ENTERPRISE Transportation Pooled Fund Study TPF-5 (231)

ENTERPRISE

Real-Time Integration of Arrow Board Messages into Traveler Information Systems

MODEL CONCEPT OF OPERATIONS

Prepared by

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The ENTERPRISE Board consists of a representative from each of the following member entities of the program.

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1.0 Introduction

1.1 Background – Understanding the Challenge

Road construction and maintenance activities that require lane or shoulder closures are not always reported to operations staff for dissemination to traveler information systems and the traveling public. The provision of construction information to transportation management center (TMC) staff, particularly for shorter duration and/or mobile work zones, if any, can be challenging given the fast-changing and temporal nature of those work zones. Details about the timing of the lane closures or the location of the closure in real time may vary with little notice, but are needed for posting specific messages for the traveling public.

Gathering and reporting information can be time consuming for staff. When construction information is known, TMC staff must often manually enter it into Road Condition Reporting Systems (RCRS). Likewise, assembling precise (i.e., detailed, timely, and accurate) information can be difficult and time consuming for staff in the field who have other responsibilities. Some agencies require contractors to provide real-time information from the field with some utilizing a specific smart phone application for this purpose, however getting this information on a consistent basis has remained a challenge.

The current state of practice generally results in limited detailed information available for agency use or traveler information. Lacking precise, consistent, and reliable details about time and location of work zone-related closures, TMC staff can only post generic information to dynamic message signs (DMS) and traveler information dissemination systems, if anything at all. Consequently, the traveling public often has limited information about lane closures during or in advance of a trip. Additionally, agency practitioners desire more detailed records on the start time, end time, and location of lane closures for improved post work zone analysis of the transportation management plan (TMP) and performance measurement. Given anticipated deployment of connected vehicles, driver notifications of work zone-related lane closures via in-vehicle displays offer opportunities for increased safety, but also increases the need for accurate information about active lane closures.

1.2 A Candidate Solution

Arrow boards are routinely used in advance of active work zones to designate lane closures in the field, and display the most current information to approaching motorists. Although no off-the-shelf system currently automatically integrates arrow board statuses into traveler information mechanisms for display to motorists, ***available technology could report the location and operation of Arrow Boards to TMC staff for improved traveler information dissemination and performance reporting, without requiring significant time of agency staff in the field or at the TMC.***

1.3 The Vision

The vision of this project is that in the near future, state and local DOTs will competitively procure systems to integrate Arrow Board status information into existing and future traveler information systems. This vision will be recognized by an initial set of agencies (the ENTERPRISE Pooled Fund members) working together to define common requirements for systems to integrate Arrow Board status information into traveler information systems that will enable Arrow Board manufacturers and third party integrators to develop systems to meet the needs of multiple agencies.

The primary benefits expected include:

- Improved situational awareness by TMC operators of real-time lane closures in the field;
- Detailed, consistent, and reliable real-time information about lane closures disseminated to travelers upstream of the closure through Dynamic Message Signs (DMS), traveler information mediums, and connected vehicle applications;
- Improved project management opportunities, including the ability to verify contractor work status to document lane closure times for use on lane rental projects or enforce restricted hours or to cross check any lane closure updates that are required of the contractor;
- Increased archived data available for evaluation, performance management, and research to better understand work zone mobility impacts and exposure for reporting purposes, use for future work zone planning efforts, analysis of TMPs, and for performance-based specifications.
- Foundational communication technology for Arrow Boards to broadcast display status and lane closure-related information to Connected and Automated Vehicles.

Depending on the amount of manual involvement by field staff, a secondary benefit of this system is the potential for faster response time in the field for maintenance needs, including times when the Arrow Board was hit by a passing vehicle or blown out of place by strong winds, given notifications to field staff of system functionality. The reporting of Arrow Board usage may also improve quality of the device, i.e., the system can report if the arrow board is level and plumb, the location can be more readily verified by field personnel.

1.4 Intent of This Project

The overall intent of the ENTERPRISE *Integrating Active Work Zone Notifications into Traveler Information Dissemination Mechanisms (Phase I)* project is for multiple states to collaborate to follow a systems engineering process to develop an ITS solution that integrates active work zone notifications regarding lane closures from Arrow Boards into agency traveler information dissemination systems. During this process, the project team identified a focus on integrating real-time information from Arrow Boards in the field; therefore, the Model Con Ops document has been titled to reflect this focus: *Real-Time Integration of Arrow Board Messages into Traveler Information Systems: Model Concept of Operations.*

1.5 Objective of This Document

This model **concept of operations** (ConOps) presents an overview of the current system, identifies the relevant stakeholders, translates current challenges into specific needs, outlines an operational concept, suggests likely roles and responsibilities, and describes scenarios for integrating active work zone lane closure information from Arrow Boards into agency traveler information dissemination systems.

1.6 Context of this Document

This document will serve as a foundation for the development of system requirements, which will complete Phase I activities. Existing requirements for ITS devices or systems could serve as examples to encourage standardized implementation. National-level requirements for ITS communications with the TMC, such as those defined by the National Transportation Communications for ITS Protocol (NTCIP) 1203 for DMS or 1207 for ramp metering, might be adapted for the development of requirements for this

concept as it pertains to Arrow Boards. Thus, as with all stages of the systems engineering process, ongoing stakeholder input and support is essential for the successful development of a useful system that effectively addresses user needs.

Phase II will subsequently evaluate existing system integration deployments and/or use these system engineering documents to support the deployment, coordination, or evaluation of deployments of this technology. The purpose of Phase II will be to facilitate a deployment of the "Integrate Active Work Zones" concepts in one or more ENTERPRISE member states and evaluate the process, lessons learned and benefits. Specifically, the current plan is for approximately 5-10 Arrow Board Reporting Systems to be deployed in up to four states for approximately six months; it should be noted that costs are sometimes higher for pilot efforts of innovative technologies than for later, more widespread deployments.

2.0 System Overview

The system of interest in this ConOps is comprised of two largely independent systems: 1) Arrow Boards and 2) traveler information dissemination systems and data archives. This section provides a brief description of those systems, as depicted in Figure 1.

2.1 Arrow Boards

The Manual of Uniform Traffic Control Devices (MUTCD) includes recommendations for the use of Arrow Boards to provide warning and directional information for the traveling public through a work zone with a lane or shoulder closure. As a possible substitute, the MUTCD notes that Portable Dynamic Message Signs (PDMS) can also perform the role of an Arrow Board. For the purposes of this ConOps, references to Arrow Boards are inclusive of PDMS functioning as an Arrow Board, but not PDMS performing other functions. Arrow Boards are routinely deployed for lane or shoulder closures on multi-lane roadways. Arrow Boards are typically locally operated, and are generally mounted on either trailers or trucks; truck-mounted Arrow Boards may be used for mobile work zones.

2.2 Traveler Information Dissemination Systems and Data Archives

Traveler information dissemination systems and data archives in this context comprises the databases, road condition reporting systems, and advanced traffic management systems used by transportation agencies to collect, process, disseminate, and store traffic data and information for use by the traveling public and agency stakeholders. Specifically, this traveler information may be available via DMS, 511 phone or web, mobile apps, social media, or as part of the connected vehicle environment. Incoming data and posted information is frequently archived in a database for some period of time for later analysis, as needed.

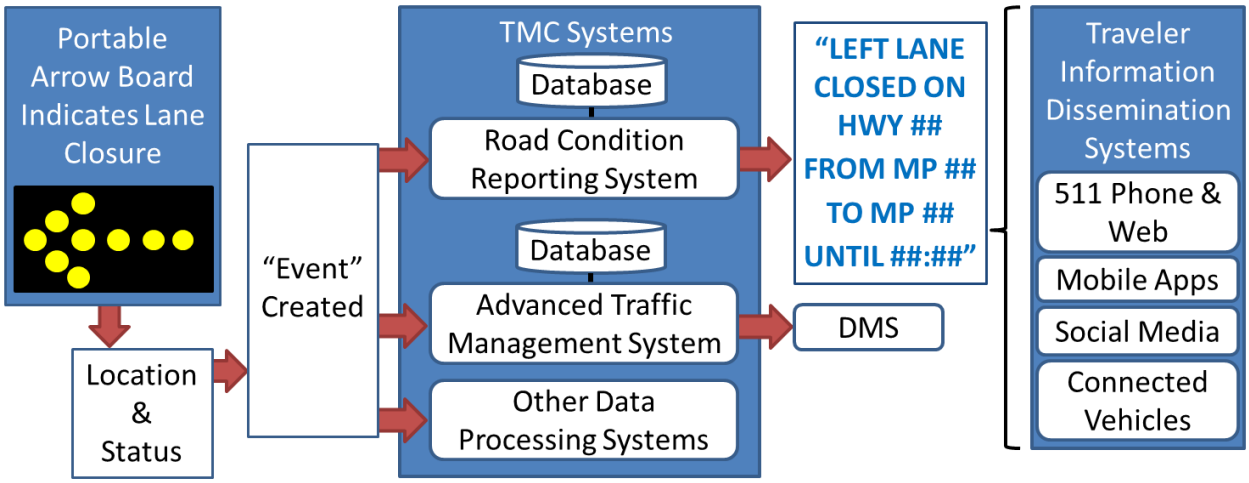

Figure 1: The systems of interest for this ConOps include Portable Arrow Boards, Road Condition Reporting Systems, Advanced Traffic Management Systems, and traveler information dissemination systems.

3.0 Stakeholders

For this project, stakeholders are defined as follows:

3.1 Primary Stakeholders

Primary stakeholders are direct end users of the eventual technology deployed to integrate the information from Arrow Board Reporting Systems into traveler information dissemination mechanisms. Additionally, these stakeholders are involved in the development of the ConOps and Requirements, and will be influenced directly by the deployment of Integrated Work Zone Notification systems. Specific stakeholders described below are more grouped into four more general categories that are used throughout this document: Transportation Management Center (TMC) staff, ITS vendors and owners, field staff, and archived data users.

TMC Staff

- *Advanced Traffic Management System (ATMS) Operator Staff.* ATMS operator staff are responsible for controlling the various systems used to manage traffic. They are stakeholders to this project because they often are not informed of temporary lane closures and would benefit from increased notifications of these lane closures. They may react by posting messages on DMS upstream of the lane closure, monitoring traffic congestion upstream of the lane closure, or by taking other actions.

- *Road Condition Reporting System (RCRS) Operator Staff.* The department of transportation (DOT) staff members that are responsible for traveler information systems are stakeholders to this effort because the systems they manage are intended to inform travelers about events impacting traffic, including lane closures. While work zone activities are typically entered into RCRS to feed the various traveler information dissemination mediums, the work zone descriptions often lack details about temporary lane closures. The systems deployed as a result of this project may create data and information that is automatically inserted into RCRSs, or manually entered by a variety of staff responsible for creating traveler information.

