Guidance for Incorporating Work Zone Data within Traffic Management Operations

Final Report
December 2024

SWZDI
Smart Work Zone Deployment Initiative

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Center for Transportation Research and Education

Iowa State University
Institute for Transportation

Sponsored by
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About the Smart Work Zone Deployment Initiative

The Smart Work Zone Deployment Initiative (SWZDI) is a transportation pooled fund that supports research investigations into better ways to improve the safety and efficiency of traffic operations and highway work in work zones. The primary objective is to promote and support research and outreach activities that focus on innovative policies, processes, tools, and products that enhance the implementation, safety, and mobility impacts of work zones.

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The mission of the Center for Transportation Research and Education (CTRE) at Iowa State University is to conduct basic and applied transportation research to help our partners improve safety, facilitate traffic operations, and enhance the management of infrastructure assets.

About the Institute for Transportation

The mission of the Institute for Transportation (InTrans) at Iowa State University is to save lives and improve economic vitality through discovery, research innovation, outreach, and the implementation of bold ideas.

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16. Abstract

The ability for agencies to notify vehicles that they are approaching a work zone has the potential to reduce crashes by increasing motorists' awareness of the conditions. A critical element of this ability involves providing accurate work zone information and reducing the potential for false alerts that motorist ignore, which can be accomplished through connected temporary traffic control devices (cTTCDs) such as connected arrow boards. Guidance is needed for agencies on integrating work zone data into traffic management operations to enhance safety and efficiency. This study focused on cTTCDs such as connected arrow boards, connected traffic cones, and other smart devices that improve the accuracy of work zone information. The research documents the current state of the practice, evaluates various cTTCDs, and explores methods for their integration into an agency's work zone management system through technology such as an advanced traffic management system (ATMS).

For a broad view of how arrow boards can be integrated, arrow board data were summarized across 18 states. In total, 498,358 arrow board activations were captured between January 2023 and August 2024. As the search radius around each arrow board decreased, the percentage of locations that were unambiguously associated with a single roadway increased, with 86.6% of locations being unambiguous at a search radius of 25 ft. In total, 62% of arrow board activations had the closest roadway within 50 ft of the arrow board, with a majority of arrow board activations within close proximity to a roadway and two-thirds of the closest activations being less than 25 ft.

In terms of the potential benefits, the arrow board activations near a work zone represented only 11.3% of the total activations in Wisconsin, 1.2% of the total activations in Colorado, and 31.1% of the total activations in Iowa. In Iowa, arrow board activations occurred on average 290 minutes before the reported start time and 0.99 miles before the reported start location for verified work zones and on average 139 minutes before the reported start time and 0.51 miles before the reported start location for estimated work zones.

The use of cTTCDs such as connected arrow boards is expected to continue to increase, which will result in the need for additional research to continue to explore how this information can be utilized for real-time and historical analysis. The potential for automating the process of associating arrow boards and work zones still faces implementation challenges, but these can be overcome with continued evaluation and deployment of cTTCDs.

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This research was conducted under the Smart Work Zone Deployment Initiative (SWZDI) and Federal Highway Administration (FHWA) Pooled Fund Study TPF-5(438), involving the following state departments of transportation (DOTs):

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EXECUTIVE SUMMARY

The ability for agencies to notify vehicles that they are approaching a work zone has the potential to reduce crashes by increasing motorists' awareness of the conditions. A critical element of this ability involves providing accurate work zone information and reducing the potential for false alerts that motorist ignore, which can be accomplished through connected temporary traffic control devices (cTTCDs) such as connected arrow boards. Guidance is needed for agencies on integrating work zone data into traffic management operations to enhance safety and efficiency. This study focused on cTTCDs such as connected arrow boards, connected traffic cones, and other smart devices that improve the accuracy of work zone information. The research documents the current state of the practice, evaluates various cTTCDs, and explores methods for their integration into an agency's work zone management system through technology such as an advanced traffic management system (ATMS).

For a broad view of how arrow boards can be integrated, arrow board data were summarized across 18 states. In total, 498,358 arrow board activations were captured between January 2023 and August 2024. As the search radius around each arrow board decreased, the percentage of locations that were unambiguously associated with a single roadway increased, with 86.6% of locations being unambiguous at a search radius of 25 ft. In total, 62% of arrow board activations had the closest roadway within 50 ft of the arrow board, with a majority of arrow board activations within close proximity to a roadway and two-thirds of the closest activations being less than 25 ft.

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The use of cTTCDs such as connected arrow boards is expected to continue to increase, which will result in the need for additional research to continue to explore how this information can be utilized for real-time and historical analysis. The potential for automating the process of associating arrow boards and work zones still faces implementation challenges, but these can be overcome with continued evaluation and deployment of cTTCDs.

INTRODUCTION

Road work is a required task for managing the safety and operations of transportation systems. Many transportation agencies are now making a commitment to zero deaths, which includes embracing a safe systems approach that considers crash risks across all agency practices. As agencies consider ways to reduce death and serious injury, improving work zone safety is a logical beginning point, which includes improving the accuracy of information on work zone locations and timing. The ability for agencies to notify vehicles that they are approaching a work zone has the potential to reduce crashes by increasing motorists' awareness of the conditions. A critical element of this ability involves providing accurate work zone information and reducing the potential for false alerts that motorist ignore. Any technology intended to provide real-time conditions should include the critical element of work zone location and status.

Currently, most agencies rely on their 511 website to communicate with the public. However, this information is often inaccurate due to the required manual input of data from field staff and traffic management center (TMC) operators. One of the common inaccuracies is showing that a work zone is active when there is no work present (see Figure 1). These examples are common across the country for infrastructure owners and operators (IOOs), but providing inaccurate data, in any feed, will result in a loss of confidence by the public. Characteristics of a smart work zone system, as defined by the Federal Highway Administration (FHWA), include the ability to provide real-time information and being portable, automated, and reliable. Many of the systems currently used to report work zone location lack all of these characteristics at this time.

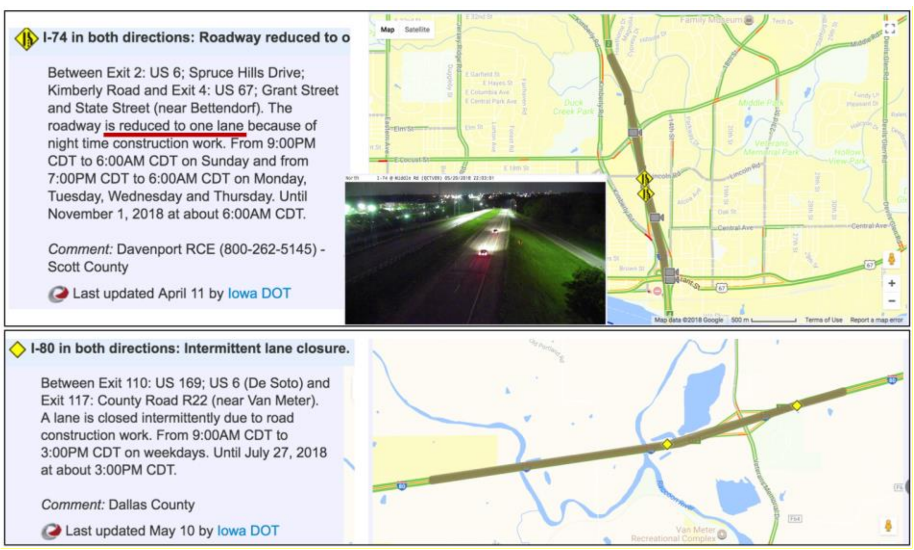


Figure 1. Example of inaccurate 511 work zone data

Connected temporary traffic control devices (cTTCDs) such as connected arrow boards, connected traffic cones and panels, temporary traffic signals, and so on can be used to improve the accuracy of information on work zone status and location. These types of devices differ from many other smart work zone devices such as sensors, cameras, and message signs in that their primary function is to report the location and status of the device in order to locate a work zone.

Fortunately, the use of cTTCDs has increased over the last several years. The Iowa Department of Transportation (DOT) began requiring connected arrow boards in work zones in 2021, with other agencies requiring similar devices for individual projects. In addition to offering connected arrow boards, multiple vendors include location capabilities in other devices, including traffic cones, panels, tapers, portable rumble strips, or multipurpose devices that can be attached to various work zone equipment, as shown in Figure 2. The market for providing connected location equipment within work zones is growing, and this equipment is being tested in multiple states.

Figure 2. Various types of cTTCDs

There are two challenges agencies face when beginning to work with cTTCDs. The first is the ability to access the data from the devices, which for arrow boards has gradually been improving with initial efforts by the Iowa DOT that were later expanded to the Work Zone Data Exchange (WZDx) device feed. The second challenge, and the more pressing issue for agencies today, is what to do with the data when access is obtained. As the number and types of devices increase and methods of collecting the data are established, guidance is needed to help transportation agencies take advantage of these technologies in order to improve their work zone data in ways that impact safety and mobility. Understanding the distinctions among different devices and the functionality of this technology is critical for agency integration and use of the data.

Purpose

Improving the accuracy of work zone data is a multilayered problem that a number of agencies have been working to address over the last several years. cTTCDs such as connected arrow boards and other connected devices have the capabilities to improve the accuracy of work zone data without the need for a contractor or agency employee to manually enter the information. As the number and types of devices have increased, little guidance has been developed on how to use information from these devices within an agency. As part of this research, various cTTCDs were documented and described to provide information that can be used by agencies for both historical and real-time applications. Additionally, integration methods were explored to provide guidance on how cTTCDs, specifically connected arrow boards, can be integrated into an agency's traffic management system or similar system.

Goals and Objective

The goal of this project was to evaluate and develop methods for integrating cTTCD data within transportation agency operations via an advanced traffic management system (ATMS) or similar system. This goal was accomplished by meeting the following objectives:

- Document the existing types of cTTCDs in terms of the state of the practice for agency use, including the purpose and need for tying cTTCDs to an ATMS or similar system
- Develop and report on methods for utilizing cTTCDs for both real-time and historical analysis
- Evaluate methods currently being used to integrate cTTCDs for the reporting of verified work zones

Report Summary

This final report documents the research effort undertaken to evaluate how cTTCDs can be integrated into traffic management operations. The report begins with a literature review and agency interviews to highlight the current practices for utilizing cTTCDs. The literature review provides a summary of the existing literature on the types of cTTCDs available as well as the current practices for integrating these devices into agency operations. The report then provides an overview of agency interviews that were used to obtain insights into the state of the practice, given that the use of cTTCDs continues to evolve beyond the practices identified in the current literature. The final section of the report then evaluates the current data available and documents the methods for integrating connected arrow boards into a WZDx data feed. Because of the limited number of agencies integrating these devices into the WZDx, an expanded analysis was completed comparing different implementations of connected arrow boards to provide guidance on methods for improving data integration.

LITERATURE REVIEW

cTTCDs such as connected arrow boards and other connected devices have the capabilities to improve the accuracy of work zone data without the need for a contractor or agency employee to manually enter the information. Due to the uniqueness of these devices, agencies are seeking to understand the current state of the practice and identify how connected equipment can be better utilized. This chapter contains a literature review of the current state of the practice for improving work zone location information. The literature review is split into two sections:

- **cTTCDs**. The first section focuses on the types of cTTCDs that are currently documented in the literature. The literature has largely focused on devices for improving information on the location and status of work zones but also includes other relevant devices such as those identifying worker presence.
- **cTTCD Integration**. The second section focuses on how cTTCDs are being integrated into DOT traffic management systems and how other agencies are then communicating that information to the public.

Connected Temporary Traffic Control Devices

Connected Equipment

cTTCDs such as connected arrow boards, connected traffic cones and panels, temporary traffic signals, and so on can be used to improve the accuracy of information on work zone status and location. These types of devices differ from many other smart work zone devices such as sensors, cameras, and message signs in that their primary function is to report the location and status of the device in order to locate a work zone. Fortunately, the use of cTTCDs has increased over the last several years. The Iowa DOT began requiring connected arrow boards in work zones in 2021, with other agencies requiring similar devices for individual projects. Iowa currently has over 140 contractor-owned connected arrow boards reporting in, with the boards built by a variety of manufacturers. In addition to offering connected arrow boards, multiple vendors include location capabilities in other devices, including traffic cones, panels, tapers, portable rumble strips, or multipurpose devices that can be attached to various work zone equipment, as shown in Figure 3. The market for providing connected location equipment within work zones is growing, and this equipment is being tested in multiple states. This section discusses specific literature on the various devices, with additional details about the integration of devices in the section on cTTCD Integration in this chapter.

Figure 3. Various types of cTTCDs

A study by Niagara International Transportation Technology Coalition (NITTEC) documented various connected work zone technologies, including traffic barrels with doppler radar and queue warning trailers (Sheckler 2022). Various other devices designed to improve work zone location information were documented, including the following:

- **Workers present beacon (iPin)**. This device is intended to allow workers to identify the location of where they are working when the device is activated. The form factor of the device is intended for placement in a traffic cone, which would then broadcast the location of that cone.
- **Flagging baton**. This device is intended for use by flaggers to broadcast their location and the start of the flagging operation. The circuitry of the devices fits into a pole for a flagger, and the worker can turn the device on to begin sharing its location.
- **Work zone connectivity box (arrow board kit)**. This device is an aftermarket kit that can be added to existing devices that are already owned by contractors and other organizations. The device can be added to various equipment, including arrow boards, signals, and truck hazard lights. The device can monitor both the status of the device, such as the arrow board pattern, as well as the location of the device.
- **Work zone connectivity box (hazard light kit)**. This device uses the same technology as the arrow board kit but is intended for installation on a vehicle. The device is installed into the power system of the vehicle and can detect when the hazard lights of the vehicle are on. When the hazard lights are on, the device then broadcasts its location and status, which can ultimately be used in navigation systems for issuing alerts.

In the NITTEC study, the devices were not integrated into the New York State 511 system due to resource constraints, but through iCone the device locations were broadcast to Google Maps and Waze. Throughout the approximately three-year study, more than 7,626 unique reports were sent to navigation companies and resulted in 5,500 positive driver feedback messages in Waze. It is estimated that 165,000 alerts were sent to drivers based on the work zone device reports. As a lesson learned, the author noted the need for simplicity for the devices. The most successful implementation involved using arrow board and truck hazard equipment because the systems are fully autonomous and do not require additional effort by workers to share the information.

Work has also been done to try to develop more economical versions of these smart work zone devices. Vorhes and Noyce (2022) used low-cost components to develop devices that can provide relevant data on work zones efficiently. Some of these components included long-range radio units, Global Positioning System (GPS) receivers, and microcontrollers, which were used to develop connected cones/barrels and connected arrow boards for reporting work zone locations and times. The proposed architecture includes communication via radio links to a central hub, allowing for low-cost expansion of connected work zone devices while simplifying management and retaining data ownership. The hub forwards information to a central server for traffic management, incident response, and work zone performance measurement. By using low-cost sensors and microcontrollers, the architecture lowers the entry barrier for implementing a greater number of devices in work zones, which would improve safety, incident detection and response, and performance monitoring and reduce delays. The cTTCD devices identified included the following:

- **Location-aware cone**. A location-aware cone is a device used in work zones to indicate construction activity or lane closures. In this research, a small GPS receiver was connected to an Arduino to generate coordinates at regular intervals. The Arduino parsed the GPS data, and the coordinates were transmitted to the ESP32-LoRa module used in this research for transmission to the base station.
- **Connected arrow board**. Connected arrow boards are used to indicate lane closures or traffic shifts in work zones. A demonstration application was created using a small liquid crystal display and a GPS receiver connected to a microcontroller. The application combined GPS coordinates with sign status information and transmitted the data to the ESP32-LoRa module for transmission to the base station.
- **Intrusion sensor**. Intrusion sensors are used to detect unauthorized vehicles entering work areas. In this research, a GY-521 combination accelerometer and gyroscope was connected to an Arduino. The GY-521 continuously monitored for sudden acceleration changes, and when the acceleration exceeded a certain threshold, the device transmitted coordinates and a message to the ESP32-LoRa module for transmission to the base station.
- **Traffic count/queue detection**. Traffic detectors were used to measure vehicle count and occupancy in work zones. The Benewake TFMini Plus, a small and low-cost light detection and ranging (LiDAR) unit, was connected to an Arduino to detect vehicles and measure distances. The Arduino processed the detection data and transmitted lane-specific vehicle counts and occupancy information to the ESP32-LoRa module for transmission to the base station.

