Smart Work Zone

Standard Operating Procedures

Version 1.1

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ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
CCTV	Closed-circuit Television
CMO	Construction Management Outline
DOT	Department of Transportation
FHWA	Federal Highway Administration
GPS	Global Positioning System
HAR	Highway Advisory Radio
HMS	Hybrid Message Sign
IMP	ITS Monitoring Plan
ITS	Intelligent Transportation System
MassDOT	Massachusetts Department of Transportation
MUTCD	Manual on Uniform Traffic Control Devices
USDOT	United States Department of Transportation
PIP	Public Informational Plan
PCMS	Portable Changeable Message Sign
RFID	Radio-frequency Identification
SOP	Standard Operating Procedures
SWZ	Smart Work Zone
TMP	Traffic Management Plans
TTCP	Temporary Traffic Control Plan

Acknowledgement *– The Smart Work Zone Standard Operating Procedures were developed by Kanaan Consulting US, Inc. in cooperation with the MassDOT Traffic and Safety Engineering Section.*

1 INTRODUCTION

MassDOT's *Work Zone Transportation Management Procedures* specify the process to prepare Traffic Management Plans (TMP) for MassDOT's construction projects. One of the requirements of the TMP for certain project impact levels includes the development of a ITS Monitoring Plan (IMP). Design consultants will use MassDOT's *Smart Work Zone Design Standards* to evaluate various ITS technology applications to help mitigate the impacts of the road maintenance or construction work.

The following Standard Operating Procedures (SOP) have been prepared to guide contractors in support of the ITS Monitoring Plan component. The purpose of the IMP is to make work zone areas safer and more efficient through the use of Intelligent Transportation Systems (ITS) equipment, software, and communications to collect and analyze real-time data, compare it to established criteria, notify appropriate construction officials of undesirable conditions, and alert drivers about traffic conditions and suggest actions to be taken. This collection of actual ITS elements reflected in the IMP are known as a Smart Work Zone (SWZ).

The purpose this SOP document is to communicate the general steps for contractors to design, deploy, and operate SWZs. The development of the SOP adheres to the Federal Highway Administration (FHWA) Work Zone Regulation 23 CFR 630 Subpart J. The steps are summarized in *Figure 1* and described within the document. The SOP contains the following sections:

- **Section 1** introduces the document goals and the general steps to design, deploy, and operate a SWZ.
- **Section 2** presents the federal and state regulations, guidance, and policy on the use of ITS for the operation of work zones.
- **Section 3** SWZ describes the chief ITS applications to work zone operation and how identify the ITS needs for construction projects.
- **Section 4** identifies the ITS devices and systems that address the needs identified in Section 3.
- **Section 5** describes how to plan the SWZ system design and developing the evaluation plan.
- **Section 6** presents the considerations when deploying a SWZ and the operational test process.
- **Section 7** presents the considerations when operating and maintaining a SWZ.

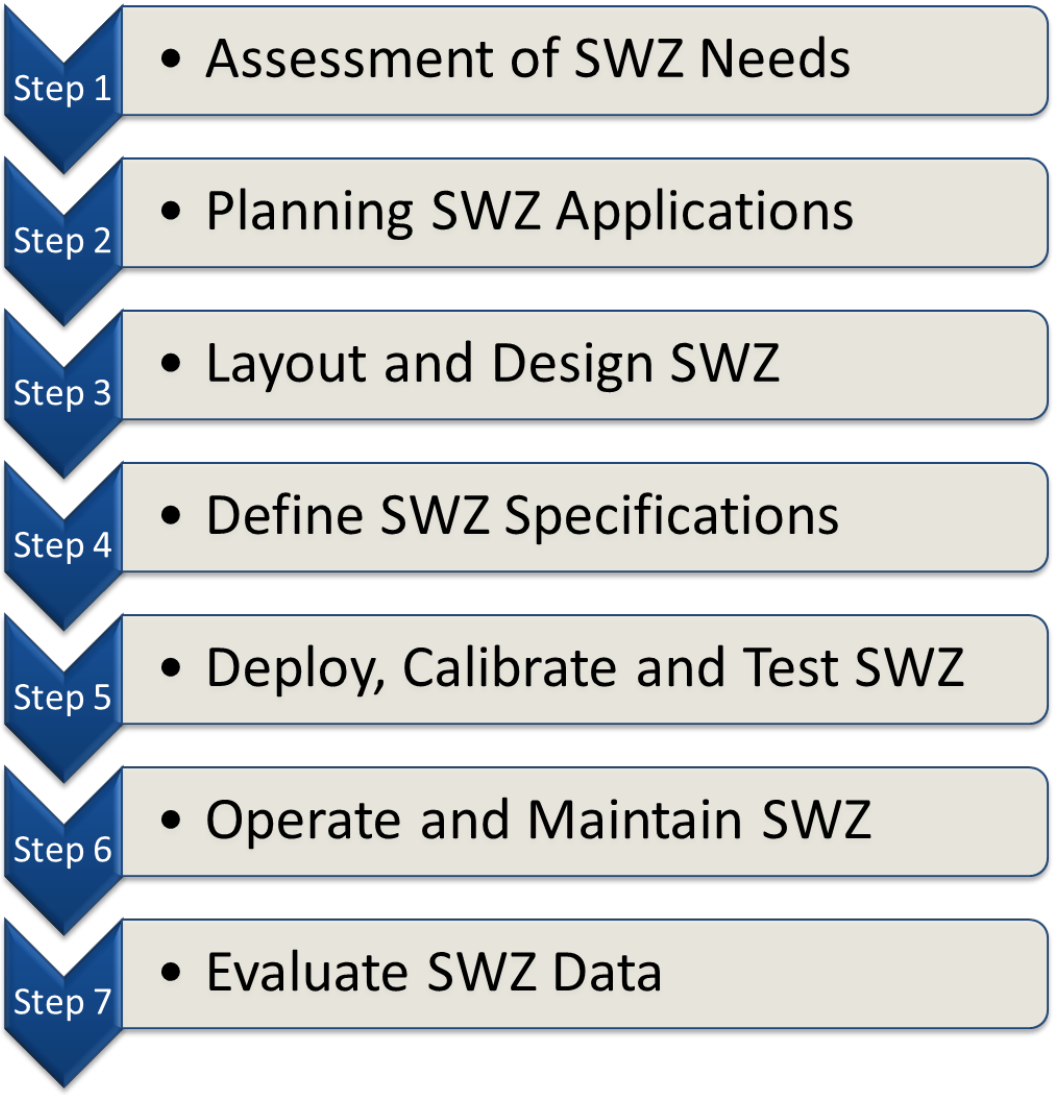


Figure 1 Process for Designing and Operating Smart Work Zones at MassDOT

2 SMART WORK ZONE REGULATION AND GUIDANCE

2.1 Federal Highway Administration (FHWA)

In September 2004, FHWA updated the *Work Zone Safety and Mobility Rule* 23 CFR 630 Subpart J. The Rule applies to all state and local governments that receive Federal-Aid highway funding for road and bridge construction projects. The rule outlined clear and definitive provisions and compliance dates for State and local transportation agencies that using Federal-Aid as follows:

- Define a clear and comprehensive process for evaluating and mitigating the impacts of construction work zones.
- Provide safe work zones for all workers and road users while also providing for the highest level of mobility.
- Define the evaluation techniques to be used during the planning, design, and construction phases of a project.

In 2007, FHWA issued the *Work Zone Operations Best Practices Guidebook* to provide a compilation of successful work zone operations practices used and recommended by several states and localities for other agencies to determine which of these practices are best suited for their particular situations. Some of those practices deal with the utilization of ITS systems to automatically collect and analyze data, and provide real-time information to motorists and to the construction team.

In addition to the aforementioned publications, FHWA has made available a number of resources developed by the academia, and local and state agencies for implementing various types of ITS in work zones. Such resources can be accessed through FHWA's Work Zone Mobility and Safety Program website[1]. The practices described in the guidebook and the website are intended as a descriptive, not prescriptive, depiction of the subject.

2.2 Massachusetts Department of Transportation (MassDOT)

In 2010, MassDOT developed the *Work Zone Transportation Management Procedures* to ensure compliance with the 2004 FHWA *Work Zone Safety and Mobility Rule* 23 CFR 630 Subpart J. The purpose of these procedures is to establish a clear and comprehensive process for evaluating and mitigating the impacts of construction work zones on the safety and mobility of both workers and the general public. The procedures built upon the existing practices and place special emphasis on evaluation of project impacts, definition of specific requirements, and collaboration between MassDOT and contractors early on the design process.

The procedures specify the steps to prepare Traffic Management Plans (TMPs) for MassDOT's construction projects. A TMP consist of four main components: Construction Management Outline (CMO), Temporary Traffic Control Plan (TTCP), Public Informational Plan (PIP), and ITS Monitoring Plan (IMP).