ITS Vendors and Owners

- *System Integrators.* These stakeholders include RCRS vendors and ATMS vendors, as well as any DOT staff, that will have a role in modifying the TMC systems per agency needs to accommodate the new data collection, processing, and archiving requirements that support Arrow Board Reporting System functionality.

- *Equipment Owners.* Equipment owners may be the DOT, work zone contractors, or other vendors who facilitate the deployment, and also verify and validate operations of the Arrow Board. They can assist with making the deployment easy and simple for other users to operate, minimizing costs, and addressing security needs.

Field Staff

- *Arrow Board Operators.* Arrow Board operators could consist of either DOT staff, local agencies, utility companies, or contractors and are identified as stakeholders because they are responsible for activating and maintaining Arrow Boards, and any field activities identified would be their responsibility.

- *Work Zone Inspectors.* Work zone inspectors are in the field and aware of the timing and location of lane closures in real time, versus the plans anticipated by the contractor. These stakeholders could verify lane closures in ATMS or RCRS, or confirm generated email alerts, in order to assist with calculating the lane rental for the contractor's performance-based specifications.

- *Construction Managers.* Construction managers are responsible for the overall work zone, but may also be responsible for several other construction sites and would benefit from having alerts when not on site. These stakeholders would need to receive real-time alerts when an Arrow Board Reporting System is activated, as well as any status changes regarding display, location, or being powered down.

Archived Data Users

- *Work Zone Planners and Managers.* Work zone planners and performance management staff are stakeholders to this project because they write specifications, review the actual operations of work zones, and compare actual operations to what was planned in the Work Zone TMP. The information about the start/end time and locations of lane closures will assist in this analyses.

- *Traffic Operations Group, Congestion and Performance Managers, and Archived Data Users.* These stakeholders focus on minimizing congestion and conduct analyses and review of archived data available, including that from portable or temporary systems used in work zones. These stakeholders also develop new performance requirements that might be applied to work zones to minimize congestion. Additional stakeholders within this group include researchers, MPOs, contractors, contract administrators, and contract inspectors who may also be interested in accessing and analyzing archived data.

3.2 Secondary Stakeholders

Secondary stakeholders are end users that do not interface directly with the system but will benefit from the information that becomes available as a result of the system integration.

- *Travelers.* Travelers and other consumers of the information such as law enforcement and freight carriers are identified as a stakeholder group in this project. While they will not interface directly with the Arrow Board Reporting System data communications, they will be the recipients of information disseminated on either TMC controlled DMS or traveler information systems.

- *Third Party Information Dissemination Providers.* Private sector information service providers that access data feeds from the DOTs and disseminate information using their own systems (e.g., Waze, Google) are secondary stakeholders in that the data feed they access at the DOTs will most likely be enhanced to include the additional detail about lane closures.

4.0 Challenges

Identification of relevant challenges facing the stakeholders described above will facilitate the specified needs and provide context for any potential constraints to consider when defining the needs.

Table 1: Challenges Facing Stakeholders

#	Challenges Facing Stakeholders
1	Details about the location and timing of lane closures is difficult and time consuming to assemble into traveler information systems, often resulting in general messages describing work zone impacts.
2	Traffic Management Center (TMC) Staff often are not aware when lane closures begin, and therefore are not able to post messages on upstream DMS or take other actions.
3	The exact timing and locations of lane closures are often not known in advance, and field personnel performing the roadwork and closing the lanes have many other responsibilities such that manually reporting a lane closure is often not possible.
4	Travelers lack detailed information, and are only given general information because known information is not accurate enough.
5	No off the shelf equipment or communications technology is currently available to automatically communicate lane closures to a central location.
6	Detailed records of the location, start and end time for lane closures is not always recorded, and this can impact the ability to do post work zone analysis of the TMP and performance measures.

An Overarching Challenge of Acceptable Levels of Automation

An additional challenge facing stakeholders that will deploy Arrow Board Reporting Systems will be the degree to which the Arrow Board messages received by the RCRS and ATMS systems are automatically inserted into the systems versus manual verification or acceptance of messages. There is no debate about the need for Arrow Boards to report automatically without field staff activation, but agencies will likely differ in their comfort level of disseminating information without human verification. ***A prescribed approach for automated or manual acceptance of messages is not included in this document*** in order to provide flexibility for agencies to adopt practices that are consistent with their current systems and comfort levels. There are several tradeoffs that are worthy of consideration, for example:

- In a fully automated system where the agency TMC Systems accept Arrow Board messages even if no one can provide visual verification, either in-person or via traffic camera, there is an increased likelihood of false reports, however this approach will likely accomplish an increased number of reports of lane closures disseminated to travelers with minimal operator involvement. Full automation also depends on the capabilities of each agency's individual ATMS and/or RCRS. Agencies may experience challenges with accurately linking detailed Arrow Board messages with higher-level ATMS and/or RCRS reports that do not require so much detail, which might hinder automated reporting.
- A system that requires manual verification or message approval before messages are disseminated to the public will have a decreased likelihood of false reports, but will have an increased likelihood that limited staff availability (or staff fatigue from receiving notifications that are not relevant to that individual) would cause more Arrow Board messages to be neglected and not be posted to ATMS, RCRS, and/or traveler information dissemination systems at all. For instance, given that many lane closures occur as a part of night-time work zones and not all TMCs operate 24 hours, requiring manual intervention by TMC staff could limit the provision of traveler information.

The initial intent of this ConOps was to provide for a fully automated system that could inform ATMS, RCRS, and/or traveler information dissemination systems of shoulder or lane closures, with minimal manual intervention in order to not place additional responsibilities on staff that are already busy. However, it is expected that operator and/or field staff verification will occur during acceptance testing to validate and gain confidence in the Arrow Board reports. After acceptance testing, some agencies may opt for a fully automated system, while others may not be comfortable or confident in the accuracy of the Arrow Board messages and continue to require verification. For example, some agencies may leverage available CCTV camera coverage of the areas where Arrow Boards are used, or may routinely have staff in the field, e.g., inspectors or district staff, who could verify the Arrow Board messages, although this may not be an option for other agencies. Agencies might also consider requiring manual intervention by TMC staff during business hours, and utilizing a more automated Arrow Board Reporting System during hours when the TMC is closed.

Anticipated Connected Vehicle Challenges

In a connected and automated vehicle environment, it is likely that Arrow Board display status regarding lane closures would be a valuable data input. The system developed as a part of this ConOps would provide a foundational technology that could be readily adapted for use by connected and automated vehicles in the future.

5.0 Needs

Three categories of Stakeholder Needs have been identified, and are presented in Table 2, Table 3, and Table 4 below:

- **End User Stakeholder Needs** – describe the needs of end users of the information to be provided from the Arrow Board Reporting Systems in the field. These needs are identified to address the challenges described above.
- **Stakeholder Needs Regarding Receiving and Processing Arrow Board Reporting System Messages** – describe the needs for functions to be automatically or manually performed to make use of data received from Arrow Board Reporting Systems in the field in order to meet the End User stakeholder needs. In other words, the functionality of the Arrow Board Reporting Systems to send messages will need to be accompanied by additional functions performed by other DOT TMC Systems (e.g., ATMS, RCRS) to make use of the messages sent.
- **Needs Regarding Functionality at the Arrow Board Reporting Systems** – describe the needs that would need to be addressed by either the Arrow Board or a related product connected to the Arrow Board.

Table 2: End User Stakeholder Needs

1. End User Stakeholder Needs		
1-1	**Traveler Information managers need near real-time notices of lane closures to be automatically ingested into the Road Condition Reporting System (RCRS) in order to be disseminated through the various traveler information mediums fed by the RCRS (e.g., phone, web, mobile apps, social media).**	
	Notes:	- DOTs will approach this in different ways, e.g., some will require operator verification of the event after acceptance testing, others may not. - Lane closures reported by Arrow Boards may be processed by the RCRS and 'snapped' to an existing Road Work Event already in the system (perhaps adding a new element to the Event for the current lane closure).
1-2	**TMC Operators need near real-time notices of lane closures to be automatically ingested into their ATMS software in order for manual and/or automated consideration of upstream DMS messages.**	
	Note:	- In situations where an automated ingest into the ATMS is not possible, operators may receive notices to be manually entered (see Need 1-3).

1-3	**Some TMC Operators and other DOT staff such as work zone inspectors and construction managers need real-time trigger alert or notification capabilities (e.g., email, pager, existing system display) to keep abreast of lane closure activities and potentially assess whether further action is needed.**	
	Notes:	- This need addresses DOTs who do not establish automated reporting into either the RCRS or ATMS, or DOTs who also wish for additional users to receive notices of the lane closures. - Note that lane closure data from the field may only include latitude/longitude values as the location description (as the 'snap' of the latitude/longitude to a DOT operated highway might happen in the RCRS or ATMS software). Therefore, these alerts might not be user friendly. - If the field device or a processed message generated from the RCRS or ATMS is able to convert the latitude/longitude to highway ID and milepost before sending, this would more appropriately address this need. - Major changes in data received between successive messages could indicate a communication or other failure in the field that requires maintenance or could indicate the end of the active lane closure, e.g., increased device speed, missed receipt of anticipated messages, display status change.
1-4	**Work zone planning staff need to be able to access information describing the location, start, and end time of lane closures associated with work zones in order to perform post-analyses.**	
	Notes:	- Analyses of work zone impacts and comparisons of Transportation Management Plans (TMPs) against actual impacts would typically not require near real-time access, but rather access to recent data (e.g., querying a month of lane closures, or querying a specific highway ID) for post-analysis. - Planning staff may need more real-time information if changes in the field are required when the work zone is active.
1-5	**Stakeholders receiving near real-time notices of lane closures need to not receive repetitive notifications of the same lane closure event.**	
	Notes:	- This 'filtering' to avoid operator overload would most likely occur within the RCRS or ATMS software. - Periodic update notifications following a reported major operational status change are expected.