Minnesota's Statewide Work Zone Information System (SWIS) represents a current application of cTTCDs that aims to enhance work zone safety by increasing driver awareness and influencing driver behavior. SWIS is part of a three-pronged approach to work zone safety, which includes a human factors study and the use of low-energy Bluetooth tags to provide real-time updates to drivers' mobile phones. One of the ways SWIS has been enhanced is through the integration of traffic control devices. To this end, SWIS uses the traffic control devices already placed by workers in work zones and outfits them with SWIS asset beacon trackers. These trackers continuously send location and device information to SWIS, allowing the system to determine work zone locations and update this information in real time. The compliance of work zones with the *Manual on Uniform Traffic Control Devices* (MUTCD) is checked through algorithms in SWIS; if compliance is met, manual inspections are not required. Users, including project stakeholders and the general public, can access SWIS through an internet interface to view active work zones, search for past or future projects, and even create or update projects (Parikh et al. 2019).

Wearables

Wearable devices present additional opportunities to improve work zone status and location information by identifying where workers are present (Vilela et al. 2022). The Virginia Tech Transportation Institute developed a prototype wearable vest that accurately localizes, monitors, and predicts potential collisions between work zone workers and passing motorists. The vest also notifies workers when they are about to depart from safe areas within the work zone. In this smart work zone system, two components were used to enhance the deployment package. The first was a base station that provides an edge computing environment for alert algorithm processing and consolidates the communication of individual worker positions. It can also broadcast work zone information to connected and automated vehicles. The second was a smart cone device that helps define safe area boundaries and improves the reliability of communication between workers and the base station.

Other smart work zone devices/systems include queue warning and intrusion warning systems. Many types and locations of devices used in queue warning systems have been evaluated (Ozan et al. 2020, Vorhes and Noyce 2022). Systems designed to track workers within a work zone as part of an intrusion warning system have been evaluated for their potential to improve worker safety (Ozan et al. 2020, Teizer et al. 2008, Roofigari-Esfahan et al. 2021, Mollenhauer et al. 2019, Gnawali et al. 2022). One such study by Ozan et al. (2020) developed a smart work zone in North Carolina by using Internet of Things (IoT) devices to detect work zone intrusions and improve worker safety, where an alert system deployed in a restricted work zone area provided mobile alerts to workers for any intrusions. Another study focused on developing a smart vest for work zone users that provides alerts based on geolocation. The vest was designed with a threat detection algorithm that communicates the worker's location to passing connected cars and warns both motorists and the worker of collisions. The work zones in this study were divided into three areas: safe zone, low-level warning zone, and high-level warning zone. The alerts were customized per the worker's location in one of these zones. However, agencies may spend a significant amount of funds to deploy such devices in the field during construction. Hence, further research has been conducted to reduce the cost of field sensors and data communication. Roofigari-Esfahan et al. (2021) developed a prototype smart vest that collects the GPS coordinates of a worker wearing the vest and, through developed algorithms, provides the information to connected and automated vehicles. The connected vest could also warn workers of potential collisions with motorists traveling within the work zone. It was noted that the current vest does not provide sufficiently accurate locations and requires a significant amount of computational power to be used in its current state for potential collision warnings.

Camera-Based Systems

Given the dynamic nature of work zones, both fixed traffic cameras and vehicle-based dashboard cameras provide opportunities for tracking work zone locations. Improvements in camera analytics could provide the ability to identify work zone locations using existing camera networks. Utilizing machine vision in work zones often requires the use of edge devices, either for preprocessing or real-time data analysis. For example, in Parks (2022), a real-time vehicle detection and tracking system that operates on an embedded edge device (NVIDIA Jetson AGX Xavier) was introduced in a work zone for vehicle detection. The system utilized a camera positioned at the work zone to track vehicle positions and estimate their trajectories. An algorithm (pipeline) analyzed the vehicle trajectories to detect anomalous behavior near the work zone. To achieve efficient vehicle detection, popular object detection networks were implemented in PyTorch and tested on the edge device, with the best-performing network chosen for the final pipeline. Optimizations, including the implementation of TensorRT, an NVIDIA inference engine, were applied to accelerate inference tasks on the graphical processing unit (GPU) used in the system. By benchmarking and combining the optimized detection and tracking pipelines, the research demonstrated the significant advantages of leveraging TensorRT and NVIDIA hardware, which resulted in improved end-to-end throughput, accuracy, and power efficiency for the vehicle detection and tracking pipeline.

In addition to using roadside traffic cameras to detect work zone locations, Su et al. (2022) showed the ability to identify traffic cones from in-vehicle cameras using camera analytics. The researchers noted that there has been a significant amount of work on identifying other roadway infrastructure, such as lane markings and edge features, but limited work on detecting traffic cones. One of the challenges is that cones are smaller and do not have a fixed position along the roadway. The research showed two successful solutions for identifying traffic cones, which could then be used for path planning by an autonomous vehicle. Although the information was intended for path planning, the ability to extract this information could have potential applications in other work zone management use cases. Seo et al. (2022) also explored the use of dashboard cameras and deep learning models to detect work zone locations. The models developed in the study evaluated the detection of eight classes of temporary traffic control devices, including barrels, traffic cones, and barricades. The model was tested on 94 sample images with 205 temporary traffic control devices and was able to identify 90% of the devices. The models exhibited the lowest performance when detecting traffic cones and construction barricades, with 86% and 50% detection rates. An additional challenge was the high number of false detection of devices including barrels, traffic cones, and right lane reduction signs.

Solutions Based on Unmanned Aircraft Systems/Unmanned Aerial Vehicles

Most uses of unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS) in work zones are related to construction operations and do not cover traffic safety. However, the tools and methods used in these applications can be useful in work zone traffic safety research. For example, Kim et al. (2021) developed a framework for UAS-based automated work zone safety monitoring by integrating a digital internal traffic control plan (ITCP), UAS, and image-based object recognition. The digital ITCP is capable of computer readability and can be integrated with UAS aerial imagery based on georeferenced coordinates, minimizing signal interference. The UAS collects aerial images of the work zone and complies with Federal Aviation Administration (FAA) regulations. The collected imagery includes metadata that is used to overlay the images on the digital ITCP model. A deep learning-based object recognition algorithm, specifically an Inception ResNet v2 Atrous convolutional neural network (CNN), is employed to detect construction workers, vehicles, and equipment from UAS images. Transfer learning is used to adapt the CNN for customized training, focusing on detecting manlifts, cranes, and workers in the aerial imagery.

Mobile Applications

Some agencies are also looking to the use of mobile applications for identifying deployed work zones. These applications are being developed to improve the methods by which DOTs can submit work zone information from the field. One method includes a mapping toolchain that allows users to collect work zone information as they are driving through the work zone (NOCOE 2019, English 2020). The toolchain that was developed is intended for collecting highly granular work zone information that can be used with roadside units (RSUs) to broadcast the work zone information to connected vehicles. The toolchain collect GPS points while the user is driving through the work zone and allows the user to indicate points of interest throughout the work zone, including lane closures. Adu-Gyamfi et el. (2019) developed a mobile application where field staff can enter work zone information through a mobile application, which includes the ability to collect location information. The interface would allow for automatic work zone geolocation by using the device's GPS to provide accurate location information. The application also logs historical activities, which could be used for future safety analysis.

cTTCD Integration

As additional cTTCDs come to market, the biggest challenge that many agencies face is how the data from these devices can be utilized within the agency to improve both operations and safety. In most cases, the existing systems used by DOTs do not have the capability to utilize information from cTTCDs and must be enhanced to allow the data to be used. This section highlights the existing literature on how agencies are currently integrating cTTCDs into their systems.

Most agencies rely on their 511 website to communicate with the public. DOTs typically enter work zone information into either an advanced traveler information system (ATIS), an ATMS, or a lane closure planning system. The information within these systems often represents an estimate of the location and duration of a work zone and is manually entered by staff. Work has been done to incorporate data from cTTCDs into agencies' work zone systems. The Minnesota DOT (MnDOT) was the first documented state to deploy connected arrow boards in 2018 (FHWA 2019). The arrow boards were used to identify maintenance operations and then send this information to MnDOT's 511 system to share publicly when and where lane closures were occurring. MnDOT also developed a concept of operations on how the arrow boards would be integrated into its traffic management system, which had the following general operations:

- The vendor supplying the connected arrow boards provides an application programming interface (API) for truck-mounted arrow boards that is updated every two minutes.
- MnDOT's ATMS pulls the arrow boards from the API and creates an incident ID.

- The arrow boards are not related to existing work zones in the ATMS entered by operators. The new work zone created from the arrow boards does not include details about the extent and duration and needs to be verified by traffic management system operators.
- Traffic management system operators keep only one arrow board if multiple are present.

MnDOT's deployment included integration with its ATMS and ATIS but primarily for sharing the work zones created by operators based on the arrow board locations. The arrow boards were only used to provide the location information for the work zone and were not integrated with any existing planned work zones within the ATMS or ATIS. Missing work zone information included the duration of the closure, the extents of the closure, and any associated projects. Information such as vehicle restrictions could be entered by traffic management operators but only after the arrow board was in operation, which did not allow for preplanning efforts.

Parikh et al. (2019) also developed a process of associating traffic control device assets in Minnesota with a database of work zones to determine whether the traffic control layout needs to be inspected. The traffic control device assets, which are described in a previous section of this report, were developed by the researchers and mounted to existing traffic control devices in the work zones. As part of the process, assets were associated with projects in what appears to be an automated way, but the researchers do not go into detail about how this process was achieved and any limitations in the approach.

Roelofs et al. (2020) provided a summary of existing cTTCD deployments in Minnesota, Iowa, and the area managed by the Regional Transportation Commission (RTC) of Southern Nevada. The general description of these deployments highlights that two independent systems were in operation. The first system was the arrow boards provided by third-party suppliers, which provide information about the location and status of the devices. The second component was the traffic management system, where the arrow board information is disseminated to various other systems such as traveler information systems.

In Iowa, Roelofs et al. (2020) note that the deployment included the development of a data communication protocol. The protocol had two options for providing data, including a JavaScript Object Notation (JSON) option for manufacturers to provide a feed for the arrow boards or the ability to directly query data from each arrow board. The Iowa DOT expected that most manufacturers would pursue the JSON protocol option, where the manufacturer would provide a data feed for the Iowa DOT to pull data for the arrow boards. At the time of the study, the Iowa DOT was still in the testing phase but hoped to have the arrow board data integrated into the ATMS system.

A generic specification was also being developed by the RTC of Southern Nevada that was anticipated to be used for all construction contracts (Roelofs et al. 2020). The arrow board data were anticipated to be available to the traffic management center through Waycare, a data integration application. No additional details were available on how the arrow boards would be actually integrated beyond showing the information on a map.

The Oregon DOT (2021) is currently sponsoring a project that is piloting the use of smart work zone technologies and demonstrating methods to provide the data in real time to traveler information websites, automated over-dimension permitting systems, and the WZDx. The effort is currently ongoing, and no published literature currently exists on its status.

Knickerbocker et al. (2021) developed a method to integrate work zone data from cTTCDs and planned work zone data to confirm work zone activity. The study utilized connected arrow boards in Iowa that were automatically associated with work zones in Iowa's ATIS using its linear referencing system. After the system validates the work zone information, which requires minimal input from field staff and operators, the data are then provided through the WZDx, which could be used to provide alerts to drivers.

For the distribution of work zone data, many agencies in recent years have focused on standards for providing work zone information to drivers, vehicles, and mapping companies. Some agencies have already begun providing data through crowdsourced applications or other mapping services. This has proven valuable but is limited in terms of the number of distributors and the amount of information that can be provided. To develop a more unified approach, the U.S. DOT Intelligent Transportation Systems (ITS) Joint Program Office (JPO) has led the WZDx, in which both IOOs and third-party data consumers create a standard for communicating work zone data (U.S. DOT 2023). The WZDx is a simple, widely adopted, open specification for work zone data and is an important future step for work zone safety. Mapping active work zones can improve safety by making construction workers visible in high-risk environments. Real-time information from workers can enhance work zone data and improve safety. Incorporating work zone data into navigation apps and consumer maps can alert drivers of the need to reduce their speed and can assist autonomous vehicles in transferring control to a human driver when necessary.

The Work Zone Consortium's syntheses of advanced technology (WZSC 2022) identified multiple agencies that are working to get work zone information directly into vehicles. Multiple DOTs, including Arizona, Kentucky, and North Carolina, are working to provide in-cab alerts to commercial motor vehicles. Arizona and North Carolina are working with Drivewyze as the vendor to provide alerts related to traffic conditions, which can include information on work zones. The Arizona DOT is also doing additional testing of RSUs to provide work zone information, but this work is currently on hold while the technology continues to advance. In addition to the RSU testing, Arizona has also tested the use of the WZDx to provide an API where work zone information can be provided without the need for roadside equipment. In North Carolina, the Drivewyze electronic logging device is being used to provide alerts of slowdowns based on INRIX data. The summary of the project also indicates that work zones are included but does not indicate the source of this information.

AGENCY INTERVIEWS ON THE STATE OF THE PRACTICE

Due to the uniqueness of devices such as connected arrow boards, agencies are seeking to understand the current state of the practice and identify how connected equipment can be better utilized. Given that the selection and use of cTTCDs is relatively new to the transportation market, there is a good chance that published information is lagging behind the experience of today's practitioner. To address this gap, the research team supplemented the literature review findings with interviews with work zone practitioners and other relevant agency staff. This chapter contains a summary of interviews with agency practitioners from five DOTs that are utilizing or plan to utilize cTTCDs within a traffic management system. The five DOTs included in the interviewers are as follows:

- Iowa DOT
- Wisconsin DOT (WisDOT)
- Colorado DOT (CDOT)
- Washington State DOT (WSDOT)
- MnDOT

Interview Summary

A primary focus of the project was to identify how connected temporary traffic control devices intended for reporting location information can be integrated into an ATMS or similar work zone reporting system. A majority of each interview was spent on this topic, and the corresponding questions from Appendix A were used to facilitate the discussion. Table 1 provides an overall summary of the current deployment and integration in each of the five states. Further details are provided under each state summary below.