[1] http://www.ops.fhwa.dot.gov/wz/its/index.htm.

The procedures establish that TMPs for projects categorized at impact Levels 3 or 4, and Significant Project Status shall include an IMP (see *Work Zone Transportation Management Procedures* for description of impact levels) as part of the 75%, 100%, PS&E deliverables. IMPs can also be requested discretionally by the State Traffic Engineer for significant construction affecting vital community facilities such as a fire station, police station, school, or hospital; involving lengthy detours for motorists; or affecting locations that are normally subject to significant congestion or high crash rates. SWZ technology can also be used to aid drivers during special non-construction events. The procedures state that the IMP shall outline what mechanisms that will be employed to monitor traffic during construction and to notify the general public as changes occur.

In 2010, MassDOT developed the *ITS Strategic Plan*, which identifies the application of ITS in work zones during construction as an effective strategy to improve safety and lessen the delay generated by reduced capacity and incidents. Then, in 2011, MassDOT issued the *ITS Deployment and Design Guide*, which establishes general technical requirements for the design and operations of SWZs, including equipment specifications, communications, SWZ setup, and collected data. With the release of the *Smart Work Zone Design Standards* document in 2015, MassDOT now has official design guidance for the incorporation of SWZ systems in maintenance and construction projects.

3 DEFINITION OF WORK ZONE NEEDS

The IMP shall identify the needs that will be addressed in every proposed work zone. Needs may be categorized into five groups, which in turn may be broken down into more specific needs as shown next. Work zones needs may be addressed using ITS solutions as described in Section 4. The IMP is only one part of the TMP, and not the unique solution to mitigate work zone impacts.

3.1 Mobility Needs

Mobility refers to SWZ's capability to ensure an efficient flow of traffic through the work zone, minimizing the congestion in the work zone through the reduction of traffic and/or the increase of the road capacity around the work zone.

- **Travel Time and Delay Estimation**: Provision of travel time and delay through the work zone in order to minimize driver's uncertainty.
- **Alternate Route Advisory**: Reduction the flow of traffic through the work zone by encouraging drivers to use alternate routes with lower travel times, comparing travel time estimations through the work zone and alternate routes, when available, to a common destination.
- **Dynamic Lane Merge**: Increase of the capacity of the road by fully utilizing available lanes up to the merge point.

3.2 Safety Needs

Safety refers to the SWZ's capability to minimize the number and severity of traffic-related incidents, injuries and fatalities, and asset damage in the work zone. Safety

strategies are intended to minimize surprise elements and sudden braking, and maximize driver alertness and predictability of driving conditions.

- **Work Zone Speed Limit**: Adjustment of the road's maximum speed according to the current nature, severity, and location of traffic, work zone, and environment conditions. *Regulatory speed limit changes determined on case-by-case basis.
- **Excessive Speed Warning**: Warning to motorists when they are approaching the work zone at unsafe speeds by posting cautionary messages, such as "Exceeded Speed Limit, Reduce Speed Now" or the vehicle's actual speed.
- **Congestion warning**: Warning to motorists upstream of a work zone to slow down when there is stopped or slow traffic ahead.
- **Vehicle Warning**: Warning to drivers about construction vehicles merging into, entering, exiting or crossing the roadway.
- **Clearance Warning**: Warning to over-weight/over-height vehicles of construction-related weight or height restrictions and advise to divert from the route through the construction area.
- **Hazardous Condition Warning**: Warnings to motorists about temporary situations that may cause a hazardous driving condition through the work zone, such as flooding, low visibility (fog, smoke), slippery or rough conditions, and hazards on roadway (falling rock, debris).
- **Intrusion Warning**: Visual and acoustic alert to drivers and workers when an unauthorized vehicle has entered a restricted work area.

3.3 Work Zone Information Needs

SWZ applications described in Sections 3.1 and 3.2 heavily rely on on-site information dissemination devices (e.g. PCMS) to post travel times, travel speeds, delays, alternate routes, work zone conditions, and warnings for drivers to make decisions when driving along the work zone. However, motorists in the vicinity of the work zone are not the only users to be informed. The information disseminated may be shared with others as well, for better work zone operation, coordination and decision support. Such users may include:

- Drivers not yet in the work zone area
- Other state or local DOTs
- Media outlets
- Contractors
- Commercial vehicle operators
- Emergency services providers
- Motorist assistance patrols
- Government and third-party traveler information providers

3.4 Monitoring Needs

Work zone monitoring allows the work zone administrator to make decisions when collected real-time data show that the metrics specified for the project are deviating from predetermined thresholds. Monitoring also refers to the action of overseeing field

equipment, hardware, and software to ensure that collected data and published information are reliable, and that devices and systems are operating as intended.

Monitoring also allows MassDOT to verify the compliance (or lack thereof) with contractual criteria and apply penalties or incentives to the contractor. See Section 5.1 for applicable performance metrics.

3.5 Enforcement Needs

Automated enforcement may provide a cost-effective solution to ensuring compliance of needs described in Sections 3.1 and 3.2. Additional ITS equipment, such as CCTV cameras, photo speed cameras, and license plate recognition technology may be useful to detect and pinpoint aggressive and speeding drivers.

4 DESIGN OF THE SMART WORK ZONE

The IMP shall identify the ITS devices and systems that will address the needs identified in Section 3. The SWZ design also includes evaluation plan to monitor the SWZ performance.

4.1 Work Zone ITS Solutions

The IMP shall identify the ITS solutions that will address the work zone needs identified in the previous section. An ITS solution shall consist of detection and surveillance equipment, central processing system, information dissemination system, and communications and power, as shown in *Figure 2*. A common characteristic of equipment and systems used in SWZ is its portability as work zones are temporary and dynamic environments that require flexible setups.

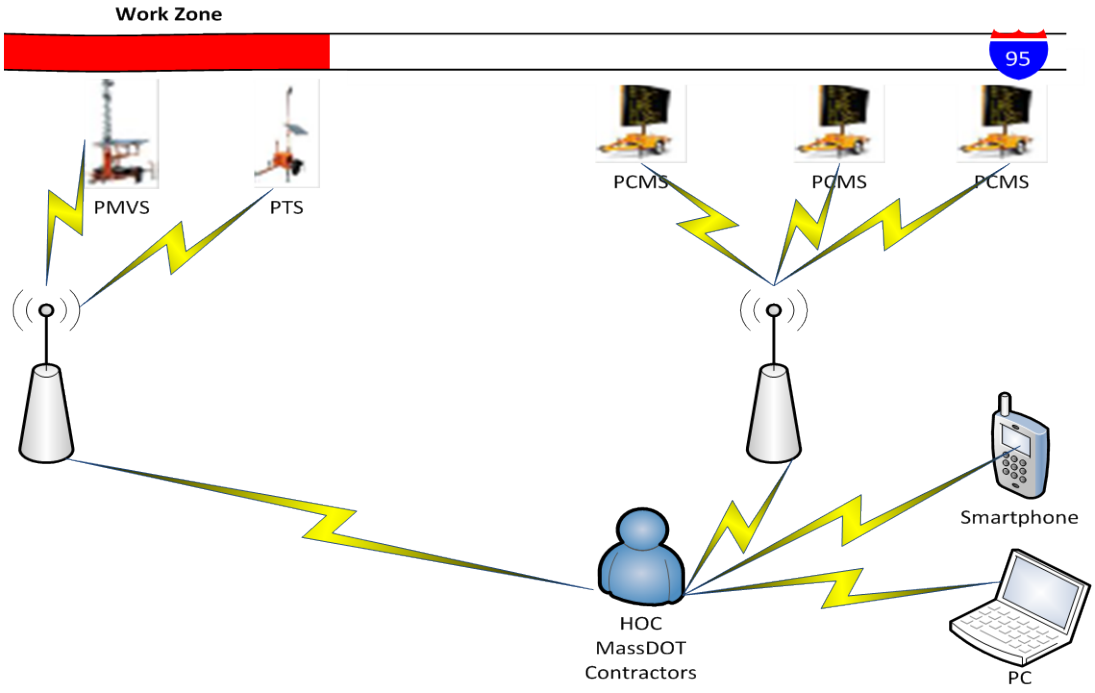


Figure 2 Smart Work Zone Overview

4.1.1 Detection and Surveillance Equipment

Various types of detection and surveillance technology may be used in SWZ. *Table 1* presents the most common technologies utilized.

