Smart Work Zone (SWZ) Technical Concept Study
Phase No. 1
Final Report

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A. Overview

1 - Background

As part of Arizona Department of Transportation's (ADOT) Implementation Guidelines for Work Zone Safety and Mobility process review, ADOT continually explores ways to expand and improve existing practices within work zones (WZ). ADOT sought assistance to help develop and implement Smart Work Zone (SWZ) operational concepts to apply to their current procedures. These concepts improve the safety for both highway workers and the traveling public using combined intelligent transportation system (ITS) technologies in real-time to optimize WZ traffic operations. Furthermore, SWZ minimizes congestion by reducing delays to the commuting public within work zone areas.

B. System Engineering

The Systems Engineering process was utilized to address SWZ system implementation considerations starting early in planning, and progressing through project design, implementation, and performance assessment. Each step of the process builds upon the previous step with more information and guidance toward ultimately developing a solution that appropriately addresses the original goals of the project through design and implementation.

The initial planning phase of the project included discovery of major challenges and issues by project stakeholders as part of the development of Working Paper #1 (WP#1). These included typical locations of where crashes occur around work zones, speed limit non-compliance, challenges with rolling work zones, the need for surveillance at work zones, limited detour options, and lane restrictions being challenging for oversized vehicles, among other issues.

As part of WP#1, a literature review was performed to summarize smart work zone efforts on a national level, identify SWZ subsystems that leading state DOTs are deploying, and document the various SWZ components, software, and systems that SWZ manufacturers and vendors have to offer. In addition, this working paper provides general cost estimates for the various SWZ subsystems. The summary of applications and costs were based on interviews with the state DOTs, manufacturers, vendors and equipment rental suppliers.

ADOT identified the following SWZ goals for this project that would then be used to determine appropriate technologies to collect appropriate data in order to evaluate the effectiveness of the SWZ concepts:

- Better inform motorists
- Speed compliance
- Improve safety in and around work zones
- Improve mobility
- Know when work zones are active
- Adapting to latest innovations

A *SWZ Operational Concepts* workshop was then facilitated with the project stakeholders to select which SWZ operational concepts should be included within ADOT roadway construction projects. These Arizona SWZ system operational concepts include the following subsystems, which are described in greater detail in WP#1:

- Traffic data collection and GPS;
- Queue warning system;
- Dynamic lane merge;

- Travel delay/times;
- Traffic monitoring camera system; and
- Variable speed limits.

The information gathered from WP#1 was used to guide a *Challenges of Implementation* workshop with project stakeholders to discuss many challenges that ADOT could come across when employing the Arizona SWZ system operational concepts. The challenges to implementation were vetted thoroughly during he workshop which resulted in consensus on what the appropriate course of action should be regarding the following topics:

- Procurement Considerations;
- SWZ System Integration; and
- Other Challenges to Implementation.

The design of the ADOT SWZ included the development of a new ADOT Standard Specification for Road and Bridge Construction that would be inserted into Section 710. The design also included the development of a tool to help designers and contractors determine the appropriate SWZ quantities and recommended placement.

C. Summary of Findings

1 - Literature Review

A literature review was conducted to identify guidelines and processes for SWZ applications at a national level and how these practices are deployed. Through this research, vendors that sell or rent SWZ ITS technologies and equipment were also discovered, along with what it costs to operate and maintain them. A detailed review of the research was prepared and is found in WP#1.

Many reports and Articles on the US Department of Transportation Federal Highway Administration (FHWA) website provide general information and guidance about how SWZ concepts are being used at the national level. From the reports, it was determined that SWZ systems should have the capability of obtaining and analyzing data in real-time, sharing continually updated information to motorists, stay portable, be largely automated with minimal human oversight, and provide precise and reliable information. Properly deploying SWZ systems provides the following benefits:

- Relieves commuter frustrations by providing motorist with dependable information
- Drivers opt to take available alternate routes
- Congestion is reduced
- Traffic incidents are cleared quicker
- Work zones are safer for both workers and motorists.