1-6	**Stakeholders receiving near real-time notices of lane closures need confirmation that the lane closure is no longer active, and to have the event end in the ATMS or RCRS.**	
	Notes:	- Arrow Boards will periodically send updated messages to indicate operational status to TMC stakeholders. - To indicate the lane closure is no longer active or terminate the event in ATMS or RCRS, one of the following will occur: o Arrow Board will send an "end" message when turned off prior to powering down. The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive. o Arrow Board message will include orientation of sign to indicate whether it is visible to passing motorists, or in a down position that would indicate that the lane closure is no longer active and terminate the event. o Arrow Board message will include location, such that the speed of the device can be calculated between the receipt of two messages, which could indicate it is traveling too fast to be part of a mobile work zone. o System could generate an automatic message after several "missed" messages from Arrow Board for field staff to confirm that the device has been turned off and the event has ended, versus a communication or power failure.
1-7	**Stakeholders receiving near real-time notices of lane closures need to be presented with information describing: the roadway where the closure is occurring, the lane closure description, direction of travel, and the number of lanes closed.**	
	Notes:	- This information may be derived from data received from one or more Arrow Boards that is processed in the TMC before being viewed by operators. - Arrow Board data will include, at a minimum: o Latitude and longitude of the Arrow Board sign (i.e., to indicate milepost, and derive speed of sign, if applicable, from consecutive messages) o If latitude and longitude is not precise enough to ascertain direction, a compass reading or suitable alternative will be included o Arrow Board orientation (i.e., visible to traffic or down) o Arrow Board status message (e.g., those listed in the MUTCD: left or right flashing, sequential, or flashing double arrow; left or right sequential chevron; flashing caution; or alternating diamond caution) o Timestamp of transmission o Device ID - The number of lanes closed will be automatically determined based on the number of Arrow Boards reporting the same arrow direction from near the same location (i.e., one Arrow Board is needed to close each lane). - The identification of multiple Arrow Boards reporting caution mode will be interpreted as redundant, e.g., being used within a lane closure where no additional lane is closed.

1-8	**Stakeholders need to be notified if the lane closure is part of a mobile work zone and is in motion along the roadway.**	
	Notes:	- The Arrow Board itself would report status and position at a regular frequency. - The determination of whether it is a mobile work zone or not would most likely need to be derived by the RCRS or ATMS. - The pre-determined speed thresholds for ascertaining a mobile work zone vs. traveling down the roadway may vary by road type (e.g., interstate, arterial) and location (e.g., urban vs. rural). - It is possible that a device attached to an Arrow Board may classify it as a mobile work zone, but this feature would likely not be available with all products.

In order to accomplish the above End User Stakeholder Needs, a series of needs were derived for functions to be performed by various systems or operators when receiving and processing Arrow Board messages. These various systems and operators are referred to as "stakeholders" in Table 3.

Table 3: Stakeholder Needs Regarding Receiving and Processing Arrow Board messages

2. Stakeholder Needs Regarding Receiving and Processing Arrow Board Messages		
2-1	**Stakeholders need a mechanism to receive wireless communications from Arrow Boards and store the messages/data that are transmitted.**	
	Notes:	- Data must arrive in a useful manner for processing by the ATMS and/or RCRS (e.g., a text message received via phone would not allow access by the ATMS or RCRS). - Data may be received by request, via a proxy server, and/or directly from the Arrow Board on its own timing.
2-2	**Stakeholders need a mechanism to automatically process the *Device ID* received in the Arrow Board message.**	
	Notes:	- Supports Need 1-5 - The Device ID can be referenced in logs for the ATMS and RCRS to recognize if this lane closure report has already been received with a notification provided to operators, and for comparison of new data to previously received data and posted information. - The Device ID may be used to look up the product type in order to process an Arrow Board "status code". - Device ID (with lookup table for Device ID to include items such as manufacturer, model, and owner of the Arrow Board) may be processed against a lookup table of devices in order to determine the DOT shop it is assigned to.

2-3	**Stakeholders need a mechanism to automatically process the *location* received as part of the Arrow Board message.**	
	Notes:	- Supports Need 1-7 - Arrow Boards may only report latitude/longitude, so the ATMS, RCRS, or other system must be able to 'snap' a latitude/longitude to the appropriate roadway and milepost, and minimize situations where an incorrect road is identified to the extent possible. - This is typically a function performed by RCRSs and ATMS (for example, this is currently done when RCRSs ingest law enforcement CAD reports). - If the DOT is planning to send lane closure alerts to others (beyond those with ATMS or RCRS access) this same 'snap' to a highway would need to be performed.
2-4	**Stakeholders need a mechanism to automatically process the *status* of the Arrow Board, as received in the message.**	
	Notes:	- Supports Need 1-7 - Some Arrow Boards may output and send the status as a message describing the Arrow Board display (e.g., "Right Arrow"). - It is recognized that if there is limited processing at the Arrow Board before the message is sent, this might simply include a "status code" describing the Arrow Board status selected by field operators (e.g., "Option A" is selected on the dial which activates the "left arrow display"). - Status options are expected to incorporate those from the MUTCD, and include: o Right flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons o Left flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons o Flashing caution or alternating diamond caution to indicate caution within existing closure area and shoulder work o Others in compliance with MUTCD Figure 6F-6 o Error o Off or blank - If only a "status code" is sent from the Arrow Board, and if different vendors use different "status codes", then the Device ID will be required to look up the vendor and interpret the "status code".
2-5	**Stakeholders need a mechanism to automatically process the *timestamp, as received in the message*.**	
	Notes:	- Supports Needs 1-5, 1-7 - The timestamp of the first message sent describing an Arrow Board being activated would need to be assigned to Events entered into either the ATMS or RCRS as the "Event Start Time".

2-6	**Stakeholders need a mechanism to automatically process received data to determine the *direction of travel* (describing the direction the Arrow Board is facing).**	
	Notes:	- Supports Need 1-7 - The system may need to process the data received regarding the Arrow Board status from the "status code" (e.g., right lane closed) in addition to the latitude/longitude data with sufficient accuracy, compass reading, and/or a suitable alternative to determine the direction of travel. - Alternatively, Arrow Board functionality could determine direction of travel, allowing the ATMS, RCRS, or other system to validate the direction of travel.
2-7	**Stakeholders need a mechanism to automatically maintain a history of messages sent from each Arrow Board Device ID, in order to determine if this is a newly activated device or a recurring message received for an active Arrow Board.**	
	Notes:	- Supports Need 1-5 - This is to enable the ATMS or RCRS to recognize an already logged lane closure and not repetitively notify operators. - The message exchange protocol and standard could include a field to indicate that this is an update message. - In lieu of an indication it is an update message, Device ID, location, and status of display could be used to derive if it is a new deployment or update.
2-8	**Stakeholders need a mechanism to automatically determine if an Arrow Board is involved in a mobile Work Zone.**	
	Notes:	- Supports Need 1-8 - The system will calculate speed based on received latitude/longitude and device timestamp information from two messages - If speed is calculated as slower than the typical local traffic speed for the road type (e.g., interstate, arterial) and location (e.g., urban vs. rural), the device will be assumed to be involved in a mobile work zone - This would likely be a function of the ATMS or RCRS
2-9	**Stakeholders need a mechanism to automatically determine when an Arrow Board has been moved to a new location, and operators should be notified that it may no longer be displaying in the same location and orientation, as originally placed.**	
	Notes:	- Supports Need 1-6 - This is for situations where the Arrow Board may have been moved from the original location, either off the road/shoulder and is no longer visible to drivers or to a new functioning location. - This needs to accommodate for the potential to receive variations in latitude/longitude data describing the location when in fact no movement has occurred.

2-10	**Stakeholders need a mechanism to automatically determine when an Arrow Board report is no longer active.**	

	Notes:	- This is to enable operators or systems to remove messages about lane closures from upstream DMS or traveler information dissemination systems.
		- Supports Need 1-6 and 3-10.
		- Arrow Board will be determined to be no longer active given the following:
		  o Arrow Board sign in a down position.
		  o The calculated speed of the device is too fast for the device to be active as part of a mobile work zone.
		  o Arrow Board transmits a message indicating a blank display status.
		  o Receipt of a message from the device communication mechanism assembled as part of the shutdown, notifying that the device is turned off. In lieu of a "turned off" message, the system will assume the Arrow Board is no longer active after several "missed" messages.
		- Optional: The system may generate an automatic message after several "missed" messages from the Arrow Board Reporting System for field staff to investigate a maintenance need (i.e., communication or power failure), or confirm that the device has been turned off and the event has ended.
		- Optional: The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive.

2-11	**Stakeholders need Arrow Board messages to be archived to a query-based database to enable Work Zone management staff access to specific details and statistics about lane closures.**	
	Notes:	- This is related to enabling the data generated by the Arrow Board to be accessed and used by individuals responsible for work zone performance and planning for future work zones.
2-12	**Stakeholders need a mechanism to automatically add a timestamp for when Arrow Board messages are received.**	
	Notes:	- This is in addition to the timestamp created at the device in order to determine latency using archived data for post analysis.

Table 4 describes the stakeholder needs for functions to be performed by the Arrow Boards.

Table 4: Stakeholder Needs Regarding Functionality at the Arrow Boards

3. Stakeholder Needs Regarding Functionality at the Arrow Boards		
3-1	**Stakeholders need the 'Integration of Active Work Zone Notifications' to be fully automated, with no reliance on field personnel to activate or enter information, beyond what they currently do to turn on and configure the Arrow Board.**	
	Notes:	- Work zone staff time is occupied with work zone and safety related actions. - Dependence on field staff introduces potential for the notices to not be sent for each lane closure.
3-2	**Stakeholders need an initial message to be available upon the Arrow Board being activated, with data describing the Arrow Board activation.**	
	Notes:	- This would be an initial message describing a newly activated device - May be transmitted automatically to a proxy server or in response to a ping from the central system. - As an example, cellular modems could be used to connect and send data. - Could include a handshake confirmation
3-3	**Stakeholders need periodic messages to be available indicating the continued status of the Arrow Board device.**	
	Notes:	- The Arrow Board device may automatically send the messages to a proxy server or the system (i.e., ATMS, RCRS, or both) may pull messages from the device. - This will allow TMC staff or an RCRS to validate that the Arrow Board is still actively displaying the message. - This would involve the receiving system(s) to maintain a history of transmissions to track and determine if something has changed. - Message transmission frequency will vary based on work zone duration and type: o Initial default frequency will be every 5 minutes, at a minimum. o Transmission frequency may be reduced for a longer, stationary deployment (e.g., hourly reporting after four hours of activation). o Transmission frequency will be increased to every 10 seconds, at a minimum, when the system determines from successive messages that the currently active Arrow Board is moving at a speed reasonably assumed to be part of a mobile work zone.
3-4	**Stakeholders need all messages sent from Arrow Boards to include a *device ID.***	
	Notes:	- Device ID may be assigned at the device communications mechanism attached to the device. - This would be used to manage multiple messages received and maintain history of which devices are located where.
3-5	**Stakeholders need all messages created by Arrow Boards to include a *timestamp*.**	
	Notes:	This is the time that the data is assembled at the device

3-6	**Stakeholders need all messages sent from currently active Arrow Boards to include the *display status* of the device (status of device refers to what is displayed on the Arrow Board).**	
	Notes:	- Given potentially limited processing capabilities at the Arrow Board, this may be a "status code" describing the status selected by field operators (e.g., "Option A" is selected on the dial is known to activate the "left arrow display"). - Given processing capabilities at the Arrow Board, the sent message may include a pre-defined description (e.g., "right arrow"). - Status options are expected to incorporate those from the MUTCD, and include: o Right flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons o Left flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons o Flashing caution or alternating diamond caution to indicate caution within existing closure area and shoulder work o Others in compliance with MUTCD Figure 6F-6. o Error o Off or blank - Field personnel typically select a setting on the Arrow Board. - The "status codes" for Arrow Boards will likely differ by vendor, therefore the Device ID would be used to interpret any "status codes" sent from the Arrow Board. - When a PDMS is used as an Arrow Board, a different type of "status code" or text description may be sent from the PDMS.
3-7	**Stakeholders need all messages sent from Arrow Boards to include the *location of the Arrow Board described using a Geospatial description*.**	
	Notes:	- The Arrow Board must include latitude/longitude information in the message to enable central systems to determine roadway and milepost. - The device communication mechanism internal GPS could provide this data.
3-8	**Stakeholders need all messages sent from currently active Arrow Boards to have data for determination of *direction of travel*.**	
	Notes:	- A compass reading would satisfy this requirement, but is not a feature all Arrow Boards have. - In lieu of a compass reading, location accuracy or a suitable alternative must be sufficient to determine direction of travel of the lane or shoulder closure, including a shoulder closure on a two-lane roadway.
3-9	**Stakeholders need all messages sent from Arrow Boards to include *display orientation*.**	
	Notes:	- Orientation of Arrow Board display will indicate whether or not it is visible to passing motorists. For example, an arrow board display may be in a "down position" or in another orientation position where the display is not visible to passing motorists, therefore indicating that the lane closure is no longer active.