Table 1. Overall summary of cTTCD interviews

	CDOT	Iowa DOT	MnDOT	WSDOT	WisDOT
Connected Arrow Boards Used	Yes - Limited	Yes – Required on state roadways	Yes – Limited	Yes – Limited but working on statewide	Yes – Limited but working on statewide
Other Planned/Tested Devices Used	ATMA and VSL	Traffic signals, sequential flashers, connected pins	Other device planned	Sequential flashers	Start/End markers
Communication Method	FTP, miscellaneous feeds, and WZDx	WZDx and custom SABP	WZDx	WZDx	WZDx
Integration Method	Automated in experimental	Operator assigns arrow boards	Automated	In progress – semi-automated planned	Currently developing automated
Data Updated from cTTCD	Start location updated and verified	Start location updated and verified	To be determined	To be determined	Start/End location updated and verified along with begin time
Deployment Level	Limited devices but available statewide	Statewide	Limited devices but available statewide	Limited devices with Interstates in future years	Limited with Interstates in 2024

CDOT

CDOT is currently testing a variety of devices but is primarily focused on connected arrow boards, automated truck-mounted attenuators (ATMAs), and digital speed limit signs. As of the interview, CDOT was receiving data for only a limited number of each type of device. Some devices are primarily located in the metropolitan district but can be available anywhere across the state. For connected arrow boards and ATMAs, CDOT has had close to 500 activations of these devices over the past several months, which could then be used to update data in a WZDx feed.

For integration, CDOT currently has an experimental WZDx work zone feed where device information is automatically associated with a planned work zone. The experimental feed currently runs independently of the official CDOT WZDx feed but does utilize the WZDx feed as input into the system to provide planned work zone locations. The planned work zones are used in conjunction with the devices listed above for the automated process of associating the devices with work zones. The devices are then used to update the location information for the associated work zone as well as to report that the work zone as verified.

The current process for the automated association of devices with work zones is based on geospatially comparing the locations of the devices with work zones. In the future, CDOT would like a system where devices can be checked out and associated with a work zone instead of relying on geospatially aligning the data. The hope is that through checking the devices out, there would be higher confidence that the devices are associated with the correct work zone and will update the data more accurately. For example, by spatially aligning the data, there are potential issues related to frontage roads or work zones in opposite directions of travel.

As part of the geospatial process, CDOT utilizes a REST end point to determine the closest roadway that each device is associated with. The location along the roadway is then compared to the extents of the planned work zones within the WZDx work zone feed. If the device is within the extents of a planned work zone, then it is associated with that work zone. The process is overall accurate in assigning devices to specific work zones but is not perfect in all situations. The automated process also considers the temporal extents of the work zone by verifying that the device's activation time is within the start and end times of the work zone. If the device is outside of those times, then it is not associated with the work zone.

For the connected arrow boards, the devices are used to update the work zone information if the device is turned on after the start time of the planned work zone. For the ATMAs, the information about the device's location, position, and heading are provided, which can then be used to integrate the device information into the WZDx. The speed, direction, and heading can then be used to identify whether the work zone is active as well as where the work zone is active within the larger planned extents of the work zone. For the digital speed limit devices, a form is currently filled out when the equipment is employed that assigns a given device to a work zone. Therefore, the speed limit devices do not rely on spatial association with a work zone. Because the devices are assigned to a given work zone, there is higher confidence that the devices are updating the correct work zone information.

If a device is not able to be assigned to a work zone, then the device information is discarded. Those situations typically arise when no planned work zone information is entered into the ATMS, which results in no work zone near the device.

Because the current system is still in an experimental phase, the next steps for utilizing the device data in the WZDx work zone feed have not been fully developed. It is believed that the next steps will simply be workflow issues and that the DOT will identify the best methods of deploying the system. A possible method that was discussed is that the experimental system will continue to run with alerts being sent to the TMC to verify that the device is associated with the identified work zone. If verified, then the work zone would be updated with the information about the device from the experimental feed and then provided through the public WZDx feed for use by others. All other options are still possible at this point, as the project has not moved to full deployment.

For the future, the CDOT team first envisions receiving unified WZDx feeds from vendors instead of processing the translations from the current feeds they are receiving. They are also interested in devices for detecting worker presence, including devices like smart vests. This type of information can be used to issue connected vehicle alerts, including for vulnerable road users, or alerts within the WZDx reporting worker presence.

Iowa DOT

The Iowa DOT is currently in the second year of requiring connected arrow boards on all state roadways. A specification was developed for this implementation that is using a custom smart arrow board protocol (SABP), which was developed before the development of the WZDx device feed. Currently, the number of arrow boards in the state varies but has ranged from 90 to 130 connected arrow boards, which also includes deployment on local roads. As a next step, the Iowa DOT is working on developing a connected temporary traffic signal specification that will utilize the WZDx device feed. The deployment will mirror the connected arrow boards, with an initial requirement starting in 2025. The Iowa DOT has also been testing various other devices, including sequential flashers, connected pins, automatic vehicle location (AVL) data, and portable rumble strip device markers. Other devices on the Iowa DOT's radar include speed feedback signs, digital speed limit signs, smart vests, and automated flagger assistance devices (AFAD). Although the Iowa DOT is using a custom protocol for the connected arrow boards, the intention is to utilize the WZDx device feed specification for any future requirements. Another opportunity identified by the Iowa DOT is the use of e-ticketing, where larger construction equipment is connected along with deliveries of materials such as concrete and asphalt.

The Iowa DOT received a WZDx demonstration grant where the integration process was developed for associating connected arrow boards with planned work zones in the ATMS. The integrated data are then provided through a WZDx work zone feed, which includes both planned and verified work zones. The integration is currently a manual process, where operators manually assign an arrow board to a work zone. Once the arrow board has been assigned to a work zone, the work zone is updated based on the information from the arrow board, including the start location and verification of the work zone. The arrow board is only used to update the work zone if it falls within the extents of the work zone. As part of the development process, there was notable discussion on how the process should operate near the begin and end times of the work zone. For the beginning of the work zone, arrow boards only update the location of a work zone if the device is activated up to 60 minutes before the work zone. This prevents an arrow board within the extents of the work zone from activating a work zone outside of the planned/prescribed work hours. For the end of the work zone, a work zone ends at the identified end time regardless of whether the arrow board is still on. For recurring events, the system will move to the next occurrence because there are currently no methods of extending the end time on a per day basis within the ATMS. For nonrecurring events, a separate notification system, which is explained below, is being developed to allow operators/field staff to extend the end time to prevent the work zone from being removed from the WZDx. The integration process is only utilizing work zones and arrow boards on state roadways and removes any devices that are located on non-state roadways. Any arrow boards that are not assigned to a work zone will still be in the device feed but are not be used in the work zone feed until they are associated with a work zone.

The Iowa DOT has recently been working to deploy connected arrow boards on maintenance vehicles, which will present similar but also new challenges for associating the devices with work zones. Various scenarios were discussed with the Iowa DOT and the ATMS vendor to determine how the system would operate during maintenance operations. One notable discussion was on how the system would perform if the maintenance crews left the work zone for lunch or other activities. Currently, if the arrow boards were to leave the work zone, then the work zone would revert back to the planned status in the WZDx feed. If the connected arrow boards for the maintenance crew return, then the work zone would be updated and verified as active again.

The integration requires TMC operators to assign arrow boards to work zones. Some minimal training has been completed to show how an arrow board can be associated with a work zone, but the process is fairly straightforward. One assumption made before the integration process began was that contractors would be able to provide the exact ID for assigning arrow boards to work zones, which does not happen in practice. Because the integration process requires operators to manually associate arrow boards with work zones, the Iowa DOT worked to develop notifications that would be sent to the Iowa DOT and TMC operators to assist in the deployment. Notifications to TMC operators include the following:

- Active arrow boards not associated with a work zone
- Active arrow boards outside of the assigned work zone or outside of the start/end times
- Active arrow boards in a work zone that is ending in the next 30 minutes
- Arrow boards that are associated with an expired work zone

In addition to the TMC operators, notifications are sent to the Iowa DOT for various other items related to the arrow boards, which include the following:

- Arrow boards from manufacturers that are not available in the ATMS
- Work zones that are incorrectly verified
- Work zones starting with an arrow board that is not active
- Identified arrow board patterns that are not allowed

A challenge that is being worked through in the current deployment include how the system functions when devices are moved from state to non-state work zones. Another challenge is that work zones are not maintained by direction in the ATMS, so only a single arrow board can be associated with a work zone. Additional processes will need to be developed to either maintain work zones in each direction or allow the capability to assign multiple arrow boards to a work zone with the current implementation. Ideally, the system in the future will be automated, which should minimize the workload of operators and potentially increase the accuracy of the data. The Iowa DOT is currently in the process of updating its 511 website to include the information from the WZDx and will include icons to indicate whether a given work zone is verified based on the information from the arrow boards.

MnDOT

MnDOT is preparing to roll out a large-scale deployment of connected arrow boards and had a project in fall 2023 whose specification requires connected arrow boards. This project will serve as a test of the specification before making the specification a standard for all projects. The expectation is that over the next couple of years, the connected arrow boards with become standard operating procedure and will be used on all construction projects. The effort also extends to MnDOT maintenance vehicles, where MnDOT is evaluating using third parties for equipping its arrow boards with connected technology. In addition to the arrow boards, MnDOT is looking at connecting its portable dynamic message signs (DMS) as well as its digital speed limit trailers. For all of the devices, the expectation is that the WZDx device feed will be used for the communication between devices and MnDOT's systems. MnDOT has identified some optional fields in the WZDx device feed that will be required, including a field that identifies whether the device is moving and a field identifying whether it is in transport.

With the connected arrow boards, a project is currently underway for integrating the devices into the ATIS through Castle Rock. As part of the integration, MnDOT will be consuming the WZDx device feeds from all manufacturers and then performing some basic quality assurance/quality control (QA/QC) checks on the data. The data from the manufacturers will then be aggregated into a single unified device feed that will then be provided to the ATIS. The devices will then be associated with corresponding work zones within the ATIS. If needed, the information about which device is associated with a work zone will be pulled from the ATIS and reintegrated into the ATMS, but this is not currently planned.

For integrating devices, the ATIS will have an automated system that associates devices to work zones based on location. At a high level, a 500 m buffer around the work zone will be used, and any device within that buffer will be associated and integrated with that work zone. At the time of the interview, the situation when a device is located near multiple work zones had not been discussed to determine how the logic would behave. Some notable discussion about the logic has occurred related to the start and end times of the work zone. For the end time, the current plan is to have different logic for recurring events and long-term events. For recurring events, at the completion of the event on a given day, the work zone will be removed and will proceed at the next occurrence of the work zone. For long-term/overnight events, if the project is reaching the end time but the arrow board is still on, then a notification will be sent to the project engineer/staff. The notification should either trigger an action by the project staff in the field or prompt them to notify the TMC that the project will either end or be extended. For the start of the work zone, if a device associated with a work zone is turned on, then it will verify that the work zone is active. At the time of the interview, there were no known restrictions on how early a work zone could be verified before the actual start time defined by the work zone. A challenge when working with the start and end times is the accuracy reported by field staff, which limits the type of logic that can be used.

Additionally, if no work zone is available within 500 m of a device, the system will create a work zone based on the arrow board. This ensures that the work zone is still available within the WZDx feed but with limited information. The work zone will be populated with as much information as possible from the device, and it is expected that additional information about the work zone will be populated if it is a long-term closure. It is expected that this may occur more frequently with maintenance operations, which are not always called into the TMC. For the extents of the work zone, the system will aggregate all devices within 500 m to create a linestring for the work zone. It is expected in these situations that multiple trucks will be reporting their location, which will allow for the extents of the unreported work zone to be created.

Using the logic for device integration above, the ATIS will then produce the WZDx work zone feed, which will be consumed by the public. The ATIS is already producing the WZDx feed for MnDOT, but the integration above is expected to enhance the feed with the information from the arrow boards. The fields that will be updated based on the connected arrow boards are not currently known.

As for future cTTCD plans, MnDOT plans to focus on arrow boards and DMS but sees opportunities with variable speed limit signs and portable traffic signals. It is not envisioned that every device will be connected, because the agency wants to focus on equipment that is already in the work zone that can easily be connected. Other possible opportunities in the future could be flaggers and location pins.

WSDOT

WSDOT has been testing a variety of devices, including connected arrow boards, connected pins, connected sequential flashers, and equipment that is connected to the flashers in a vehicle to indicate when they have been activated. These devices are being tested using both maintenance and construction vehicles. The information from the connected arrow boards and other devices is currently going out to Waze and other platforms, but WSDOT is looking to also bring these data into the DOT through a WZDx device feed.

For the sequential flashers, WSDOT has been testing these devices for around a year and is currently planning a larger scale deployment on incident responder vehicles. For connected arrow boards, there are currently 22 projects that have a special provision requiring a connected arrow board as part of the project. WSDOT is beginning by requiring connected arrow boards on Interstates and then in the following year expanding that to all state roadways. Other devices, specifically devices that are at sites for a short duration of time such as connected pins and equipment connected to vehicle flashers, have been tested by maintenance crews. For all three of the types of products being tested, WSDOT feels that the devices are working as intended and hope to find methods of bringing the data into its systems in the future.

As part of the WZDx demonstration grant received by WSDOT, data are being ingested from the connected arrow boards/pins and connected sequential flashers. Some data are being provided using the WZDx device feed, while others are using a custom API/file transfer protocol (FTP). The data from the various manufacturers are then being combined, and a comprehensive WZDx device feed is being provided. In addition to the device feed, WSDOT is also producing a WZDx work zone feed that includes any planned work zone information. WSDOT is currently in the process of connecting the device data with the work zone data. Currently, field staff need to call in to the traffic management center to notify operators that a work zone is starting, but the hope is that the devices would be able to provide a similar type of notification for updating the planned work zone information to active. The method of integration is currently a work in progress, but WSDOT sees a process that is semi-automated in the future. Ideally, any devices that are turned on would be associated with a planned work zone, and then this information would be provided to an operator to confirm that the devices are correctly associated. No firm plans are currently in place that will allow WSDOT to determine the best approach as the current work moves forward.

When the devices are integrated, WSDOT envisions that the devices can be used to update information such as the start location and verification of the work zone. Additionally, WSDOT sees the devices being used for compliance issues to identify whether work zones are starting outside of their prescribed hours. Although this information is not available currently, WSDOT views these data and the WZDx as a method of providing information to connected vehicles. The ongoing efforts by WSDOT and others are the beginning steps for training the workforce in what and how information can be collected/provided to prepare for the use of these data by connected vehicles.

Looking to the future, WSDOT sees additional connected devices in work zones such as begin and end locations along with devices for worker presence. The devices are overall intended for improving safety so providing the ability to know when workers are present enables other safety enhancements within the agency. The begin and end location are also critical as they provide the ability to notify vehicles where work zones are located.

WisDOT

WisDOT is currently testing devices that include two connected arrow boards, which are deployed on county maintenance trucks, and two connected pins. Starting in 2024, work zones on Interstates will have a connected arrow boards along with a start and end connected location marker. It is expected that there will be 10 to 15 projects in 2024 in which these devices will not be required but that will allow WisDOT to test how the devices are integrated into the system. In 2025, WisDOT will begin requiring arrow boards on Interstates. For the start/end markers, WisDOT would like some indication of the purpose of the devices to avoid the devices being switched for a given work zone. As an example, one vendor colors the start and end markers differently so that they are always placed in the correct location. For all devices, the WZDx device feed will be used to access the data.

The arrow boards are currently available in the ATMS but are not directly associated with any work zones. WisDOT is currently developing a process to integrate the arrow boards with work zones through the ATMS. The process is currently being designed and will include an automated process that associates devices to the planned work zones in the lane closure system. The start/end location markers along with the arrow boards will be assigned to a work zone in the lane closure system based on their spatial proximity to the work zone. The information from the devices will then be used to update the start and end locations in the WZDx work zone feed, show that those locations are verified, and update the time for the work zone. In the case of nightly/daily closures, the current expectation is that the start and end location markers will remain in place and that the connected arrow boards' activation status will drive whether the work zone is verified as active or not.

