the data collection was conducted during work at night, the presence of AWAD was not observed with significant speed reduction under the lower traffic volume.

Table 48. Effectiveness of Test Scenarios at Upstream on US-92 (EB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Left-most lane:			45	Lane closure
Baseline (no device)	48			
AWAD	47	2%		
AWAD + LE	43.5	9%		
Outer lanes (middle and right-most lanes):				
Baseline (no device)	46			
AWAD	47	-2%		
AWAD + LE	43	7%		

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

4.5.3 ***Qualitative Analysis***

4.5.3.1 Driving Behavior

During construction on EB US-92, video review for driving behavior indicates that smooth transition increased from 40% in the baseline scenario to 52% for AWAD and 64% for AWAD + LE. The trend for risky transition decreased from 12% in the baseline scenario to 8% for AWAD and to 0% for AWAD + LE. Figure 96 presents the qualitative analysis translated from ratings by video observers to understand the changes in smooth, rough, and risky transition for the baseline, AWAD, and AWAD + LE scenarios at the US-92 construction site.

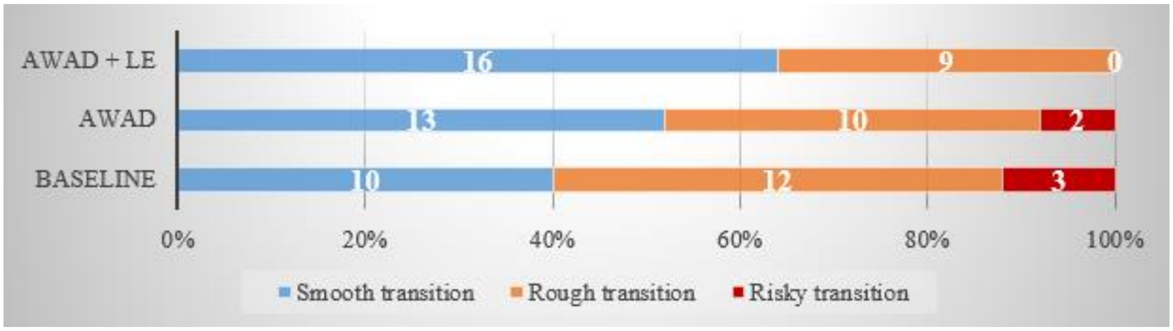


Figure 96. Driving Behavior on US-92 (EB)

4.5.4 ***Summary Results***

The US-92 WZ site is 6-lane divided urban arterial highway with the installation of HAWK at 50th Street. As noted, left-most lane closure was targeted with SWZ applications with speed observations on the EB direction. These applications suggest that driving behavior in terms of speed reduction while approaching the WZ had significant safety improvement. The results of speed reductions and improved driving behavior are summarized below.

Table 49 presents the effectiveness of these SWZ applications at the US-92 construction site, where AWAD and AWAD + LE showed speed reductions compared to the baseline. At the upstream of 50th St, the effectiveness of AWAD and AWAD + LE in speed reduction was 2% and 9%, respectively, for the left-most lane. The effectiveness of AWAD and AWAD + LE was -2% (increase) and 7% (reduction), respectively for outer lanes.

Table 49. Comparison of Effectiveness of Test Scenarios at Upstream on US-92 (EB)

	Baseline (No Device) (mph)	**AWAD (mph)**	**AWAD + LE (mph)**	**Lane Configuration**
Upstream	48	47	43.5	Left-most lane
Effectiveness in speed reduction		2%	9%	
Upstream	46	47	43	Outer lanes
Effectiveness in speed reduction		-2%	7%	

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenario and baseline speeds, the hypothesis noted in Eq. 2 was tested and indicates a null hypothesis with no difference on speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggested that the null hypothesis was accepted at a 95% confidence level for AWAD as the computed Z-statistics (Eq. 3) suggested that it is below the critical Z-score. However, the computed Z-statistics (Eq. 3) suggested that it is above the critical Z-score for AWAD + LE. This concludes that the speed for AWAD + LE was statistically and significantly different from the baseline speed. Table 50 presents the statistical test results on the differences between baseline and test scenarios.

Table 50. Statistical Tests on Test Scenarios at Upstream on US-92 (EB)

Scenario Comparison		**Z-statistics (Critical Z-score = 1.96)**	**Statistical Significance**
Baseline	***Scenarios***		
No device	AWAD	0.36	Insignificant
	AWAD + LE	5.1	Significant

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

The result of driving behavior in terms of qualitative rating scale for smooth, rough, and risky transition suggested that drivers transitioned smoothly with both AWAD and AWAD + LE scenarios at this site.

4.6 Site 4: US-19

*4.6.1 **Construction Project***

The US-19 segment in this study site is a 6-lane divided arterial (three through lanes in each direction) with a continuous right-turn lane also in each direction in suburban areas, with a posted speed limit of 45 mph. The section near Dipaola Dr and Beach Blvd was widened at the sidewalk and resurfaced by FDOT at the right-turn lane on US-19. At this construction site, resurfacing was performed at the right-turn lane and widening was performed at the sidewalk; this area was closed except for the three through lanes in each direction. The speed limit near Dipaola Dr and Beach Blvd remained unchanged during construction. As the right-turn lane was closed, it was operationally very similar to the three through lanes open to traffic with work on the right shoulder.

*4.6.2 **Quantitative Analysis***

4.6.2.1 Right-turn Lane Closure on US-19 (NB)

Spot speeds for the different test scenarios with respect to the baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ, even with the right-turn lane closed. These spot speed readings were taken by a sensor (Sensor 1 at upstream) at the approach to the WZ area where the expected change of driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 51. On US-19

(NB) near Dipaola Dr and Beach Blvd, the work was mostly on the right-turn lane (equivalent to work on the shoulder with open traffic on three through lanes), with a posted speed limit of 45 mph due to this WZ.

At this site, with the closure of right-turn lane, the effectiveness of AWAD and AWAD + LE was 21% and 12% (reduction), respectively, from the baseline speed of 43 mph. However, for the inner lanes (all three through lanes combined), the effectiveness of AWAD and AWAD + LE was 6% and 15% (reduction), respectively.

Table 51. Effectiveness of Test Scenarios at Upstream on US-19 (NB)

<table>
<tr><th>Test Scenarios</th><th>Avg. Spot Speed (mph)</th><th>Effectiveness in Speed Reduction</th><th>Posted Speed Limit (mph)</th><th>Work Zone Type</th></tr>
<tr><td colspan="3">Continuous right-turn lane:</td><td rowspan="9">45</td><td rowspan="9">Lane closure (work on shoulder)*</td></tr>
<tr><td>Baseline (no device)</td><td>43</td><td></td></tr>
<tr><td>AWAD</td><td>34</td><td>21%</td></tr>
<tr><td>AWAD + LE</td><td>38</td><td>12%</td></tr>
<tr><td colspan="3">Inner lanes (all 3 through lanes):</td></tr>
<tr><td>Baseline (no device)</td><td>48</td><td></td></tr>
<tr><td>AWAD</td><td>45</td><td>6%</td></tr>
<tr><td>AWAD + LE</td><td>41</td><td>15%</td></tr>
</table>

* Equivalent WZ type
AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

*4.6.3 **Qualitative Analysis***

4.6.3.1 Driving Behavior

During construction on NB US-19, video review for driving behavior indicates that smooth transition increased from 32% in the baseline scenario to 41% for the AWAD scenario and 47% for AWAD + LE. The trend for risky transition decreased from 15% in the baseline scenario to 12% in AWAD and 10% for AWAD + LE. Figure 97 presents the qualitative analysis translated from rating of video observers to understand the changes in smooth, rough, and risky transition for the baseline, AWAD, and AWAD + LE scenarios at the US-19 construction site.

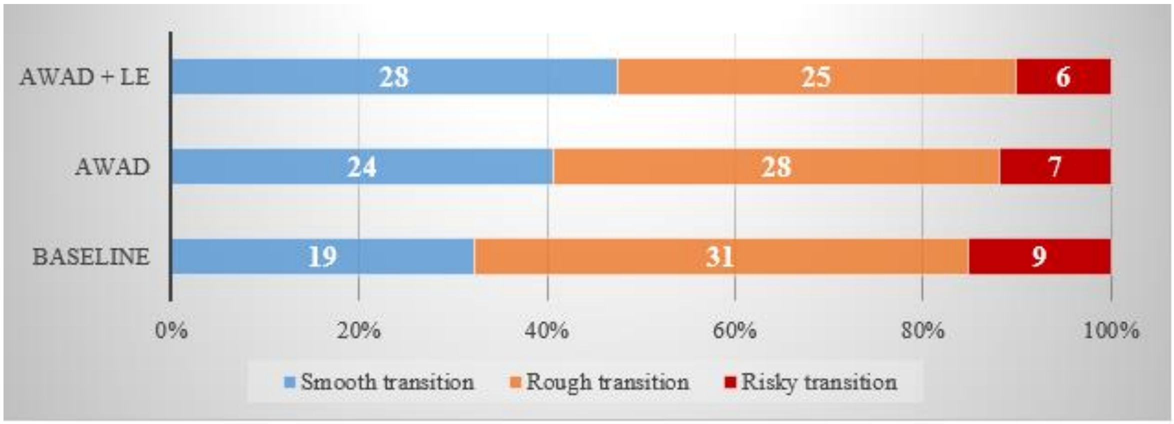


Figure 97. Driving Behavior on US-19 (NB)

4.6.4 Summary Results

The US-19 WZ site is 6-lane divided urban arterial highway a continuous right-turn lane in each direction with resurfacing and widening of the sidewalk at Dipaola Dr and Beach Blvd. As noted, right-turn lane closure was targeted with SWZ applications, with speed observations on the NB direction. These speed observations were taken upstream of the lane closure and prior to an intersection. These applications suggested that driving behavior in terms of speed reduction while approaching the WZ site had significant safety implications. The results of speed reductions and driving behavior improvements are summarized below.

Table 52 presents the effectiveness of the SWZ applications at the US-19 construction site, where AWAD and AWAD + LE showed significant speed reductions compared to the baseline. At the upstream of Dipaola Dr and Beach Blvd, the effectiveness of AWAD and AWAD + LE in speed reduction was 21% and 12%, respectively, for the right-turn lane. Similarly, the effectiveness of AWAD and AWAD + LE was 6% and 15% (reduction), respectively, for the inner through lanes.

Table 52. Comparison of Effectiveness of Test Scenarios at Upstream on US-19 (NB)

	Baseline (No Device) (mph)	AWAD (mph)	AWAD + LE (mph)	Lane Configuration
Upstream	43	34	38	Right-turn lane
Effectiveness in speed reduction		21%	12%	
Upstream	48	45	41	Inner through lanes
Effectiveness in speed reduction		6%	15%	

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenarios and baseline speed, the hypothesis test noted in Eq. 2 was conducted and indicates the null hypothesis with no differences in speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggest that the null hypothesis was rejected at a 95% confidence level for both scenarios for AWAD and for AWAD + LE, as the computed Z-statistics (Eq. 3) suggest that they are above the critical Z-score for the scenario of AWAD and AWAD + LE. This indicates that the speed in the AWAD and AWAD + LE scenarios was statistically and significantly different from the baseline speed. Table 53 presents the statistical test results on the differences between the baseline and test scenarios.

Table 53. Statistical Tests on Test Scenarios at Upstream on US-19 (NB)

Scenario Comparison		**Z-statistics (Critical Z-score = 1.96)**	**Statistical Significance**
Baseline	***Scenarios***		
No device	AWAD	10.1	Significant
	AWAD + LE	10.5	Significant

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number

The result of driving behavior in terms of qualitative rating scale for smooth, rough, and risky transition suggested that drivers transitioned smoothly with both AWAD and AWAD + LE scenarios at this site.

4.7 Site 5: SR-597

4.7.1 ***Construction Project***

SR-597 (Dale Mabry Hwy) is a 4-lane divided arterial with a 57-ft vegetated median in urban areas with a posted speed limit of 55. The section near Sunlake Blvd was widened at the sidewalk and resurfaced by FDOT. At this construction site, resurfacing was performed on the right shoulder, and widening was performed on the sidewalk. The speed limit near Sunlake Blvd remained unchanged during the construction.

Considering SWZ applications at other sites, the research team introduced the iCone message display system for drivers in their road navigation system (such as the WAZE app) to be notified about a “Work Ahead” message. As such, instead of LE combined with other applications, the research team deployed AWAD + Arrow Board Device combined with an iCone device to evaluate their effectiveness in speed reduction.

4.7.2 ***Quantitative Analysis***

4.7.2.1 Right Lane Closure on SR-597 (SB)

Spot speeds for different test scenarios with respect to the baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ, even with right through lane closed. These spot speed readings were taken by a sensor (Sensor 1 at upstream) at the approach to the WZ area, where the expected change of driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 54. On

SR-597 (SB) near Sunlake Blvd, the work was primarily on the right shoulder area; to achieve the work, the right through lane was closed, with a posted speed limit of 55 mph.

Table 54. Effectiveness of Test Scenarios at Upstream on SR-597 (SB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Right through lane:			55	Lane closure
Baseline (no device)	51			
AWAD	49.2	4%		
AWAD + iCone	49.2	4%		
Arrow board + iCone	50.6	1%		
Inner lane:				
Baseline (No device)	51.2			
AWAD	48.4	5%		
AWAD + iCone	48.6	5%		
Arrow board + iCone	51.2	0%		

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

At this site, with the closure of the right through lane, the effectiveness in vehicle speed reduction was AWAD 4%, AWAD + iCone device 4%, and Arrow Board + iCone device 1% from the baseline speed of 51 mph. For the inner lane, the effectiveness of AWAD and AWAD + iCone device in vehicle speed reduction was 5% and 5%, respectively.

*4.7.3 **Qualitative Analysis***

4.7.3.1 *Driving Behavior*

During construction on SB SR-597 (Dale Mabry Hwy), video review for driving behavior indicates that smooth transition increased from 30% in the baseline scenario to 45% in the AWAD scenario. The trend for risky transition decreased from 32% in the baseline scenario to 19% for AWAD. Figure 98 presents the qualitative analysis translated from ratings by video observers to understand the changes in smooth, rough, and risky transition for the baseline and AWAD scenarios at the Dale Mabry Hwy construction site.