FHWA launched the Smarter Work Zones initiative to encourage agencies in 2015 to better design, plan, coordinate and operate work zones. Two strategies for SWZ include: (1) project coordination to harmonize construction projects and reduce work zone impacts (2) technology applications to dynamically control traffic in and around work zones. Deploying these strategies minimized delays and encouraged effective traffic, which is especially beneficial in metropolitan areas and high impact corridors during major events.

Other reports by the FHWA and other national associations were reviewed. In 2002, four case studies of real work zones using ITS were examined by FHWA researchers in Michigan, Illinois, New Mexico, and Arkansas.

Other than detailing how ITS systems can be utilized for reducing crash rates, delays, and congestion costs, the following observations were found in most, if not all, of the case studies:

- Systems need to have reliable communications.
- It is important to allow start-up time when deploying a system.
- Use a proactive approach in building public awareness of the project and the information that the ITS application will provide.
- It is vital to deliver accurate information to the public.
- Other stakeholder agencies, such as those responsible for incident management, need to be involved early.
- Consider how to set up automated information delivery and sharing with other agencies.

ITS components of SWZs were further examined from a review of four FHWA case study reports that were prepared in 2004. The case studies provide a system description, identify specific equipment used, and present system performance and the benefits and impacts to mobility, safety, and cost savings. The case studies focused on mobile traffic monitoring and management system, automated technologies, dynamic lane merge to help with transition into the construction area. Benefits from deploying the SWZ applications included a decrease in average peak period travel time and aggressive driving. The final case study examined how a real time traffic control system can be used to reduce congestion and improve safety. The system included real time traveler information and a speed reduction within the work zone. Illinois Department of Transportation (IDOT) reported that the system provided safety benefits due to the decreased number of moving violations after deployment and the low number of reported crashes that occurred in the work zone. Other resources provided guidance for the implementation process of ITS in work zones.

SWZ applications were further examined as part of WP#1 and were compiled into a summary matrix. The matrix organized ITS technologies with their associated states, how SWZ ITS systems have been implemented, along with documentation of their results in a case study or research effort. A complete list of references is also included in WP#1.

2 - Smart Work Zone Vendors and Systems/Components Costs

To best understand what SWZ systems were available, six smart work zone vendors were contacted as part of this research. Comprehensive information about each SWZ component/application is available within WP#1. The SWZ technologies include portable ITS equipment, vehicle detection and license plate recognition capabilities, various warning systems, and iCones. The costs for the SWZ technology are dependent on many factors, such as location, duration and length of the project. SWZ systems can also be obtained through an separate bid for individual components or as one lump sum cost, however, system integration should also be factored into the overall cost and bidding process. A table is included in WP#1 to show the costs per device for three separate contracts. Other factors, such as communications needs, must also be determined and vary per project. The cost for communications will differ depending on the needed options. Vendors suggested that a system integrator be used for troubleshooting communications issues that may occur within a SWZ.

D. SWZ Operational Concepts

1 - Determining the Need for a SWZ

a. Identifying Work Zones that Should be 'Smart'

Projects must have a comprehensive Transportation Management Plan if they have been deemed "Significant" per ADOT Work Zone Policy. A "Significant" project as defined by FHWA is "one that, alone or in combination with other concurrent projects nearby is anticipated to cause sustained work zone impacts (as defined in 630.1004) that are greater than what is considered tolerable based on State policy and/or engineering judgement" and "all Interstate system projects within the boundaries of a designated Transportation Management Area (TMA) that occupy a location for more than three days with either intermittent or continuous lane closures". Interstate segments in higher volume urban areas are classified as significant projects under this definition, however, lower volume rural Interstates are not required to be classified as significant projects unless the DOT chooses to implement that criteria. The following questions should be considered to determine SWZ:

- Is the work zone going to have a substantial negative impact to traffic?
- Are there existing traffic issues/concerns in the area?