3-10	**Stakeholders need data from the Arrow Board to understand when it is no longer active.**	
	Notes:	- Data must sufficiently inform operators or systems to remove messages about lane closures from upstream DMS or traveler information dissemination systems. - Respecting Need 3-1, data will support an automatic determination. - Supports Need 1-6 and 2-10. - Understanding of Arrow Board status will be made based on the following: o Per Need 3-9, Arrow Board signs in a down position would indicate that the lane closure is no longer active. o Given Need 3-7, the speed of the device can be calculated by the system, given the location of the device in two messages, to indicate it is traveling too fast to be active as part of a mobile work zone. The pre-determined speed thresholds for ascertaining a mobile work zone vs. traveling down the roadway may vary by road type (e.g., interstate, arterial) and location (e.g., urban vs. rural). o Given Need 3-6, Arrow Boards that send a message about off or blank display status would indicate the lane closure is no longer active. o When the Arrow Board display is turned off, the device communication mechanism may assemble one last message for transmission as part of the shutdown, notifying the Arrow Board is turned off. In lieu of a "turned off" message, the system could assume the Arrow Board is no longer active after several "missed" messages. The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive. o More broadly, data may also indicate when an Arrow Board is being placed out of service.
3-11	**In situations where multiple Arrow Boards are activated for a multiple lane and/or shoulder closure, Stakeholders need all Arrow Boards deployed within a cohesive work zone to transmit status messages.**	
	Notes:	- This allows TMC Systems receiving the messages to determine that multiple lanes are closed (i.e., two devices displaying 'left arrows' would indicate the right two lanes are closed). - This would likely be determined by TMC Systems based on the location and proximity of adjacent Arrow Boards on the same roadway and facing the same direction.

6.0 Operational Concept

The operational concept is presented below to detail how the new system will impact the roles and responsibilities of field staff, ATMS operator staff, and RCRS operator staff. The changes experienced from the perspective of equipped Arrow Board devices and the TMC Systems, i.e., back-office data gathering and processing systems such as ATMS, RCRS, and/or other systems, are also presented.

While the majority of concepts presented below describe actions using "will" statements, there are several instances where "may" is used. This is partially because this document is a model ConOps to be used by agencies who will differ in the approach to some aspects, either based on systems used by their agency or their selected approach to integrating of Arrow Board reports.

One area where the approach to integrating Arrow Board reports is likely to vary by agency is the extent to which each agency is comfortable with a fully (or near fully) automated process of messages being communicated from the Arrow Board and integrated into the RCRS and/or ATMS systems without operator verification. It is expected that agencies might initially adopt a process of manual approval of messages, particularly during acceptance testing, but over time, as comfort increases, they would transition to accepting a more automated approach. The automated vs. manually verified synopsis represents a possible conflict in needs, where a possible need to not disseminate unverified information conflicts with the need to increase the information delivery while not increasing demand on existing staff. This conflict is particularly poignant for agencies that do not have 24-hour TMC operations with staff available to manually verify Arrow Board messages from off-hour, night-time work zones that have lane closures.

6.1 Arrow Board Reporting System Device Perspective

The Arrow Board device is deployed, tested, and activated in the field as in the current state (i.e., with no functionality to communicate its status beyond locally, to oncoming traffic), with the exception that it is equipped with an Arrow Board Reporting System. The Arrow Board Reporting System will vary in design by manufacturers, but is likely to include a physical device that is either attached to the Arrow Board or included as part of the Arrow Board. The Arrow Board Reporting System will involve wireless communications capabilities, which could include a local, one-way communication broadcast (e.g., via DSRC or other suitable communication method) to enable future connected vehicle applications, and a centrally located server to perform some post-processing of the data before it is relayed to TMC Systems, which includes ATMS, RCRS, and/or other related back-office data processing systems. The centrally located server could be any of a variety of configurations, ranging from vendor specific central servers supporting multiple states, to a state or local DOT operated server supporting multiple vendor Arrow Boards. Figure 2 illustrates examples of the possible options for Arrow Board Reporting Systems functionality.

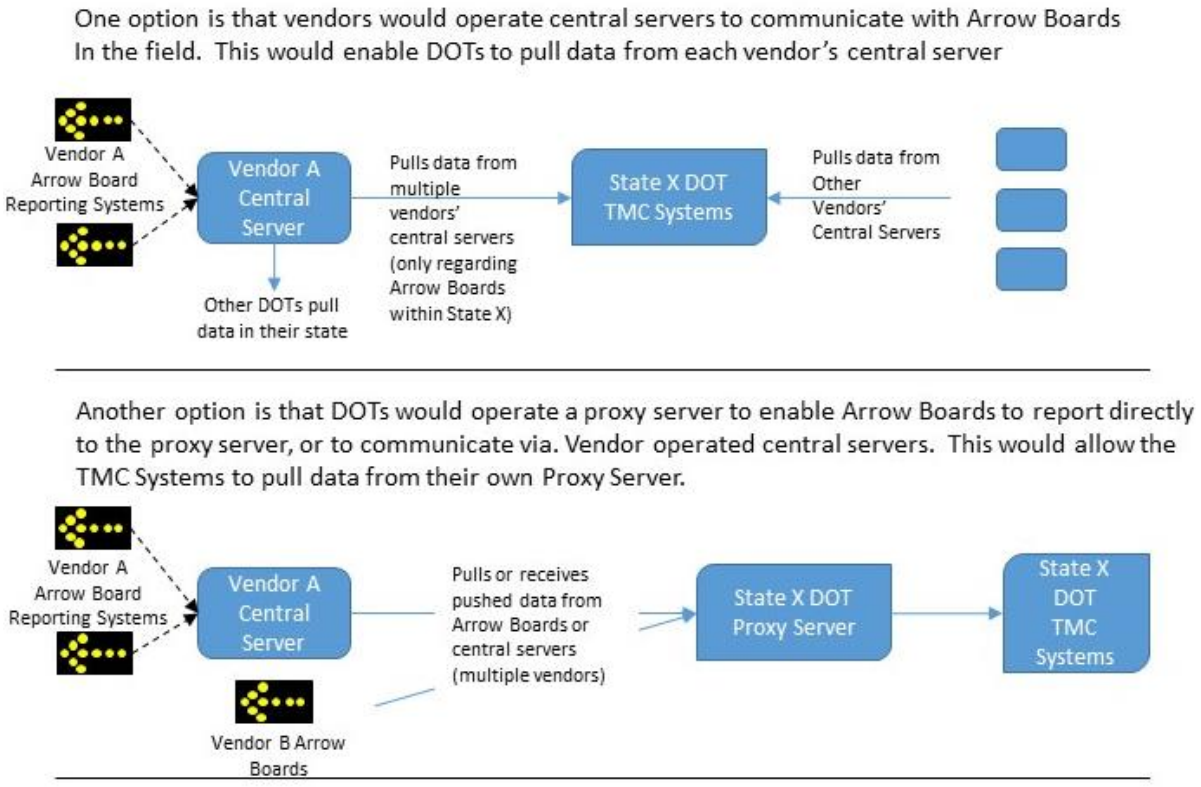

Figure 2: Illustration of Possible Options for Arrow Board Reporting Systems

The following section defines the operational concept from the perspective of the entire Arrow Board Reporting System (field device and central processing).

6.1.1 When an Arrow Board device equipped with automated reporting functionality (i.e., an Arrow Board Reporting System) is activated by field personnel, the Arrow Board Reporting System will deliver or make available an initial message to report the Arrow Board device ID, location, direction of travel, display status, and orientation. This message will be used by the TMC Systems, however a local, one-way communication broadcast of this information (e.g., via DSRC or other suitable communication method) may also be desired for use by field staff or to support connected vehicle applications (Needs 3-1, 3-2, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9)

6.1.2 The Arrow Board Reporting System communications and data exchanges will either be directly to a DOT operated server or to a proxy server established between the Arrow Board and the DOT TMC Systems. (Need 2-1)

6.1.3 As equipped Arrow Board Reporting Systems continue to operate, they will periodically collect and re-send all critical information to the DOT TMC Systems. (Needs 3-3, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9)

6.1.4 With each message sent by the Arrow Board Reporting System to the DOT TMC Systems, the Arrow Board Reporting System will include a Device ID. (Need 3-4)

6.1.5 The Arrow Board Reporting System will generate an Arrow Board status message and include the status message with each message delivered to the TMC Systems. (Need 3-6) The status message will describe the current display of the Arrow Board device, as one of the following options:

- Right flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons
- Left flashing arrow, sequential arrow, flashing double arrow, or sequential chevrons
- Flashing caution or alternating diamond caution to indicate caution within existing closure area and shoulder work
- Others in compliance with MUTCD Figure 6F-6.
- Error
- Off or blank

6.1.6 The Arrow Board Reporting System will determine the location of the Arrow Board device and include the location with each message delivered to the TMC Systems. The location will include the latitude/longitude of the Arrow Board device, as a minimum. In addition, the location may include a text description of the location (e.g., road and mile point, or nearest address). (Need 1-7, 3-7)

6.1.7 The Arrow Board Reporting System will determine the direction of travel that the Arrow Board device display is facing and include the direction of travel with each message delivered to the TMC Systems. (Note: In the event that an Arrow Board Reporting System is not equipped to determine direction of travel, the TMC Systems will determine direction of travel.) (Need 1-7, 3-8)