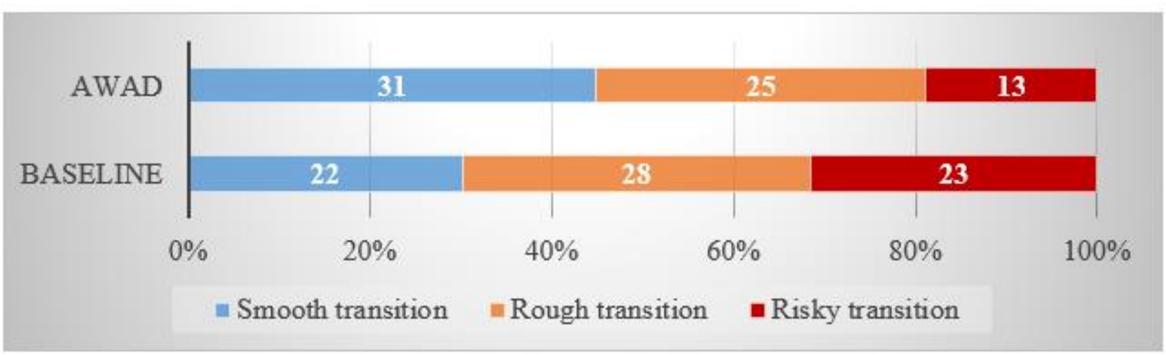


Figure 98. Driving Behavior on SR-597 (SB)

4.7.4 Summary Results

The SR-597 WZ site is 4-lane divided urban arterial highway with resurfacing and widening of the sidewalk at Sunlake Blvd. As noted, right-through lane closure was targeted with SWZ applications with speed observations in the SB direction. These applications suggest that driving behavior in terms of speed reduction while approaching the WZ had significant safety implications. The results of speed reductions (quantitative) and driving behavior (qualitative) are summarized below.

Table 55 presents the effectiveness of these SWZ applications at the SR-597 construction site, where AWAD, AWAD + iCone, and Arrow Board + iCone showed significant speed reductions compared to the baseline. At the upstream of Sunlake Blvd, the effectiveness was AWAD 4%, AWAD + iCone 4%, and Arrow Board + iCone 1% in speed reduction for the right through lane. Similarly, the effectiveness was AWAD 5%, AWAD + iCone 5%, and Arrow Board + iCone 5%, and no reduction for the left through lane.

Table 55. Comparison of Effectiveness of Test Scenarios at Upstream on SR-597 (SB)

	Baseline (No Device) (mph)	AWAD (mph)	AWAD + iCone (mph)	Arrow Board + iCone (mph)	Lane Configuration
Upstream	51	48.4	49.2	50.6	Right through lane
Effectiveness in speed reduction		4%	4%	1%	
Upstream	51.2	49.2	48.6	51.2	Left through lane
Effectiveness in speed reduction		5%	5%	0%	

AWAD = Active Work Zone Awareness Device; iCone = iCone Message on WAZE app; computed values rounded to higher number.

To assess the statistical significance between the test scenario and baseline speeds, the hypothesis noted in Eq. 2 was tested. This hypothesis testing indicates the null hypothesis with no difference in speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggested that the null hypothesis was rejected at a 95% confidence level for AWAD and AWAD + iCone as the computed Z-statistics (Eq. 3) suggested that they are above the critical Z-score for AWAD and AWAD + iCone. However, the computed Z-statistics (Eq. 3) suggest that it is below the critical Z-score for the scenario Arrow Board + iCone. This indicates that the speeds in the AWAD and AWAD + iCone scenarios were statistically and significantly different from the baseline speed. However, this is not true for the Arrow Board + iCone scenario, indicating acceptance of the null hypothesis. Table 56 presents the statistical test results on the differences between the baseline and test scenarios.

Table 56. Statistical Tests on Test Scenarios at Upstream on SR-597 (SB)

Scenario Comparison		Z-statistics (Critical Z-score = 1.96)	Statistical Significance
Baseline	***Scenarios***		
No device	AWAD	10.4	Significant
	AWAD + iCone	6.3	Significant
	Arrow Board + iCone	1.0	Insignificant

AWAD = Active Work Zone Awareness Device; iCone = iCone Message on WAZE app; computed values are rounded to higher figure.

The result of driving behavior in terms of qualitative rating scale for smooth, rough, and risky transition suggests that drivers transitioned smoothly with both AWAD and AWAD + LE scenarios at this site.

4.8 Site 6: US-301

*4.8.1 **Construction Project***

US-301 is a 6-lane divided principal arterial in urban areas, with a posted speed limit of 50 mph. The section near Wes Kearney Way and Windermere Lake Dr on US-301 was improved at the median by FDOT, and the speed limit near Wes Kearney Way was reduced to 45 mph in both directions during construction. As the main work was for median improvement, it was operationally safe to close the lane adjacent to the median.

Considering different SWZ applications, the research team deployed AWAD, arrow board, iCone device, and LE in different combinations to evaluate the effectiveness of speed reduction at the upstream of the lane closure at US-301 site.

*4.8.2 **Quantitative Analysis***

4.8.2.1 Lane Closure on US-301 (NB)

Spot speeds for different test scenarios with respect to the baseline (no device) indicate that there were reductions of spot speeds due to awareness of drivers traveling through the WZ, even with left-most lane (adjacent to the median) closed. These spot speed readings were taken by a sensor (Sensor 1 at upstream) at the approach to the WZ, where the expected change in driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 57.

On US-301 (NB) near the Wes Kearney Way, the work was primarily on median improvement; the left-most lane (adjacent to the median) was closed, with a posted speed limit of 45 mph.

Table 57. Effectiveness of Test Scenarios at Upstream on US-301 (NB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness in Speed Reduction	Posted Speed Limit (mph)	Work Zone Type
Left-most lane:			45	Lane closure (Work on median)*
Baseline (no device)	32.5			
AWAD	32.1	1%		
AWAD + iCone	31.7	2%		
Arrow board + iCone	32.4	0.3% (<1%)		
AWAD + LE	29.2	10%		
AWAD + iCone + LE	28.8	11%		
Arrow board + iCone + LE	29.2	10%		
Outer lanes (middle and right-most lanes):				
Baseline (no device)	35			
AWAD	33.6	4%		
AWAD + iCone	33.4	5%		
Arrow board + iCone	33.9	3%		
AWAD + LE	31.6	10%		
AWAD + iCone + LE	30.8	12%		
Arrow board + iCone + LE	30.6	13%		

* Equivalent WZ type
AWAD = Active Work Zone Awareness Device; iCone = iCone Message on WAZE app; computed values are rounded to higher number.

At this site, with closure of the left-most lane, the effectiveness was AWAD 1%, AWAD + iCone 2%, Arrow Board + iCone <1%, AWAD + LE 10%, AWAD + iCone + LE 12%, and Arrow Board + iCone + LE 13% in speed reduction from the baseline speed of 32.5 mph. For the outer lanes (middle and right-most lane combined), the effectiveness in speed reduction was 4%, 5%, 3%, 10%, 12%, and 13%, respectively.

As the iCone device is in its initial stage of development on arterial roadways, the exact percentage of driver use of WAZE while traveling through the lane closure section at the US-301 site was not assessed or referenced. The combination of the iCone device with other SWZ was not found statistically significant except in combination with LE.

*4.8.3 **Qualitative Analysis***

4.8.3.1 Driving Behavior

During construction on NB US-301, video review for driving behavior indicates that smooth transition increased from 18% in the baseline scenario to 38% for AWAD and 43% for AWAD + LE. The trend for risky transition decreased from 26% in the baseline scenario to 7% for AWAD and 13% for AWAD + LE. Figure 99 presents the qualitative analysis translated from rating by video observers to understand the changes in smooth, rough, and risky transition for the baseline, AWAD, and AWAD + LE scenarios at the US-301 construction site.

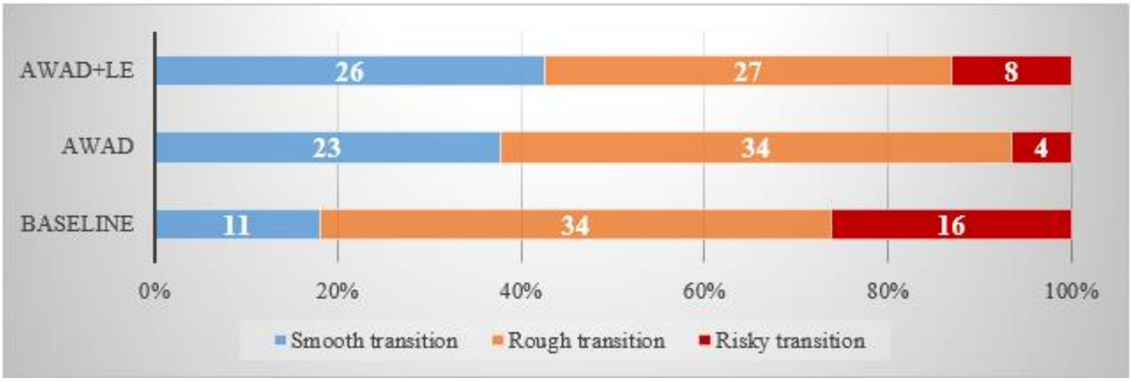


Figure 99. Driving Behavior on US-301 (NB)

4.8.4 Summary Results

The US-301 WZ site is 6-lane divided urban arterial highway with median improvement work at Wes Kearney Way and Windermere Lake Dr. As noted, closure of the left lane (adjacent to the median) was targeted with SWZ applications for speed observations on NB direction. Due to the presence of an intersection prior to the section of the Wes Kearney Way Lane closure, drivers lowered their speed with an expectation to merge with the left through lane at the intersection. These applications suggest that driving behavior in terms of speed reduction while approaching the WZ had significant safety implications. The results of speed reductions and driving behavior improvements are summarized below.

Table 58 presents the effectiveness of the SWZ applications at the US-301 construction site, where AWAD + LE, AWAD + iCone + LE, and arrow board + iCone + LE showed significant speed reductions compared to the baseline. At the upstream of US-301, the effectiveness was AWAD + LE 10%, AWAD + iCone + LE 12%, and arrow board + iCone + LE 10% for the left-most lane in speed reduction. Similarly, the effectiveness was AWAD + LE 10%, AWAD + iCone + LE 12%, and Arrow Board + iCone + LE 13% in speed reduction for the outer lanes.

Table 58. Comparison of Effectiveness of Test Scenarios at Upstream on US-301 (NB)

	Baseline (No Device) (mph)	AWAD + LE (mph)	AWAD + iCone + LE (mph)	Arrow Board + iCone + LE (mph)	Lane Configuration
Upstream	32.5	29.2	28.8	29.2	Left-most lane
Effectiveness in speed reduction		10%	11%	10%	
Upstream	35	31.6	30.8	30.6	Outer lanes
Effectiveness in speed reduction		10%	12%	13%	

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenarios and baseline speed, the hypothesis noted in Eq. 2 was tested. This hypothesis testing indicates the null hypothesis with no difference on speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggested that the null hypothesis was rejected at a 95% confidence level for

AWAD + LE, AWAD + iCone + LE, and arrow board + iCone + LE, as the computed Z-statistics (Eq. 3) suggest that they are above the critical Z-score for these scenarios. This concludes that the speed for AWAD + LE, AWAD + iCone + LE, and arrow board + iCone + LE was statistically and significantly different from the baseline speed. Table 59 presents the statistical test results on the differences between the baseline and test scenarios.

Table 59. Statistical Tests on Test Scenarios at Upstream on US-301 (NB)

Scenario Comparison		Z-statistics (Critical Z-score = 1.96)	Statistical Significance
Baseline	***Scenarios***		
No device	AWAD + LE	9.6	Significant
	AWAD + iCone LE	11.6	Significant
	Arrow Board + iCone + LE	12.6	Significant

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

The result of driving behavior in terms of the qualitative rating scale for smooth, rough, and risky transition suggested that drivers transitioned smoothly with AWAD but to a lesser extent for both AWAD and AWAD + LE scenarios at this site.

4.9 Site 7: SR-589 Off Ramp

4.9.1 Construction Project

SR-589 is a 2-lane off ramp from Memorial Highway (Veterans Expressway) to Independence Parkway in urban areas, with a posted speed limit of 25 mph. The section of off-ramp was improved with high friction surface by FDOT. As the main work was at the outer lane (right lane of travel direction), it was operationally safe to close the lane adjacent to the shoulder.

Considering different SWZ applications, the research team deployed AWAD and LE in different combinations to evaluate the effectiveness on speed reduction at the downstream of the lane closure at SR-589 site, so this study site was treated as work on shoulder WZ type.

4.9.2 Quantitative Analysis

4.9.2.1 Lane Closure on SR-589 (NB)

Spot speeds for different test scenarios with respect to the baseline (no device) indicates that there were reductions of spot speeds due to awareness of drivers traveling through the WZ, even with the right lane (adjacent to the right shoulder) closed. These spot speed readings were taken by a sensor (Sensor 1 at upstream) at the approach to the WZ, where the expected change in driving behavior in the form of reduction of spot speed was observed and computed, as presented in Table 60. On SR-589 (NB) from Memorial Highway to the Independence Parkway, the work was primarily on right lane; the right lane (adjacent to the right shoulder) was closed, with a posted speed limit of 25 mph.

At this site, with closure of the right lane, the effectiveness was AWAD 8%, and AWAD + LE 9% in speed reduction from the baseline speed of 43.8 mph.

Table 60. Effectiveness of Test Scenarios at Upstream on SR-589 (NB)

Test Scenarios	Avg. Spot Speed (mph)	Effectiveness (%)	Posted Speed Limit (mph)	Work Zone Type
Baseline (No device)	43.8		25	Lane Closure
AWAD	40.3	8		
AWAD + LE	39.8	9		

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

4.9.3 *Qualitative Analysis*

4.9.3.1 *Driving Behavior*

During construction on NB SR-589, video review for driving behavior indicates that smooth transition increased from 21% in the baseline scenario to 39% for AWAD and 40% for AWAD + LE. The trend for risky transition decreased from 61% in the baseline scenario to 22% for AWAD and 16% for AWAD + LE. Figure 100 presents the qualitative analysis translated from rating by video observers to understand the changes in smooth, rough, and risky transition for the baseline, AWAD, and AWAD + LE scenarios at the SR-589 construction site.