If at least one answer to the above questions is yes, then a work zone is an ideal candidate for expending the additional costs/resources to deploy a smart work zone system.

b. Identifying SWZ Subsystems

Impacts to traffic from work zones must be monitored and measured using a SWZ application. There are several factors that must be weighed to determine which application to use. To aide with this determination, five specific factors should be considered to help identify the relevant subsystems that should be utilized in the ADOT SWZ. The factors include and are specifically linked to subsystems when the answer is affirmative:

- **Congestion** – Is the work zone going to cause congestion or a case where the volume to capacity ratio will exceed 1.0?
  - If yes, utilize a **Queue Warning** system.
- **Lane Restriction** – Is the work zone going to be restricting or closing lanes of traffic?
  - If yes, utilize a **Dynamic Merge** system.
- **Delay information** – Is there an alternate route option within 5 miles in advance of the work zone and/or to alleviate drive frustration?
  - If yes, utilize a **Travel Delay** system.
- **Surveillance Capability** – Is there no permanent camera or surveillance capability existing to be able to monitor the work zone?
  - If yes, utilize a **Traffic Monitoring (Camera)** system.
- **Length of Work Zone and Need for Changing Speeds when Workers are Present** – Is the length of the work zone exceeding 2 miles and there is a desire to be able to lower posted speed limits when workers are present?
  - If yes, utilize a **Variable Speed Limit** system.

These SWZ applications will provide will provide ADOT with traffic data so that real-time conditions can be understood both during and in advance of the work zone. Other SWZ applications, such as entering/exiting vehicle system, pedestrian applications, or rolling closure should be determined by ADOT personnel on a project-by-project basis but were not included in the ADOT concept for consistent SWZ application.

2 - Recommended Technologies

Based on the SWZ subsystems that are included in the Arizona SWZ concept, a set of associated technologies will be required to achieve the subsystem functions and purposes. **Table 1** outlines the required technology components for each subsystem.

Table 1: Arizona SWZ Technologies

Subsystem	Associated Technologies						
	CCTV Camera	Sensors	Communications	Solar power	Message sign	Software	Geolocation
Traffic Data Collection and GPS		X	X	X		X	X
Queue Warning		X	X	X	X	X	X
Dynamic Lane Merge			X	X	X	X	X
Travel Delay			X	X	X	X	X
Traffic Monitoring	X		X	X		X	X
Variable Speed Limits		X	X	X	X	X	X

A detailed description of each subsystem is provided in WP#1, which included the technologies used as well as conceptualized placement of the technologies to collect the data to determine success in achieving the goals and objectives of the SWZ.

3 - Subsystem Integration Opportunities

The data and outputs from SWZ deployment strategies can be used to obtain better information about real-time and historical work zone conditions, such as delays and closures. By integrating the SWZ subsystems with existing ADOT systems and/or providing the TOC operators access to the SWZ system, the data and information from the SWZ system can be collected and disseminated more efficiently and then be used to support informed decision making, both from ADOT and the traveling public.

Currently, most SWZ software vendors have their own proprietary systems that are not capable of fully integrating with ADOT's TOC systems. Achieving full interoperability would likely not be cost-effective, as vendors would need to be compensated for their time and efforts. It is more beneficial for ADOT to allow the SWZ software industry time to establish more open-sourced systems [i.e., Work Zone Data Exchange (WZDx) Specification] before pursuing system-level integration.

4 - Performance Measures

The following performance measures were recommended as part of the SWZ system development process as part of the project goals and objectives. The performance measures are shown in **Table 2**.

Table 2: Arizona SWZ Proposed Performance Metrics

Goal	Objective	Proposed Metric
Better inform motorists	Improved traveler information	Travel times/delay * Number of messages provided by SWZ (unique messages could be speeds, travel times, queue messages, etc.)