Table 1 Detection and Surveillance Technologies Used in SWZs

Detection Technology	Collected Data
Radar	Volume, Speed
Pneumatic Road Tubes	Volume, Speed, Classification
Infrared	Volume, Speed, Classification
Acoustical	Volume, Speed
Ultrasonic	Volume, Occupancy
Microwave	Volume, Speed, Classification
Magnetic	Volume, Speed
Piezo-electric	Volume, Speed, Classification, Weight
Image (Video – Photo)	Volume, Video, Photo, Incident
RFID	Volume, Travel Time, Identification
Probe Technology	Volume, Travel Time
License Plate Recognition	Travel Time, Plate Number (for enforcement)
Environmental	Weather data, Road conditions

Although video technology has the capability to automatically detect vehicle passing and incidents, Closed-circuit Television (CCTV) surveillance cameras may also be used by traffic management personnel to monitor the work zone and verify traffic conditions and incidents.

RFID and probe technologies (e.g. cellular signal, Bluetooth, GPS) are adequate technologies as long as the vehicles or drivers have the ability to emit the appropriate signals for the detection devices to read them.

4.1.2 Central Processing System

The central control system is a collection of hardware and software that acts as SWZ computer to control the field devices, use algorithms to analyze and process traffic data, and send information to the output devices and systems. The processing system also includes the databases to store collected data. The processing system may be a located in the work zone, a MassDOT office or a third-party provider facility.

4.1.3 Information Dissemination System

Various types of dissemination devices and systems may be used in SWZ.

- Portable Changeable Message Sign (PCMS): Electronic signs used to display traffic conditions, travel times, incident information, and advisory messages.
- Hybrid Message Sign (HMS): Static signs with a fixed legend and two-character electronic insert for the provision of travel times.

- Highway Advisory Radio (HAR): Broadcasting of travel information in low band, AM frequencies, typically used in conjunction with a static signs or PCMS that tells drivers which frequency to turn to.
- Audible alarms: Acoustic alerts as a complement of visual devices for specific needs (e.g. work zone intrusion).
- Websites: Publication of travel information on MassDOT, 511, and third-party websites for pre-trip planning purposes. They may provide detailed information on speeds, delays, congestion alternate routes, PCMS messages, video images, and contractor schedules.
- 511 Telephone System: Travel information may be relayed to Mass 511 operator to be consulted by drivers.

4.1.4 Communications and power

Given the portability of SWZ equipment, communications commonly use wireless technology to integrate detection devices, central processing system, and dissemination systems. Hard wired communications may be possible if physical connections are available in the work zone area. Communications technology for SWZ may include:

- Wireless Ethernet
- Cellular telephone
- Hard wired cable
- Optical
- Radio frequencies
- Satellite

Battery and solar technologies are typically the power choices for SWZ. As the communications case, hard wired power may be used if available in the area.

4.2 Smart Work Zone Setups

Each combination of ITS elements leads to a different SWZ setup that addresses a specific need, as presented in *Table 1*. Column “Data Requirements” describes the type of data that must be collected for each need. The SWZ designer shall pick a technology from *Table 1* that is capable of collecting such data. The SWZ designer shall also define a central processing system, and communications and power options that better suits each specific setup.

The last column of every need in *Table 1* shows an appendix number to this document that presents a typical setup that may be used as guidance to design the appropriate SWZ setup. Those diagrams are intended as guidelines that should lead to practical solutions by the designer. Dimensions are not drawn to scale, and the location and quantity of devices are merely conceptual, so engineering judgment is required to customize the system to a specific project. The Massachusetts ITS Deployment and Design Guide, and other MassDOT and FHWA documentation provide guidance on devices location, but the designer should always keep in mind that the detection equipment usually extends beyond the limits of the work zone. The designer may propose emerging technologies outside what is recommended in this document as long as functionalities remain intact.

Table 2 SWZ Setups

Need	Specific Need	Data Requirements	Dissemination Device/System	Appendix
Mobility Needs	Travel Time and Delay Estimation	- Speed or Travel Time	- PCMS and/or HMS - Website - 511 Telephone - HAR (Optional)	B
	Alternate Route Advisory	- Speed or Travel Time	- PCMS and/or HMS - Website - 511 Telephone - HAR (Optional)	C
	Dynamic Lane Merge	- Volume - Occupancy	- PCMS - HAR (Optional)	
Safety Needs	Variable Speed Limit	- Speed or Travel Time - Volume - Occupancy - Weather - Road Conditions - Incident (Optional)	- PCMS and/or HMS - HAR (Optional)	
	Excessive Speed Warning	- Speed	- PCMS and/or HMS	
	Congestion warning	- Speed or Travel Time - Volume - Occupancy	- PCMS - Website - 511 Telephone - HAR (Optional)	D
	Vehicle Warning	- Volume - Identification	- PCMS	
	Clearance Warning	- Classification - Weight	- PCMS - Audible Alarm	
	Hazardous Condition Warning	- Weather - Road Conditions	- PCMS - Website - 511 Telephone - HAR (Optional)	
	Intrusion Warning	- Identification	- PCMS - Audible Alarm	
Work Zone Information Needs	N/A	Subject to specific mobility or safety need	Subject to specific mobility or safety need	
Monitoring Needs	N/A	Subject to specific mobility or safety need	Subject to specific mobility or safety need	

Need	Specific Need	Data Requirements	Dissemination Device/System	Appendix
Enforcement Needs	N/A	- LiDAR or Radar / Speed Reader Board	- PCMS - HAR (Optional)	

The SWZ designer shall include collection of video feed from all work zones regardless the addressed need in order to ensure continuous monitoring, incident and conditions verification, and support on incident response activities.

Additional considerations shall be taken into account when designing a SWS setup:

- An IMP shall be prepared specifically for each construction project categorized at impact Levels 3 or 4, Significant Project Status, or requested discretionally by the State Traffic Engineer. The IMP shall be submitted as part of the 75%, 100%, PS&E project deliverables. The IMP shall include:
    - Work zone needs to address
    - Proposed devices and systems plans, specifications, and locations
    - Data to be collected
    - Central processing system specifications
    - Communication and power systems specifications
    - SWZ deployment plan
        - Physical deployment plan
        - Operational Testing plan
        - Training and support plan
    - SWZ operation and maintenance plan
    - SWZ evaluation plan (see Section 5.1)
- The SWZ design shall incorporate adequate flexibility given work zones highly variable environments, temporality, and potential need for adjustments during deployment.
- SWZ design shall be prepared by professional engineers with appropriate training and experience. SWZ must be designed in accordance with the general guidelines contained in this document, and include details outlined by MassDOT for each individual construction project.

5 PREPARATION OF THE SMART WORK ZONE

The first step of SWZ deployment is to review the SWZ design and plan for equipment installation. The design provided in a contract should meet MassDOT's SWZ Design Standards, but it may not specify all of the details required to implement a SWZ. For example, MassDOT may describe the data that needs to be collected and allow the contractor to decide which technologies to use. MassDOT may also allow the contractor to set the construction schedule and phasing. The contractor is ultimately responsible for ensuring that the SWZ deployment meets contractual obligations and MassDOT standards, so the contractor must revisit the design and proposed approach before deployment.

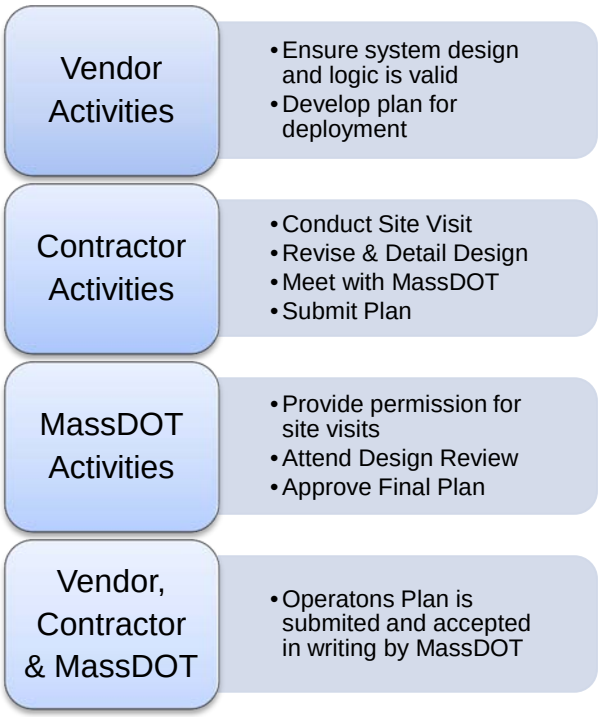


Figure 3: Preparation for Smart Work Zone Deployment

The following steps can be taken:

1. Review the proposed construction schedule and confirm that the SWZ design provides adequate coverage for each phase. If construction activity will move, plan SWZ set-ups for each configuration, relocating equipment as necessary.

2. Identify equipment to be used on the job. Confirm that the proposed equipment on the SWZ design is adequate, that is, ensure that it meets the contractual obligations and work zone requirements, discussing any discrepancies or changes with MassDOT.