6.1.8 The Arrow Board Reporting System will determine the display orientation of the Arrow Board device and include the orientation description with each message delivered to the TMC Systems. The orientation will describe whether the Arrow Board device display is visible to motorists, or in a "down position", which may vary depending on the Arrow Board manufacturer. (Need 3-9)

6.1.9 As field staff turn the Arrow Board off, the Arrow Board Reporting System will send a message to the TMC Systems indicating that the message is no longer active. If this functionality is not possible with the selected Arrow Board Reporting System, alternate solutions (e.g., the central system inferring the system is turned off after not receiving an updated status) may be employed. The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive. (Needs 2-10, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9, 3-10)

6.1.10 The Arrow Board Reporting System may automatically generate and send a message directly to field staff, ATMS operator staff, and RCRS operator staff when data is reported by the Arrow Board Reporting System, using a medium such as text message, pager, or email. The approach to sending alerts to staff will likely be determined at each location, and will need to identify a mechanism that enables specific individuals to receive notices about Arrow Board device activations of interest to them while not being overwhelmed with notices of Arrow Boards outside their jurisdiction. This functionality may also be performed by the ATMS and/or RCRS operated by the agency. (Need 1-3)

6.1.11 The Arrow Board Reporting System may generate system functionality status messages (e.g., error codes) to indicate when basic system functions are not performing properly. System

functionality status messages may be generated for the following Arrow Board Reporting System functions: Ability to generate arrow board status messages; ability to generate arrow board location and position messages; and ability to communicate with TMC Systems. The system functionality status messages will either be available at the Arrow Board Reporting System device (enabling field staff to troubleshoot maintenance needs at the device) or alternatively could be deduced from the TMC Systems. (Need 1-3)

6.1.12 The Arrow Board Reporting System will have an expected service life, to be specified based on system components, functionality, anticipated use, and environmental conditions. This information will be used to help determine when Arrow Board Reporting System devices should be placed in and out of service for maintenance needs, and to manage inventories of devices. (Need 3-10)

6.2 Field Staff Perspective

Depending on the state DOT, scope of construction, and ITS contracts in place, field staff may include the construction contractor, a separate ITS vendor or support contractor, DOT maintenance or inspection staff, or a combination of these stakeholders. Depending on agency practices and confidence in the Arrow Board Reporting System messages, the system described here is automated, however additional manual verification by field staff may be desired, particularly during acceptance testing. The following section defines the operational concept from the field staff perspective.

6.2.1 Field staff will carry out all duties performed under the current state, including placement, testing, and activation of the Arrow Board, without any additional expectations. (Needs 1-5, 3-1)

6.2.2 In situations where multiple lanes are closed, field staff will deploy Arrow Boards with reporting capabilities in each lane, enabling the system to determine that multiple-lane closures are in place. (Need 3-11)

6.2.3 In some deployments, automated notifications will be sent to field staff regarding the Arrow Board location and display at activation, when location or display change, and when powered down. In addition to providing field staff with information about the changing status of lane or shoulder closures, these notifications may also help to identify maintenance needs or when the Arrow Board has been hit by a passing vehicle or blown out of place by strong winds and needs to be repaired or moved back into place. (Needs 1-3, 1-7, 3-2)

6.2.4 As in the current state, field staff are responsible for moving and updating the device as conditions change in the work zone as a part of normal operations. For example, the device may need to be moved as part of a mobile work zone or the display changed when it is moved to the shoulder. These changes would be automatically detected and reported by the Arrow Board Reporting System. (Needs 1-3, 1-5, 1-7, 1-8, 2-8, 2-9)

6.2.5 At the end of the lane or shoulder closure, as in the current state, field staff are responsible for powering down the device and removing it from the roadway. (Needs 1-6, 2-10, 3-10)

6.2.6 As in the current state, designated field staff will examine the device for maintenance needs, as necessary. Additional skills may be required to assess, maintain, and repair the new Arrow Board Reporting System components, which could be covered by warranty or contracted to specialists for repair needs. (Need 1-3)

6.3 TMC Systems (ATMS, RCRS, and/or other data processing systems) Perspective

TMC Systems routinely receive and process field data from devices. ATMSs typically pull data from external systems or devices (as opposed to accepting pushed data). RCRSs either pull data or accept pushed data, provided the protocols are followed for the data exchange. It is expected that the new data received from equipped Arrow Board devices will be acquired in a similar manner as data from other field devices, and will be processed according to the capabilities, practices, and policies of each agency. It is possible, for example, that agencies may experience challenges with accurately linking detailed Arrow Board messages with higher-level ATMS and/or RCRS reports, which could hinder automated reporting. Once data is received from Arrow Board Reporting Systems (either pulled or pushed), TMC Systems may either:

- Require some manual intervention by RCRS and/or ATMS operator staff prior to the Arrow Board data being ingested or used for traveler information purposes, or
- The Arrow Board data may be automatically processed and posted to traveler information dissemination systems and recommendations made for DMS messaging, as with other data such as speed and travel time data.

The following section defines the operational concept from the TMC Systems perspective. However, less detail is included for this perspective because it is expected that each agency (and vendor providing the ATMS or RCRS) will determine their specific approach to integration of Arrow Board data.

6.3.1 Depending on the type of device and TMC processes, the TMC Systems may send a “ping" to a proxy server or the device itself to request data, or may automatically receive data from the equipped Arrow Board. (Need 2-1, 3-1)

6.3.2 The TMC Systems will receive data describing Arrow Board status, including: the Arrow Board device ID, location, direction of travel, display status, orientation, and timestamp. (Needs 3-1, 3-2, 3-4, 3-5, 3-6, 3-7, 3-8, 3-9)

6.3.3 Upon receiving this data, it may be automatically processed to be ingested into the agency RCRS and/or ATMS. A multiple-lane closure would be determined by TMC Systems based on the location and proximity of adjacent Arrow Boards on the same roadway and facing the same direction. The use of multiple Arrow Boards reporting caution mode will be interpreted as redundant, e.g., being used within a lane closure where no additional lane is closed. (Needs 1-1, 1-2, 1-7, 2-2, 2-3, 2-4, 2-5, 2-6, 3-11)

6.3.4 A timestamp will be added to the data to indicate when it was received by the TMC Systems. (Need 2-12)

6.3.5 The TMC Systems may link this new Arrow Board information to a pre-existing event in the RCRS and/or ATMS. This pre-existing RCRS or ATMS event might include the anticipated extent and duration of the event. (Need 1-1)

6.3.6 The data received by the TMC Systems may not include any details about the extent (distance along the road) that the lane is closed or about the anticipated end time of the lane closure. Therefore, an approach may need to be determined to address any reliance on these data items (e.g., some RCRSs may require an “end time” for event creation). (Needs 1-7, 3-1)

6.3.7 The TMC Systems may need to determine the direction of travel that the Arrow Board field device is facing if this information is not included in the messages received, given sufficiently accurate latitude/longitude or by snapping to existing road work events in the RCRS or ATMS database. (Need 3-8)

6.3.8 The TMC Systems may automatically generate and send a message to staff and/or alert RCRS and ATMS operator staff via the user interface when data is received from an Arrow Board device ID that was not previously operational. The approach to sending alerts to staff will likely be determined at each location or by Arrow Board Reporting System vendor, and will need to identify a mechanism that enables specific individuals to receive notices about Arrow Board activations of interest to them while not being overwhelmed with notices of Arrow Boards outside their jurisdiction. (Needs 1-1, 1-2, 1-3, 1-7, 3-2)

6.3.9 Alerts and messages may contain either pre- or post-processed location information, i.e., latitude and longitude or, preferably, highway and milepost, depending on TMC System capabilities. (Need 1-3)

6.3.10 The TMC System may require a response from RCRS and/or ATMS operator staff prior to ingesting the Arrow Board information into the RCRS, ATMS, and traveler information dissemination systems. (Needs 1-1, 1-2, 1-3)

6.3.11 The TMC System will archive the raw and processed Arrow Board data. (Needs 1-4, 2-11)

6.3.12 The TMC System will continue to periodically receive, process, and archive Arrow Board data, identifying any changes to location or display status from the previous data received for each device ID. (Needs 2-2, 2-3, 2-4, 2-5, 2-6, 2-7, 2-8, 2-9)

6.3.13 When the TMC System identifies a significant change in the Arrow Board device location or display status, which could indicate a lane change, mobile work zone, being hit by a passing vehicle, blown out of place by strong winds, or system malfunction, a message may be automatically generated and sent to field staff, and/or the RCRS and ATMS operator staff may automatically be alerted via the user interface at the TMC. The pre-determined speed thresholds for ascertaining a mobile work zone vs. traveling down the roadway may vary by road type (e.g., interstate, arterial) and location (e.g., urban vs. rural.) (Needs 1-3, 1-5, 1-7, 1-8, 3-3)

6.3.14 Alerts and messages generated from change in Arrow Board device location or display status may contain either pre- or post-processed location information, and may require RCRS and/or ATMS operator staff action prior to updates being made in RCRS, ATMS, and/or traveler information dissemination systems. (Needs 1-1, 1-2, 1-3, 1-7)

6.3.15 When the TMC System receives a “power down” message from an Arrow Board or does not receive data as expected from an Arrow Board device, a message will be automatically generated and sent to RCRS and ATMS operator staff via the user interface at the TMC, to indicate that the Arrow Board device is no longer active. The message may also be sent to field staff. (Needs 1-6, 2-10, 3-10)

6.3.15.1 The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive, if queried.

6.3.16 Alerts and messages generated when the Arrow Board device is "powered down" may contain either pre- or post-processed location information, and may require RCRS and/or ATMS operator staff action prior to the event being closed in RCRS, ATMS, and/or traveler information dissemination systems. (Needs 1-1, 1-2, 1-3, 1-7)

6.4 ATMS Operator Staff Perspective

ATMS operator staff are sometimes alerted to planned lane closures and road work activities. However, many road work and maintenance activities are short duration within a larger timeframe or subject to change (e.g., due to inclement weather), and ATMS operator staff are not alerted in advance or, if so, unaware of the precise times the closure and road work activities are underway. The role of ATMS operator staff under the proposed system may vary based on the rules and policies set forth by the agency. Regardless, receiving notifications from the Arrow Board devices about their display and location when they are activated will help ATMS operator staff to better understand real-time conditions in the field and provide more accurate traveler information. The frequency of updates and whether verification is required will be configurable in order to balance needs to not overwhelm ATMS operators, while receiving sufficient updates as to maintain confidence in the Arrow Board reports. Specifically, operator verification is expected during acceptance testing to validate and gain confidence in the Arrow Board reports. The following section defines the operational concept from the ATMS operator staff perspective.