Goal	Objective	Proposed Metric
	Know when work zones are active	Number of work zones using SWZ
Speed compliance	Improved speed compliance in work zone	Speed variation Speed compliance when workers are present
Improve safety in and around work zones	Safer for traveling public and workers	Number of crashes * Queue length * Reduce speed limits when workers are present Traveler compliance with posted speed limits
Improve mobility	Posted speed limits coordinated with worker activity	Reduced length (distance) and/or time lower speed limits are posted
Adapting to latest innovations	Ability to be flexible with advances in SWZ technology	Performance specification flexible to new technologies

** Metrics specifically cited in ADOT's Work Zone Policy*

E. Implementations Considerations

1 - SWZ Equipment Ownership and Deployment Responsibility

ADOT may procure and deploy some SWZ technologies as part of their roadway maintenance activities, but ADOT has decided that all SWZ equipment deployed within a roadway construction project shall be provided by the roadway construction Contractor. With this approach ADOT achieves some consistency with how other types of non-intelligent Temporary Traffic Control (TTC) are covered within the roadway construction contract documents; and it provides ADOT the ability to require the roadway construction Contractor to include the SWZ field devices as part of the overall roadway construction Traffic Control Plan (TCP).

2 - Contract Documents

Contract Documents should require the roadway construction Contractor to be responsible for operating the SWZ system, but ADOT representatives will need to be involved in the SWZ system configuration and deployment process. The following are some types of ADOT construction administration activities that may be needed:

- Approve the messages that can be posted on the portable trailers;
- Approve the system logic and associated thresholds for triggering different CMB messages, variable speed limits, etc.;
- Defining what types of SWZ system alerts/notifications are desired;
- Providing a list of ADOT representatives that need/want access to the SWZ software application to view/download the data being collected/generated by the system, to view CCTV cameras, etc.;
- Providing a list of ADOT representatives that want various types of system generated alerts or notifications;

- Verifying that the SWZ system is fully functioning as intended and documenting when it is not, so the Contractor pay item requests can be approved/rejected accordingly; and
- Observing how the field devices are deployed and reporting any associated concerns with safety, traveling public mobility, and potential impacts to the SWZ system performance.

For each roadway project requiring SWZ systems, it is important to identify the needs and desires of all stakeholders involved with the SWZ and TTC operations and establish explicit channels of communication between all of them. The following list is not comprehensive, but rather identifies key ADOT stakeholders (detailed in WP#2) that will be involved on most projects using SWZ systems:

- Resident Engineer
- Region Traffic and/or District Engineer
- Traffic Operations Center

Because ADOT is not going to own any of the SWZ equipment that is to be deployed within a roadway construction project, and ADOT is not at this time going to require any SWZ system vendors to integrate their system software with existing ADOT software platforms (see Section C. - SWZ System Integration), there is no current need for ADOT to develop a Request for Proposal (RFP) to purchase the SWZ system components or establish an approved Qualified Products List (QPL) of SWZ systems that have successfully integrated with existing systems. To effectively administer the SWZ systems within a roadway construction project, the following two types of contract documents are needed:

a. SWZ System Standard Specifications

A new section of the Standard Specifications for SWZ systems was developed using Section 710. This new SWZ system Standard Specifications section includes the following standard subsections:

- 710 - 1 Description,
- 710 - 2 Materials,
- 710 - 3 Construction Requirements,
- 710 - 4 Method of Measurement, and
- 710 - 5 Basis of Payment.

The new SWZ system Standard Specifications section is limited to providing general functional requirements of the SWZ system and the associated operational concepts of each subsystem. The SWZ system Standard Specifications section avoids having specific requirements about current SWZ technologies that may become obsolete as these technologies evolve over the next 5-10 years. This approach will require the development of performance specifications rather than method specifications.

b. Special Provisions to the SWZ System Standard Specifications

During the design phase of each roadway construction project that will require a SWZ system, a Project Special Provisions section may need to be developed to add project specifics to the SWZ system section of the Standard Specifications. This is a typical process undertaken by designers to add project specific details that are needed beyond the performance requirements identified within the Standard Specifications. It is anticipated that Standard Specifications were created to minimize the additional work required when developing the project Special Provisions for incorporating SWZ into the specific projects. These SWZ system special provisions will be needed to define the following types of project specific and/or technology specific requirements:

- When and where each type of SWZ subsystem is required on the project;

- What are the specific minimum requirements of the SWZ technologies that can be used;
- What non-WZ deployments are required, if any, for proof of concept evaluations or acceptance testing;
- What additional data needs to be collected/submitted for evaluating the SWZ subsystem performance or for archiving general traffic data within WZ of a specific type or location;
- What types of system testing/data is required to demonstrate that system is fully functional and operating as intended; and
- What type of training will be required for ADOT representatives accessing the SWZ system software and/or observing the field deployments for proper implementation and field device deployment methods.