One challenge in the automated process that was identified was utilizing direction to associate a device to a work zone. Devices like arrow boards do not have a direction associated with them to ensure that they are associated with the correct roadway. It is possible that the start and end location markers could be used in conjunction with each other to determine the direction. The direction can be beneficial in situations where a closure is present in both directions and there is ambiguity as to which closure the device should be associated with.

WisDOT has a flowchart for the integration process that includes various situations that must be accounted for, along with any error handling from the devices. For the start and end times of a work zone, a configurable variable will be used to determine whether a device can be associated with a work zone. Possible values discussed were 30 to 60 minutes before or after the defined work hours, which appears to be a reasonable range for allowing a device to be associated with a work zone. Some examples of the error handling discussed by WisDOT include what happens if a device goes offline, how long a device can remain offline before the work zone is not verified, and, if a device comes back online, when to assume that it is associated with the same work zone and update the times.

As a future step, WisDOT sees additional devices being connected, including digital speed limit signs or other smart work zone device systems. The use of the WZDx device feed can help support these efforts by allowing data from various systems to be incorporated more easily into the ATMS. Worker presence indicators are another type of equipment that WisDOT would like to begin incorporating, including devices like smart vests and connected work truck lights. A challenge that must be discussed within the industry is the coordination as to who sends what information to various third parties. Currently, many manufacturers provide data to WisDOT but also send that information to Waze and other mapping companies. Third parties may get multiple reports for the same work zone with different information if there is no coordination as to who is providing the data.

In addition to the integration effort, WisDOT was recently awarded a SMART grant to incorporate local agency work zones into the WZDx by using connected temporary traffic control devices like connected pins and arrow boards. The actual implementation will be worked out through Phase 1, which will include the development of a system to incorporate the data as well as some equipment for testing. It is then anticipated that as local agencies use the connected equipment, WisDOT will have a mechanism for reporting closures through the WZDx feed.

DATA SUMMARY AND PROCESSING

To support the analysis of current practices for integrating connected arrow boards with planned work zones, two primary data sources were utilized, including work zone data from the WZDx registry and connected arrow board data directly from device manufacturers. Based on the agency interviews, these two data sources are the inputs used by traffic management or similar systems to create a verified WZDx feed for distribution to vehicles and mapping companies. The work zone data from the WZDx represents the planned data that an agency uses for all work zones that are expected. The WZDx can be enhanced by utilizing the start location, end location, and start date or end date verification fields, which indicate to end users of the data feed that the data have been generated by a GPS-equipped device rather than human entry. The connected arrow board data represent the actual work zone activity based on physical equipment in the field that is turned on and active. These data are intended to be used in conjunction with the WZDx to provide the verification indicators noted above. These two data sources allow for an evaluation of the current methods for integrating cTTCDs as well as potential future methods or expansions in the use of cTTCDs. The chapter describes each data source and the data preprocessing necessary to analyze the data.

The research team focused on 3 states (Iowa, Wisconsin, and Colorado) for the analysis of integration methods and then used a broader analysis across 18 states (Arizona, California, Colorado, Connecticut, Florida, Illinois, Iowa, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Pennsylvania, Texas, Virginia, Washington, and Wisconsin) to identify factors for consideration when integrating arrow boards. The broad analysis allows for a wider view of how arrow boards are associated with roadways, while the detailed analysis focuses on integrating the devices with work zones.

Work Zone Data (WZDx)

The U.S. DOT maintains the WZDx Feed Registry, which provides a single location for third parties to access the latest WZDx feeds across the nation. The registry provides a summary of all active and inactive feeds, including which state the feed is from, what agency is issuing the feed, the version of the feed, and various other attributes. The registry also includes a work zone data archive that provides access to historical data from each agency's WZDx feed. The archive includes raw and semi-processed data that are downloaded from each registered WZDx feed every 15 minutes. The data are hosted in Amazon Web Services (AWS) Simple Storage Service (S3) in raw GeoJSON format. The archived data are the primary source of planned work zone data and any verified work zone information.

For Iowa and Wisconsin, the WZDx data were downloaded from the archive using a command line interface to access the raw data in S3. The Wisconsin data were downloaded from March 2023 to December 2023. The Iowa data were initially downloaded for the same time period but expanded to include January 2024 to August 2024 due to some improvement in the verification of work zones in Iowa. For Colorado, the official WZDx only reported estimated work zones, but in the interview with CDOT it was reported that an experimental feed was available that verified work zones through an automated process. To utilize the experimental feed, the research team developed a process to download the experimental feed every 15 minutes, the same download frequency used by the WZDx archive. The Colorado data were downloaded from October 2023 through April 2024 for analysis.

For all of the WZDx work zone data available, a process was developed to extract the elements from the WZDx GeoJSON feed into a comprehensive database. Between the three states, there were differences in the WZDx version number, which were accounted for in the data extraction so that a common format could be used across the three states. The data also had to be cleaned because the 15 min WZDx archive contains all of the reported work zones for the given timeframe. This means that each work zone is duplicated if it is not updated or removed from the feed. To support the research effort, the data were processed so that only one unique record was available for each work zone occurrence. A simple operation was implemented to remove all duplicate values in the database across all fields. This addressed a majority of the duplicate work zones in the database, but additional data processing was needed to address various nuances with the data.

One notable challenge causing duplicate work zones was related to recurring work zones and bidirectional work zones. In these situations, each occurrence and/or direction of the work zone is reported independently, but the ID field is modified to include a direction or number indicating the occurrence. Figure 4 provides an example of the suffixes added to the ID field to indicate occurrence (i.e., -1, -2) or direction (i.e., -NB, -EB). In Iowa, recurring work zones are shown for the next 14 days, so a work zone for which work is scheduled each night would have 14 records in the database with different start and end dates for each night of work. The occurrence value would also be updated as the recurring event progressed so that the second occurrence would end with -2 but the next occurrence would update to -1. To account for this, any records for which the ID was modified with an occurrence or direction indicator were updated to strip the occurrence or direction indicator from the ID. Figure 4 provides an example where all six records represent the same night of work but the ID was updated after each previous occurrence. With the suffixes removed, the operation to remove duplicate work zones was repeated, which removed the duplicate values but kept each individual occurrence because the start and end dates were retained.

id	road_names	direction	start_date	end_date	start_date_accuracy	end_date_accuracy	beginning_accuracy	ending_accuracy
OpenTMS-Event14082943536-1-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated
OpenTMS-Event14082943536-2-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated
OpenTMS-Event14082943536-3-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated
OpenTMS-Event14082943536-4-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated
OpenTMS-Event14082943536-5-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated
OpenTMS-Event14082943536-6-EB	['US-30']	eastbound	2024-05-08T12:00:00Z	2024-05-09T01:00:00Z	estimated	estimated	estimated	estimated

Figure 4. Example with repeated records for occurrences

The final data cleaning of the WZDx was related to the field indicating the date when the record was last updated. If any changes were made to a work zone, then the date on which the record was last updated would change to the date the change was made. A majority of the changes were related to the end date as work zones were extended, but other common changes included updates to the description or location of the work zone. To account for this, the research team made the decision to keep only the latest update of the work zone and discard any prior work zone records. This decision was made because the most common update found was related to extending the end date of the work zone, and the latest update would more accurately represent the actual impacts of the work zone. Keeping only the latest update can cause other issues if the location of the work zone is updated, but the number of work zones fitting this category was minimal, and it was determined that this approach would not have a significant impact on the analysis.

The final database represented all work zones that were included in each state's respective WZDx for the selected time periods and was used in the remainder of the analysis. A final issue with the data that was addressed was related to the geometry type of each work zone. In Colorado and Wisconsin, linestrings were used that showed the path of the work zone along the roadway. This was the ideal geometry type because it would easily allow arrow boards to be related to work zones regardless of where the arrow boards were located within the work zones. In Iowa, only the start and end coordinates were provided as a multipoint geometry type. The use of only the start and end coordinates would result in issues with any spatial analysis because the line between the coordinates would likely not follow the actual roadway. To address this issue, the start and end coordinates were related to Iowa DOT's linear referencing system. Both coordinates were required to be located on the same route, which then could be used to display the line segment. Figure 5 provides an example work zone where the red circles represent the data within the WZDx while the green line represents the linestring after the data were processed.

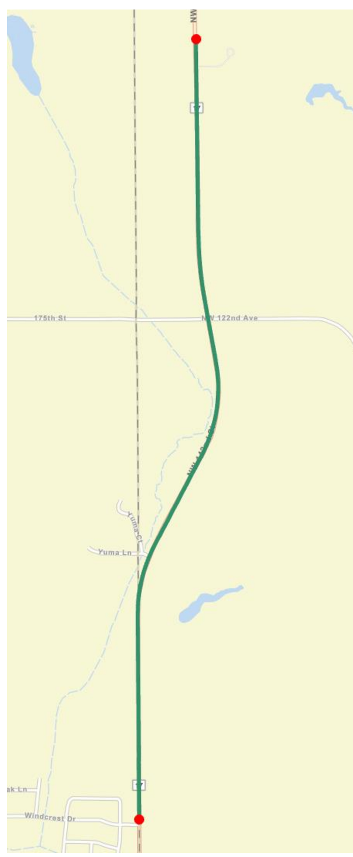


Figure 5. Correction of Iowa geometry to linestring

Connected Arrow Board Data

Connected arrow boards provide an effective way for locating and tracking work zones in real time. The devices continuously report their location and the pattern displayed, which can allow practitioners to understand the precise location of the work zone along with what lanes are closed. Connected arrow boards behave like IoT devices, in that they continuously report their status through data feeds that can be integrated into other systems.

For this study, the connected arrow board data archived by the research team were utilized to determine the location of work zones compared to the WZDx-reported data. The connected arrow board data were downloaded every minute from data feeds provided by various manufacturers. The data allowed the precise times an arrow board was turned on or off and its precise location to be identified. The arrow board data in Iowa were assumed to be nearly comprehensive because they were compiled from data feeds from all major manufacturers and have been required by contractors since 2021. Most manufacturers only provided the research team data within Iowa, which were the data utilized for this research project. One manufacturer provided data for multiple states, which allowed for a broader analysis across multiple states of the use of connected arrow boards and their relation to the roadway and reported work zones.

The arrow board data were downloaded from the archived database from January 2023 to August 2024. The raw data included duplicate data points because the archive represents a snapshot of each minute. To make the data usable, the raw arrow board data were processed to create unique clusters of arrow board activations representing work zone durations. The clusters represented the time the arrow board first displayed a pattern, what the arrow board pattern was, the location of the arrow board, and the time the arrow board turned off or changed to a different pattern. The remainder of this section describes the process for clustering the data.

The first step in the clustering process was to eliminate records where the arrow board was reported as off. Only time periods when a pattern was displayed, indicating that it was part of a work zone, were retained. Because the data were downloaded every minute, after the data feed was filtered it was assumed that no data represented times when the arrow board was not active. With the remaining data, the database was sorted by the local process time field, which is the time the data were downloaded (i.e., a timestamp indicating the download minute). The data were then grouped based on the unique identifier for each arrow board.

With the data sorted sequentially and grouped by each arrow board, a process was used to check whether each record should be grouped with the previous record. The records were linked if the arrow board patterns were the same and if there was less than 120 seconds between the records. The duration of 120 seconds was used to account for slight variations in the time the data were downloaded every minute but not to group instances in which a contractor moved the arrow board and then turned it on to the same pattern at a different location. Figure 6 provides an example of data sorted by the process time and grouped by the identifier. For each row, the process checks the previous row and determines whether the records should be clustered. For example, the records labeled as Cluster 1 start on 9/18/2023 at 11:55 p.m. and then continue to report a right arrow pattern until 7:30 a.m. on 9/19/20023. The next record starts at Cluster 2 because the pattern has changed and the difference in the timestamps is more than 120 seconds. The third cluster begins when the identifier changes, meaning that these records are related to a different arrow board and location.

id	name	gps-lat	gps-lon	display-pattern	local-processtime	Cluster Check	Cluster #
0xd000c9	SAB #2	43.0363002	-88.2536777	Right Arrow, flashing	9/18/2023 11:55:06 PM	Cluster Start	1
0xd000c9	SAB #2	43.0363002	-88.2536777	Right Arrow, flashing	9/18/2023 11:56:03 PM	Match	1
0xd000c9	SAB #2	43.0363002	-88.2536777	Right Arrow, flashing	9/18/2023 11:57:03 PM	Match	1
...	...	...	...	...	...	...	1
0xd000c9	SAB #2	43.0493514	-88.2869566	Right Arrow, flashing	9/19/2023 7:29:06 AM	Match	1
0xd000c9	SAB #2	43.0493514	-88.2869566	Right Arrow, flashing	9/19/2023 7:30:04 AM	Match	1
0xd000c9	SAB #2	43.0350175	-88.2533262	Left Arrow, flashing	9/19/2023 11:39:06 PM	Cluster Start	2
0xd000c9	SAB #2	43.0350175	-88.2533262	Left Arrow, flashing	9/19/2023 11:40:04 PM	Match	2
0xd000c9	SAB #2	43.0350175	-88.2533262	Left Arrow, flashing	9/19/2023 11:41:03 PM	Match	2
...	...	...	...	...	...	...	2
0xd000c9	SAB #2	43.0357969	-88.2529698	Left Arrow, flashing	9/20/2023 12:05:05 AM	Match	2
0xd000c9	SAB #2	43.0357969	-88.2529698	Left Arrow, flashing	9/20/2023 12:06:03 AM	Match	2
0xd000ca	SAB #1	43.5822307	-89.4699914	Left Arrow, flashing	9/28/2023 12:13:03 PM	Cluster Start	3
0xd000ca	SAB #1	43.5822322	-89.4699914	Left Arrow, flashing	9/28/2023 12:14:04 PM	Match	3
0xd000ca	SAB #1	43.5822322	-89.4699914	Left Arrow, flashing	9/28/2023 12:15:07 PM	Match	3
...	...	...	...	...	...	...	3
0xd000ca	SAB #1	43.5823762	-89.4700155	Left Arrow, flashing	9/28/2023 6:06:02 PM	Match	3
0xd000ca	SAB #1	43.5823762	-89.4700155	Left Arrow, flashing	9/28/2023 6:07:03 PM	Match	3

Figure 6. Arrow board processing for clustering

Throughout the clustering process, a unique identifier was assigned to each record to indicate which cluster it was associated with. The arrow board data were then aggregated based on the cluster identifier to obtain a single record for each cluster. The aggregation included identifying the minimum local process time as the start time of the cluster and the maximum local process time as the end time of the cluster. For the coordinates, each cluster used the first and last record in the cluster's latitude and longitude fields. The coordinates were expected to update continuously throughout the duration of the cluster and in some cases may represent a moving operation. The research team decided to keep only the first and last coordinates to simplify the analysis and not introduce additional complexities in relating the devices to work zones. For a majority of the analysis, only the first coordinates were used because these are the coordinates most likely to be used in initially associating the arrow board to a work zone. Table 2 shows the final cluster output (showing only first coordinates) that was generated based on the data presented in Figure 6. The hundreds of raw data points are summarized as individual records that each represent a single work zone lane closure.