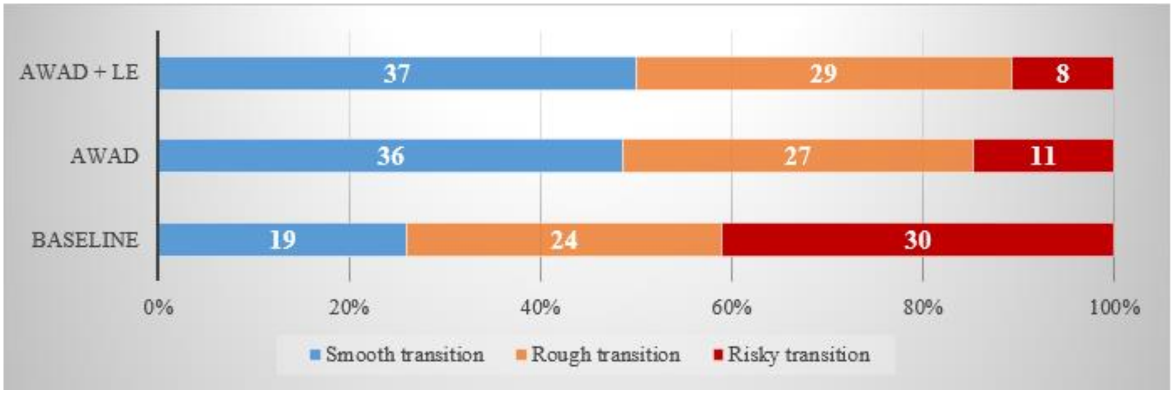


Figure 100. Driving Behavior on SR-589 (NB)

4.9.4 *Summary Results*

The SR-589 WZ site is 2-lane off ramp in the north direction from Memorial Highway to Independence Parkway with high friction surface installation work. As noted, closure of the right lane (adjacent to the right shoulder) was targeted with SWZ applications for speed observations on NB direction. Even the speed limit was 25 mph for this off-ramp, drivers kept the initial speed until they are close to the curved off-ramp area. However, the speed readings were taken upstream on the curved area to reduce any noise of driver speed reduction. These applications suggest that driving behavior in terms of speed reduction while approaching the WZ had significant safety implications. The results of speed reductions and driving behavior improvements are summarized below.

Table 61 presents the effectiveness of the SWZ applications at the SR-589 construction site, where AWAD and AWAD + LE showed significant speed reductions compared to the baseline. At the upstream of Memorial Highway, the effectiveness was AWAD 8 % and AWAD + LE 9%, for the left lane in speed reduction.

Table 61. Comparison of Effectiveness of Test Scenarios at Upstream on SR-589 (NB)

	Baseline (No Device) (mph)	AWAD (mph)	AWAD + LE (mph)	Lane Configuration
Upstream	43.8	40.3	39.8	Left lane
Effectiveness in speed reduction		8%	9%	

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

To assess the statistical significance between the test scenarios and baseline speed, the hypothesis noted in Eq. 2 was tested. This hypothesis testing indicates the null hypothesis with no difference on speed between the baseline and test scenarios. The Z-statistics (computed following Eq. 3) suggested that the null hypothesis was rejected at a 95% confidence level for AWAD and AWAD + LE, as the computed Z-statistics (Eq. 3) suggest that they are above the critical Z-score for these scenarios. This concludes that the speed for AWAD and AWAD + LE was statistically and significantly different from the baseline speed. However, the speed difference between AWAD and AWAD + LE is not statistically significantly different. Table 62 presents the statistical test results on the differences between the baseline and test scenarios.

Table 62. Statistical Tests on Test Scenarios at Upstream on SR-589 (NB)

Scenario Comparison		Z-statistics (Critical Z-score = 1.96)	Statistical Significance
Baseline	***Scenarios***		
No device	AWAD	14.0	Significant
	AWAD + LE	16.5	Significant
AWAD	AWAD + LE	1.6	Insignificant

AWAD = Active Work Zone Awareness Device; LE = Law Enforcement; computed values rounded to higher number.

The result of driving behavior in terms of the qualitative rating scale for smooth, rough, and risky transition suggested that drivers transitioned smoothly with AWAD and at similar extent with AWAD + LE at this site.

4.10 Summary of Analysis Results

The CUTR research team, with support from FDOT District 7 on data collection efforts, performed data analysis for this pilot study of SWZ applications on arterials, including AWAD and iCone along with LE and their combinations. The research team conducted detailed data analysis at seven sites with different WZ types, traffic conditions, and geometric attributes and one site (SR-580) with WZ safety educational campaign.

Quantitative data analysis was performed based on speed sensors to collect vehicle spot speeds, vehicle classification, and traffic count by lane. Qualitative data analysis was performed based on video recording observations with GoPro cameras. The research team analyzed hundred hours of speed data and reviewed selected video data on driving behaviors approaching WZs. These data were processed for quantitative analysis (speed data) and qualitative analysis (video data). Table 63 presents a summary of this study showing WZ type for the studied sites, facility types, speed limits for regular traffic flow (non-WZ), and WZ condition. Effectiveness in speed reduction and increase of safe behaviors were statistically significant and shows promising direction for using AWAD application or combined AWAD and LE applications for all three types of WZ studied here.

Table 63. Study Summary for Work Zone Type of Effectiveness of Test Scenarios

Site	**Studied Work Zone Type**	**Posted Speed Limit (mph)**		**Facility Type**	**Effectiveness for Test Scenarios (% Reduction of Travel Speed)**		**Behavioral Observation**
		Non-work Zone	***Work Zone***		***AWAD***	***AWAD + LE***	**Incremental Lane Change / Declaration**
US-98	Lane shift/ work on shoulder/ median	45	25	2-lane undivided roadway	5%–16%	33%–43%	Smooth slow-down / transition using AWAD + LE
SR-580	Lane closure	40	40	6-lane divided roadway	5%–19%	*	
US-92	Lane closure	45	45	6-lane divided roadway	2%	7%–9%	
US-19	Work on shoulder	45	45	6-lane divided roadway	6%–21%	12%–15%	
SR-597	Lane Closure	55	55	4-lane divided roadway	4%	–	Smooth transition using AWAD
US-301	Work on median	50	45	6-lane divided roadway	1%	10%	
SR-589	Lane Closure	25	25	2-lane off ramp	8%	9%	

* Insignificant effectiveness in speed reduction (as explained in SR-580 site data analysis).

5. Research Findings, Conclusions, and Recommendations

5.1 Research Findings, Successes, and Lessons Learned

This pilot study on SWZ applications in FDOT District 7 provided valuable research findings, successes, and lesson learned, as highlighted below. Based on these research findings, the research team identified the effectiveness of deployment of AWAD in reducing vehicle speeds approaching arterial WZs, increasing safe driving behaviors, and decreasing risky driving behaviors. Combining AWAD deployment and LE presence at an arterial WZ can achieve a further improvement of WZ and worker safety. It is recommended to standardize AWAD deployment and include AWAD in FDOT WZ MOT design so designers, contractors, PMs, and administrators can routinely use it on arterial and freeway WZs to improve safety and protection of WZ workers.

*5.1.1 **Major Findings***

- Innovative SWZ applications and strategies identified for arterials to improve or enhance WZ safety include AWAD and iCone applications with combination with LE.
- Under low or moderate traffic conditions, the deployment of AWAD or combined AWAD and LE applications are effective in reducing vehicle speeds and increasing safe driving behaviors for various WZ scenarios considering different WZ types, posted speed limits, number of lanes, and urban/rural areas.
- Under heavy traffic or traffic congestion, the deployment of AWAD does not impact vehicle speeds.
- Lane closure was found to be most common WZ scenario among all three WZ types in this pilot study, including work on shoulder or median and lane shift. For some WZ activities on a turn lane, its adjacent through lane was closed to ensure the safety for WZ workers.
- Deployment of AWAD applications in this pilot study can reduce vehicle speeds approaching a WZ up to 21%, with an average reduction of 10%; the deployment of combined AWAD and LE applications can reduce vehicle speeds approaching a WZ up to 43%, with an average reduction of 19%.
- When a posted speed limit in a WZ is much lower than in a non-WZ, deployment of AWAD or combined AWAD and LE applications is effective to reduce vehicle speeds.
- When there is no change in posted speed limit in a WZ area, reduction of vehicle speeds via deployments of AWAD is less than that with a lower posted speed limit at a WZ.
- Deploying an AWAD application alone generally can reduce vehicle speeds considerably and increase safe driving behaviors. The capability of AWAD deployment to reduce vehicle speeds will gradually decrease with time.

- Deploying combined AWAD and LE applications generally can further reduce vehicle speeds and increase safe driving behaviors than AWAD alone.
- When flag operations are implemented in a WZ and vehicle queues are backed up to the AWAD location, AWAD does not impact vehicle speeds.
- LE is always effective for speed management in WZs. With the presence of LE, the effectiveness of AWAD was observed as having a reduction in speed variance, which can be translated to smoothing the speed variation along the traffic steam nearby the work area
- The combination of LE and AWAD is superior, especially for WZs on rural roads with high posted speed limits and a high reduction of posted speed limits from regular segments to WZ areas.
- Deployment of iCone + AWAD or Arrow Board showed little impact on reduction of vehicle speeds due to the need for drivers to use WAZE navigation systems and click on the iCone WZ message. If a WZ message can be displayed and/or broadcasted automatically via WAZE and other navigation systems, it is anticipated to have an impact on reducing vehicle speeds approaching a WZ.
- Results from field observation show that safe driving behaviors such as smooth lane change or slow-down increased up to 109% for deployment of AWAD from the baseline, with an average increase of 44%. Safe driving behaviors increased up to 136% for deployment of combined AWAD and LE from the baseline, with an average increase of 67%.
- Results from field observation show that risky driving behaviors such as sudden lane change or deceleration decreased up to 75% for deployment of AWAD from the baseline, with an average decrease of 43%. Risky driving behaviors decreased up to 100% for deployment of combined AWAD and LE from the baseline, with an average decrease of 54%.
- The deployment of AWAD or a combination of AWAD and LE is effective in reducing vehicle speeds and risky behaviors entering an arterial work zone for all work zone types.
- Education campaigns via billboards with WZ safety messaging combined with WZ safety PSA radios broadcasted can achieve reduction of vehicle speeds by 4% to 11%.
- The percentage of WZ-related fatalities involving large trucks (commercial vehicles) was higher than that in non-WZ-related crashes in Florida with an average of 21%.
- The SWZ applications have more impacts on vehicle speed reduction in WZs on rural highways than those on urban or suburban arterials because slower speed limits are usually posted in rural, not in urban or suburban WZs.

- The SWZ applications have more impacts on vehicle speed reduction for a travel lane immediately adjacent to the WZ activity area than those for other lanes on urban or suburban arterials.
- It is important to collaborate with construction industries on their safety needs and concerns about WZs.

5.1.2 ***Successes***

- This pilot study covered three major types of WZs, successfully collected vehicle speeds, and captured driving behaviors under various scenarios at the upstream of work activity area at six selected study sites for detailed evaluation of SWZ applications and their combinations with LE implementation.
- Although there were many challenges to collect WZ data, including frequent changes in WZ schedules and duration, weather conditions, traffic conditions, availability of law enforcement, and need for close communication among all entities involved with WZ operations, the field data collection was successfully accomplished with the support of FDOT District 7 and diligent efforts by CUTR on planning, coordination, communication, and data collection.
- Deployment of AWAD applications and combinations of AWAD and LE were demonstrated via this research project on effectiveness to reduce vehicle speeds, increase safe driving behaviors, and decrease risky driving behaviors on arterial WZs.

5.1.3 ***Lessons Learned***

- The process for conducting a successful field data collection at WZs required intensive communication, coordination, and collaboration among all entities involved. It is likely to take a much longer time than expected for WZ field data collection because of many factors, including time needed to obtain final WZ MOT plans, frequent changes in WZ schedules and durations, weather conditions, traffic conditions, availability of LE, and the need for close communication with the FDOT PM, the WZ site manager and contractor field supervisor, and FDOT Tampa Traffic Operations for transporting AWAD trailers to the study sites.
- Due to many factors affecting WZ field data collection, a data collection plan should build in extra time, and data collection staff must be flexible to accommodate changes in WZ schedules and impacts from adverse weather conditions; alternative data collection plans should be in place to accommodate unexpected situations.
- It is promising that iCone products can improve WZ safety and mobility. However, at present, the benefit of using iCone devices connected to an arrow board or AWAD to communicate WZ conditions to drivers to reduce vehicle speeds and risky behaviors when they approach a WZ is not clear. It could be due to usage level of the WAZE app

by motorists and the requirement for drivers to click the WZ icon on the WAZE navigation system to see the WZ message.

5.2 Conclusions

- This research project demonstrates successful use of advanced technologies to improve safety in arterial roadway WZs, slowing down drivers and improving driver behavior.
- Deployment of AWADs alone can effectively reduce vehicle speeds approaching a WZ on arterials, increase safe driving behaviors, and reduce risky driving behaviors. Combining AWAD deployment and LE presence in an arterial WZ can achieve significant improvement of WZ and worker safety.
- Deployment of iCone + AWAD or Arrow Board showed little impact on reduction of vehicle speeds due to the need for drivers to use the WAZE navigation system and click on the iCone WZ message. If a WZ message can be displayed and/or broadcasted automatically via WAZE and other navigation systems, it is anticipated to have an impact on reducing vehicle speeds approaching a WZ.

5.3 Recommendations

- AWAD implementation should be standardized and included in FDOT WZ MOT design so designers, contractors, and PMs and administrators can routinely use it on arterial and freeway WZs to improve WZ safety and protection of WZ workers.
- AWADs should be implemented in WZs on arterials with low or moderate traffic conditions to reduce approach speed, increase safe driving behaviors, and reduce risky driving behaviors.
- Combined AWAD + LE at WZs should be implemented to achieve the maximum effectiveness in improving WZ safety, especially on rural roads with high posted speed limits.
- The capability of AWAD deployment to reduce vehicle speeds will gradually decrease with time. If LE cannot be always available to support AWAD deployment, an agency still can deploy LE periodically to help maintain the effectiveness of AWAD.
- LE vehicle should be placed just upstream of a WZ, not at a WZ activity area on arterials, to increase their visibility.
- AWAD application or combined AWAD and LE should be deployed for any work type, including work on shoulder or median, lane closure, and lane shift.
- To prevent an incident of trailer battery stolen during a field data collection, it is important to secure trailers during the data collection.
- Although this SWZ pilot deployment focused on WZs on arterials, the recommended implementations can be applied to WZs on freeways.

- Further study should be conducted on the effectiveness of iCone devices or similar devices connected to AWAD or arrow boards to reduce vehicle speeds and risky behaviors when the iCone WZ message can be automatically displayed or broadcasted by WAZE and other navigation systems.