Over time as the use of various types of SWZ subsystems become more common to ADOT and Construction personnel, it is anticipated that the need for Special Provisions covering system training of DOT representatives, system acceptance testing, and system performance evaluations will become less frequent. However, it is anticipated that SWZ system Special Provisions will be needed on all projects requiring the use of SWZ subsystems to define when and where different types SWZ subsystems will be required, and what the SWZ technology minimum requirements are.

3 - SWZ System Configuration and Field Operations

As ADOT develops SWZ system requirements and administers contract documents that require the use of SWZ systems, it is important that ADOT design and construction administration representatives understand the following three (3) different types of subcontractors (described in WP#2) that the General Contractor may need on their team to perform the required SWZ system work:

- Vendor Providing the SWZ System Software
- Vendor Furnishing the SWZ Field Devices
- Subcontractor Deploying the Field Devices within the WZ

The following additional considerations were identified as part of the *Challenges to Implementation* workshop covered in WP#2.

a. Public Interest Findings (PIF)

A Public Interest Finding (PIF) is required by FHWA and ADOT whenever an agency specifies the use of a proprietary device or product on a project that uses FHWA or state funds. Not all SWZ systems will require a PIF, so each project requiring SWZ technology must be assessed separately to determine if the requirements within the Contract Documents can be provided by multiple vendors. If only one vendor can achieve all the desired functionality, then a PIF letter will need to be prepared and approved, before the project goes to bid.

b. Crashworthiness

The Contract Documents will need to require the Contractor to be responsible for protecting the SWZ field devices in a manner similar to other non-crashworthy devices that are deployed as part of the roadway construction project. The associated pay items and quantities for that protection will need to be coordinated during the design phase of the project.

c. System Communications

A key component of any SWZ is the ability to communicate between the SWZ field devices, SWZ system software, and the field personnel operating the system while it is deployed within the work zone. To do this, some manner of wireless communications must be available at all times during the deployment. Whether this is cellular coverage, satellite coverage, or some other method should not be specified but rather left up to the Contractor to decide what communications method would work best for the system the proposing and the associated project limits.

d. Design Phase Considerations

The first decision is the one whether to use SWZ or not during a work zone project, which should be made as early as possible. Making that decision to use a SWZ system at Project Scoping is ideal but required by Stage II (60% design). The decision should be made by a committee made up of the District Engineer, Regional Traffic Engineer, design engineers, TOC representative (if necessary), and others as appropriate.

The design of SWZ systems and the design process will be a new process for many engineering firms and contractors. It should be expected that the first few projects that ADOT deploys a SWZ system on will be a learning process for all stakeholders, and ADOT should document lessons learned and best practices as those projects progress.

F. SWZ Design Tool

The design also included the development of a tool to help designers and contractors determine the appropriate SWZ concepts to utilize that would also provide quantities and recommended placement within the work zone.

To aid ADOT in designing the deployment of SWZ applications within construction projects, two matrixes were created which could be manipulated to support the individual needs of the project. The matrixes are to be used for non-signalized ADOT owned facilities. The first matrix is for projects with one or two lanes with roadways in one direction, and the second is for three or more lanes in one direction or when high truck volumes are greater than 15%.

This SWZ Design Tool uses Microsoft Excel to ask the designer the series of five factors (parameters) about the work zone that would determine which SWZ technologies to utilize based on ADOT's SWZ concepts. The five factors to be answered by the designer are as follows:

- **Congestion** – Is the work zone going to cause congestion or a case where the volume to capacity ratio will exceed 1.0?
    - If yes, utilize a **Queue Warning** system.
- **Lane Restriction** – Is the work zone going to be restricting or closing lanes of traffic?
    - If yes, utilize a **Dynamic Merge** system.
- **Delay information** – Is there an alternate route option within 5 miles in advance of the work zone and/or to alleviate drive frustration?
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    - If yes, utilize a **Variable Speed Limit** system.