Table 2. Arrow board cluster final output

ID	Cluster	Display Pattern	Start Time	End Time	First Latitude	First Longitude
0xd000c9	1	Right arrow, flashing	9/18/2023 11:55:06 p.m.	9/19/2023 7:30:04 a.m.	43.0363002	-88.2536777
0xd000c9	2	Left arrow, flashing	9/19/2023 11:39:06 p.m.	9/20/2023 12:06:03 a.m.	43.0350175	-88.2533262
0xd000ca	3	Left arrow, flashing	9/28/2023 12:13:03 p.m.	9/28/2023 6:07:03 p.m.	43.5822307	-89.4699914

The final output for the arrow board processing represents a comprehensive summary of the work zone lane closures based on the connected arrow boards. The data could be utilized by an agency to summarize the duration of work zone lane closures throughout the state when an arrow board is utilized. This output was utilized in the analysis described in the following chapter when associating the arrow boards to the WZDx work zones and when evaluating the arrow boards independently.

DATA ANALYSIS

Using the WZDx work zone data and data from connected arrow boards, the current practices for integrating cTTCD with work zones were evaluated. Through the interviews with agencies, various methods of integration were identified as well as potential concerns with how arrow boards could be used to enhance work zone data. The analysis of the WZDx and connected arrow board data was completed to evaluate the various integration methods used by select states and, more broadly, to evaluate the potential for automating the process of associating arrow boards with work zones. Various performance metrics were developed to evaluate current practices, evaluate the potential benefits of automated methods of integrating cTTCDs, and summarize potential issues with automated methods. A summary of the analysis measures is as follows:

- Potential issues with automated methods
  - Ambiguity in associating a device with a roadway (i.e., two roads within a certain distance from an arrow board)
  - Distance between roadways and arrow boards
- Evaluation of current practices
  - Number of reported work zones in WZDx
  - Number of verified work zones in WZDx
- Evaluation of the potential benefits of automated methods
  - Ambiguity in associating a device with a work zone (i.e., two work zones within a certain distance from an arrow board)
  - Number of arrow board activations within a WZDx work zone using spatial methods
  - Number of arrow board activation within a WZDx work zone using route-based methods for Iowa
  - Number of device activations with no associated work zone
  - Time from the activation of verified status to the time the arrow board was turned on
  - Distance between reported work zone location and arrow board location

This chapter begins with an analysis of the connected arrow boards independently to address the concerns with ambiguity and then evaluates at a broad scale the potential benefits of utilizing connected arrow boards. The work zone data from the WZDx is then evaluated independently to evaluate the current methods of integrating connected arrow boards and reporting a work zone as verified. The remainder of this section then evaluates the WZDx and connected arrow boards by evaluating spatial and route-based methods for integrating connected arrow boards and WZDx work zones. The analysis next identifies potential and missed opportunities where arrow boards were located near work zones and then evaluates the broad-scale integration of connected arrow boards.

Potential Issues with Automated Integration

Connected arrow boards have considerable potential for agencies because the data can be used in real time to enhance the accuracy of work zone data but can also be used historically to identify the location and status of arrow boards. The connected arrow board data in this study were aggregated to provide the start and end times of each arrow board activation, which could be used as a historical reference for work zones. The challenge with the data and with their use in real time is that arrow boards only represent the start of the work zone and miss the additional context of the work zone, such as the end location, type of impact, and the estimated end date.

To improve the utility and accuracy of arrow boards, the integration with planned work zone data can provide the additional context missing from the arrow boards themselves. Automating the process of associating arrow boards with planned work zones has various challenges, which were identified through agency interviews and in working directly with the data. This section evaluates the arrow board data independently of any work zone data to determine the position of arrow board in relation to the roadway and summarize the number of activations by roadway type.

To evaluate the arrow board data, a broad approach was taken to summarize the arrow board data across 18 states, including Arizona, California, Colorado, Connecticut, Florida, Illinois, Iowa, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Pennsylvania, Texas, Virginia, Washington, and Wisconsin. The states were selected based on the number of arrow boards activations within each state as well as their membership in the Smart Work Zone Deployment Initiative (SWZDI) pooled fund. The analysis provides a broad perspective and accounts for various types of roadway configurations and work zones utilizing arrow boards, from moving operations to static lane closures.

In total, 498,358 arrow board activations were captured between January 2023 and August 2024. As described in the previous chapter, the arrow board data for Iowa are comprehensive and were obtained from multiple vendors, while the data for the other 17 states were from only one manufacturer. It should be noted that these arrow board activations can represent false calls such as when an arrow board is left on along the roadway or in a storage area. The deployed position was utilized when available but was not broadly available for each arrow board, which can result in false arrow board activations existing in the database. Also note that arrow board activations should not necessarily be treated as individual work zones. Some situations may result in multiple arrow board activations, such as changing an arrow board from a left lane closure to a right lane closure or closing multiple lanes, which requires the use of multiple arrow boards. Additional data processing could be used to cluster the arrow board activations but was not considered in this analysis because the focus of the effort was on associating arrow boards with work zone data, which would account for this.

Ambiguity, an issue that was highlighted by multiple agencies, describes a situation where an arrow board may activate near multiple roadways or work zones. Since the arrow board represents only a single point at the time of activation, the roadway or work zone it should be associated with may be ambiguous. To broadly evaluate this, the arrow board activations were associated with state Highway Performance Monitoring System (HPMS) line segments to determine the distance of each arrow board from nearby roadways. A near table was utilized that associated each arrow board activation to all roadways within 500 ft. Table 3 provides a summary of the arrow board activations and whether the activations were ambiguous based on the distance from nearby roadways. The larger search radius shows that a majority of the locations would be considered ambiguous, which is expected for situations such as multiple directions on undivided roadways, frontage roads, or cross streets. Figure 7 visually shows the data from Table 3, in which two trends are visible. As the search radius decreases, the percentage of locations that are not ambiguous increases, with 86.6% of locations unambiguous at a search radius of 25 ft. The decrease in search radius also increases the number of arrow boards with no associated roadways. With a 25 ft search radius, over half of the arrow board activations had no roadway nearby.

Table 3. Total arrow board activations across 18 states

Radius	Ambiguous	Unambiguous	Missing
500 ft	441,288	57,070	-
250 ft	362,998	82,682	52,678
150 ft	289,088	114,110	95,160
50 ft	96,534	203,886	197,938
25 ft	27,660	178,118	292,580

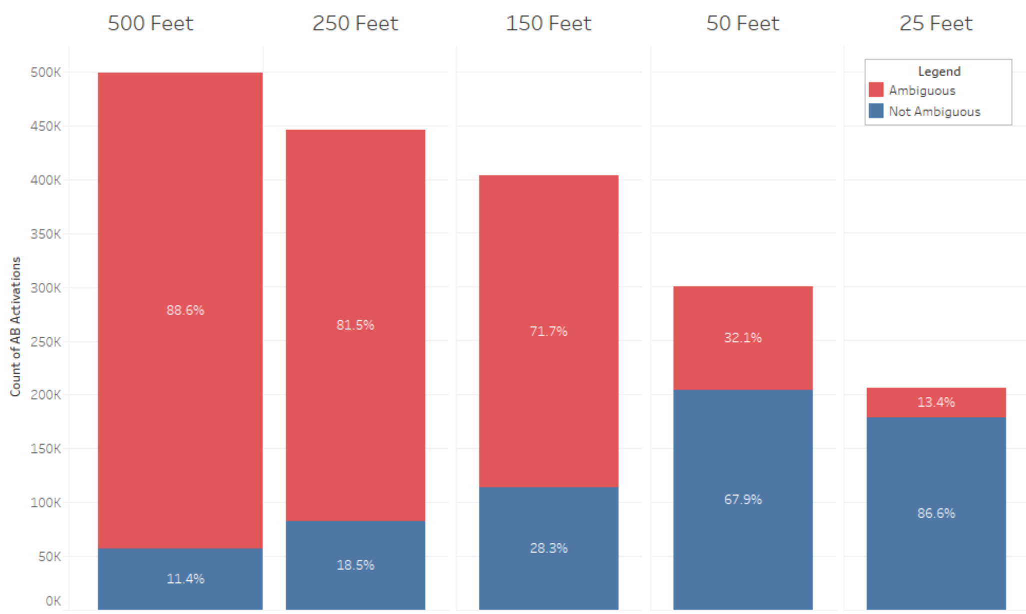


Figure 7. Percentage of ambiguous arrow board activations

Using a 50 ft search radius, the difference in the number of ambiguous arrow boards was compared across the 17 states, as shown in Figure 8 and Figure 9. Figure 8 shows the number of activations by state, while Figure 9 compares the percentage of activations by state. In almost all states, between 60% and 83% of arrow board activations were not ambiguous, indicating only a single potential roadway that they could be associated with. The state with the highest number of unambiguous arrow board activations was Arizona, with 94.4% of the activations being near a single road, followed by Illinois, with 82.8%. The state with the lowest number of unambiguous arrow board activations was Iowa, with 55.5% of activations near a single road, followed by Massachusetts, with 60.4%.

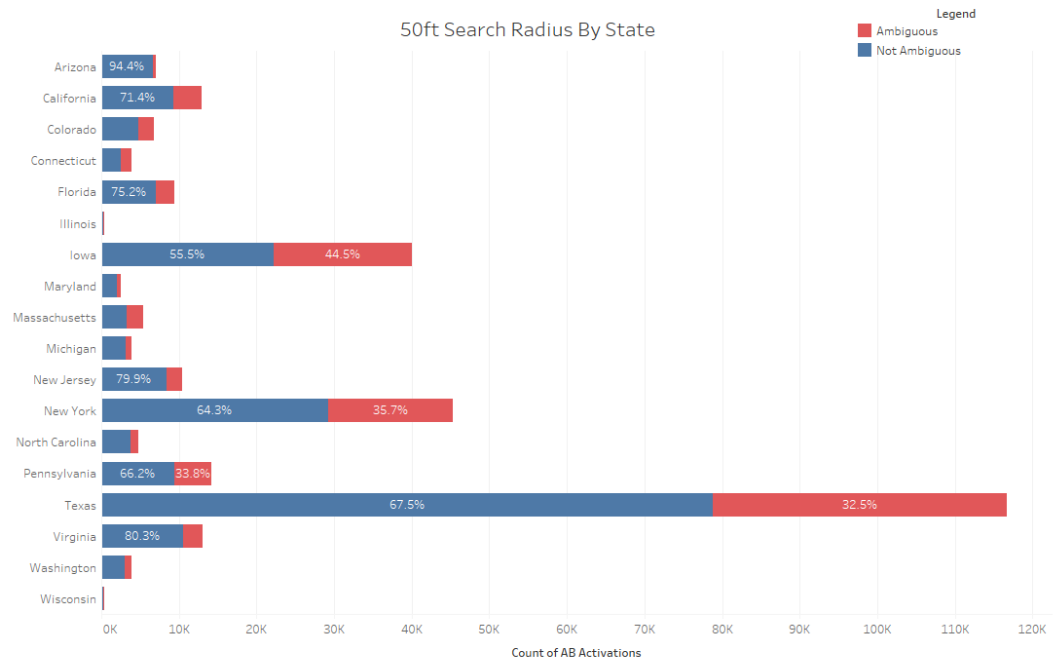


Figure 8. Arrow boards activations by state using a 50 ft radius

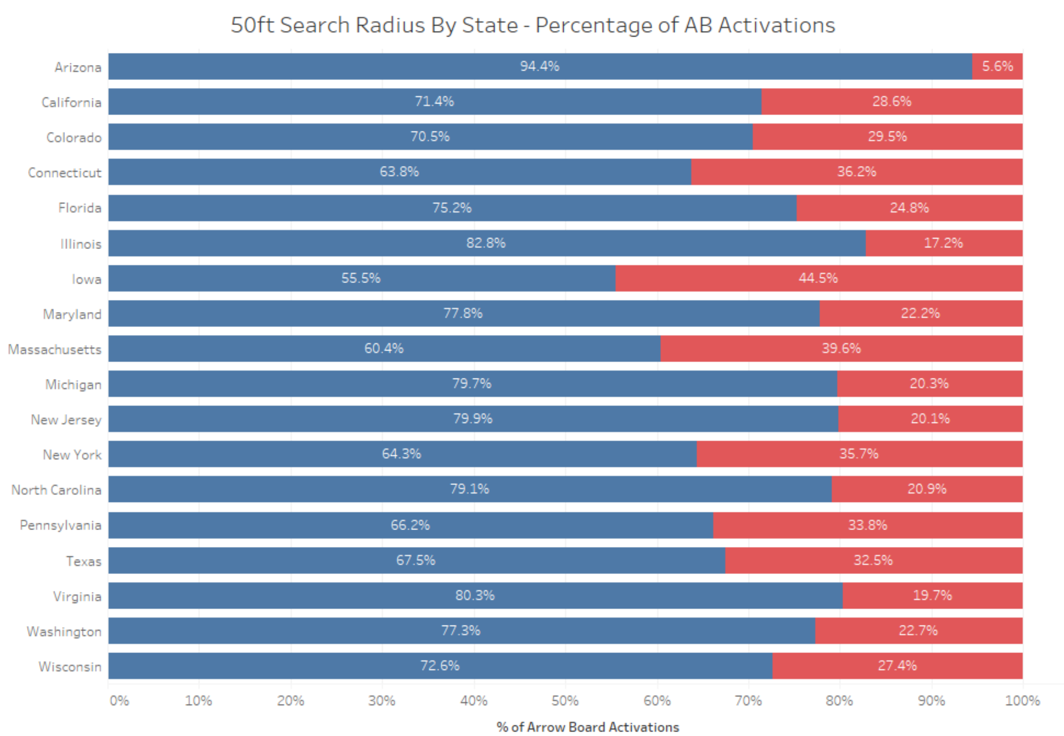


Figure 9. Percentage of arrow board activations by state using a 50 ft radius

To further explore the distance arrow boards are placed from a roadway centerline, the closest roadway to an arrow board was used. In total, 62% of arrow board activations had the closest roadway within 50 ft of the arrow board. Figure 10 provides the distribution of arrow board activations in 5 ft bins up to 55 ft. The majority of arrow board activations are within close proximity to a roadway, with two-thirds of the closest activations being less than 25 ft.