6.4.1 ATMS operator staff will carry out all duties performed under the current state at the TMC. (Need 1-2)

6.4.2 ATMS operator staff will view information about a lane closure when an Arrow Board has been activated in the field through the operator interface of the ATMS. Information will include the current Arrow Board display and location information. This notification to ATMS operator staff may indicate that the data received from the Arrow Boards has been automatically processed and ingested to the ATMS, matches a pre-existing event in the ATMS and provides updated information, and/or may require further action, such as a confirmation "click" or "response" from ATMS operator staff before being accepted by the ATMS. (Needs 1-3, 1-7, 3-2)

6.4.3 It is likely that additional action would be required by ATMS operator staff, either to approve a message recommended by the ATMS for a specific DMS, or to generate a message and identify an appropriate DMS on which to post the message. This traveler information message about the event would be more specific than any message posted without receipt of this Arrow Board information. (Need 1-2)

6.4.4 When the Arrow Board display changes or a detected change in location is significant enough to indicate it has changed lanes, is part of a mobile work zone, was hit by a passing vehicle, or blown out of place by strong winds, for example, a notification(s) will automatically be generated for receipt by ATMS operator staff. While the information received in the alert will be similar to the activation alert, whether the update is automatically or manually made to the ATMS may not be the same process as for the activation message. (Needs 1-3, 1-7, 1-8, 2-8, 2-9, 3-3)

6.4.5 ATMS operator staff will update any posted DMS message, as necessary. (Need 1-2)

6.4.6 While the Arrow Board Reporting System will periodically send messages to confirm it is still operational, these periodic updates will not be sent to ATMS operators, thus avoiding an overload of information. Depending upon the functionality of the ATMS, information about the most recent

update may be available to ATMS operator staff on demand; this could include icons or a map layer showing the location, status, and timestamp of latest update of various reporting Arrow Board devices. (Need 1-5)

6.4.7 ATMS operator staff will receive a notification when the Arrow Board is no longer active, upon receipt of a final device power down message, when expected messages from the device are no longer received, or when the display is turned off. Again, actions to close the event in the ATMS may be automatic or manual. (Needs 1-3, 1-6, 1-7, 2-10, 3-10)

6.4.8 ATMS operator staff will remove any posted DMS message regarding the lane closure event, as necessary. (Need 1-2)

6.4.9 Periodically, ATMS operator staff may check the accuracy and reliability of automated reports from Arrow Boards. This may be done by using CCTV cameras to verify locations of closures or checking with other DOT staff that may observe closures. (Need 1-5, 3-1)

6.5 RCRS Operator Staff Perspective

RCRS operator staff are sometimes alerted to planned lane closures and road work activities. However, many road work and maintenance activities are short duration within a larger timeframe or subject to change (e.g., due to inclement weather), and RCRS operator staff are not alerted in advance or, if so, unaware of the precise times the closure and road work activities are underway. Receiving notifications from the Arrow Board devices about their display and location when they are activated will help RCRS operator staff to better understand real-time conditions in the field and provide more accurate traveler information. The frequency of updates and whether verification is required will be configurable in order to balance needs to not overwhelm RCRS operators, while receiving sufficient updates as to maintain confidence in the Arrow Board reports. Specifically, operator verification is expected during acceptance testing to validate and gain confidence in the Arrow Board reports. As such, the role of RCRS operator staff under the proposed system may vary based on the rules and policies set forth by the agency. The following section defines the operational concept from the RCRS operator staff perspective.

6.5.1 RCRS operator staff will carry out all duties performed under the current state. (Need 1-1)

6.5.2 RCRS operator staff may be automatically be alerted when an Arrow Board has been activated in the field, which will include its display and location information. This notification may be received by the RCRS and displayed to the operator staff using an RCRS alert function. This notification to RCRS operator staff may indicate that the data received from the Arrow Boards has been automatically processed and ingested to the RCRS and/or traveler information dissemination systems, matches to a pre-existing event in the RCRS and/or traveler information dissemination systems and provides updated information, and/or may require further action by the RCRS operator staff, such as a confirmation “click” or “response” from RCRS operator staff before being accepted by either of those systems. (Needs 1-1, 1-3, 1-7, 3-2)

6.5.3 The data delivered to RCRS operator staff may not include any details about the extent (distance along the road) that the lane is closed or about the anticipated end time of the lane closure. Therefore, RCRS operator staff might need to automatically or manually create RCRS events without these specific details. (Needs 1-7, 3-1)

6.5.4 When the Arrow Board location (i.e., indicating it has changed lanes, is part of a mobile work zone, was hit by a passing vehicle, or blown out of place by strong winds) or display changes, a notification(s) may also be generated for receipt by RCRS operator staff. While the information received in the notification might be similar to the activation notification, whether the update is automatically or manually made to the RCRS and/or traveler information dissemination systems may not be the same process as for the activation message. (Needs 1-1, 1-3, 1-5, 1-7, 1-8, 2-8, 2-9, 3-3)

6.5.5 While the Arrow Board Reporting System will periodically send messages to confirm it is still operational, these periodic updates will not be sent to RCRS operator staff, thus avoiding an overload of information. Depending upon the functionality of the RCRS, information about the most recent update may be available to operators on demand. (Need 1-5)

6.5.6 RCRS operator staff may receive a notification when the Arrow Board is no longer active, upon receipt of a final device power down message, when expected messages from the device are no longer received, or when the display is turned off. Again, actions to close the event in the RCRS and/or traveler dissemination systems may be automatic or manual. (Needs 1-1, 1-3, 1-6, 1-7, 2-10, 3-10)

6.5.7 Periodically, RCRS operator staff may check the accuracy and reliability of automated reports from Arrow Boards. This may be done by using CCTV cameras to verify locations of closures or checking with other DOT staff that may observe closures. (Needs 1-5, 3-1)

6.6 Archived Data Users Perspective

A variety of DOT staff will benefit from non-real-time access to data describing the lane closures. Examples of the uses will include: understanding actual times when lane closures occurred, relating lane closures to crashes, delays, or other operational situations, and comparisons of planned TMPs to actual.

6.6.1 DOT staff wishing to access the lane closure data will most likely utilize a database access tool to query the data stored in the database of either the RCRS or the ATMS (or a separate database created specifically for Arrow Board notifications). DOT staff will likely search segments of roads or geographic areas to identify lane closures in their query. (Needs 1-4, 2-1)

6.6.2 Data stored in the database will enable DOT staff to learn details of the location of the start of the lane closure, time the lane closure began, and the time the lane closure ended. Additional details such as the extent (distance along the road) that the lane was closed will not be available. (Needs 1-4, 2-1)

7.0 Roles and Responsibilities

Based on the approaches selected in the operational concept, the high-level tasks for Arrow Board Reporting Systems are further described as specific roles in this section. For each role, the parties who may potentially be responsible for the role will vary by location and contracting mechanism. There is a high degree of variability between and within agencies regarding stakeholders responsible for operating and maintaining work zone devices like Arrow Boards.

The approach to this section is to assist agencies considering deploying Arrow Board Reporting Systems by understanding the likely roles that would be performed by the following groups of individuals that were identified as primary stakeholders in Section 3.0:

- ***TMC Staff.*** Includes ATMS operator staff and RCRS operator staff, either DOT or contractor staff, who work with ATMS or RCRSs (whether physically in a TMC or not) to manage traffic and provide traveler information dissemination.
- ***ITS Vendors.*** Includes the equipment owners and system integrators who develop and support operations of the ATMS and/or RCRS, regardless of where it is hosted. Note that in some states, the DOT may be the developer of the ATMS and/or RCRS.
- ***Field Staff.*** Includes Arrow Board operators, work zone inspectors, and construction managers, that are DOT staff and/or contractors, who perform work zone activities. May also include the suppliers of Arrow Boards and/or Arrow Board Reporting Systems to be attached to existing Arrow Boards. Include local agencies, utility companies, etc. as operators.
- ***Archived Data Users.*** Includes work zone planners and managers, the traffic operations group, congestion and performance managers, and others who may benefit from archived Arrow Board data for quantitative analysis.

The suggested role of each group identified above reflects the fact that Arrow Board Reporting Systems are primarily intended to enhance the functionalities of TMC Systems, i.e., ATMS, RCRS, and/or other data processing systems, in order to improve traveler information and archived data. Therefore, the concepts presented in this ConOps (and particularly the responsibilities in Table 5) attempt to minimize the manual actions requested of field staff.

Table 5: Roles and Expected Stakeholder Group to be Considered for Performing Role

Role	Stakeholder Group to be Considered for Performing Role
Up-front / One-time Roles:	
Install Arrow Board Reporting System equipment on existing Arrow Boards or procure Arrow Boards with reporting capabilities	ITS Vendors and Owners; Field Staff
Determine strategy to integrate Arrow Board reports with ATMS and/or RCRS systems.	TMC Staff; ITS vendors and Owners
Perform modifications to ATMS and/or RCRS systems to integrate with Arrow Board Reporting System.	TMC Staff; ITS vendors and Owners
Determine DOT specific approach to interfacing with Arrow Board Reporting Systems (e.g., proxy server or direct TMC Systems communication to vendor Arrow Boards or servers)	TMC Staff; ITS vendors and Owners
Establish any needed proxy servers and communication services.	TMC Staff; ITS vendors and Owners
Determine DOT specific approach for archiving lane closure reports and allowing access to archived data by DOT staff outside the TMC.	TMC Staff
Develop and establish database for storage and data access retrieval system.	TMC Staff
Regular Roles (Typically performed daily):	
Place, activate, and operate Arrow Board (with no additional tasks beyond typical Arrow Board setup and field operation)	Field Staff
Review Arrow Board notifications as received in real-time, and take appropriate action.	TMC Staff
Review Arrow Board messages as received in real-time.	Field Staff
Periodic Roles (Performed as needed):	
Periodically perform some form of manual check on the accuracy and functionality of Arrow Board reports (e.g., CCTV verification).	ITS Vendors and Owners; TMC Staff; Field Staff
Perform any needed repairs to Arrow Board Reporting Systems, following detection from periodic checks.	ITS Vendors and Owners; Field Staff
Access, query, and utilize archived Arrow Board data, as needed.	Archived Data Users

8.0 Scenarios

This section presents a series of typical scenarios that illustrate how the Arrow Board Reporting System functionality would be used by stakeholders. For illustrative purposes, five scenarios are described, each highlighting various aspects of Arrow Board Reporting System functionality. The intent of the scenarios is not to describe all possible situations, but rather to highlight specific functionality for discussion among the project team.