Figure 1 shows the Design Tool request for these factors and other work zone parameters readily known to the designer. In order for ADOT to collect data at work zones, it is recommended to always enter "Y" for yes in the data parameter, at least until such time that ADOT does not need to evaluate work zone performance in the future.

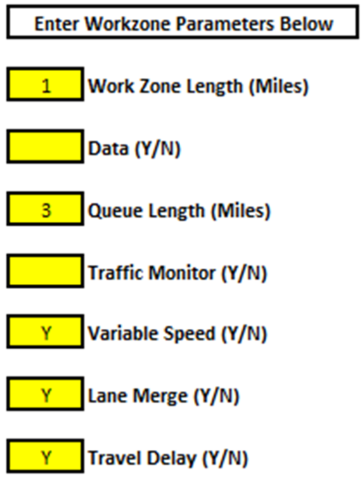
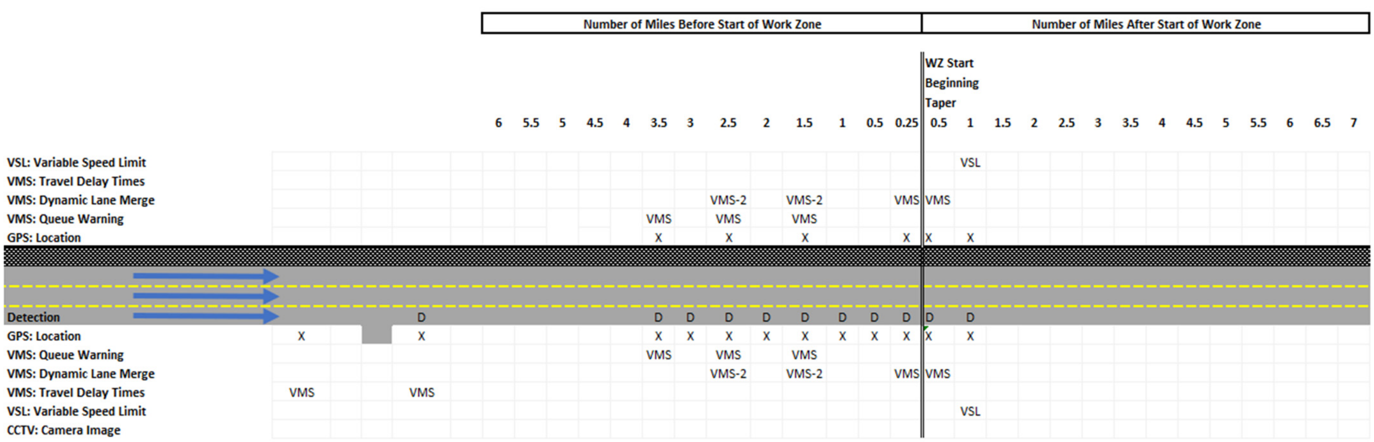


Figure 1: Work Zone Parameter Entry for SWZ Design Tool

A separate Excel-based tool called "Work Zone Queue and Delay Estimate Tool" is being developed for determining the anticipated length of the queue that needs to be entered in the "Queue Length (Miles)" box above.

The designer will enter the information about the parameters into the tool that will then "design" an appropriate SWZ system for the work zone. For instance, an input for a Work Zone Length of 1 mile, a Queue Length of 3 miles, including Variable Speed, Lane Merge, and Travel Delay stipulates based upon the characteristics defined in each concept the graphic as shown in **Figure 2**. This graphic shows that VMS should be placed before the work zone at 3.5 miles, 2.5 miles, 1.5 miles, and 0.25 miles, and after the construction zone at 0.5 miles. VMS with two message phases of messages occur at 2.5 and 1.5 miles before the work zone to show both dynamic lane merge and queue warning messages. GPS location is also indicated at various points before and after the work zone area in addition to Variable Speed Limit.