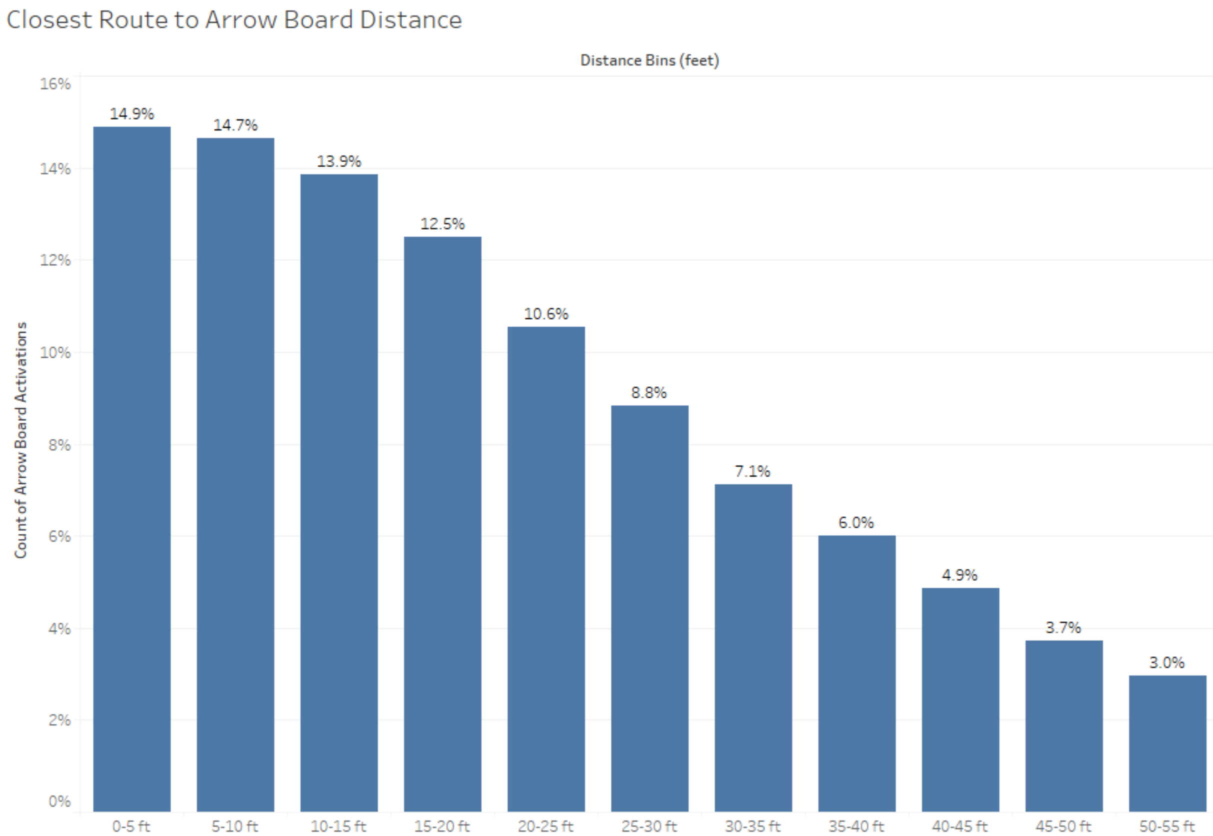


Figure 10. Distribution of closest route to arrow board activations

The percentages of the closest arrow board activations were also compared across states, with most states following similar trends. Figure 11 provides the distribution of the closest arrow board activations up to 55 ft, with each line representing a different state. To simplify the chart, only six states are shown, with a focus on SWZDI states. All states showed a higher percentage of arrow board activations close to a roadway before the percentage decreased with distance. For the six states, the percentage of closest arrow board activations that were less than 50 ft ranged from 40.5% to 71.8%. Michigan had the highest percentage of closest arrow board activations that were less than 50 ft (71.8%), followed by Wisconsin (66.1%), Texas (65.6%), Illinois (59.3%), Iowa (58.7%), and then Pennsylvania (40.5%).

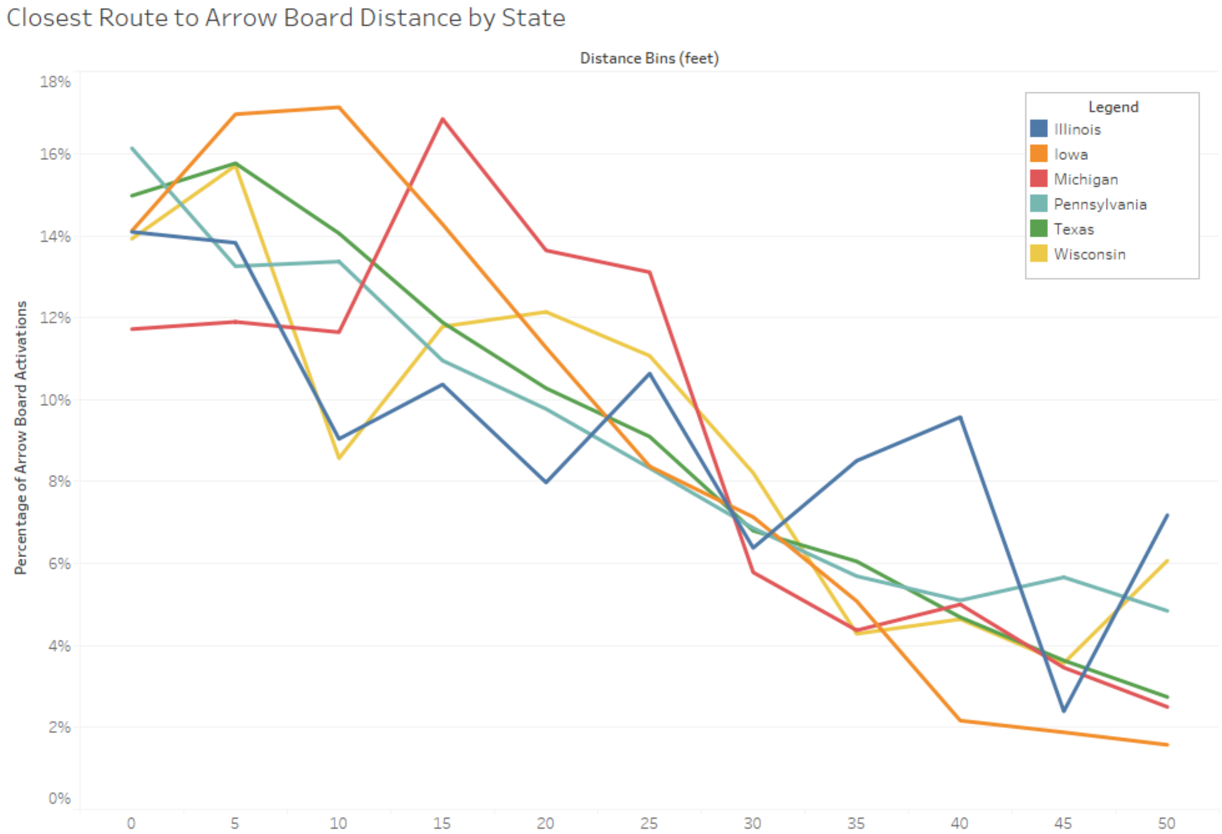


Figure 11. Percentage of arrow board activations by state

A benefit of connected arrow boards is that the information is provided on all types of roadways, including state-maintained roads, county roads, and local roads. The value of connected arrow boards will continue to grow as more agencies utilize the data for communicating to vehicles or better understanding the number of work zones within a given jurisdiction. Using the closest arrow board activation, Figure 12 provides the percentage of activations by roadway type across all 17 states in the left pie chart and the percentage of time in the right pie chart. The percentage of time was added in addition to the number of activations to take into account the duration of time the arrow boards were active. This gives more weight to longer-duration work zones, which would have sustained impacts in terms of alerting motorists of work zone locations. For both metrics, the majority of activations occurred on Interstates. Overall, 81.4% of the activations were on state-maintained roads, indicating that these roads are the primary roads on which arrow boards are being activated. When evaluating the duration, state-maintained roadways still represent the majority, but local roads represent a higher percentage of time compared to the number of activations. This may indicate that activations on local roads may typically last longer in duration.

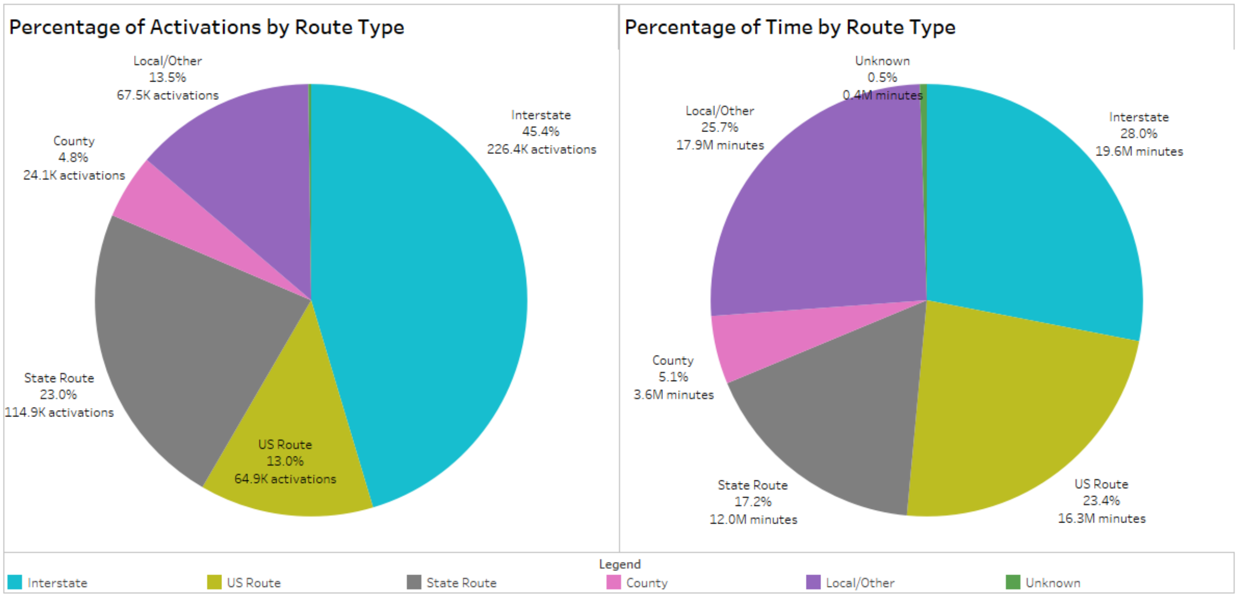


Figure 12. Arrow board activations by route type

The arrow board data were then broken down for each of the six SWZDI states by roadway type, as shown in Figure 13. These charts only evaluated the number of activations and did not vary significantly in their proportions regarding the percentage of time by roadway type. The amount of activations by roadway type varied between the states. The state with the highest number of activations on state-maintained roadways (Interstates, US routes, and state routes) was Pennsylvania (92.7%), followed by Illinois (91.5%), Texas (89.5%), Wisconsin (89.2), Michigan (81.1%), and then Iowa (61.2%). The number of activations by roadway type may be dependent on the type of deployment of connected arrow boards, where some states only use state DOT maintenance vehicles while a state such as Iowa primarily use contractors that operate on a variety of roads. Iowa differs significantly from the other states in that local roads represent the highest percentage of arrow board activations, with 36.1%.

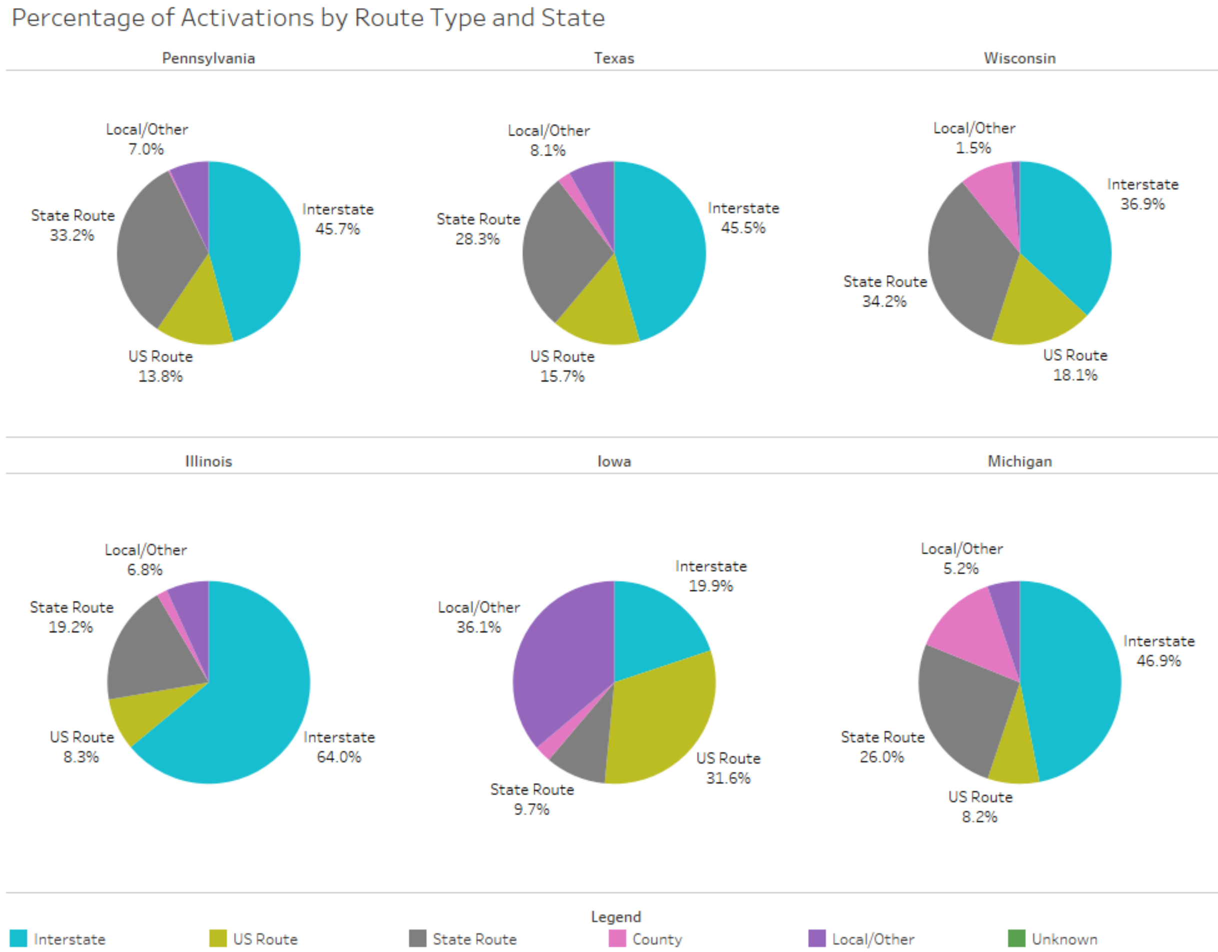


Figure 13. Arrow board activations by route type and state

The closest arrow board activations were evaluated across all 17 states to determine whether there were differences in the distances based on the type of roadway. The percentage of the closest activations varied significantly by roadway type, with Interstates having 73.3% of activations that were less than 50 ft, followed by US routes (64.3%), state routes (61.8%), local roads (45.1%), and county roads (34.2%). The information shows that a high percentage of arrow boards on state-maintained roads are within 50 ft, while the local and county roads may require a larger search radius. Figure 14 shows the distribution of closest arrow board activations that were less than 55 ft, which again shows similar trends to the previous results, with a higher percentage of activations being close to the roadway. Note that a review of the individual state data showed that most states follow the overall trend, with the exception of Iowa. In Iowa, the county roads had a lower percentage of arrow board activations near the roadway, after which the number spiked in the 30 to 35 ft bin, indicating some differences in how arrow boards should be handled on county roads.