3. Check the manufacturers' guidelines for installation and operation requirements.

4. Coordinate with MassDOT to schedule a visit to the work site. concluding

5. At the site, visit the proposed location for each device (use coordinates provided by designers). Check that the equipment location is[2]:

    a) In compliance with manufacturers' guidelines.
    b) Located outside clear zones unless approved by MassDOT.
    c) Protected with barriers (such as guardrails or concrete barriers) when practical and does not interfere with the devices' intended capabilities.
    d) Placed on level and firm ground.

[2] These location guidelines are also taken into account for the design of the SWZ. However, site conditions may change between the design period and the deployment and operation periods. The contractor must ensure that the standards are still met.

e) Located where it can be easily installed, uninstalled, moved, and maintained with minimal disruption to traffic.
f) Not impacting wetlands.
g) Not disrupted or obstructed by bridges, trees, rock walls, etc. This is especially critical for wireless communications and solar power.
h) Located in such a way that it can satisfy the applications or purposes for which it was intended, including more than one if required. Ensure that:

i. Cameras provide good sight coverage of the relevant location. Cameras should avoid blind spots, seasonal sun-blindness, and visual obstructions (bridges, overpasses, viaducts, foliage, buildings, etc.). Placement of cameras on the outside of a highway curve usually provides better visual coverage. Use a bucket truck or similar lifting device to check the actual coverage that the camera would provide.

ii. Detection equipment is placed in a way that guarantees collection of accurate data. When placing detection equipment take into account:

- Orientation, distance, and height of the device with respect to the traffic
- Spacing between devices
- Extreme congestion with stop-and-go traffic conditions
- Presence of obstructing structures such as bridges, median barriers, and signs

iii. Signs (PVMS and HMS) are correctly placed. Make sure that signs:

- Meet MassDOT minimum spacing requirements. If minimum spaces are not possible, it may be necessary to strategically co-locate signs or use one sign for multiple purposes.
- Be placed in locations where motorists would find them useful, typically before major decision points (e.g. exits or intersections), with enough advance warning that motorists can safely change course.
- Be visible and understandable to motorists at a reasonable site distance despite embankments, medians, slopes, and sunlight exposure present in the area.

6. Prepare a general deployment schedule, indicating the activities required to deploy, initialize and test the equipment.

7. Meet with MassDOT to present the planned approach and deployment schedule. During this meeting, present the field visit results, updated site plans, data

collection plans, and an equipment phasing schedule. Be prepared to justify any changes to the original design or specifications.

8. When the plan is approved by MassDOT (this may require a period of time and several discussions with MassDOT), procure the SWZ equipment.

9. Complete licensing and registration of new trailers with the RMV. Check with RMV for the required documentation (e.g. Certificates of origin, vehicle information sheets, RMV forms). If trailers are already licensed, ensure they are properly registered in the US.

10. Coordinate with MassDOT and other contractors within the contractor team as necessary to plan the site preparation, equipment installation, integration, and testing. **See Section 5.1 Deployment*

11. Setup contracts for communication services, such as FCC licensing, cellular telephone, wireless data networks, satellite and Internet subscriptions.

12. Configure the central processing system and ensure that it is prepared to receive, analyze, archive, and disseminate data and meet contractual requirements.

13. Set up a SWZ web interface for monitoring the work zone. The web interface must include at least the following:

    a) Continuous operation (24 hours a day, 7 days a week) for the duration of the project, unless otherwise directed by MassDOT.
    b) Full color map depicting the project area with locations of field equipment. The map must reflect the current traffic conditions (e.g. travel time, delay, and queues) at each detector location, the messages being shown by each PVMS and HMS, and equipment operational status.
    c) Video images from the cameras on the work zone.
    d) Capability to manually override devices, messages and systems.
    e) Monitoring of equipment and systems to detect malfunction in devices, power, and communications.
    f) Submission of alerts to designated personnel when equipment and systems malfunction. Alerts include communications disruptions, loss of power, low battery, etc.

    g) Multiple user types with different access and permission levels to applications and actions.

14. Verify with MassDOT the level of access and privileges of the agency staff to view data and video, and control and monitor the work zone through the web interface.

15. Assign usernames and passwords to MassDOT personnel according to each person's privileges.

5.1 Evaluation plan

The IMP shall include an evaluation plan with specific, measurable and attainable metrics to establish the degree of usefulness of the proposed SWZ. The specific measures tracked shall be aligned with the needs and SWZ setup defined previously. Metrics may be used to make changes to the SWZ during deployment and operation stages, as well as to the work zone itself.

Typically, metrics of a SWZ can be categorized as follows:

- Mobility
  - Travel time
  - Delay
  - Rate of diversion (traffic volumes on mainline and alternate routes)
  - Speeds
  - User satisfaction with travel through the work zone(surveys)
  - Queue lengths
- Safety
  - Number of incidents
  - Incident severity
  - Citations
  - Reduction in observed aggressive maneuvers and forced merges
- Dissemination of information
  - User satisfaction with disseminated information (surveys)
  - Penetration of alternate dissemination systems (HAR, website, 511)
- System performance
  - Collected and published data accuracy
  - Collected and published data availability
  - Error logs
  - Devices and system status
  - Down time
  - Productivity
  - Workers' exposure to hazards
  - Construction efficiency

Additional considerations shall be taken into account when developing the evaluation plan:

- The IMP shall determine acceptable thresholds and ranges for selected metrics, according to:
  - Work zone location and size
  - MassDOT and FHWA regulations
  - Road capacity
  - Day of the week and hour of the day
  - Accident rate in the area
  - Historic information
  - Anecdotal evidence from MassDOT operations and planning staff

- The IMP shall determine the periodicity of metric estimation and reporting to MassDOT.
- The IMP shall describe the data sources and computation method for every metric.

6 DEPLOYMENT OF THE SMART WORK ZONE

Once MassDOT has approved the design, the entire SWZ setup shall be deployed according to the SWZ deployment plan. SWZ deployment shall have three components:

- Physical deployment
- Testing
- Training and support

6.1 Physical Deployment

The physical deployment (installation) of field equipment and the provision of ancillary services should occur within a week of construction activity or as required by contract. This step should be coordinated with MassDOT Districts and other contractors on the site. Deploy equipment according to the following steps:

1. Prepare the locations to receive the equipment in accordance with the site visit findings and the updated design.

2. Coordinate the delivery of the devices and mobilize them off-site. Coordinate with MassDOT if a MassDOT facility should be used. Coordinate with MSP, if required.

3. Prepare the devices as directed by the manufacturer:

    a) Assign a unique ID, name, and IP address to each device.
    b) Install support hardware, such as trailer, hydraulic lift, display, keyboard, controller, GPS, etc.
    c) Install and update equipment software and firmware, including library messages and control applications.
    d) Install communications equipment and systems, such as modems, wireless data networks, base stations, cell phone data interfaces, Ethernet network interfaces, internet interfaces, and security protocols.
    e) Install power equipment, such as solar panels, battery or continuous power sources.
    f) Install security elements, such as padlocks, to prevent unauthorized access to cabinets and configuration systems.
    g) Furnish and install other elements required by the project's contract.

4. Test the individual components and systems before installation in the field to ensure components are operational and fully functional before deployment in the field.

5. Install the equipment in the field, coordinating with MassDOT districts as needed to gain shoulder access and coordinate lane closures.

6.2 Testing

Test the SWZ system to ensure that it complies with the design and the contract. Individual equipment testing should be conducted off-site (e.g. depot, warehouse) and on-site (work zone). SWZ system testing conducted on-site must be approved by MassDOT prior to testing. Test the SWZ according to the following steps:

1. Develop an Operations Test Plan and reporting mechanism for submitting records of the tests to MassDOT.

2. The contractor shall test the SWZ setup to ensure it is operating as designed, including but not limited to:
   a) System functionality
   b) System performance
   c) Data availability, reliability, and storage
   d) System failure
   e) Communications and power

3. The contractor shall maintain records of the tests results and submit reports to MassDOT detailing the daily activity during the operational test.

4. Testing Reports should include:

   a) Tested requirements
   b) Minimum pass/fail criteria
   c) Test result discrepancy
   d) Testing equipment used

   Table 3 and *Table 4* provide sample criteria for testing detection and surveillance equipment and dissemination equipment, respectively.