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Appendix A – Historical Work Zone Crash Data in Florida, 2012–2019

Overall Statistics

Table A - 1. Work Zone Crashes in Florida by Work Zone Type, 2012–2019

Work Zone Type	2012	2013	2014	2015	2016	2017	2018	2019	Total
Lane Closure	1,293	1,619	1,897	2,271	2,147	2,139	1,903	1,547	14,816
Lane Shift	607	835	718	880	1,007	909	890	682	6,528
Work on Shoulder/ Median	2,561	3,310	3,436	3,949	4,680	4,550	4,589	3,743	30,818
Intermittent	334	453	439	456	501	543	510	493	3,729
Total:									55,891

Table A - 2. Work Zone Crashes in Florida by Work Zone Type and Functional Class of Roadway, 2012–2019

Work Zone Type	Interstate	Arterial	Collector	Local	Total*
Lane Closure	3,009	7,692	94	8	10,803
Lane Shift	1,292	3,114	12	4	4,422
Work on Shoulder or median	11,151	13,521	42	18	24,732
Intermittent	709	1,374	10	4	2,097
Total:					42,054

*Calculation based on available WZ crashes categorized by functional class of roadway.

Table A - 3. Work Zone Crashes in Florida by Work Zone Type and Injury Severity, 2012–2019

Work Zone Type	Severe	Minor	No Injury	Total*
Lane Closure	578	4,295	8,812	13,685
Lane Shift	222	1,700	3,610	5,532
Work on Shoulder or median	1,799	9,823	17,297	28,919
Intermittent	179	952	1,619	2750
Total:				50,886

*Calculation based on available WZ crashes categorized by injury severity.

Table A - 4. Work Zone Crashes in Florida by Work Zone Type and Time of Day, 2012–2019

Work Zone Type	12 am–6 am	6 am–9 am	9 am–12 pm	12 pm–2 pm	2 pm–4 pm	4 pm–6 pm	6 pm–9 pm	9 pm–12 am	Total*
Lane Closure	2,165	1,215	2,129	1,694	1,589	1,069	1,244	2,757	13,862
Lane Shift	601	720	876	686	762	636	684	613	5,578
Work on Shoulder or Median	2,433	5,366	4,737	3,554	3,940	3,921	3,304	1,938	29,193
Intermittent	324	430	445	368	405	299	278	232	2,781
Total:									51,414

*Calculation based on available WZ crashes categorized by time of day.

Table A - 5. Work Zone Crashes in Florida by Work Zone Type and Location within Work Zone, 2012–2019

Work Zone Type	Before First Warning Sign	Advance Warning Area	Transition Area	Activity Area	Termination Area	Total*
Lane Closure	1,109	1,832	3,633	6,936	352	13,862
Lane Shift	280	517	1,528	3,100	153	5,578
Work on Shoulder or Median	596	2,034	3,383	22,615	565	29,193
Intermittent	98	190	427	2,002	64	27,81
Total:						51,414

*Calculation based on available WZ crashes categorized by location within WZ.

Table A - 6. Work Zone Crashes in Florida by Contributing Circumstances: Road, 2012–2019

Work Zone Type	Lane Closure	Lane Shift	Work on Shoulder /Median	Intermittent
Unknown	50	23	79	11
Other	68	34	112	21
Non-highway Work	22	2	13	3
Traffic Control Device Inoperative	11	3	20	3
Debris	20	11	137	14
Obstruction in Roadway	50	21	164	12
Road Surface Conditions	160	168	1,251	121
Worn, Travel-polished Surface	1	4	10	2
Rut, Holes, Bump	12	10	39	5
Shoulder	3	3	35	5
Work Zone	4,730	1,963	4,625	687
None	8,735	3,336	22,707	1,897
Total	13,862	5,578	29,192	2,781
Total*:				51,413

*Calculation based on available WZ crashes categorized by contributing circumstances: road.

Table A - 7. Work Zone Crashes in Florida by Contributing Circumstances: Environment, 2012–2019

Work Zone Type	Unknown	Other	Animal	Glare	Physical Obstruction	Weather	None	Total*
Lane Closure	78	176	9	41	104	331	13,123	13,862
Lane Shift	34	78	6	14	47	289	5,109	5,577
Work on Shoulder/ Median	124	170	28	92	136	1,683	26,956	29,189
Intermittent	22	32	7	10	26	173	2,511	2,781
Total:								51,409

*Calculation based on available WZ crashes categorized by contributing circumstances: environment.