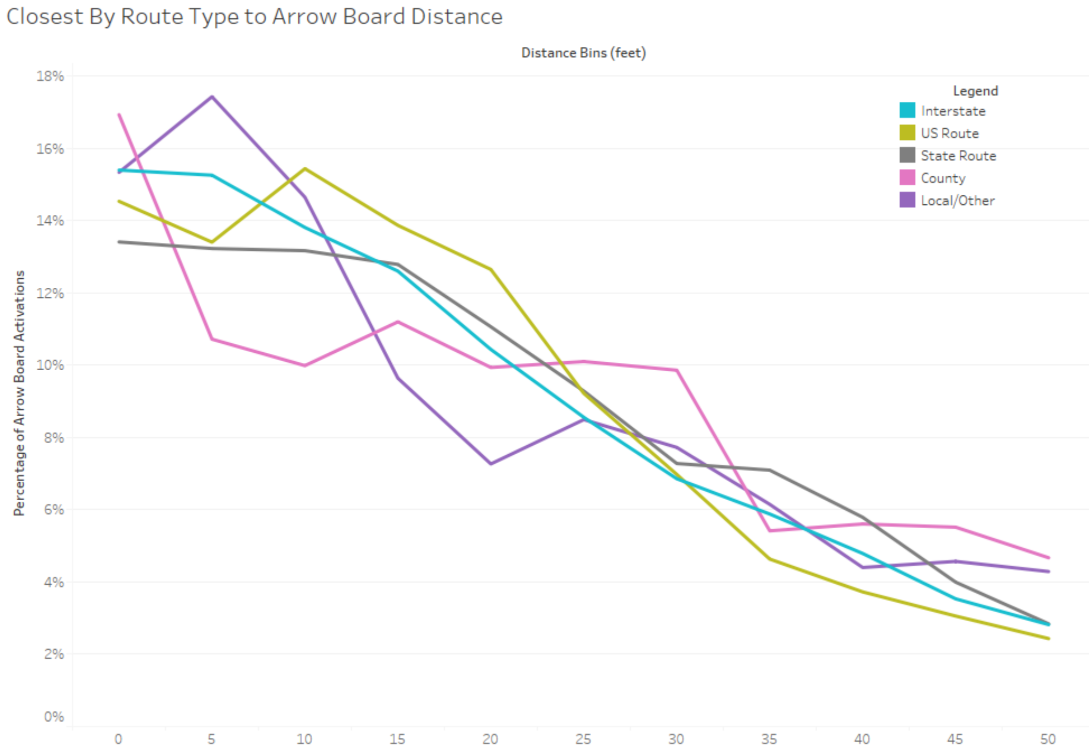


Figure 14. Distribution of closest route by route type

The analysis of arrow board activations near roadways was intended to provide a high-level analysis of the proximity of arrow boards to roadways as well as summarize the activations by roadway type. The analysis found that decreasing the search radius reduces the amount of ambiguity, with multiple roads potentially associated with each arrow board, but also increases the number of arrow boards with no roadways nearby. Note that this analysis looked at any roadway, but the introduction of a planned work zone database, which is explored in the next section, reduces the potential for ambiguity. The analysis also showed the potential for other non-state roadways to utilize connected arrow boards, with almost one-third of the time arrow boards were active recorded on a local or county roadways.

Evaluation of Current Practices

The WZDx feeds provided by each state allow for an understanding of the end products being delivered to vehicles and mapping companies. The data can be evaluated to determine how many work zones are being verified, which is an indicator of when a connected arrow board or similar cTTCD is being used to update the location or time of the work zone. The work zone data from the WZDx described in the previous chapter was used to understand the current use of cTTCDs in Iowa, Colorado, and Wisconsin. This section summarizes the number of work zones that were present in each of the three states, along with how many of the work zones were indicated as verified.

The WZDx in Iowa includes all work zones that are reported by the Iowa DOT. The data are entered into the ATMS system as individual work zones and then converted to the WZDx standard format. Figure 15 provides a count of the number of work zones that were reported in the WZDx after all duplicate records were removed, as described in the previous chapter. The top chart shows the number of reported work zones from January 2023 to August 2024 and includes all occurrences of a work zone as defined by the WZDx. The WZDx represents each direction and time period as a unique event, while in many DOT systems these would be considered a single work zone. For example, in recurring night work, each night of the lane closure would be counted as a separate work zone due to each occurrence having a unique start and end date. The bottom chart provides a more traditional count of work zones by counting only the distinct work zone identifiers, which accounts for recurring or bidirectional work zones.

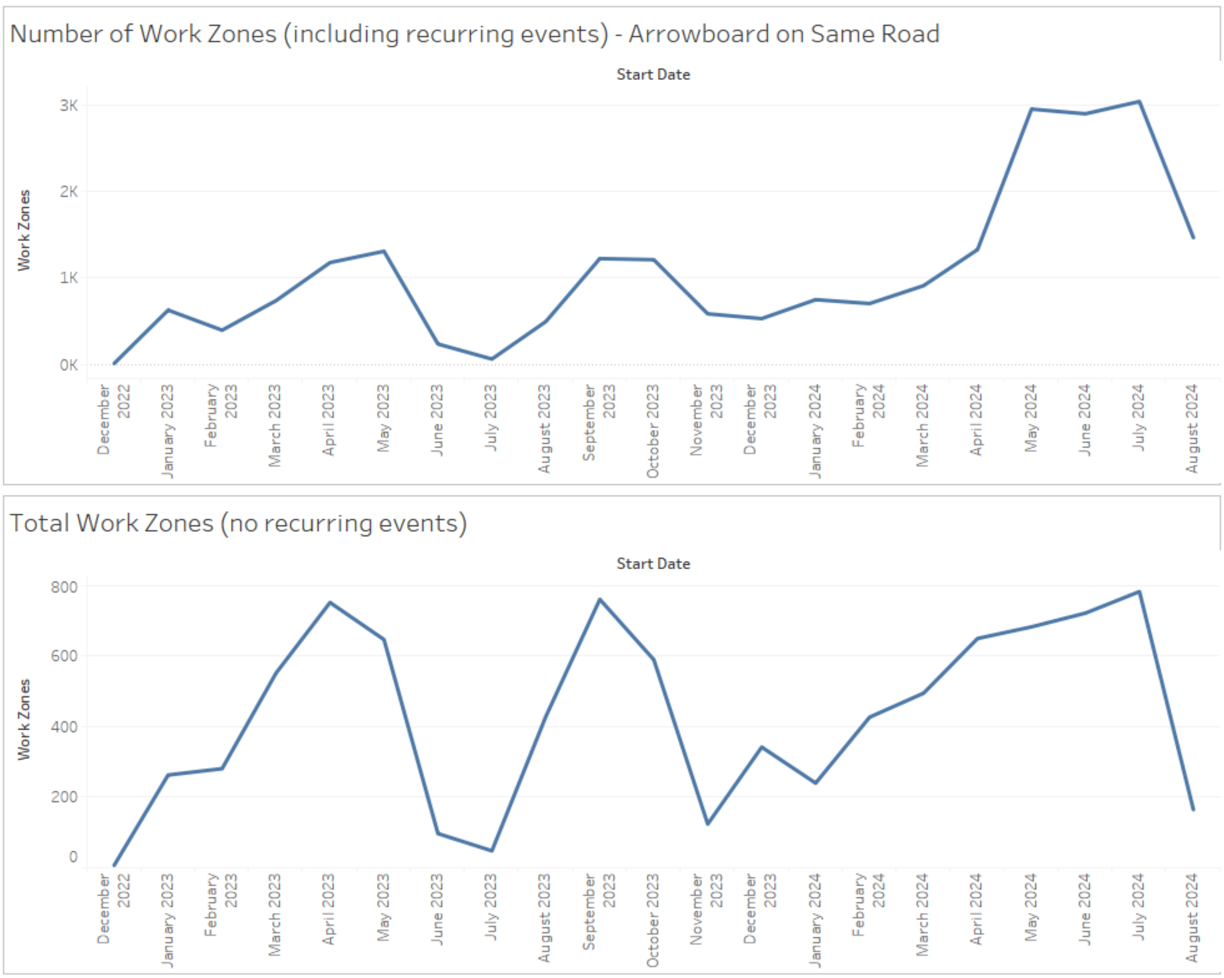


Figure 15. Number of reported work zones by month in Iowa

Iowa DOT has integrated smart arrow boards into its ATMS, including using the data from these devices to update the start location of the work zone in the WZDx. A detailed description of the current approach is described in the agency interview chapter of this report. The system currently requires arrow boards to be manually associated with work zones by operators in the TMC. The system has been active since 2022, but early on a notification system was developed to alert operators when an arrow board was active. The arrow board alerts were not fully implemented until early 2024, which is also reflected in the amount of work zones marked as verified in the WZDx data. Figure 16 provides a summary of the number of verified work zones in Iowa by month. Similar to Figure 15, the top chart indicates the number of work zone occurrences that were verified, while the bottom chart indicates how many unique work zones were verified. In both charts, the number of work zones being verified saw a significant increase starting in February 2024, which aligns with the implementation of the arrow board alerts. In discussions with the operators receiving the alerts, the operators noted that they associate arrow boards with longer-term work zones because doing so updates the location and does not require adding/removing the arrow board over time. Arrow board alerts that were associated with short-duration or recurring work zones were not always acted on because of the significant amount of time required to add or remove the association between the arrow board and the work zone and because different arrow boards may be used on the same project or the same arrow board may be used on multiple projects on a given day.

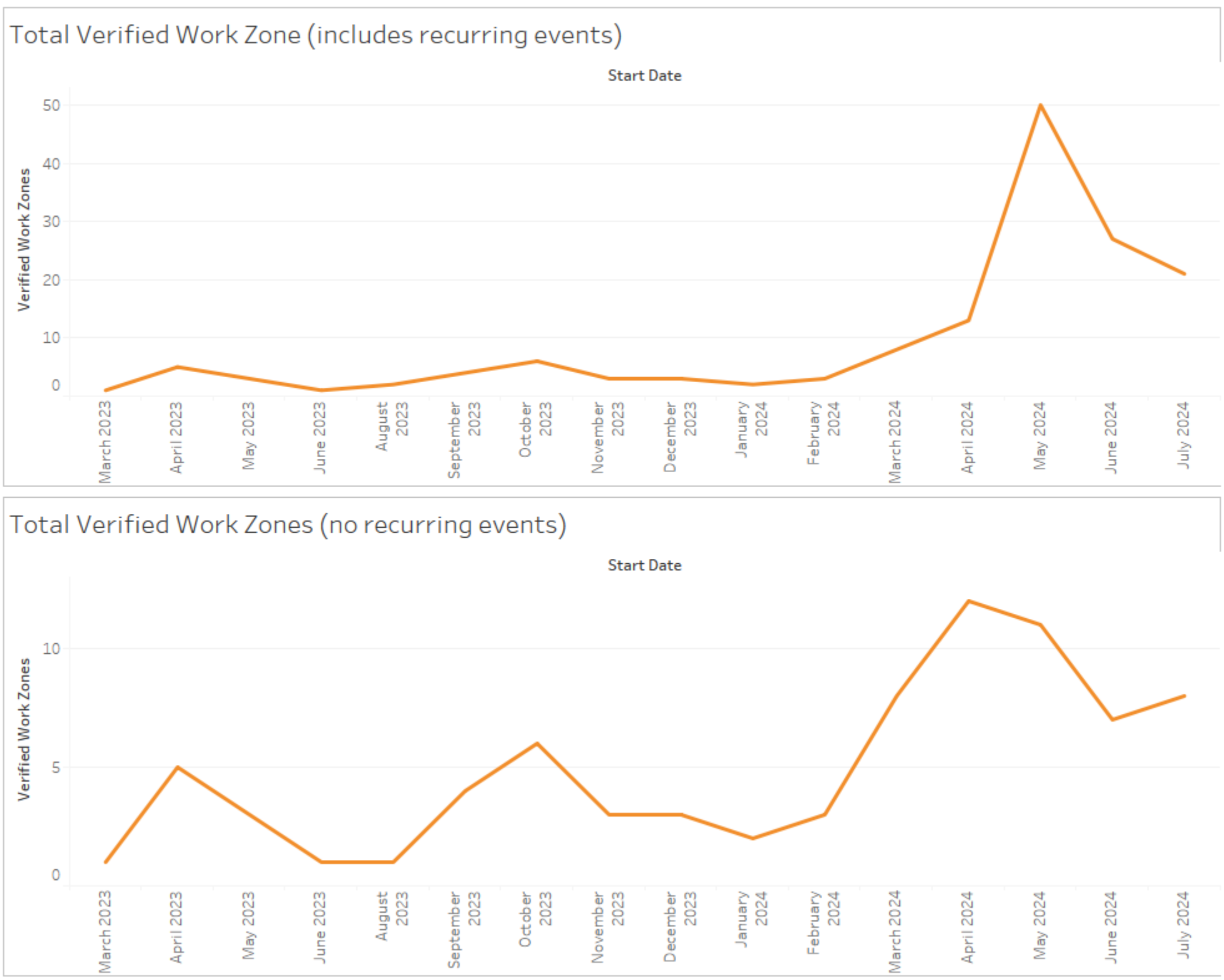


Figure 16. Number of verified work zones by month in Iowa

Connected arrow boards only have the potential to update a fraction of the work zones deployed by an agency because they are not used on undivided roadways, work zones with no lane closures, and various other work zone configurations. With the current work zone data, it is not possible to identify which work zones should have an arrow board. Figure 17 provides a summary of the percentages of estimated versus verified work zones by the total number of occurrences and the total number of work zones. The current process of utilizing arrow boards only updates a small percentage of work zones, with a peak of 1.7% of the work zone occurrences in May 2024. It is not expected that this number would ever reach 100%, but monitoring the percentage of verified work zones can provide a method for monitoring data quality in the future.

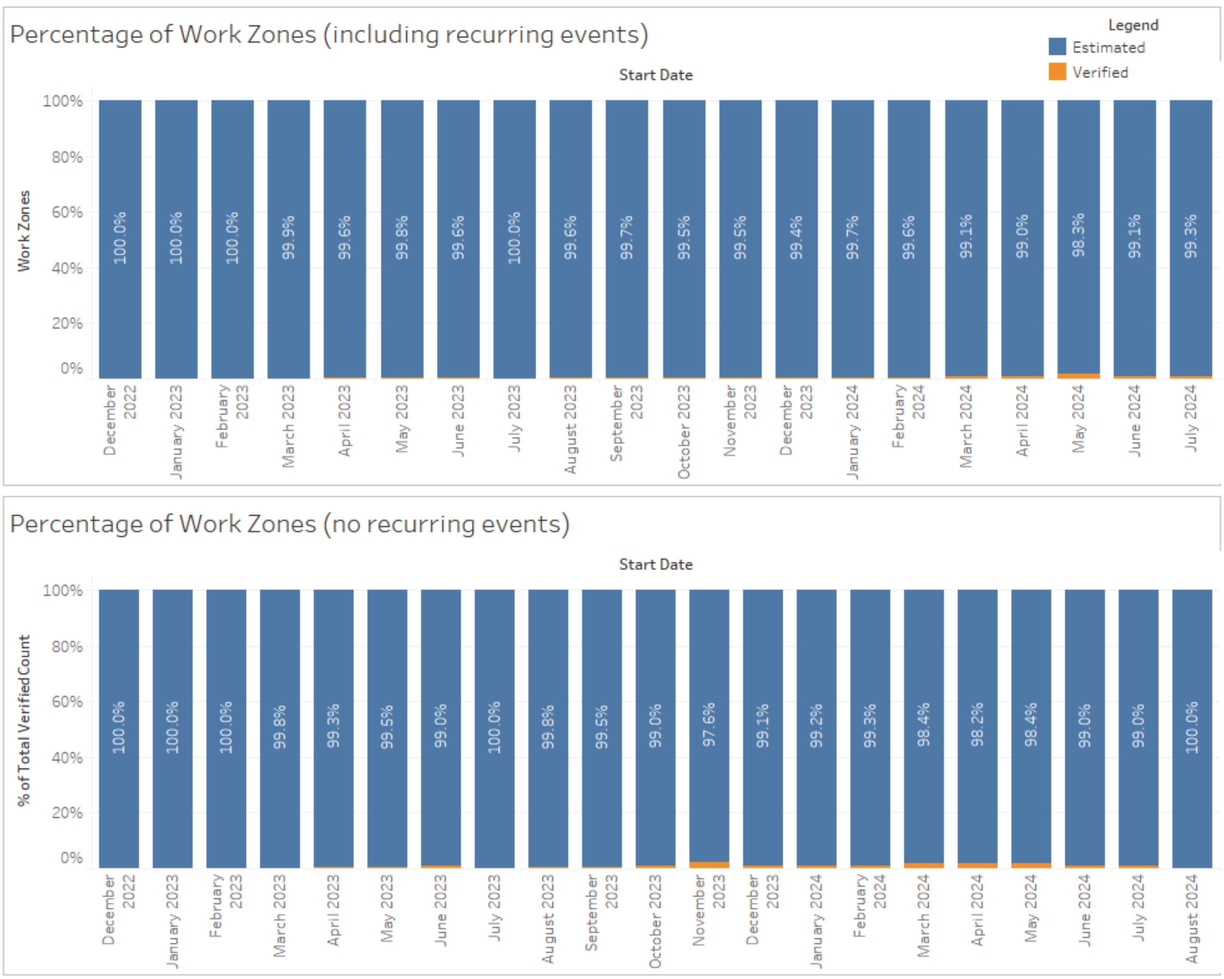


Figure 17. Percentage of verified work zones by month in Iowa

Similar to Iowa, Wisconsin has a statewide deployment of its WZDx. Figure 18 summarizes the total number of work zones reported in the WZDx in Wisconsin from January 2023 to December 2024. The top chart summarizes the total number of work zone occurrences, while the bottom chart counts the total number of work zones. WisDOT is currently working on implementing an automated process for associating arrow boards with work zones, but this process was not available during the analysis period. This resulted in no work zones in the Wisconsin WZDx being reported as verified.