5. During the testing period, if any equipment or system malfunctions or is damaged due to crashes, vandalism, adverse weather, etc. during the operational test, the contractor shall conduct the necessary activities to fix the anomaly. The contractor shall report:

   a) Date and time of malfunction
   b) Identification of the defective equipment or system
   c) Cause of equipment or system malfunction
   d) A description of the type of work performed
   e) Time required to repair or replace the equipment or system
   f) Field testing results

Table 3: Test Criteria for Detection and Surveillance Equipment

Equipment	Testing criteria
Traffic Sensor[3]	- Device is detecting individual passing vehicles. - Device is collecting correct data (e.g. volume, speed, occupancy, classification, weight, motion). - Device can be operated and data can be viewed locally at the device's cabinet.
Video cameras	- Camera has pan-tilt-zoom capabilities. - Camera has the capability to configure "presets", each with defined pan/tilt position, zoom and focus settings. - Camera has image stabilization capabilities. - Camera has image processing capabilities for low light conditions and balance of light and dark areas. - Camera can be controlled and video images can be viewed locally at the device's cabinet.
Short-Range Transmitter Receiver Systems[4]	- Device is capturing electronic signals of passing vehicles. - Device can be operated and data can be viewed locally at the device's cabinet.
Vehicle Probes	- Device is collecting correct data (e.g. speed, location).
Environmental	- Device is collecting correct data (e.g. weather). - Device can be operated and data can be viewed locally at the device's cabinet.

Table 4: Testing Criteria for Dissemination Equipment

Equipment	Testing criteria
Portable Variable Message Sign (PVMS)	- All sign LEDs are fully functional. - When turned off or blanked, all LEDs are off. - Device automatically adjusts visibility for low light conditions or nighttime operations. - Device can be operated and messages can be posted and overridden locally at the device's cabinet. - Phase duration is at least one second per word. - Device is visible from ¼ mile and letters on the device are legible from 800 feet.
Hybrid Message Sign (HMS)	- All sign LEDs are fully functional. - When turned off or blanked, all LEDs are off. - Device automatically adjusts visibility for low light conditions or nighttime operations. - Device can be operated and messages can be posted and overridden locally at the device's cabinet. - Device is visible from ¼ mile and letters on the device are legible from 800 feet.

[3] Many technologies exist including Radar, Microwave, Pneumatic Road Tubes, Infrared, Acoustical, Ultrasonic, Magnetic, and Piezo-electric. Radar and Microwave are the most common at MassDOT.
[4] There are many different technologies. Radio Frequency Identification (RFID) and Bluetooth are the most common at MassDOT.

Highway Advisory Radio (HAR)	- Information is broadcast in the correct AM frequency. - Broadcast range covers at least the closest upstream decision point.
Audible alarms	- Alarm sounds at 125 dB for at least 15 seconds.

6. Test ancillary services (communications and power).

    a) Verify that the device's modem is sending and receiving data to/from the SWZ web interface.
    b) Verify that communications are reliable (e.g. sufficient bandwidth during peak periods).
    c) Verify that solar panels are adequately installed and batteries are charging.
    d) Verify that power source is reliable (e.g. sufficient battery size), as evidenced in provided power calculations provided by the designer.

7. Test SWZ data collection, dissemination, and archiving functionalities. See Section 7.6 for data collection and archiving requirements and criteria.

8. Test the SWZ setup as a whole from the public viewpoint, that is, test the accuracy of data and information disseminated to the public through on-site devices (PVMS, HMS, HAR, Alarms). The following table (Table) provides suggested testing methodologies and results for each SWZ application[5]:

Table 5: Testing Criteria for Smart Work Zone Functions

Application	Testing methodology	Required Result
Driver Alerts	- Observation of posted messages	- Clear messages
Travel Time and Delay Estimation	- Floating vehicle - Comparison of travel times to those provided by external sources (e.g. Google, INRIX, Traffic.com), if matching segments available	- Published travel time or delay through the work zone is 95% accurate
Alternate Route Advisory	- Floating vehicle - Comparison of travel times to those provided by external sources (e.g. Google, INRIX, Traffic.com), if matching segments available	- Published travel times are 95% accurate
Dynamic Lane Merge	- Use of detection devices' internal software*	- Messages directing motorists to use all open lanes up to a metered merge point - Messages directing motorists to merge at the merge point

[5] See the *Smart Work Zone Design Standards* document for a detailed description of the mobility and safety SWZ applications that disseminate data and information to the public.

Application	Testing methodology	Required Result
Congestion Warning	- Drive through congested road (if available before initiating works) - Use of detection devices' internal software*	- Messages recommending motorists to take alternate routes - Messages warning motorists upstream of the work zone to slow down
Excessive Speed Warning	- Detection of speeding vehicles during SWZ operation - Use of detection devices' internal software*	- Messages warning motorists about their unsafe speeds - Messages indicating the vehicles' actual speeds
Vehicle Warning	- Construction vehicle merging into, entering, exiting, or crossing the roadway	- Messages and audible alarms warning motorists about construction vehicles merging into, entering, exiting, or crossing the roadway
Clearance Warning	- Oversized vehicles driving through the detection zone - Use of detection devices' internal software*	- Messages and audible alarm warning motorists and workers about construction-related weight, height, or width restrictions. - Messages urging motorists to exit the road
Hazardous Condition Warning	- Detection of hazardous conditions during SWZ operation - Use of detection devices' internal software*	- Messages recommending motorists to take alternate routes - Messages warning motorists about hazardous situations
Intrusion Warning	- Unauthorized/unidentified vehicle entering the restricted area	- Messages and audible alarm warning motorists and workers about an unauthorized entering the work area - Messages urging the motorists to stop or abandon the work zone
Enforcement	- Detection of speeding vehicles during SWZ operation - Use of detection devices' internal software*	- Messages indicating the vehicle actual speed and enforcement activities.

* Some applications cannot be tested under real conditions until the work zone is in operation. Devices' internal software can be used to mimic the desired traffic conditions by generating artificial inputs and measuring the outputs (e.g. PVMS/HMS messages, audible alerts) to verify that the requirements have been met.

9. Test additional software (e.g. programming, firmware) and hardware (e.g. cabling, mechanical connections) requirements as indicated by manufacturers and the project's contract.

10. The contractor, under MassDOT supervision, shall validate the accuracy of collected and published data through various means, such as manual observation of field volumes and probe vehicles to measure travel time and delays.

11. Set up on-site and/or off-site demonstration of the SWZ for MassDOT personnel if requested.

12. Once the operational test report and in-situ demonstration are approved by MassDOT, the SWZ system will be considered operational and the system will be accepted for use.

6.3 Training and Support

Training and support ensures that SWZ operation knowledge is transferred to MassDOT for monitoring and oversight purposes.

1. Set up training sessions for MassDOT personnel that will monitor, operate, and control the SWZ.

2. Design the training sessions as hands-on, practical exercises utilizing the actual installed equipment when possible.

3. The contractor shall provide MassDOT with login information (users and password) according to access privileges (see Section 7.8), as well as procedures to use the SWZ web interface

4. Furnish MassDOT with procedures, manuals, notes, and other materials necessary for the SWZ operation including but not limited to:

    a) Data monitoring, video viewing, and device control procedures
    b) Contents and format of posted messages
    c) Instructions to override messages on PVMS in the event of an emergency
    d) Instructions to troubleshoot the system in the event of a power failure, communications, and equipment failure
    e) List of telephone numbers to request technical support

5. Conduct follow-up training sessions in order to address operational issues or additional training if requested by MassDOT.

6. Coordinate with MassDOT Public Information Office to determine ways to educate the public about the dissemination tools (e.g. project's website, MassDOT website, Mass 511 website) if necessary and available.

7 OPERATION AND MAINTENANCE OF THE SMART WORK ZONE

The contractor shall operate and maintain the SWZ setup according to the SWZ operation and maintenance plan:

1. The contractor shall perform routine inspection, and corrective and preventive maintenance of the SWZ equipment and systems.
2. ITS equipment and systems shall be capable of autonomously restarting to normal operations when communications or power is resumed after a failure.

3. The contractor shall relocate, uninstall, and remove SWZ elements if the field conditions require it, without compromising the setup performance. Modifications shall be approved by and coordinated with MassDOT.
4. If any equipment or system malfunctions or is damaged due to crashes, vandalism, adverse weather, etc. during regular operation, the contractor shall conduct the necessary activities to fix the anomaly. The contractor shall report:

    a) Date and time of malfunction
    b) Identification of the defective equipment or system
    c) Cause of equipment or system malfunction
    d) A description of the type of work performed
    e) Time required to repair or replace the equipment or system
    f) Field testing results

7.1 Operation of Detection and Surveillance Equipment

1. The detection devices shall continuously send data to the central processing system.
2. Flaggers, police officers, and construction workers may also be used as detection sources. For instance, they may operate devices to identify construction vehicles, which is an input for intrusion and vehicle warning applications.
3. The contractor shall maintain equipment unobstructed and in operating conditions to ensure appropriate data collection.

7.2 Operation of Information Dissemination Systems

1. Data received from the central processing system shall be continuously published.
2. Audible alarms should be used for application in which non-compliance with posted messages may lead to serious incidents (e.g. oversized vehicle restriction, work zone intrusion).
3. PCMS used in temporary ITS applications (e.g. dynamic lane merge, congestion warning, vehicle warning, clearance warning) should post alternative messages when the primary application is no needed (e.g. no congestion, no construction vehicle entering or exiting). Messages for other ITS applications, such as travel times and advisory messages, should be posted instead of having a blank PCMS.
4. Dissemination devices, such as PCMS and HMS, shall not override or replace required static signs as stipulated by MUTCD.