Work Zone Crash Analysis for Florida with Districts, 2011–2017

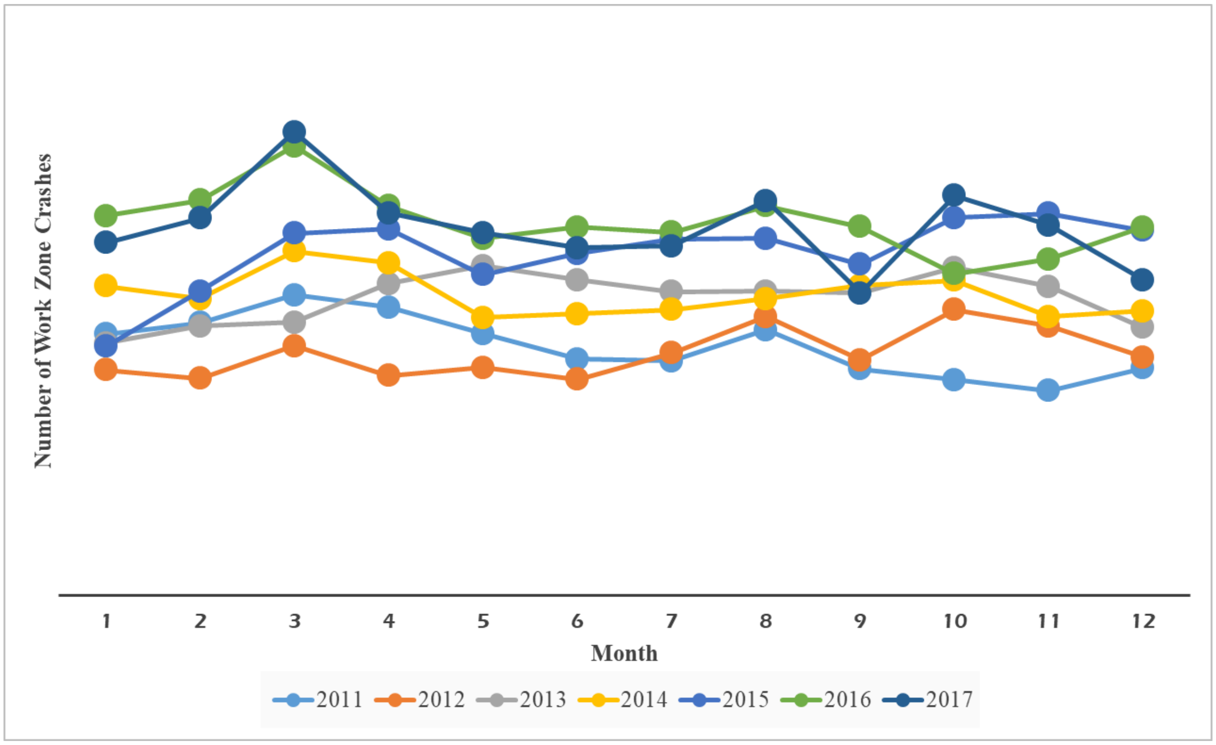

Figure A - 1. WZ Crashes by Month in Florida, 2011–2017

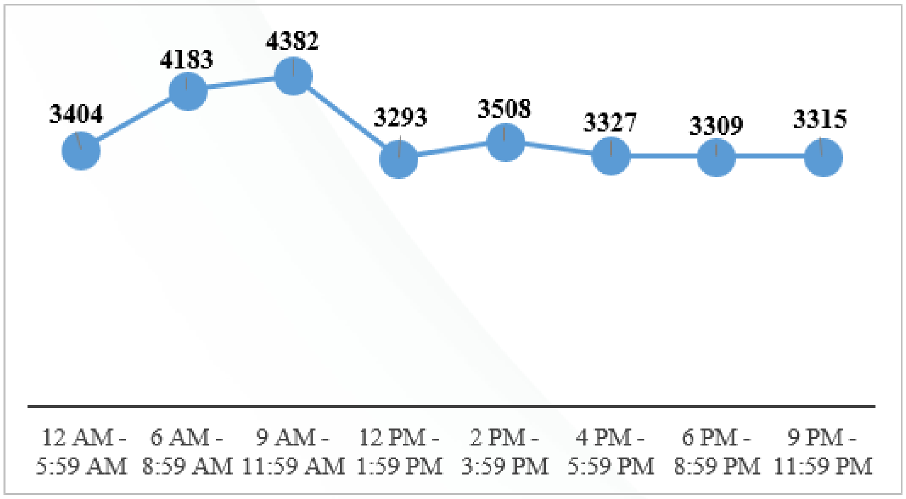

Figure A - 2. WZ Crashes by Time of Day in Urban Florida, 2011–2017

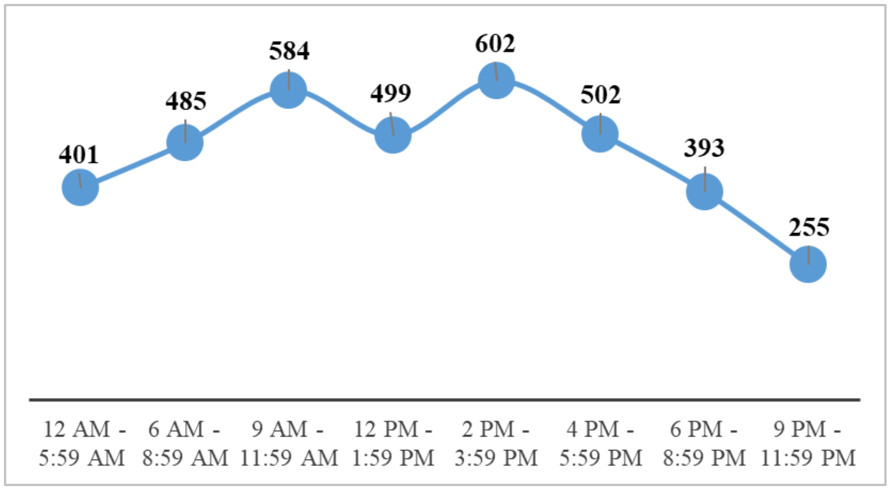

Figure A - 3. WZ Crashes by Time of Day in Rural Florida, 2011–2017

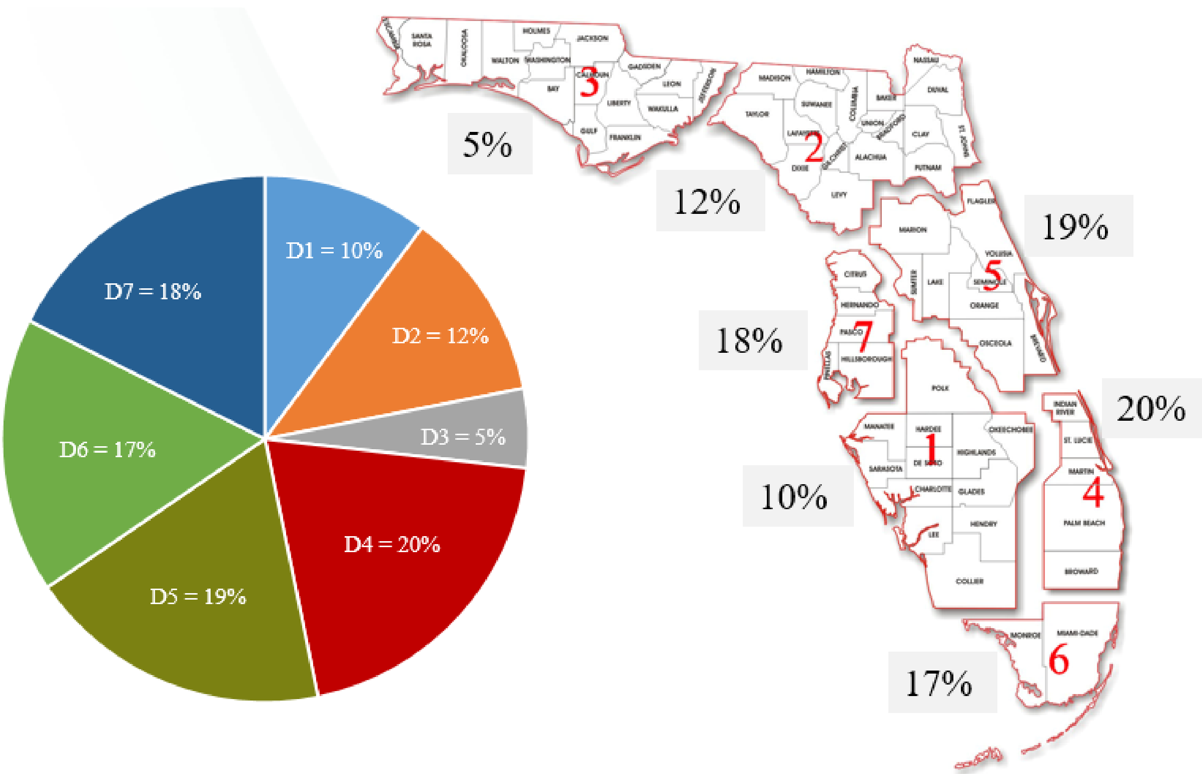

Figure A - 4. WZ Crash Distribution (%) in Florida Districts, 2011–2017

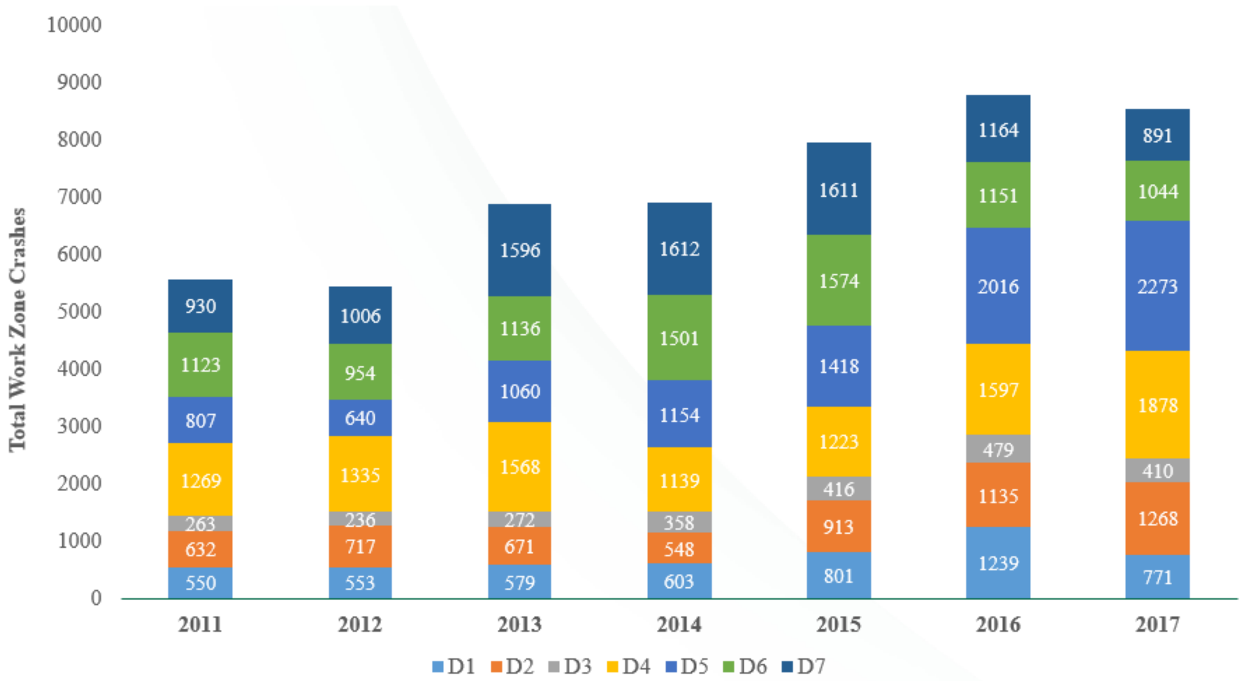

Figure A - 5. WZ Crashes by Florida District, 2011–2017

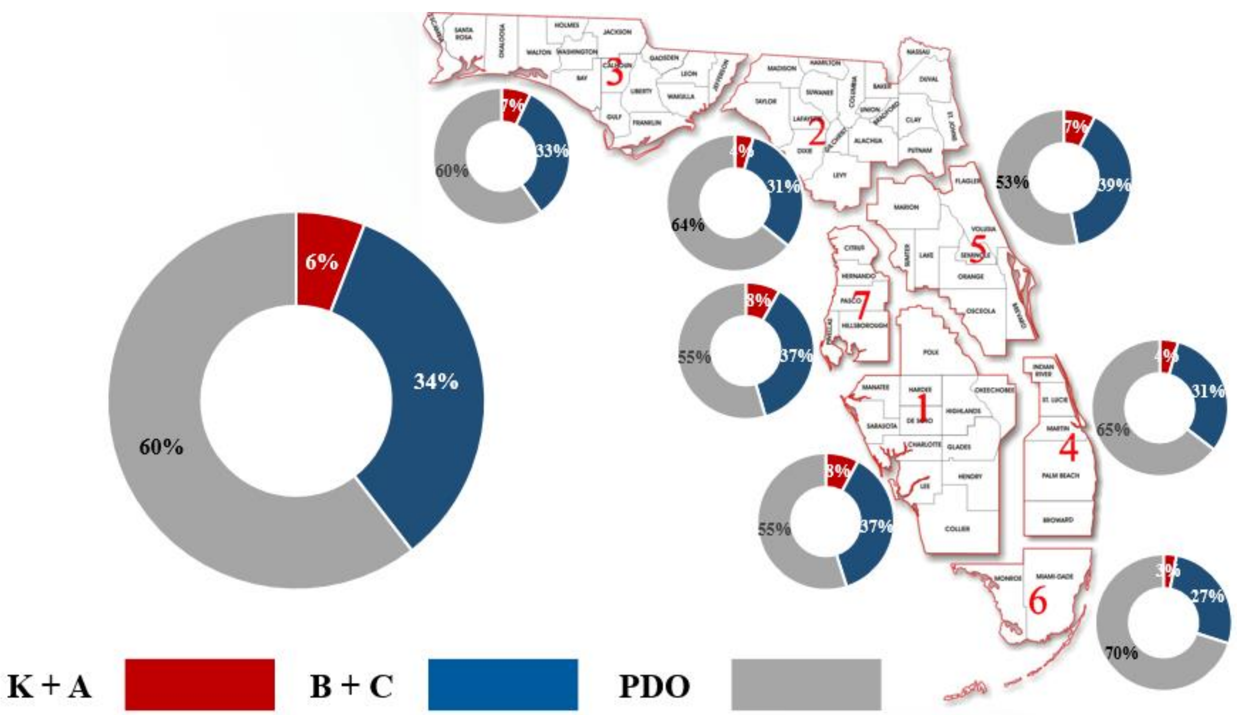

Figure A - 6. WZ Crash Severity by Florida District, 2011–2017

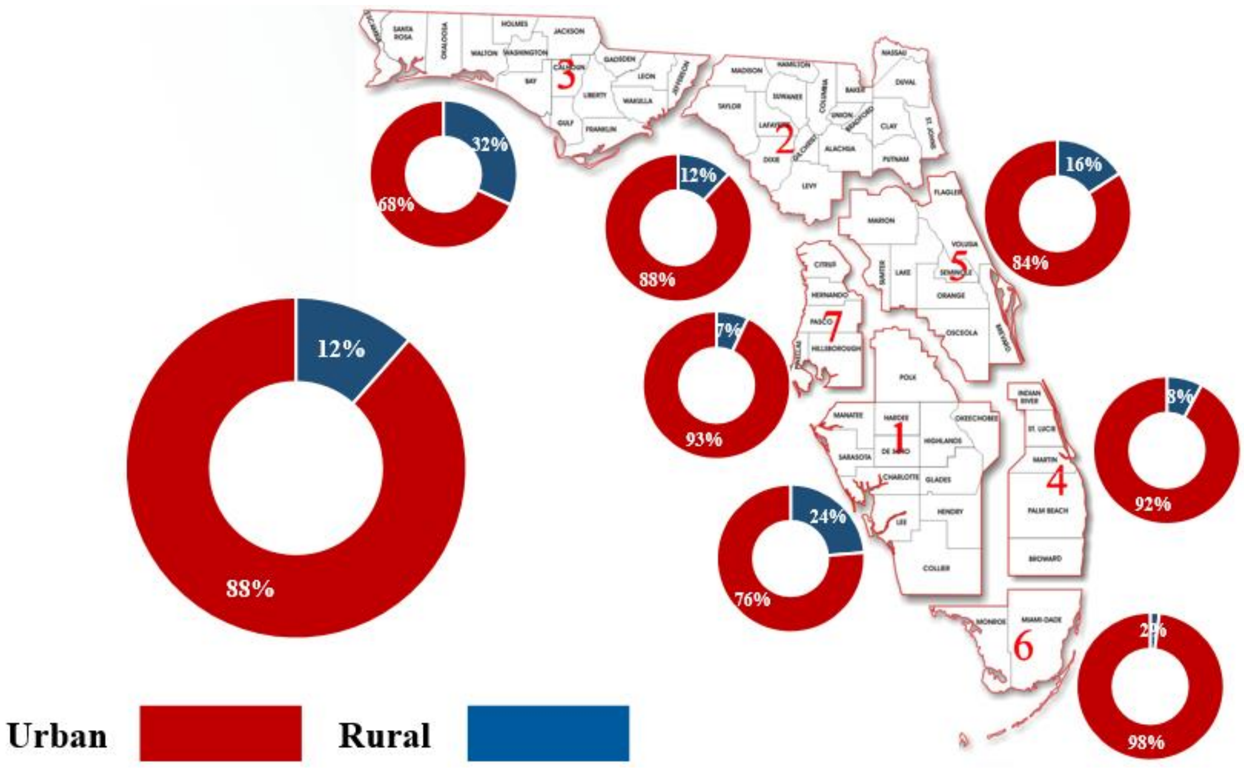

Figure A - 7. WZ Crashes by Land Use in Florida Districts, 2011–2017

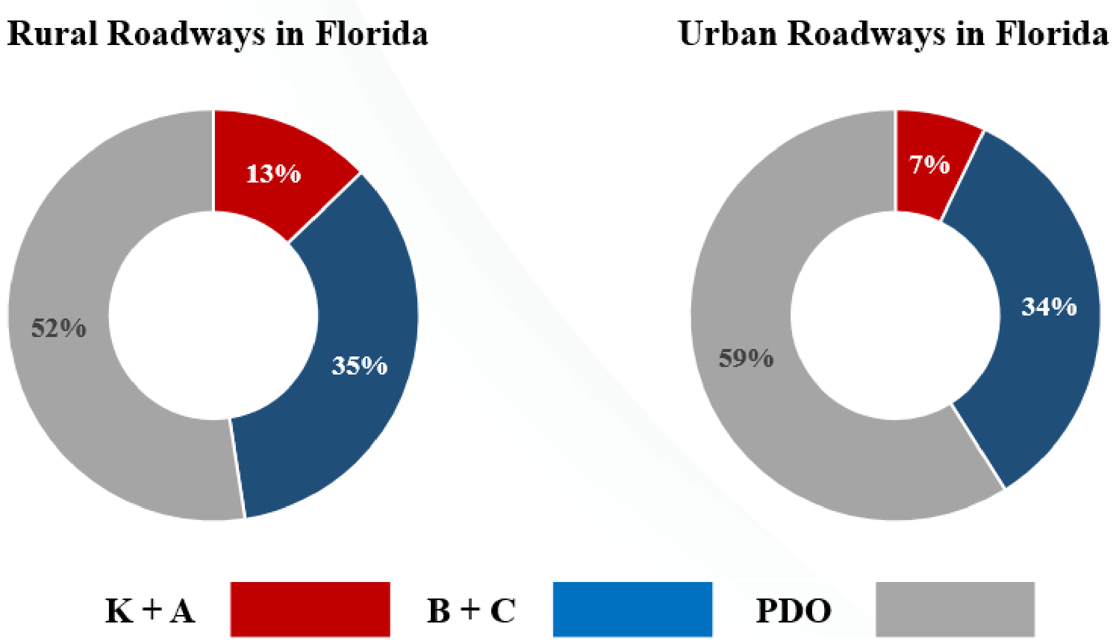

Figure A - 8. WZ Injury Severity by Land Use in Florida, 2011–2017

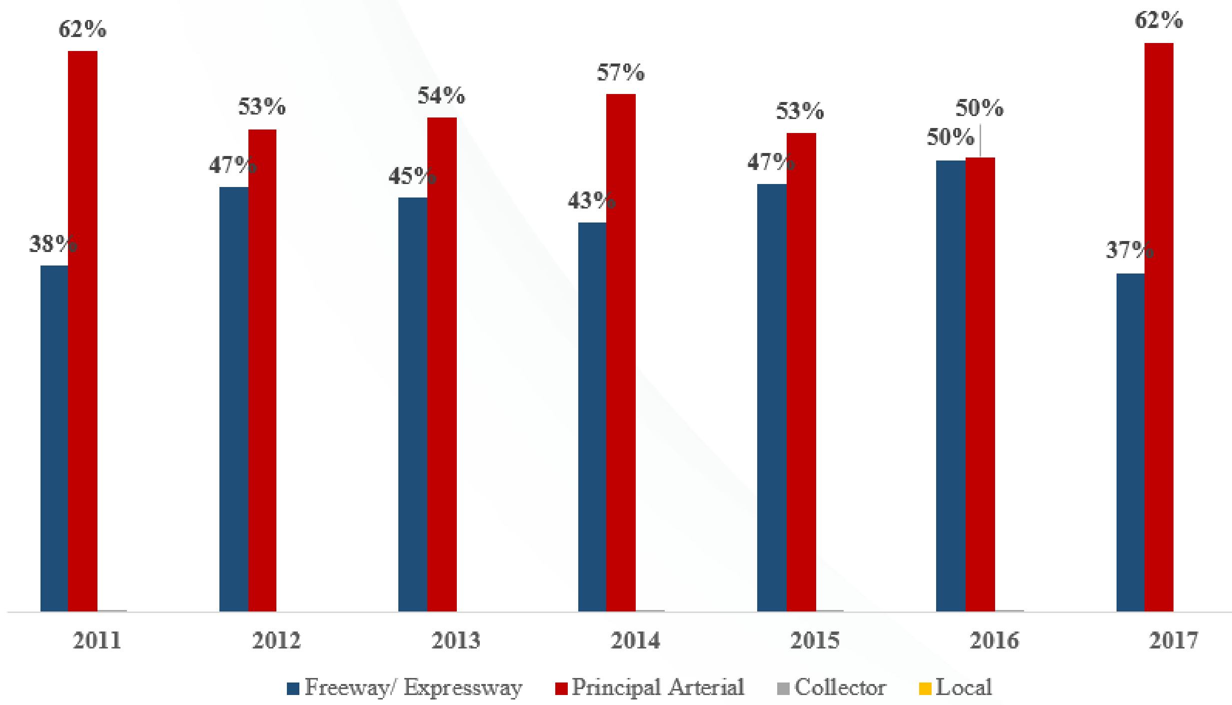

Figure A - 9. WZ Crashes by Florida Urban Roads, 2011–2017

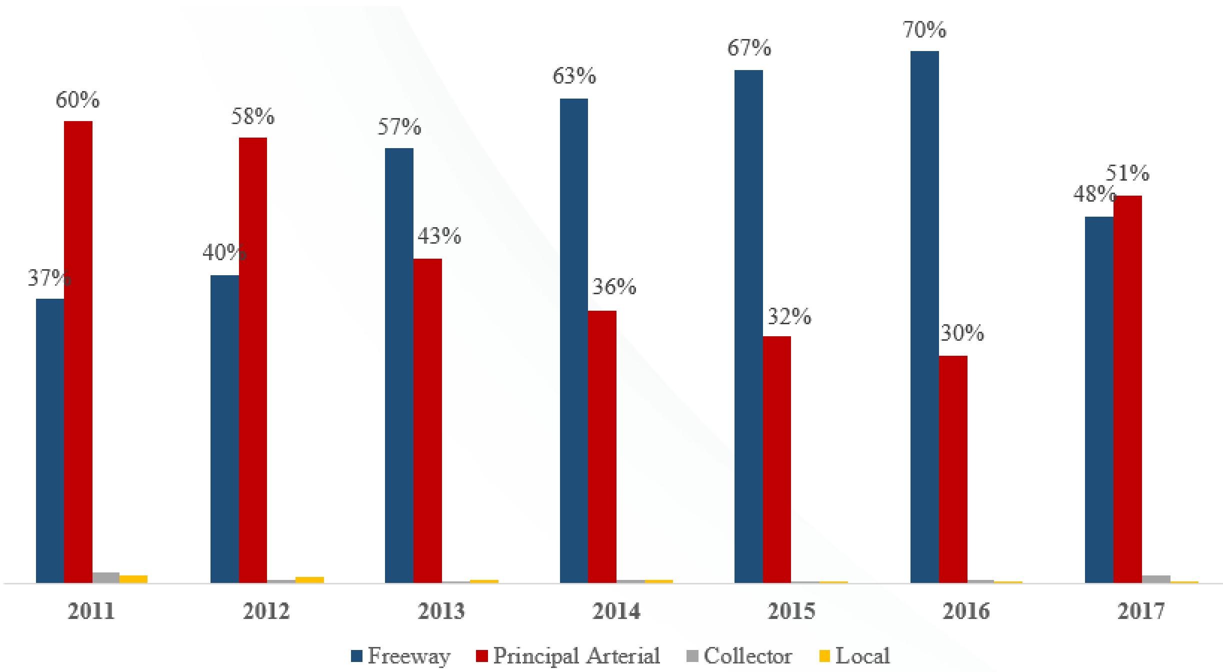

Figure A - 10. WZ Crashes by Florida Rural Roads, 2011–2017

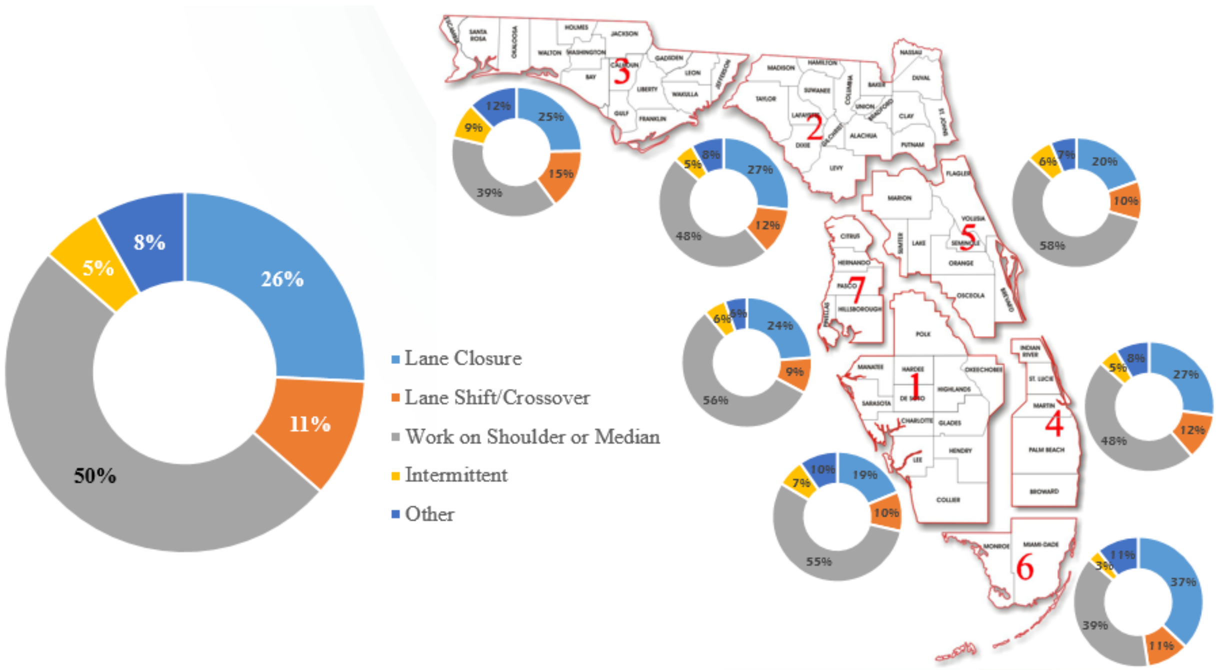

Figure A - 11. WZ Crashes by WZ Types in Florida Districts, 2011–2017

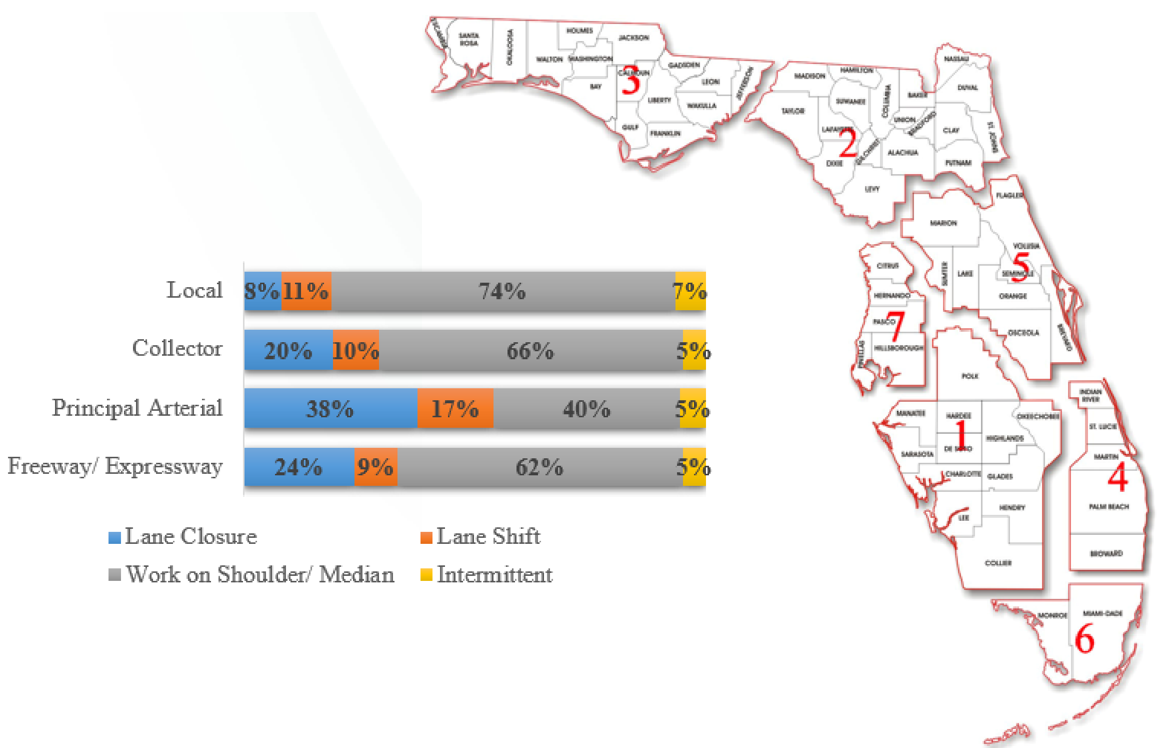

Figure A - 12. WZ Crashes by Functional Class in Florida Districts, 2011–2017

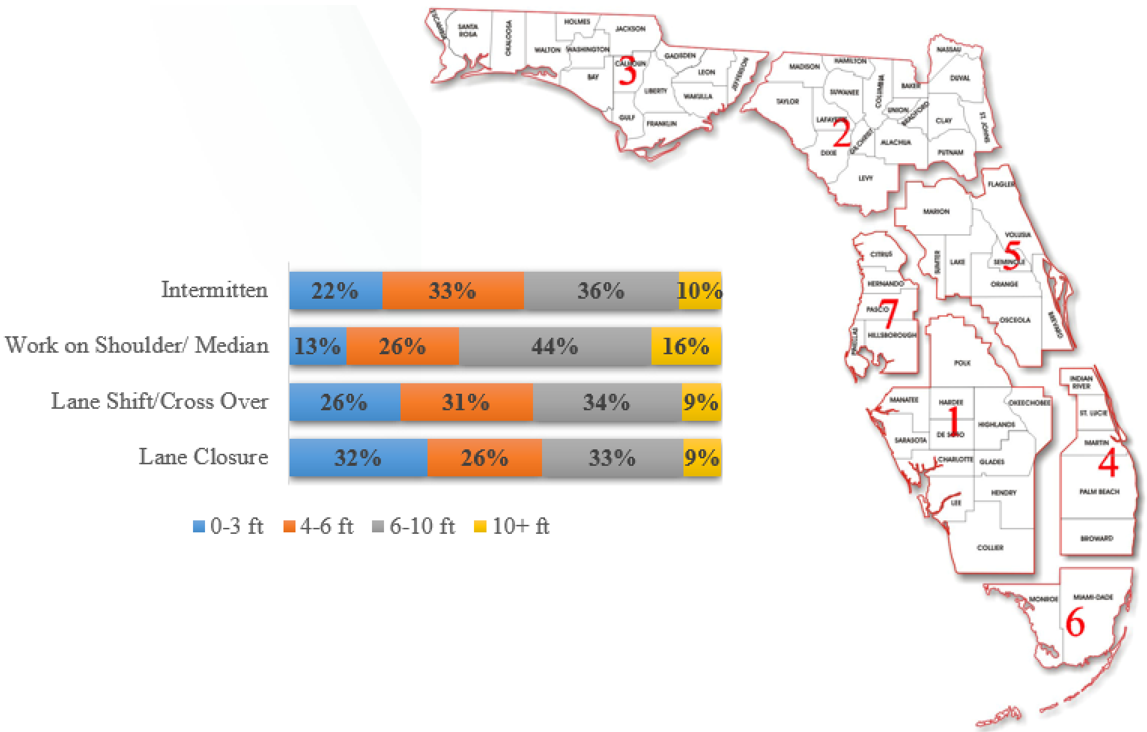

Figure A - 13. WZ Crashes by Shoulder Width in Florida, 2011–2017

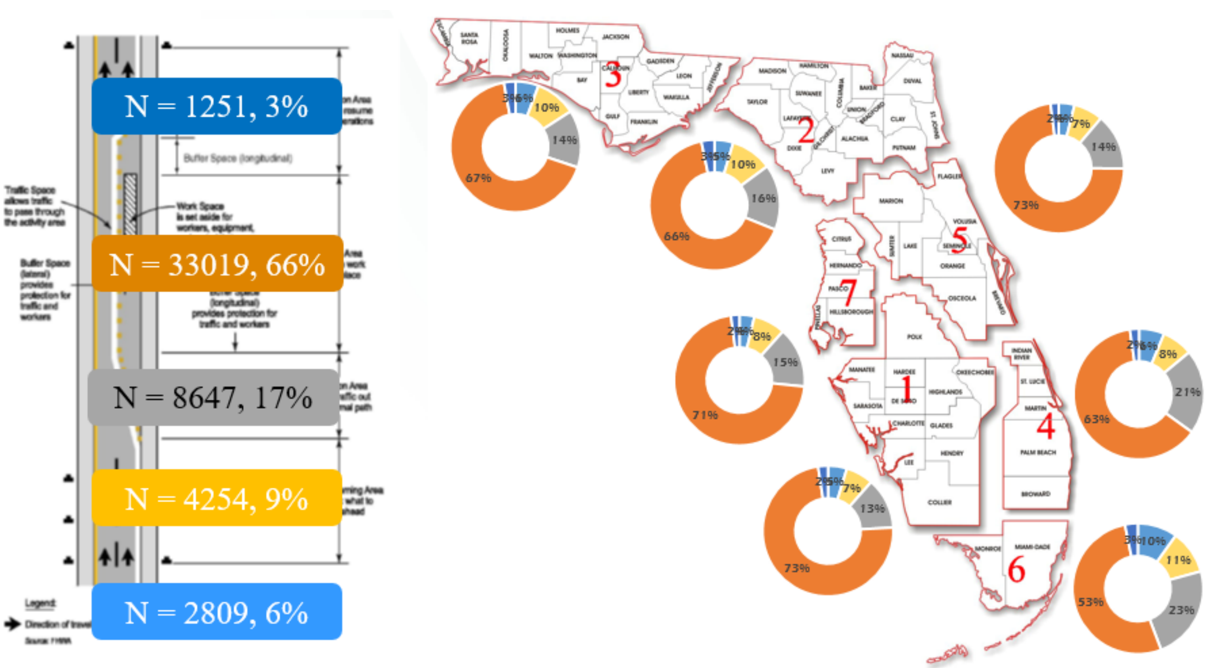

Figure A - 14. WZ Crashes by Location in Florida Districts, 2011–2017

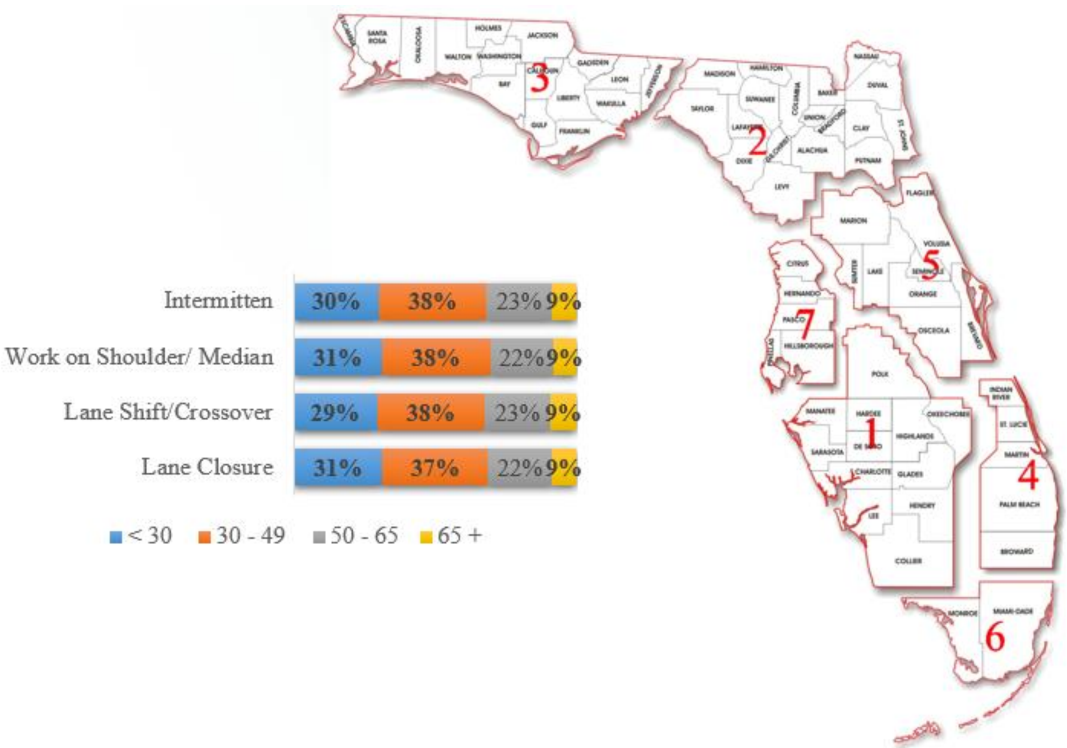