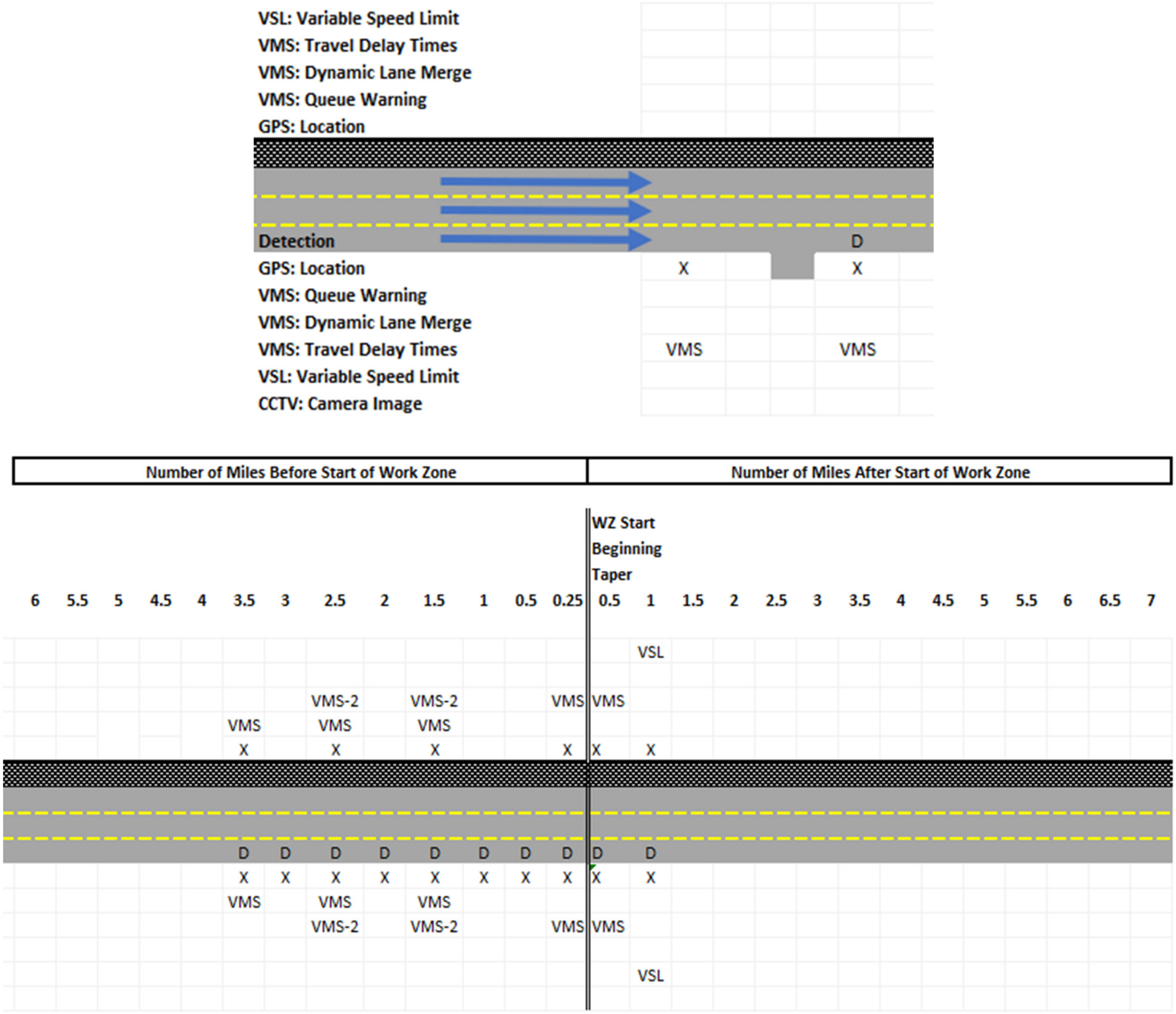


Figure 2: ADOT SWZ Matrix

It is anticipated that ADOT can utilize this tool in-house or provide the tool to Contractors or designers to determine appropriate SWZ technologies. It is also anticipated that this tool will need to be updated over time to respond to the potential changing landscape of technology evolution, such as the use of private sector data or drones in work zones.