7.3 Operation of the Central Processing System

1. For suitable applications (see Section 4.2), the central processing system shall send XML and video feeds to the websites publishing the project's information.
2. Raw and processed data shall be formatted and archived according to the construction contract and MassDOT standards.
3. The central processing system shall send alerts to designated personnel (see Section 7.8) when evaluation plan's metrics are deviating from the established thresholds.

7.4 Operation of Communications and Power

1. The SWZ design shall ensure reliable communications, such as sufficient bandwidth during peak periods.
2. The contractor shall ensure the provision of communication services, such as FCC licensing, cellular telephone, wireless data networks, satellite and Internet subscriptions.

7.5 Monitoring

The work zone must be monitored to better understand how construction affects traffic flow and safety, and to help develop work zone policy and planning for future projects. Use the following guidelines for monitoring:

1. Define a monitoring schedule:

    a) Schedule periodic checks of video and travel time during the work zone regular operation hours.

    b) Monitor video and travel time continuously during congestion periods and when an incident has occurred.

2. If a traffic incident is detected, notify MassDOT immediately through the established channels.

3. When congestion conditions are detected:

    a) Determine the cause of congestion and act accordingly (e.g. notify MassDOT of a traffic incident).
    b) Coordinate with MassDOT to determine whether the construction works must be suspended until flow rates return to normal.
    c) If construction work must continue, verify that the system is disseminating the appropriate information.
    d) Determine if the cause and magnitude of congestion deserve overriding automatic messages on dissemination outlets.
    e) Continue to monitor the situation.
    f) If in manual message mode, verify that the disseminated information is returned to the automatic mode once the congestion has been cleared.

4. Log other events when detected manually (e.g. traffic incident, queue length and duration).

5. If equipment, systems, communications or power damage or failure is detected, notify MassDOT immediately and follow maintenance procedures.

7.6 Data Management & Archiving

The SWZ will collect, disseminate, and archive data and video. The following guidelines show how to handle data and video, unless otherwise specified in contract documents:

1. Ensure that detection devices send data to the central processing system at least every 60 seconds except when a response action is required immediately (e.g. clearance warning, intrusion warning). In that case, the alarm should be sent upon detection.

2. Ensure that video images are viewable on the web interface at a rate of no less than one frame per second.

3. Ensure that data and messages on PVMS and HMS are updated at least every three minutes except when a response action is required immediately (e.g. clearance warning, intrusion warning). In that case, the message should be sent upon detection.

4. Ensure that data on the SWZ web interface is updated at least every three minutes.

5. Ensure that the XML feed for public websites (project, MassDOT, 511) is updated at least every three minutes.

6. Consolidate, process, and store collected data for all hours that the construction site is in place. Prepare reports for MassDOT in spreadsheet or database format with the data types shown in the following table.

Table 6: Data to Be Reported to MassDOT

Data Type	Units	Interval
Travel Time and/or Delay	min	5 minutes
Speed	mph	1 minute
Volume	PCE per unit time	1 minute
Classification	Vehicle class per unit time	1 minute
Capacity	vphpl	1 hour
Queue length	feet	Occurrence
Queue duration	min	Occurrence

7. Consolidate and store collected video with time stamps for all hours that the construction site is in place.

8. Consolidate PVMS, HMS, HAR messages and audible alarms disseminated with time stamps for all hours that the construction site is in place.

9. Submit data and video reports to MassDOT periodically during the construction project. Define submission frequency, format, and medium (e.g. DVD/CD, email) with MassDOT.

7.7 System Maintenance

The contractor must maintain the SWZ elements and repair malfunctions. Conduct the following activities as required:

1. Perform and report maintenance activities during the operation of the SWZ:

    a) Routine inspection
    b) Preventive and scheduled maintenance
    c) Software and firmware updates and upgrades
    d) System monitoring
    e) On-site support when failure is detected or reported by MassDOT
    f) On-call support when requested by MassDOT

2. If any equipment or system malfunctions or is damaged due to crashes, vandalism, adverse weather, etc. conduct the necessary activities to repair/replace the equipment within the time frame specified in the contract.

3. Remove SWZ equipment when work is complete and relocate or reinstall as required by MassDOT and contract documents.

7.8 Smart Work Zone Supervisory Chain

1. The contractor shall be the primary operator of the SWZ and should designate a Local System Manager to serve as the point-of-contact with MassDOT.
2. MassDOT shall designate the SWZ system point(s) of contact for communication on system operation and trouble-shooting efforts.
3. Depending on the project requirements, the SWZ may be required to provide data, and control and monitoring capabilities to the MassDOT traffic engineer, the MassDOT project manager, the MassDOT District Construction Office, MassDOT's Highway Operations Center, and/or other MassDOT offices in downtown Boston.
4. The contractor shall verify with MassDOT the level of access and privileges regarding communications, data feeds, video feeds, alarms and notifications, control of CCTVs, or other connection to the SWZ devices.
5. According to the established privileges, the contractor shall provide access through a web interface (Internet website) with password-controlled levels of control and data access.
6. The contractor, under MassDOT supervision, shall periodically validate the accuracy of collected and published data through various means, such as manual observation of field volumes and probe vehicles to measure travel time and delays.
7. MassDOT shall designate staff to receive and analyze the evaluation plan metrics reports for the application of penalties and incentives.

8 REFERENCES

8.1 Federal/State Laws and Code

- 23 CFR 630 Subpart J-- Work Zone Safety and Mobility, FHWA
  http://www.ops.fhwa.dot.gov/wz/resources/final_rule.htm

- "Final Rule on Work Zone Safety and Mobility," Federal Highway Administration (FHWA), Effective Date October 12, 2007
  http:// www.ops.fhwa.dot.gov/wz/resources/final_rule.htm

- Manual on Uniform Traffic Control Devices (MUTCD), FHWA
  http://mutcd.fhwa.dot.gov/

- SAFETEA-LU section 1201, FHWA
  http://www.fhwa.dot.gov/safetealu/factsheets/realtimesmi.htm

- Best Practices in Project Delivery Management. NCHRP Domestic Scan Team Report 07-01, Project 20-68A. TRB, National Research Council, Washington, DC. October 2009.
  http://onlinepubs.trb.org/onlinepubs/nchrp/docs/nchrp20-68a_07-01.pdf

8.2 Design Guidance

- ITS Safety and Mobility Solutions--Improving Travel Through America's Work Zones,
  http://www.atssa.com/galleries/defaultile/2008July21_ITS_Safety_and_Mobility.pdf

- MassHighway Standard Details and Drawings for the Development of Temporary Traffic Control Plans, MassDOT
  http://www.massdot.state.ma.us/portals/8/docs/flaggers/tcp.pdf

- AASHTO Guidelines For Traffic Data Program, USDOT
  https://bookstore.transportation.org/item_details.aspx?id=1392

8.3 Supplemental Documents

- ITS in Work Zones, FHWA
  www.ops.fhwa.dot.gov/wz/its/

- Work Zone Analysis Series, FHWA
  http://ops.fhwa.dot.gov/wz/traffic_analysis/techresources.htm

- Work Zone Performance Measures Pilot Test, FHWA
  http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop11022/fhwahop11022.pdf

- A Primer On Work Zone Safety And Mobility Performance Measurement, FHWA
  http://www.ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/fhwahop11033.pdf
- Work Zone Operations Best Practices Guidebook, FHWA
  http://www.ops.fhwa.dot.gov/wz/practices/best/bestpractices.htm

- Minnesota IWZ Toolbox, FHWA
  http://wwwcf.fhwa.dot.gov/exit.cfm?link=http://www.dot.state.mn.us/trafficeng/workzone/iwz/MN-IWZToolbox.pdf