Figure A - 15. WZ Crashes by Driver Age Group in Florida, 2011–2017

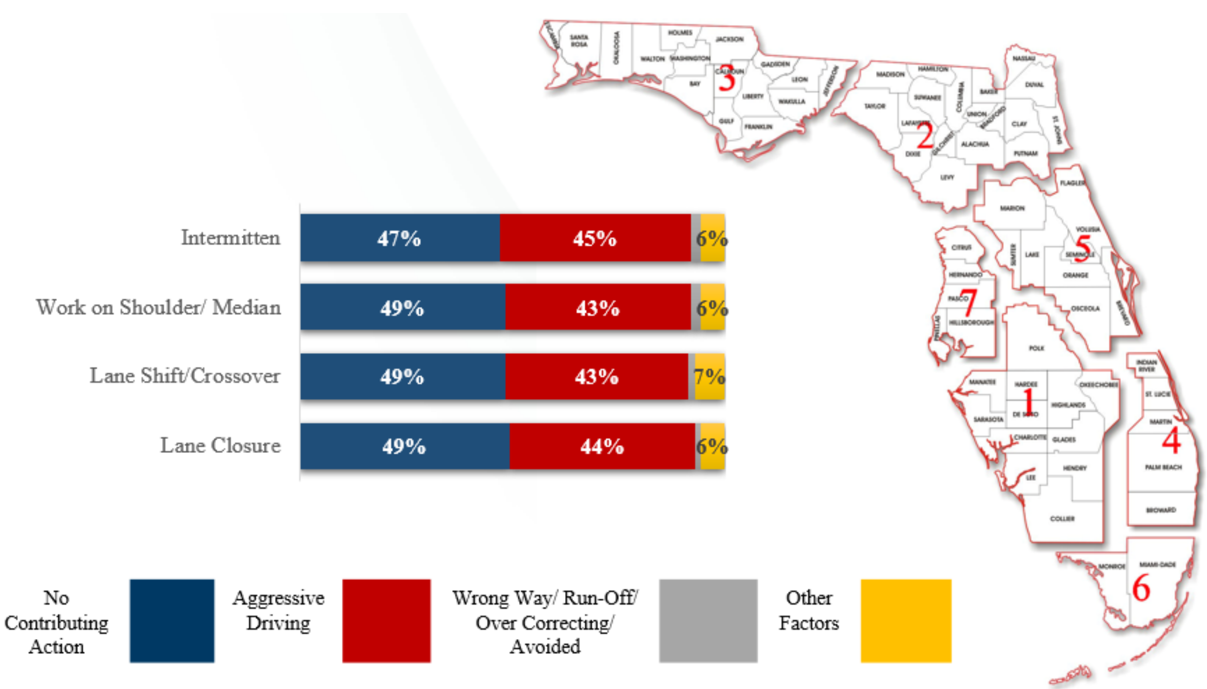

Figure A - 16. WZ Crashes by Driver Actions in Florida Districts, 2011–2017

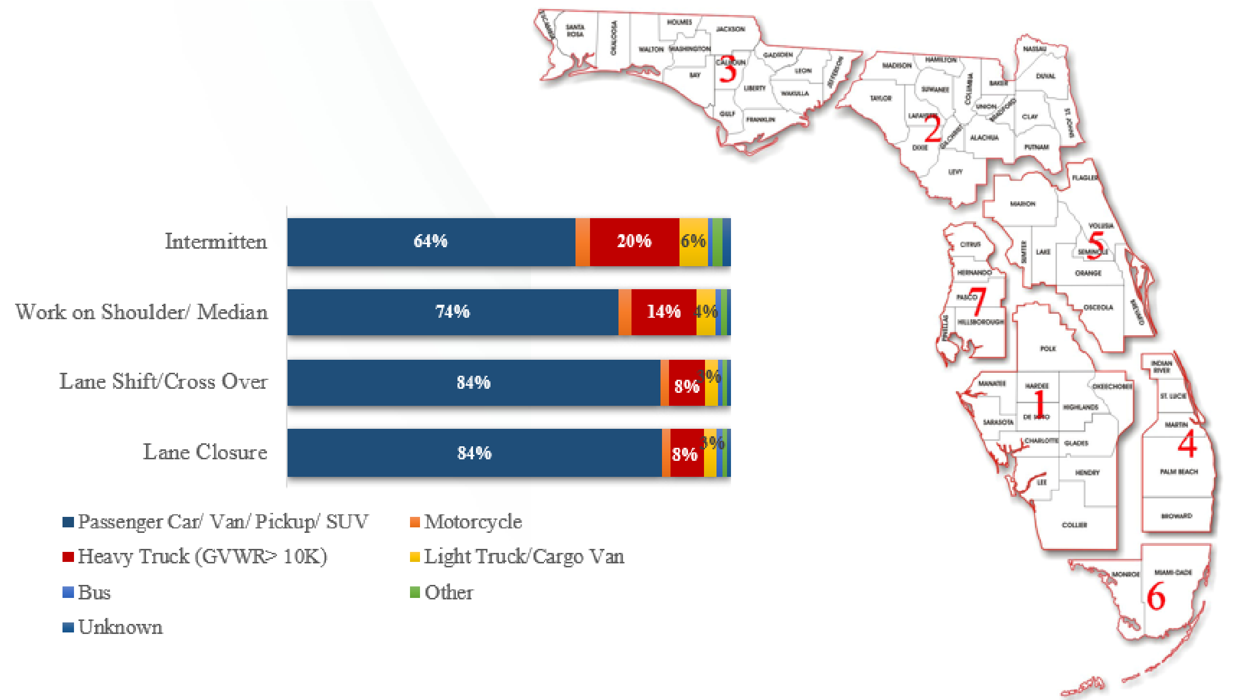

Figure A - 17. WZ Crashes by Vehicle Involved in Florida Districts, 2011–2017

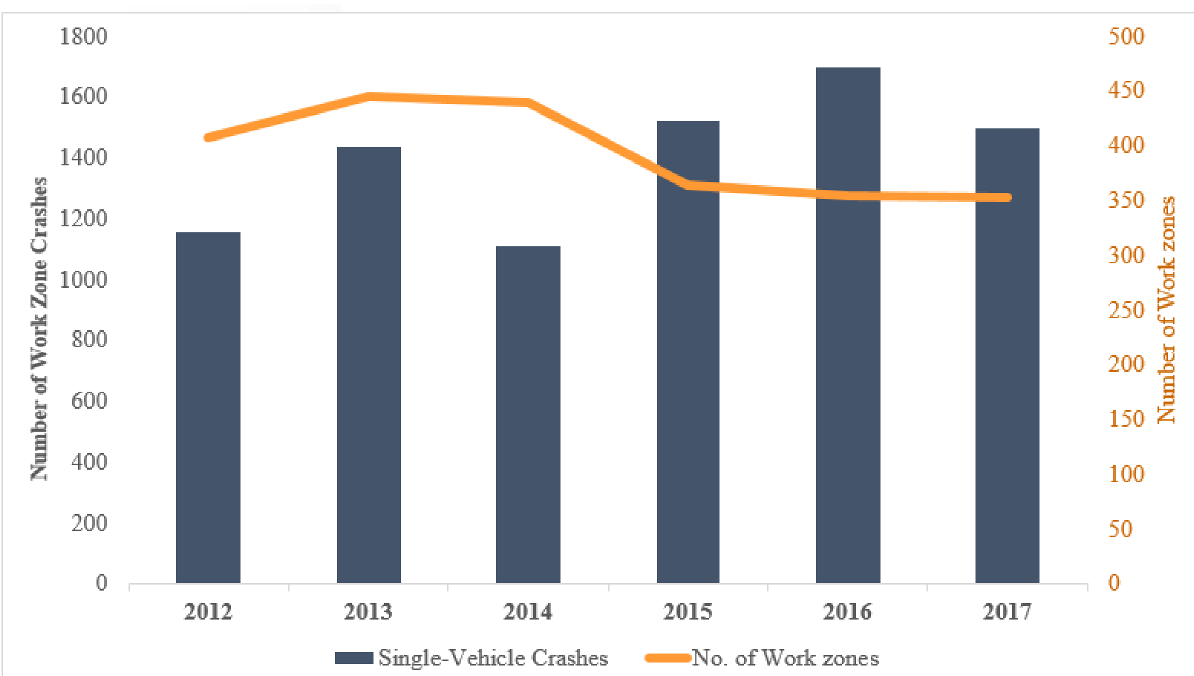

Figure A - 18. Single-Vehicle Crashes in Florida Work Zones, 2012–2017

Criteria to Justify SWZ Application with Feasibility Assessment

Table A - 8. Example Set of Scoring Criteria to Establish Feasibility of Work Zone ITS

Criteria
Factor 1 – Duration of work zone: Long-term stationary work will have a duration of: • >1 construction season (10 points) • 4-10 months (6 points) • <4 months; procurement and installation timeline is available prior to work starting (3 points)
Factor 2 – Impact to traffic, businesses, other destinations, or other users (e.g., extremely long delays, high risk of speed variability, access issues) for the duration of work is expected to be: • Significant (10 points) • Moderate (6 points) • Minimal (3 points)
Factor 3 – Queuing and Delay: Queue lengths are estimated to be: • ≥2 miles for periods ≥2 hours per day (8 to 10 points) • 1-2 miles for periods of 1-2 hours per day (6 to 8 points) • ≤1 mile, or queue length estimates are not available but pre-construction, recurring congestion exists for periods <1 hour per day (4 points)
Factor 4 – Temporal Aspects of Traffic Impacts: Expected traffic impacts are: • Unreasonable for a time period that covers more than just peak hours (10 points) • Unreasonable during most of both morning and afternoon peak hours in either direction (6 points) • Unreasonable during most of a peak hour in either direction (3 points) • Unpredictable; highly variable traffic volumes (1 point)