8.1 Scenario 1: Arrow Board Deployment and Activation

Arrow Boards equipped with data collection and communication technologies will be deployed in the field in a similar fashion as in the current state. However, Arrow Board activation now includes the transmission of data messages to the TMC for processing. Processed information is sent to TMC operators and stakeholders in the field, e.g., the contractor or DOT inspector, ingested to RCRS and ATMS systems, and posted to traveler information dissemination systems and/or upstream DMS.

1.1 At 6:00 a.m., an Arrow Board trailer equipped with data collection and communication technologies is parked at the side of State Highway 32 at milepost 9.12, a 4-lane divided highway where a planned temporary work zone that includes a lane closure is scheduled. It is delivered to the field in a similar fashion as in the current state, after having undergone standard testing procedures. The data collection and communication technologies were tested upon installation, and are inspected periodically by DOT staff or the Arrow Board supplier when the Arrow Board device is not in the field.

1.2 At 6:30 a.m., the Arrow Board device is pulled into position on the northbound left side shoulder with a narrow median and the display board is rotated vertically to be visible to passing drivers.

1.3 At 6:32 a.m., the Arrow Board is powered on and programmed to display lights in each of the four corners to indicate a caution message to passing drivers.

1.4 At 6:33 a.m., the Arrow Board automatically collects data to assemble an initial data message containing: device ID, current time, latitude and longitude, display status (i.e., lights in the four corners for caution), display orientation (i.e., visible to drivers), and sufficient data for determining the direction the Arrow Board is facing.

1.5 The initial data message assembled by the Arrow Board is transmitted to the TMC. The method by which this is accomplished will vary based on the policies and procedures of the TMC and DOT, as detailed in the three options below.

1.5.1 *Option 1:* The TMC, knowing the equipped Arrow Board devices that may be deployed to the field, has been "pinging" the devices periodically (e.g., every five minutes) to request data. Upon receipt of this "ping", the Arrow Board transmits the data message directly to the TMC. The TMC may be aware of equipped Arrow Boards by referencing a dynamic vendor-provided inventory message that contains the device IDs of all equipped Arrow Boards.

1.5.2 *Option 2:* The Arrow Board Reporting System consists of the Arrow Board in the field and a central server operated by either the vendor or the DOT. The Arrow Board in the field automatically transmits data from the field to the central server where post-processing determines the remaining data. The data is then available on the central server. The TMC periodically pings this central server for new or updated information and collects the Arrow Board data message.

1.5.3 *Option 3:* The Arrow Board Reporting System transmits data to a proxy server. The TMC periodically checks this proxy server for new or updated information and collects the Arrow Board data message.

1.5.4 *Option 4:* The Arrow Board automatically transmits the data message directly to the TMC.

1.6 At 6:35 a.m., upon receipt of the Arrow Board data message, the data is processed. The latitude/longitude data element is translated to generate two new data elements: highway and milepost (e.g., SH32, 9.12); the location, compass reading, and/or a suitable alternative is used to generate a new data element: direction of travel (e.g., NB); and a new timestamp is added (i.e., the message now contains the time the data was collected: 6:33 a.m., and time the processed data package is available: 6:36 a.m.).

1.7 At 6:36 a.m., the TMC System determines from the processed information and device ID that an Arrow Board has been recently activated and is displaying a caution message on the northbound left side shoulder of State Highway 32 at milepost 9.12. This information may be displayed as icons or a map layer showing the location and status of the reporting Arrow Board device(s). The TMC System has verified that no other Arrow Board devices are transmitting information that would indicate a current or anticipated multi-lane closure.

1.8 Within seconds, the TMC System automatically sends messages containing the processed Arrow Board information to ATMS and RCRS operators and stakeholders in the field who had previously registered to receive alerts of Arrow Board activations in this area, such as contractors and/or DOT work zone inspectors.

1.8.1 Upon receipt of the notification, the stakeholder in the field may note that the contained information is incorrect. This might be communicated to the TMC operators and would trigger the initiation of maintenance activities in the field to troubleshoot the issue.

1.9 Simultaneously, the TMC readies the information and ingests to the ATMS and/or RCRS, as appropriate. The method by which this is accomplished will vary based on the policies and procedures of the TMC and DOT, as detailed in the five options below.

1.9.1 *Option 1:* Shoulder closure information is automatically posted to the ATMS and/or RCRS.

1.9.2 *Option 2:* Shoulder closure information is automatically checked against existing road construction events, and automatically posted as a new event or merged with an existing event to update it, as necessary. This includes the possibility that an adjacent Arrow Board facing the same direction on the same roadway is active as part of a work zone that impacts multiple lanes.

1.9.3 *Option 3:* Shoulder closure information is automatically posted to the ATMS and/or RCRS upon receipt of a one-click approval by the TMC operator who reviews the received notification.

1.9.4 *Option 4:* Shoulder closure information is manually posted to the ATMS and/or RCRS upon review by the TMC operator who may also edit the information after receipt of the notification, or use the information to update an existing event in the ATMS and/or RCRS, which may include noting that multiple lanes are closed given reports from adjacent Arrow Boards facing the same direction on the same roadway.

1.9.5 *Option 5:* Shoulder closure information may not be posted to the ATMS and/or RCRS if the TMC operator decides existing event information in those systems is already up to date.

1.10 After the shoulder closure is logged in the ATMS and/or RCRS as a new event, a message is automatically generated for posting to traveler information dissemination systems, e.g., 511 phone and website, mobile applications, and/or etc. The content included in this message will vary based

on the policies and procedures of the DOT and TMC, e.g., the information may not indicate a shoulder closure, but be a more general roadwork message. Similarly, the method by which this message is posted will vary based on DOT and TMC policies and procedures, as well as the option used in 1.9, as detailed in the five options below.

1.10.1 *Option 1:* Shoulder closure information is automatically posted to the traveler information dissemination systems.

1.10.2 *Option 2:* Shoulder closure information is automatically checked against existing road construction events in the traveler information dissemination systems, and automatically posted as a new event or merged with an existing event to update it, as necessary.

1.10.3 *Option 3:* Shoulder closure information is automatically posted to the traveler information dissemination systems upon receipt of a one-click approval by the TMC operator who reviews the message.

1.10.4 *Option 4:* Shoulder closure information is manually posted to the traveler information dissemination systems by the TMC operator who may also make changes, include additional information like the expected duration of the event, or use the provided information to update an existing event in the traveler information dissemination systems.

1.10.5 *Option 5:* TMC operator decides not to post the information, e.g., if the TMC operator decides existing event information is already up to date.

1.11 Upon receipt of the shoulder closure notification, the TMC operator examines whether any DMS are immediately upstream of the event and, if so, considering various factors (e.g., how far upstream the DMS is, other messages being displayed, etc.), determines whether a message should be posted. A DMS is located less than two miles upstream and the TMC operator posts a message: "Left shoulder closed ahead; Use Caution". Alternately, if the ATMS used by the agency includes an incident response functionality, the ATMS may automatically located upstream DMS and recommend messages for these DMS, requiring only that the TMC operator accept or edit the recommended displays.

1.12 Scenario 2 commences.

8.2 Scenario 2: Arrow Board Ongoing Reporting of Operational Status – No Changes

Following Arrow Board activation, ingest of information to the ATMS and/or RCRS, and posting on traveler information dissemination systems, data will continue to be collected and periodically transmitted to the TMC. Received data will be processed to identify any changes in the Arrow Board operational status. Pending the determination by the TMC System of no major changes, no notifications are issued to stakeholders and no updates to the ATMS, RCRS, or traveler information dissemination systems are necessary.

2.1 Following the initial collection of data at 6:33 a.m., the Arrow Board described in Scenario 1 again collects the same data at a pre-defined interval (e.g., one minute, five minutes, etc.).

2.2 The second (and subsequent) data message assembled by the Arrow Board is transmitted to the TMC System. The method by which this is accomplished will vary based on the policies and procedures of the TMC and DOT, as outlined above. Note that the timing of data collection frequency in 2.1 will ideally be programmed to be equal or less than the timing for the transmission frequency described here. The frequency of information updates will vary depending on the movement and duration of the Arrow Board device, regarding a mobile or longer-duration, stationary work zone, respectively.

2.3 Upon receipt of the second (and subsequent) Arrow Board data message, the new data is processed as described in 1.6.

2.4 The TMC System determines from the device ID and timestamp that previous messages have recently been received from this Arrow Board.

2.5 The TMC System compares the current information against the previous information message to identify changes in: location, display status, and display orientation.

2.6 The TMC System automatically makes a determination on whether action is needed.

2.7 If no changes are identified, no notification is issued to any stakeholders and no updates are created for the ATMS, RCRS, or traveler information dissemination systems.

2.8 Scenario 2 repeats with data being requested / received by the TMC System pre-determined frequency, unless status changes are detected as per Scenario 3.

2.8.1 If the Arrow Board display status and location has not changed within X hours, the frequency of requesting / receiving data from the Arrow Board will be lowered.

8.3 Scenario 3: Arrow Board Ongoing Reporting of Operational Status – Changes Identified

Following Arrow Board activation, ingest of information to the ATMS and/or RCRS, and posting on traveler information dissemination systems, data will continue to be collected and periodically transmitted to the TMC as described in Scenario 2. Received data will be processed to determine changes in status that may indicate: 1) the Arrow Board is part of a mobile work zone, 2) the Arrow Board display has changed, indicating a change in the field regarding the status of the lane closure, 3) the Arrow Board has been hit by a passing vehicle or blown out of place by strong winds, or 4) as detailed in Scenario 4, the lane closure is no longer active. Major status changes will be communicated to TMC operators and stakeholders in the field, and used to update the ATMS, RCRS, and traveler information dissemination systems.

3.1 At 7:30 a.m., the Arrow Board is re-programmed to display a right arrow and begins moving in the left lane as part of a mobile work zone.

3.2 As described in Scenario 2, the Arrow Board continues to collect and transmit the same data at pre-defined intervals to the TMC System for processing.

3.3 The TMC System compares the current information against the previous information message to identify changes in location and display status.

3.4 Because a change in location is identified, the new location is checked by TMC Systems to check that the device has not been hit by a passing vehicle or blown out of position. [If so, a notification message will be issued that there is a maintenance need.] If not, the TMC systems will check that the device is still on the roadway. [If the device is no longer on the roadway, Scenario 4 is initiated.]

3.5 Because the device is moving along the same roadway, the speed is calculated. Calculated speed is equal or less than the speed assumed for a mobile work zone. [If the speed is calculated to be greater than the speed assumed for a mobile work zone, Scenario 4 is initiated.] The pre-determined speed thresholds for ascertaining a mobile work zone vs. traveling down the roadway may vary by road type (e.g., interstate, arterial) and location (e.g., urban vs. rural).

3.6 The TMC System automatically generates a notification of the new Arrow Board display, previous Arrow Board display, and the speed the device is moving as part of a mobile work zone.