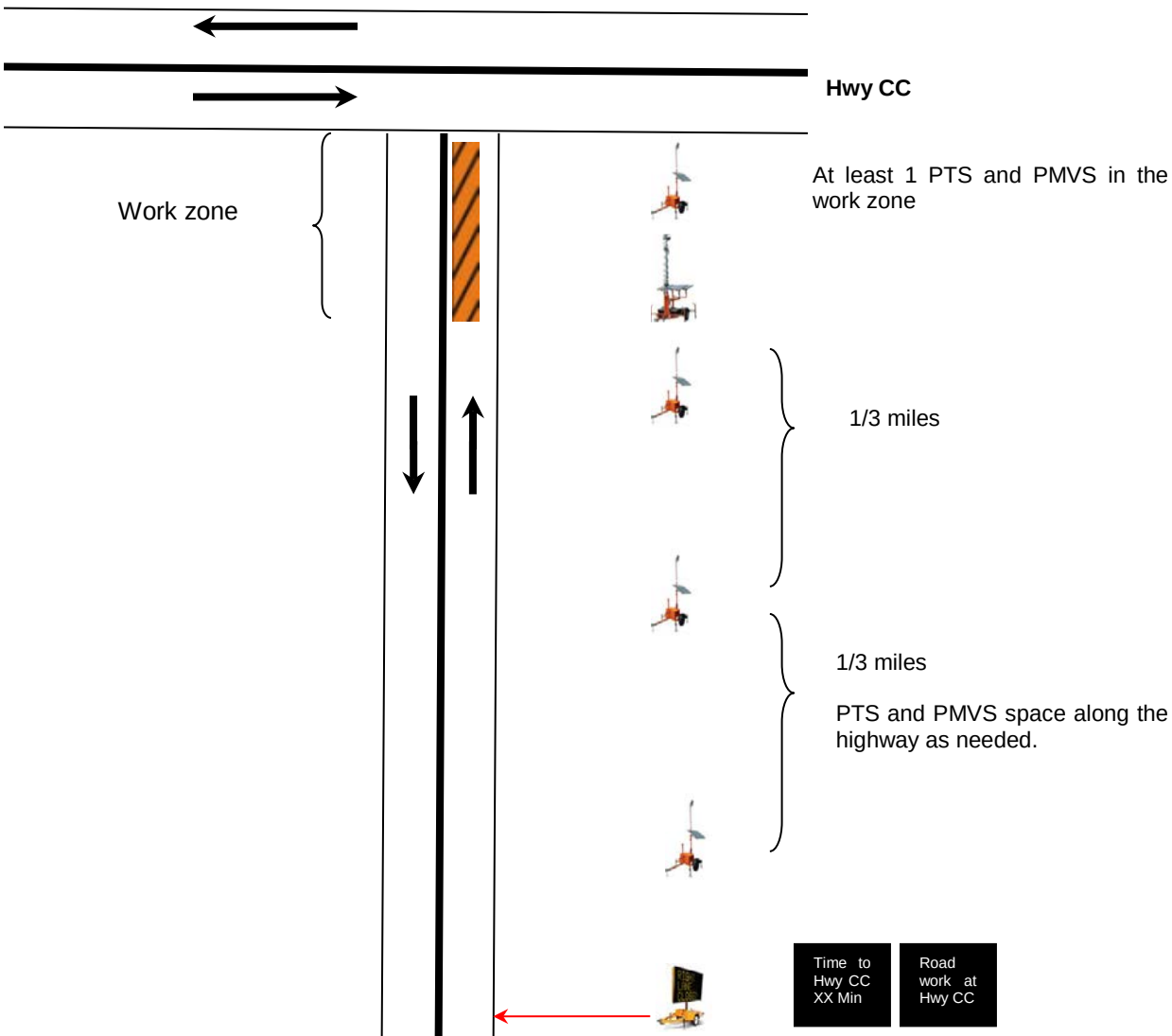
- In Case Of Fire--Technology Helps Clear A Path For First Responders
  http://www.ops.fhwa.dot.gov/wz/resources/news/wznews_detail.asp?ID=479

- ITS Deployment and Design Guide June 2011, MassDOT

- Strategic Plan for Massachusetts Statewide Traffic Data Collection and ITS Traffic Monitoring, MassDOT

- IWZ Presentation from ATSSA Conference- February 2008
  http://wwwcf.fhwa.dot.gov/exit.cfm?link=http://www.dot.state.mn.us/trafficeng/workzone/iwz/PlantingSeedMoney.ppt

APPENDIX A. MOBILITY SURVEILLANCE SWZ LAYOUT



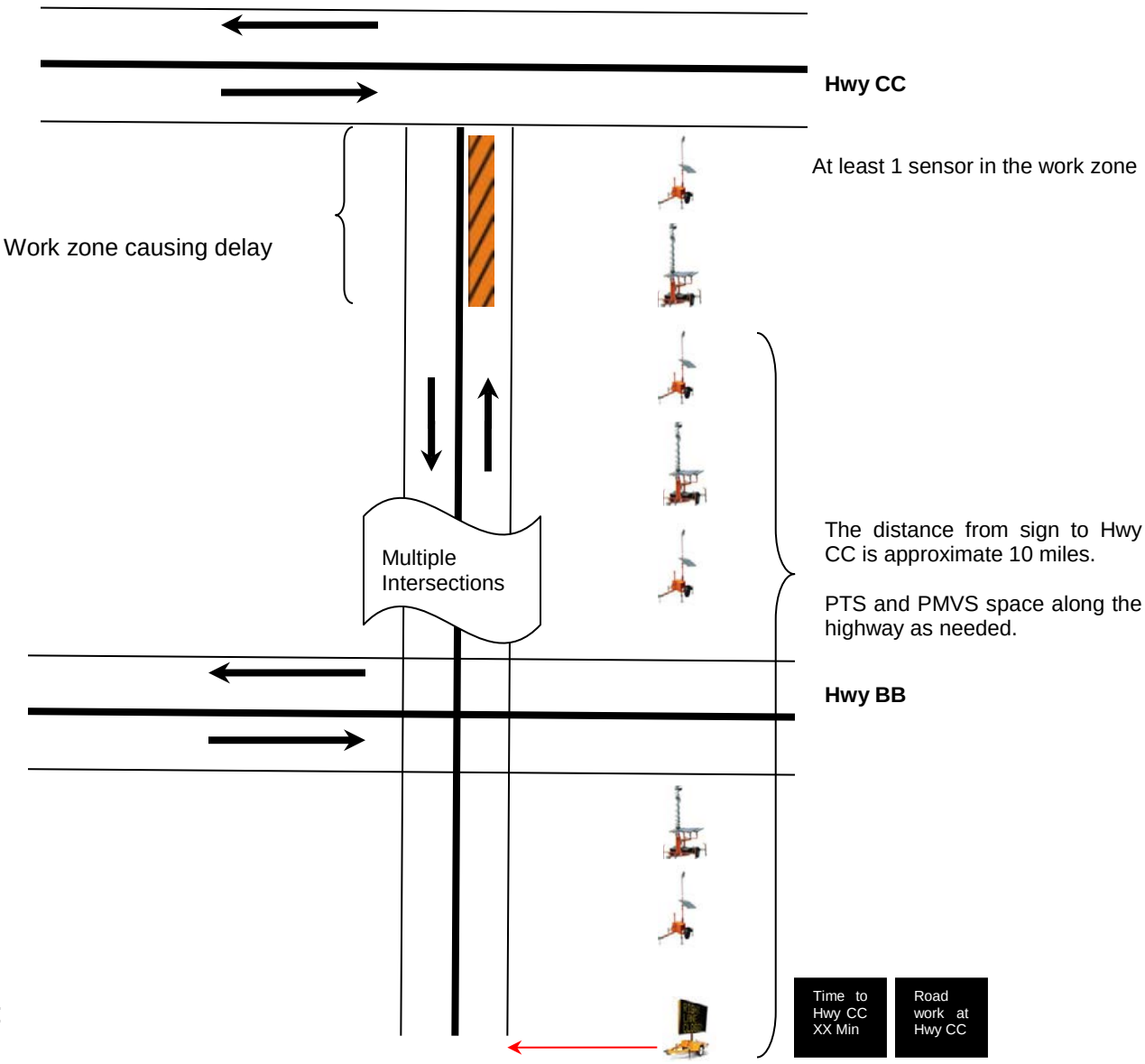
Legend:

- Portable Traffic Sensor (PTS)
- Portable Video Cameras System (PMVS)
- Portable Message Sign (PMS)
- Construction Zone

Notes:

1. The above setup is for work zone monitoring and does not replace traffic control devices installed as MUTCD and MassDOT standards.
2. The location of the portable equipment shall not conflict with or obstruct view of any existing and/or proposed permanent and/or temporary traffic control devices.
3. Layouts are not drawn to scale.
4. The number of PTS and PMVS shown above are not accurate but for illustration.