Factor 5 – Specific Issues Expected (0 to 3 points each based on judgment) • Traffic Speed Variability • Back of Queue and Other Sight Distance Issues • High Speeds/Chronic Speeding • Work Zone Congestion • Availability of Alternate Routes • Merging Conflicts and Hazards At Work Zone Tapers • Work Zone Hazards/Complex Traffic Control Layout • Frequently Changing Operating Conditions for Traffic • Variable Work Activities (That May Benefit From Using Variable Speed Limits) • Oversize Vehicles (Percent Heavy Vehicles >10%) • Construction Vehicle Entry/Exit Speed Differential Relative to Traffic • Data Collection for Work Zone Performance Measures • Unusual or Unpredictable Weather Patterns Such as Snow, Ice, and Fog

(Source: Ullman et al., 2014)

Example of Novel SWZ Application—Novel Approach with Practical Implementation (AWAD)

The Versions B and D of AWADs as shown in Figure A - 19 were installed on February 4, 2019, on I-4 and remained inplace through March 2019; it was not used in April and May 2019. The analyzed data were produced by Houston Radar Stats Analyzer and available through the Florida Highway Patrol of the Office of Analytical Support (Florida Highway Patrol, 2019)**.**

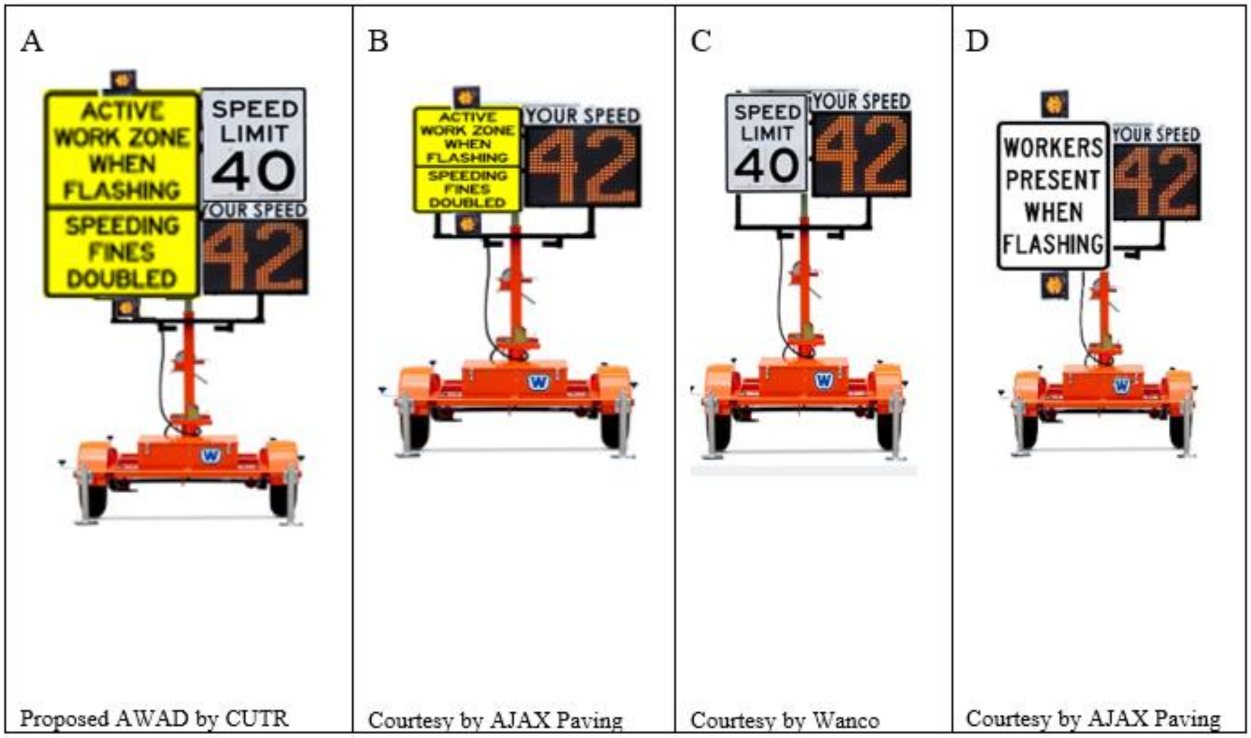

Figure A - 19. Advanced Warning Device: A – modified version, B-D – original version

To evaluate the effectiveness of the AWAD, reviewed were the speeds of vehicles traveling through the zone for October 2018 through May 2019 (Table A-8).