3.7 The TMC System automatically sends separate notifications to TMC operators and stakeholders in the field, as applicable, such as contractors and/or DOT work zone inspectors.

3.7.1 Upon receipt of the notification, the stakeholder in the field may note that the contained information is incorrect. This should be communicated to the TMC operators and would trigger the initiation of maintenance activities in the field to troubleshoot the issue.

3.8 Simultaneously, the TMC System readies the information and ingests to the ATMS and/or RCRS, as appropriate. The method by which this is accomplished will vary based on the policies and procedures of the TMC and DOT, as detailed in the three options below.

3.8.1 *Option 1:* New lane closure information is automatically posted to the ATMS and/or RCRS to update the earlier, related event associated with the same device ID.

3.8.2 *Option 2:* New lane closure information is automatically posted to the ATMS and/or RCRS upon receipt of a one-click approval by the TMC operator who reviews the received notification

3.8.3 *Option 3:* New lane closure information is manually posted to the ATMS and/or RCRS upon review by the TMC operator who may also edit the information after receipt of the notification.

3.9 After the new lane closure information is updated in the ATMS and/or RCRS as a new event, a new message is automatically generated for posting to traveler information dissemination systems, e.g., 511 phone and website, mobile applications, and/or etc. The content included in this message will vary based on the policies and procedures of the TMC and DOT, e.g., the information may not indicate the specific location of a mobile work zone, but be a more general lane closure message. Similarly, the method by which this message is posted will vary based on DOT and TMC policies and procedures, as well as the option used in 3.8, as detailed in the three options below.

3.9.1 *Option 1:* New lane closure information is automatically used to update the earlier, related event in the traveler information dissemination systems associated with the same device ID.

3.9.2 *Option 2:* New lane closure information is automatically posted to the traveler information dissemination systems upon receipt of a one-click approval by the TMC operator who reviews the message.

3.9.3 *Option 3:* New lane closure information is manually posted to the traveler information dissemination systems by the TMC operator who may also make changes or include additional information like the expected duration or project boundaries for the event.

3.10 Upon receipt of the new lane closure notification, the TMC operator examines whether any DMS are immediately upstream of the event and, if so, considering various factors (e.g., how far upstream the DMS is, other messages being displayed, etc.), determines whether a message should be posted. A DMS is located less than two miles upstream and the TMC operator posts a message: "Left lane closed ahead; Use Caution".

3.11 The frequency for the TMC System requesting information / receiving data is automatically adjusted to be increased given the fast-changing nature of a mobile work zone and Scenario 3 repeats to update location information.

8.4 Scenario 4: Arrow Board De-activation and Powering Down

At some point in time when the lane closure is ended, the Arrow Board will be de-activated and powered down. Depending on the Arrow Board capabilities, the TMC Systems may be directly notified

about the lane closure ending via a final message transmitted by the Arrow Board or this may be inferred when consecutive anticipated data messages are not received. This scenario follows Scenario 2 and/or Scenario 3.

4.1 Per Scenario 2 and Scenario 3, the Arrow Board gathers and transmits data to the TMC Systems at pre-determined intervals. At 12:45 p.m., the lane closure ends and the Arrow Board is no longer needed.

4.2 The TMC System processes available data (or lack thereof) and determines that the lane closure is no longer active. Depending on the Arrow Board technology capabilities and stakeholder actions in the field, the system may come to this conclusion as described by the following four options. Note: when more than one Arrow Board is operational for a lane closure event, the identification of a single Arrow Board powering down would follow Scenario 3 to modify the event, rather than end it.

- 4.2.1 *Option 1:* The Arrow Board is pulled off to the side of the road, facing away from traffic. The display remains active. Per Scenario 3, step 3.4 the TMC can make the determination that the lane closure is no longer active.
- 4.2.2 *Option 2:* The Arrow Board is pulled off to the side of the road and the display board is rotated down. Per Scenario 3, step 3.3 the TMC can make the determination that the lane closure is no longer active.
- 4.2.3 *Option 3:* The Arrow Board display is turned off. Per Scenario 3, step 3.3 the TMC can make the determination that the lane closure is no longer active.
- 4.2.4 *Option 4:* The Arrow Board is transported down the highway at full speed. Per Scenario 3, step 3.5 the TMC can make the determination that the lane closure is no longer active.
- 4.2.5 *Option 5:* The Arrow Board is fully powered down. The TMC does not receive consecutive messages as anticipated and draws the conclusion that the device has been turned off and determines the lane closure is no longer active.
- 4.2.6 *Option 6:* The Arrow Board is powered down and one final "turn off" message is generated for communication to the TMC. The device communication mechanism may remain on given the provision of a power source, and also provide location and battery status when the Arrow Board is inactive.

4.3 The TMC System automatically generates a notification of that the Arrow Board has been powered down and the lane closure has ended.

4.4 The TMC System automatically sends separate the notifications to TMC operators and stakeholders in the field, such as contractors and/or DOT work zone inspectors.

4.5 Simultaneously, the TMC Systems ingest the information to the ATMS and/or RCRS, as appropriate. The method by which this is accomplished will vary based on the policies and procedures of the TMC and DOT, as detailed in the five options below.

- 4.5.1 *Option 1:* The respective event associated with that device ID is automatically ended within the ATMS and/or RCRS.
- 4.5.2 *Option 2:* The respective event associated with that device ID is automatically modified within the ATMS and/or RCRS to indicate the lane closure has ended; the event remains in the system until the previously assigned time or until further action is taken, which assumes that other construction activities may still be underway in the area or take place on other days.
- 4.5.3 *Option 3:* The respective event associated with that device ID is automatically ended within the ATMS and/or RCRS upon receipt of a one-click approval by the TMC operator who

reviews the received notification. This may or may not follow confirmation from stakeholders in the field that the information is correct.

4.5.4 *Option 4:* The respective event associated with that device ID is automatically modified within the ATMS and/or RCRS to indicate that the lane closure has ended upon receipt of a one-click approval by the TMC operator who reviews the received notification. This may or may not follow confirmation from stakeholders in the field that the information is correct.

4.5.5 *Option 5:* The appropriate lane closure event is manually modified within the ATMS and/or RCRS upon review by the TMC operator. This may or may not follow confirmation from stakeholders in the field that the information is correct.

4.6 After the lane closure event is ended or edited within the ATMS and/or RCRS, the respective event is automatically flagged for termination or modification (per the Option selected within 4.5) within the traveler information dissemination systems, e.g., 511 phone and website, mobile applications, and/or etc., reflecting the change in the ATMS and/or RCRS. The method by which the message is ended may vary based on DOT and TMC policies and procedures, as detailed in the three options below.

4.6.1 *Option 1:* The relevant event is automatically ended/modified per the change in the ATMS and/or RCRS within the traveler information dissemination systems.

4.6.2 *Option 2:* The relevant event is automatically ended/modified within the traveler information dissemination systems upon receipt of a one-click approval by the TMC operator who reviews the message. This may or may not follow confirmation from stakeholders in the field that the information is correct.

4.6.3 *Option 3:* The relevant event is manually ended/modified within the traveler information dissemination systems by the TMC operator who may also make changes or include additional information like the expected duration or project boundaries for the event. This may or may not follow confirmation from stakeholders in the field that the information is correct.

4.7 Upon receipt of the notification that the lane closure has ended, the TMC operator examines messages posted on any DMS upstream of the event and modifies or removes the message, as appropriate.

8.5 Scenario 5: Non-Real Time Data Use

Data that is collected in the field from Arrow Boards is valuable to stakeholders for evaluation, performance measurement, research, and future planning purposes. Both internal and external stakeholders are interested in accessing data collected from the Arrow Boards months or possibly even years after the work zone was active. This scenario assumes access to archived data will be through a database maintained by the DOT.

5.1 Throughout the Summer 2016 construction season, per Scenario 1, Scenario 2, Scenario 3, and Scenario 4, equipped Arrow Boards are deployed in the field and when activated collect data. Available data regarding current device status includes device ID, latitude/longitude, display status (i.e., arrow left or arrow right), timestamp, and, if location accuracy is insufficient to determine the lane closure, a compass reading and/or a suitable alternative. Other data of interest from the device may also be collected, as available.

5.2 As data is generated from activated Arrow Boards, it is transmitted to the TMC as described in Scenario 1, Scenario 2, Scenario 3, and Scenario 4. Data transmission may be automatic, to a proxy server, or by request from the TMC, depending on the deploying DOT.

5.3 As described in Scenario 2, Scenario 3, and Scenario 4, this data is received, labelled with an additional timestamp, and archived.

5.4 As described in Scenario 1, Scenario 2, Scenario 3, and Scenario 4, the data is processed for the generation of traveler information and appropriate ingest by the RCRS and/or ATMS, pending any approvals by TMC operators, as well as transmission of any messages to other stakeholders in the field.

5.5 As information is made available to the RCRS, ATMS, and/or traveler information systems, as well as the respective time of approvals and posting, it is saved for later use in the DOT data archive.

5.6 The data and information generated from the Arrow Boards, as described above, reside in the DOT data archive for a designated period of time, per DOT policy, and supplement other data that may be available from permanent or temporary devices adjacent to or within the various work zones that Arrow Boards were deployed.

5.7 On October 3, 2016, DOT database managers receive a data request about work zones involving lane closures from a work zone performance manager. The managers are interested in mobility and safety impacts from these work zones in June 2016.

5.8 On October 4, 2016, DOT database managers query the data archive for information from active Arrow Boards displaying a message from June 1, 2016 through June 30, 2016. Available information includes the ATMS and RCRS logs, as well as the raw data from the Arrow Boards.

5.9 Data records with Arrow Board activation data and information are saved in a separate file and sent to the work zone performance manager.

5.10 This Arrow Board data file allows work zone performance managers to identify relevant traffic counters and other available mobility data sources either within or adjacent to each work zone, and also query other databases, with crash records for instance, to conduct data analysis and generate performance measures regarding the mobility and safety impacts of work zones with lane closures.

5.11 On November 14, 2016, DOT database managers receive a data request for planning purposes about work zones in 2016 involving lane closures from a contractor developing a work zone TMP.

5.12 On November 15, 2016, DOT database managers modify the earlier query to capture all work zones with Arrow Board activations from April 1, 2016 to September 30, 2016. Available information includes the ATMS and RCRS logs, as well as the raw data from the Arrow Boards.

5.13 Data records with Arrow Board activation data and information are saved in a separate file and sent to the contractor.

5.14 This Arrow Board data file allows the contractor to first separate work zones involving lane closures on similar roadways to the roadway with the future work zone (i.e., similar traffic volumes or functional class). After identifying and collecting data from relevant traffic counters and other available mobility data sources either within or adjacent to those work zones to analyze the mobility impacts, the contractor has an improved understanding of the impacts to expect for the planned work zone and countermeasures necessary for mitigation.