APPENDIX B. TRAVEL TIME INFORMATION SWZ LAYOUT



Legend:

Portable Traffic Sensor (PTS)

Portable Video Cameras System (PMVS)

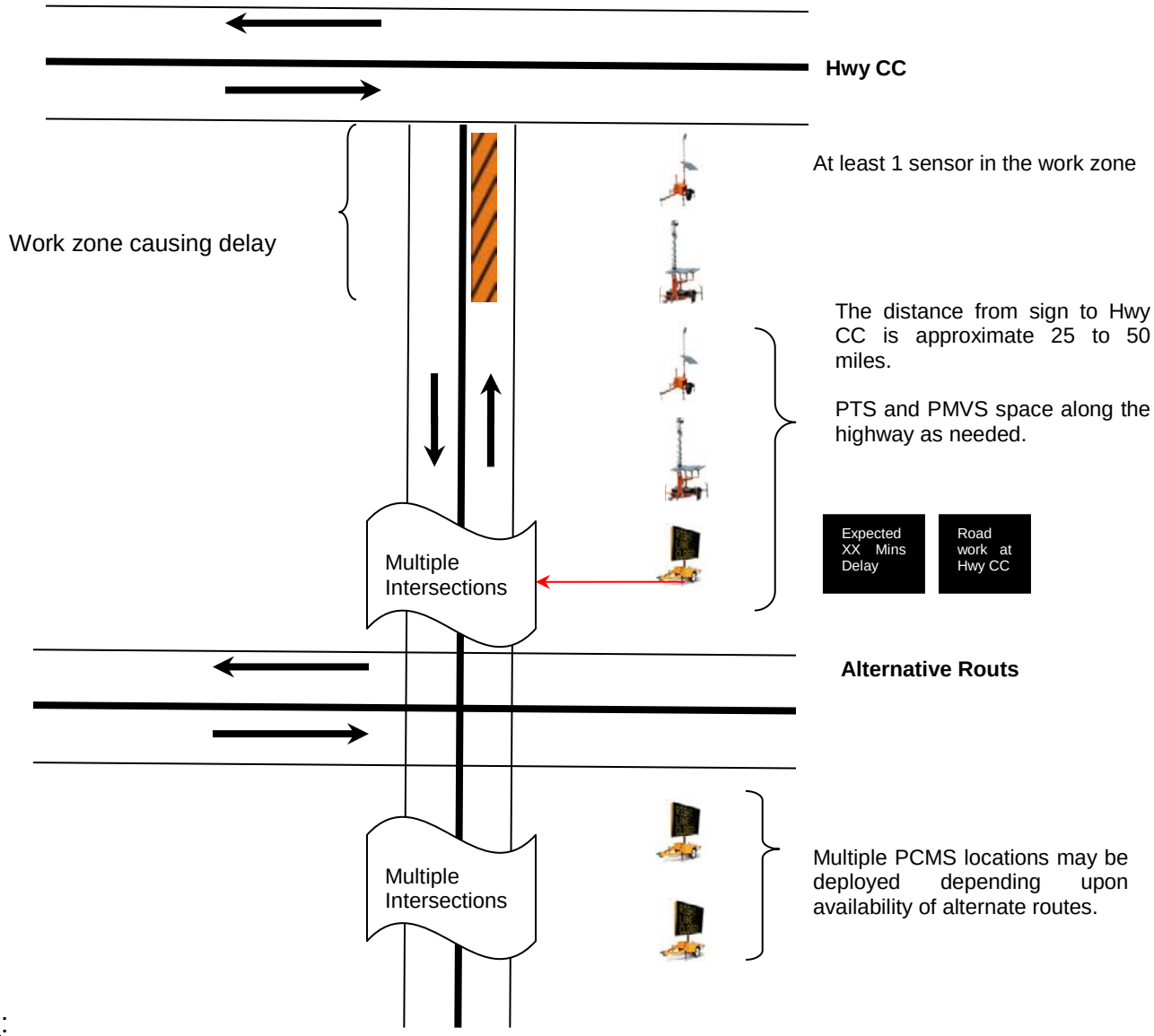
Portable Message Sign (PMS)

Construction Zone

Notes:

1. The above setup is for work zone monitoring and does not replace traffic control devices installed as MUTCD and MassDOT standards.
2. The location of the portable equipment shall not conflict with or obstruct view of any existing and/or proposed permanent and/or temporary traffic control devices.
3. Layouts are not drawn to scale.
4. The number of PTS and PMVS shown above are not accurate but for illustration.

APPENDIX C. EXPECTED DELAY INFORMATION SWZ LAYOUT



Legend:

Portable Traffic Sensor (PTS)

Portable Video Cameras System (PMVS)

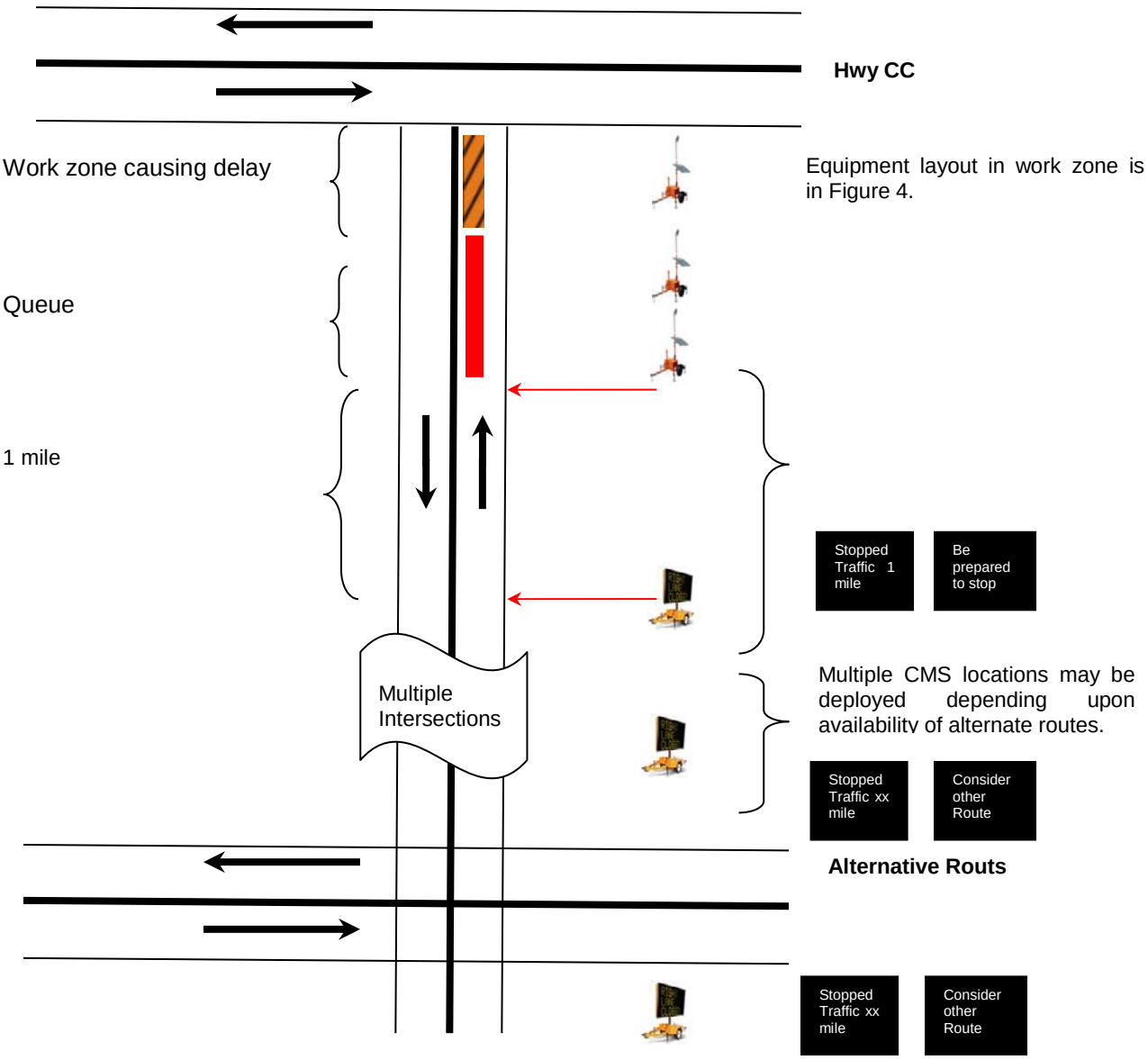
Portable Message Sign (PMS)

Construction Zone

Notes:

1. The above setup is for work zone monitoring and does not replace traffic control devices installed as MUTCD and MassDOT standards.
2. The location of the portable equipment shall not conflict with or obstruct view of any existing and/or proposed permanent and/or temporary traffic control devices.
3. Layouts are not drawn to scale.
4. The number of PTS and PMVS shown above are not accurate but for illustration.

APPENDIX D. STOPPED OR SLOW TRAFFIC SWZ LAYOUT



Legend:

- Portable Traffic Sensor (PTS)
- Portable Video Cameras System (PMVS)
- Portable Message Sign (PMS)
- Construction Zone

Notes:

1. The above setup is for work zone monitoring and does not replace traffic control devices installed as MUTCD and MassDOT standards.
2. The location of the portable equipment shall not conflict with or obstruct view of any existing and/or proposed permanent and/or temporary traffic control devices.
3. Layouts are not drawn to scale.
4. The number of PTS and PMVS shown above are not accurate but for illustration.
5. When no queue is detected, all the PCMS should be blank unless used for another SWZ system.
6. When the queue extends beyond any PCMS location, the PCMS should be blank, or it may be utilized for another SWZ system.