Table A - 9. Total Number of Vehicles by Speed and Month

Speed	2018			2019 AWAD in USE				
	October	***November***	***December***	***January***	***February***	***March***	***April***	***May***
5-10	21	54	9	271	148	76	2,232	20
10-15	82	62	3	266	206	286	2,786	94
15-20	246	536	1	671	888	580	2,830	290
20-25	324	1,090	1	2,082	3,559	636	3,460	594
25-30	413	400	3	5,360	9,449	928	3,162	1,134
30-35	490	202	1	5,285	13,297	1,246	2,886	1,270
35-40	525	260	12	3,794	22,727	4,324	3,418	1,238
40-45	879	535	46	4,096	47,690	12,492	5,286	1,298
45-50	2,827	1,943	49	5,423	89,656	23,776	8,744	2,046
50-55	10,354	7,635	130	15,689	124,427	19,980	22,110	4,766
55-60	19,736	16,179	307	29,401	106,684	8,942	50,584	12,080
60-65	18,153	18,104	320	29,073	55,445	4,782	91,334	23,410
65-70	9,117	12,673	248	17,743	20,886	4,198	100,776	25,498
70-75	2,964	6,167	140	7,277	7,722	2,800	70,384	18,188
75-80	809	2,110	47	2,151	2,660	978	28,036	7,576
80-85	172	580	16	536	685	258	6,692	1,476
85-90	41	136	4	123	193	58	1,348	188
90-95	20	30	3	34	40	18	302	32
95-100	5	7	0	18	15	4	70	6
100-105	3	4	0	2	0	0	22	2
Total:	67,181	68,707	1,340	129,295	506,377	86,362	406,462	101,206

Analysis of the vehicle speed revealed that before AWAD installation, on average, 40% of vehicles traveled at speeds of 45–60 mph (Figure A - 20. Vehicles by Speed Categories and by Month). During the time the AWAD was in use, on average, 62% of vehicles traveled at speeds of 45–60 mph. After the device was no longer in use, on average, 20% of vehicles traveled at the speeds of 45–60 mph. On average, the number of vehicles traveling at speeds of 45–60 mph increased by about 55% when the device was installed and decreased by about 67% when the device was no longer in use.

Before AWAD installation, on average, 52% of vehicles traveled at speeds of 60 mph or more (Figure A - 21. Percentage of Vehicles Driving Up to and Over 60 mph). During the time the AWAD was in use, on average, 16% of vehicles traveled at speeds of 60 mph or more. After the device was no longer in use, on average, 75% of vehicles traveled at speeds of 60 mph or more. On average, the number of vehicles traveling at a speed of 60 mph or more decreased by about 69% when the device was installed and increased by about 369% when the device was no longer in use.

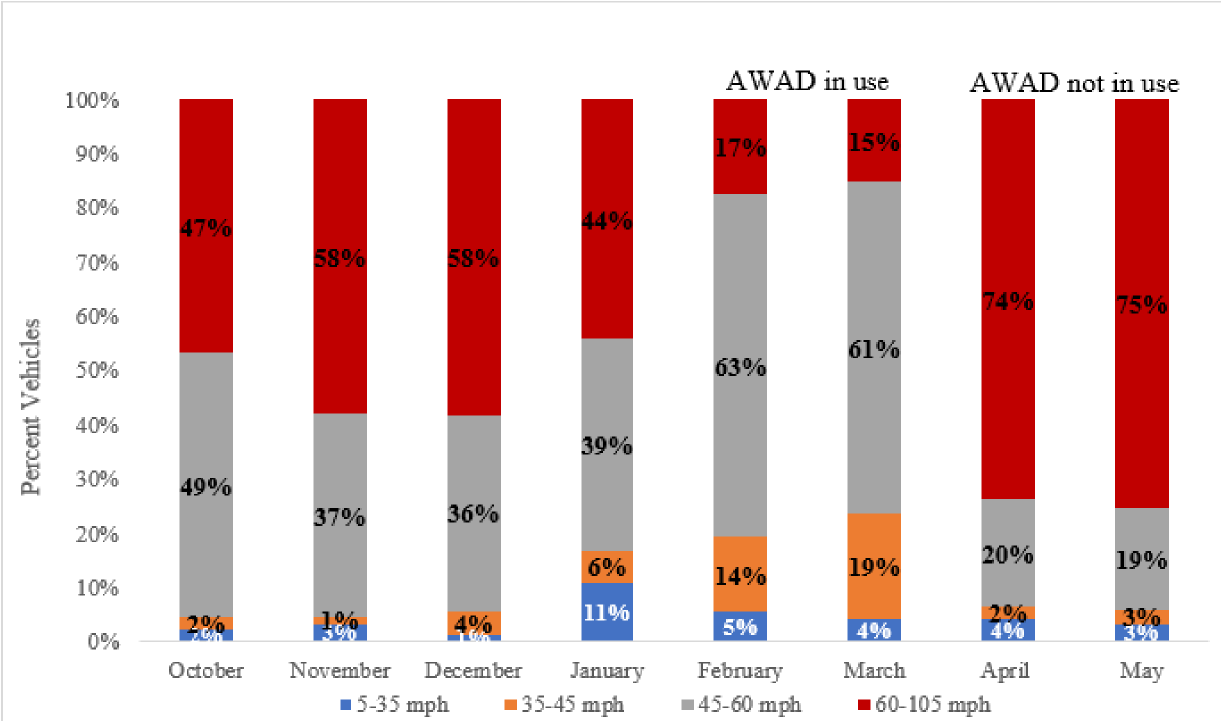

Figure A - 20. Vehicles by Speed Categories and by Month

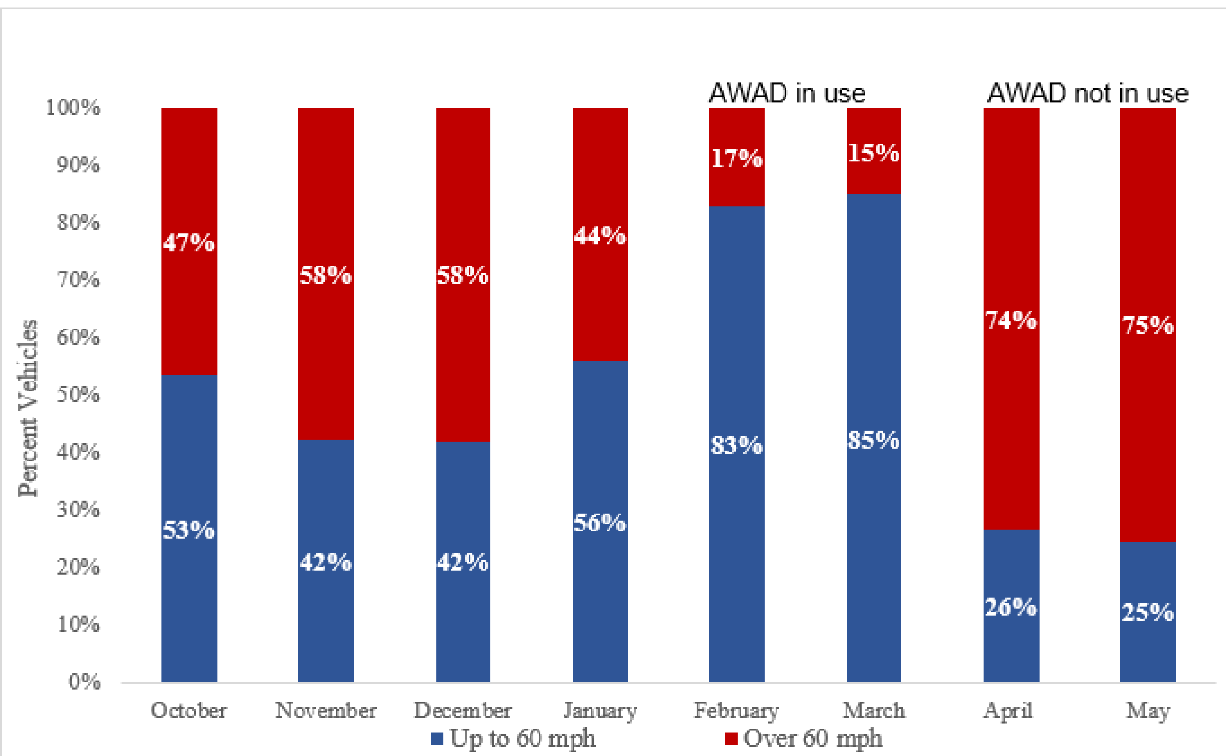

Figure A - 21. Percentage of Vehicles Driving Up to and Over 60 mph

Additionally, before AWAD installation, on average, 11% of vehicles traveled at speeds of 70 mph or more (Figure A - 22. Percentage of Vehicles Driving Up to and Over 70 mph). During the time the AWAD was in use, on average, 3.5% of vehicles traveled at speeds of 70 mph or more. After the device was no longer in use, on average, 27% of vehicles traveled at speeds of 70 mph or more. On average, the number of vehicles traveling at speeds of 70 mph or more decreased by about 68% when the device was installed and increased by about 671% when the device was no longer in use.

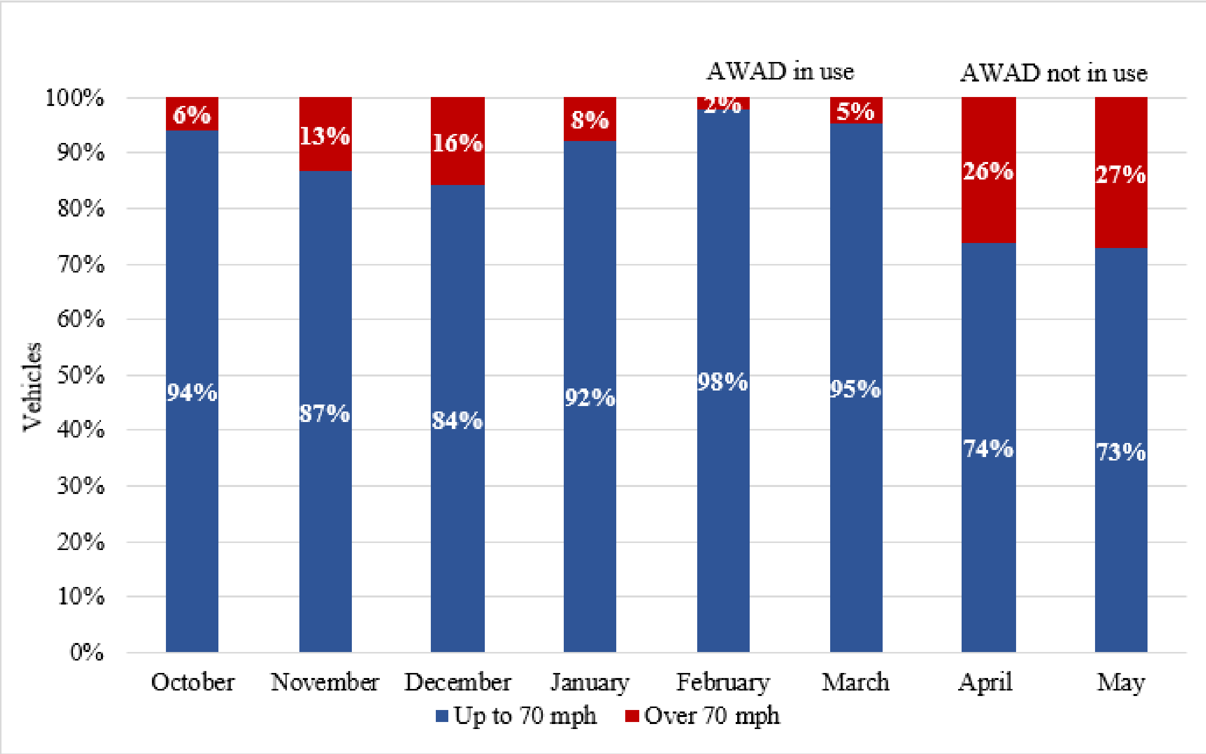

Figure A - 22. Percentage of Vehicles Driving Up to and Over 70 mph

Speed of 60 mph and more:

- Before AWAD – 52% of vehicles
- During AWAD – 16% of vehicles (drop of 69%)
- After AWAD – 75% of vehicles (increase of 369%)

Speed of 70 mph and more:

- Before AWAD – 11% of vehicles
- During AWAD – 3.5% of vehicles (drop of 68%)
- After AWAD – 27% of vehicles (increase of 671%)

The results indicate that presence of AWAD influenced the speed of vehicles—vehicles moved more slowly when AWAD was installed.

ITS Applications for SWZ Systems by Vendors

Table A - 10. ITS Applications and Vendor Information

Vendor Name	ITS Application	Experience
Hill and Smith	• Trailer-mounted queue detection • Mobile video trailer • EGRESS warning system • Variable speed limit trailer • Smart arrow boards • Smart drums	• N/A
ITERIS	• WAZE application • DSRC for V2V • In-vehicle On Board Unit (OBU) • Trip talk application	• Iteris Traveler alert system developed and demonstrated connected vehicle WZ piolet for PTC in 2018 • Iteris WZ data analytics implementation on I-405 in California • Work zone analysis conducted based on ClearGuide
HAAS Alert	• HA-Transponder • HA-D Direct system	• HAAS alert enables drivers, connected apps, and autonomous vehicles to "see" what's ahead. • HAAS alert system is used by Air Force, Michigan DOT, Kansas DOT, North Dakota DOT, DC, NY, and others
iCone	• Connected arrow boards (lane closure) • Connected work trucks (Hazard) • Connected delineators (Work Zone Boundary) • Connected flaggers (Alternating Single Lane)	N/A
SAWS (solar advanced warning system)	• Standard sign on wigwag trailer • LED regulatory sign trailer • Traffic sensing devices	• Prevent end of queue crashes with haul trucks caused by distracted drivers • Can be used in smart WZ to detect merging traffic, advice drivers to stop or yield and warn the traveling public of approaching dangers • Currently used in TX, NC, MI • Do not require any cellular connections • Can be easily paired or programmed in the field to meet any configurational needs.

Table A - 10. ITS Applications and Vendor Information, Continued

Vendor Name	ITS Application	Experience
Blyncsy Smart Work Zone Application	N/A	• Used in I-15 corridor and Blackrock project to improve mobility. • System collects identifiers via Bluetooth and by tire pressure monitoring system
AI Applied Information	• DMS sign message • Arrow boards • DSRC	• Travel safety app used to connect vehicle to vehicle • Can be connected to DMS sign message signs, arrow boards, DSRCs
Waycare	• Cloud-based operational tool that can collaborate among different agencies such as traffic control, freeway service patrol, law enforcement and emergency services	N/A
Nexar	• Smart dash camera paired with Nexar mobile app, uses cloud services to provide services such as LIVE map (city stream, roadway inventory detection and monitoring, road view, hotspot map, construction zone detection monitoring)	N/A
Connected Wise	• AI that can analyze roadway • Recognizes V2I signs and generating messages • V2I signs can provide vehicular message, MAP message for detour, update of message content for WZs • Communication with OBU	
Ver-Mac	• PCMS • Radars • Multilane sensors • Travel time routes • Weather station inputs • Work zone digital speed limit • Variable speed limit • Work zone location sensors • Dynamic automated queue warning • Truck entry system • Smart Arrow board	N/A

ClearGuide = Real-time contextual mobility intelligence, OBU = On board unit, V2V = Vehicle to vehicle, DSRC = Dedicated short-range communications