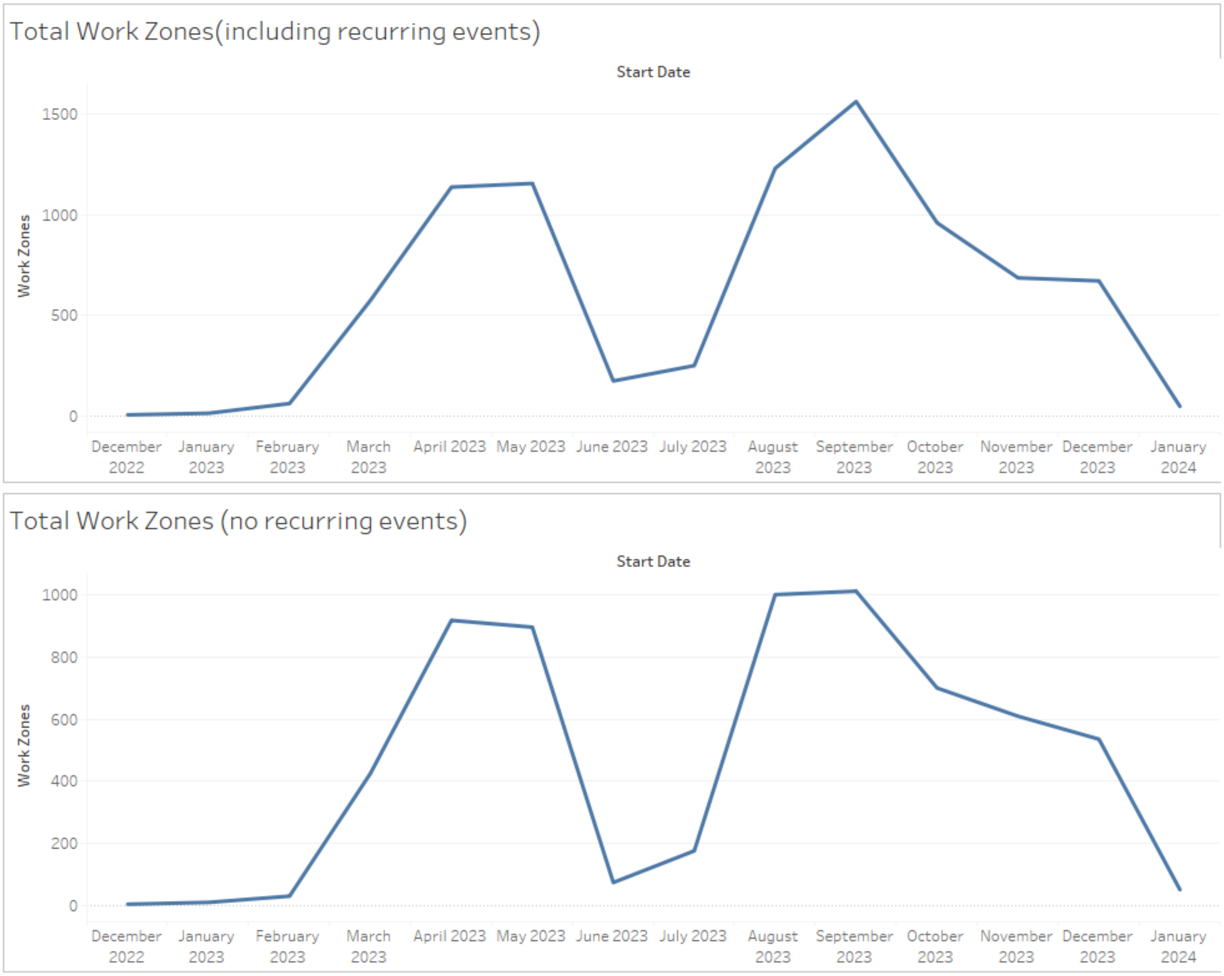


Figure 18. Reported work zones in Wisconsin's WZDx feed

The deployment in Colorado is limited and includes data from an experimental WZDx feed developed by a third party on behalf of CDOT. The experimental WZDx feed utilizes various cTTCDs and has an automated process for associating the devices to work zones. Figure 19 summarizes the number of work zones in Colorado from October 2023 to April 2024 by the total number of work zone occurrences (top) and the total number of work zones (bottom). Although the experimental feed was intended to have an automated process for verifying work zones, no verified work zones were archived over the seven-month analysis period. This is likely due to the limited number of cTTCD deployments in Colorado, along with the fact that the process is in an experimental phase.

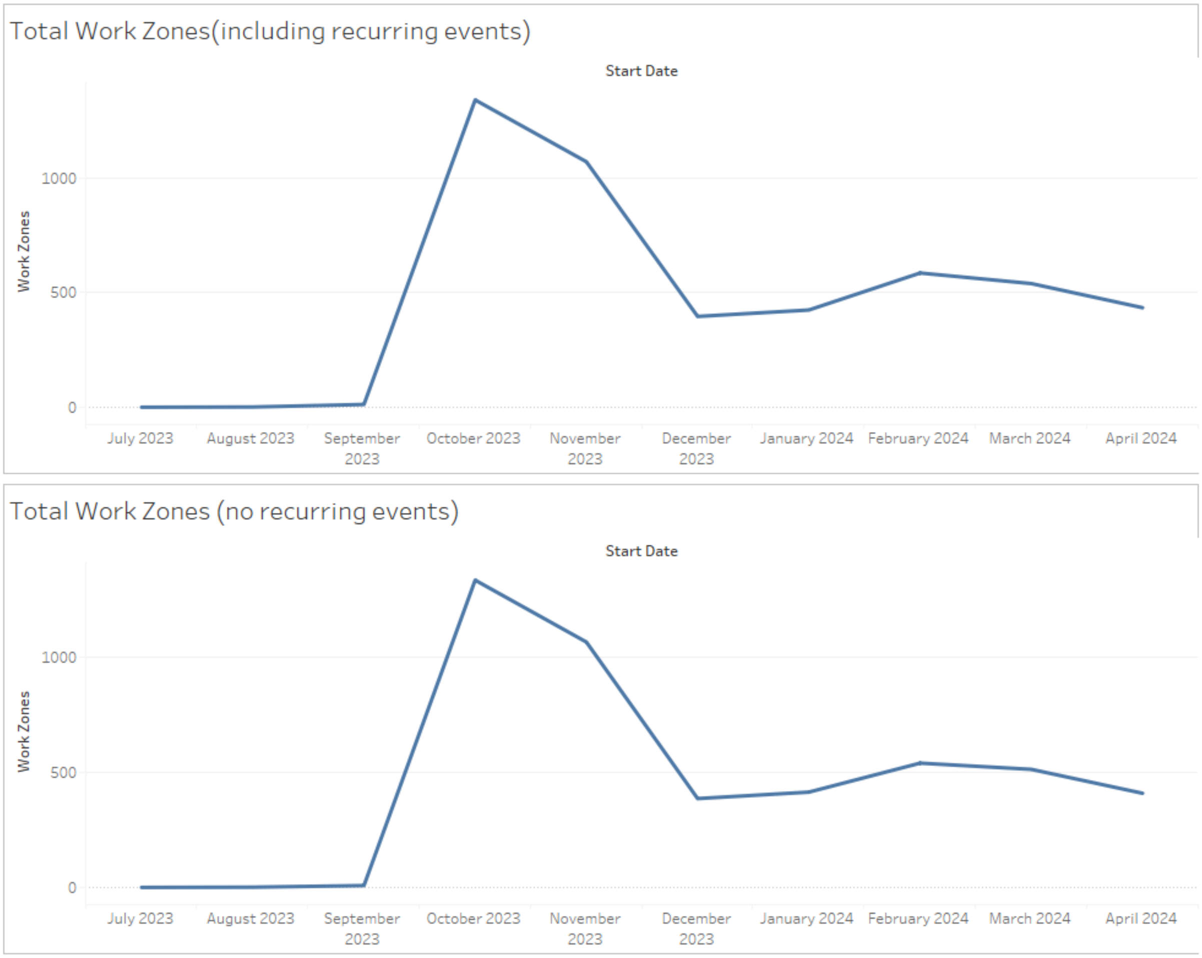


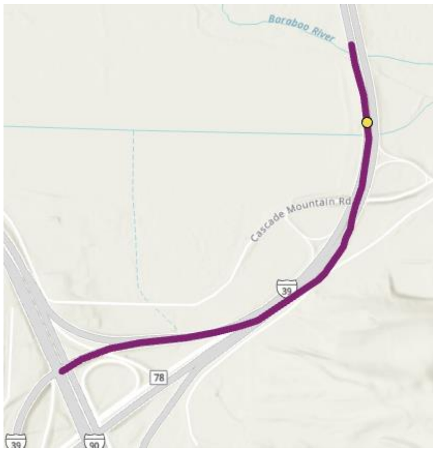
Figure 19. Reported work zones in Colorado's experimental WZDx feed

Evaluation of Missed Opportunities/Potential Benefits

The analyses of arrow boards and work zones were independent and highlighted insights into the arrow boards' performance as well as a summary of the current reported work zones. As part of the final analysis, the arrow board and work zone data were combined to identify potential opportunities for using the arrow boards with planned work zone data and future benefits of automating the process of associating the arrow boards with work zones. Two types of analyses were completed to associate the arrow boards with work zones, including a spatial analysis for Iowa, Wisconsin, and Colorado and a route-based analysis for Iowa. The analyses are intended to provide insights into how arrow boards can be better integrated into traffic management or similar systems.

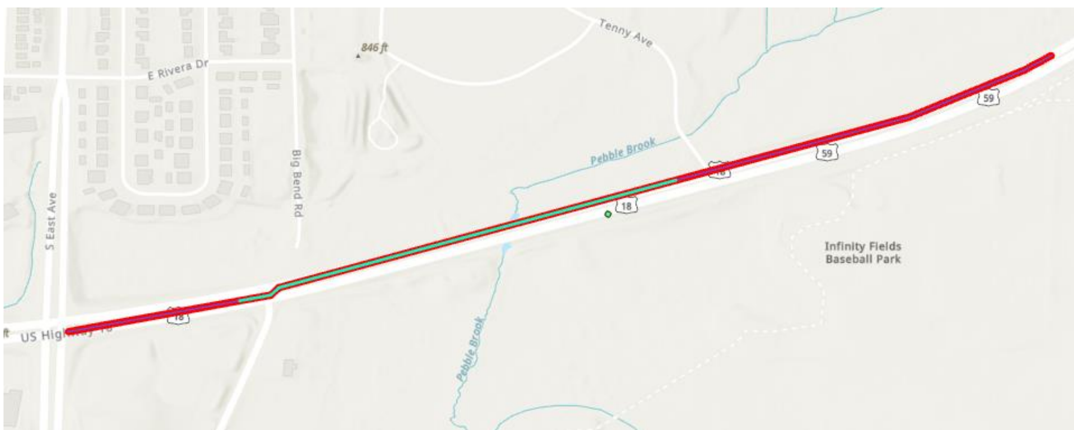
The spatial analysis of arrow boards and work zones was similar to the spatial analysis of arrow boards using HPMS line segments in that each arrow board was associated with any work zone with 500 ft for all three states. The spatial analysis did not initially consider whether the arrow board and work zones were temporally related. A separate process was completed that retained only the records where the arrow board start and end times overlapped with the work zone start and end times. Because of this, multiple arrow boards could be associated with the same work zone and a single arrow board could potentially be related to multiple work zones (ambiguity).

In Wisconsin, 36 unique activations of arrow boards were captured in the spatial analysis, with only a single activation having ambiguity. Figure 20 provides three examples of the types of integration that were found, with the points representing arrow boards associated with the given lines indicating the work zone extents.



(a)

(b)



(c)

Figure 20. Example spatial integration in Wisconsin

Figure 20a shows a simple relationship where a single arrow board was associated with a single work zone. The work zone data indicated that it would start at 6 a.m. on August 21 and end at 4 p.m. on August 24. The arrow board data showed a left arrow was displayed from 8:07 a.m. on 8/21 and ending at 10:47 a.m. on August 23. The arrow board was also approximately 0.19 miles downstream from where the work zone data located the start of the work zone. Figure 20b represents a complex scenario where a single work zone was associated with five activations of an arrow board. The work zone was planned for 3 days, while all five of the activations of the arrow board occurred on the first day of the planned work zone. The five activations likely indicated the areas where the work zone was active. Figure 20c represents a single location with ambiguity, in which two work zones represented the same section of roadway. One work zone represented a long-term work zone with only the shoulder closed, while the second work zone lasted five days. This type of issue with the planned work zone data will present challenges for automating the process of associating arrow boards with a single work zone. In addition to the work zones that could be enhanced using the arrow board data, additional arrow board activations were documented in Wisconsin that had no work zones nearby. These work zones represent potential opportunities for enhancing work zone data beyond the existing data provided by a DOT.

Figure 21 provides an overview of the number of minutes arrow boards were active, while Figure 22 provides a map showing the locations with active arrow boards. In Figure 21, the arrow board activations that were near a WZDx work zone represented only 11.3% of the time arrow boards were active in Wisconsin. As shown on the map, the deployment of arrow boards is currently limited, so an expansion of arrow board usage will further increase the amount of time arrow boards can provide additional work zone messaging.

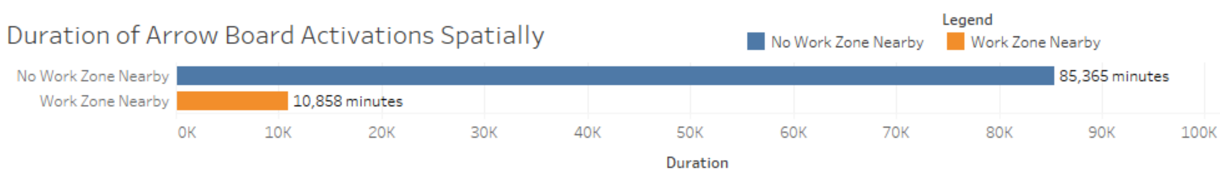


Figure 21. Minutes of arrow board activations in Wisconsin

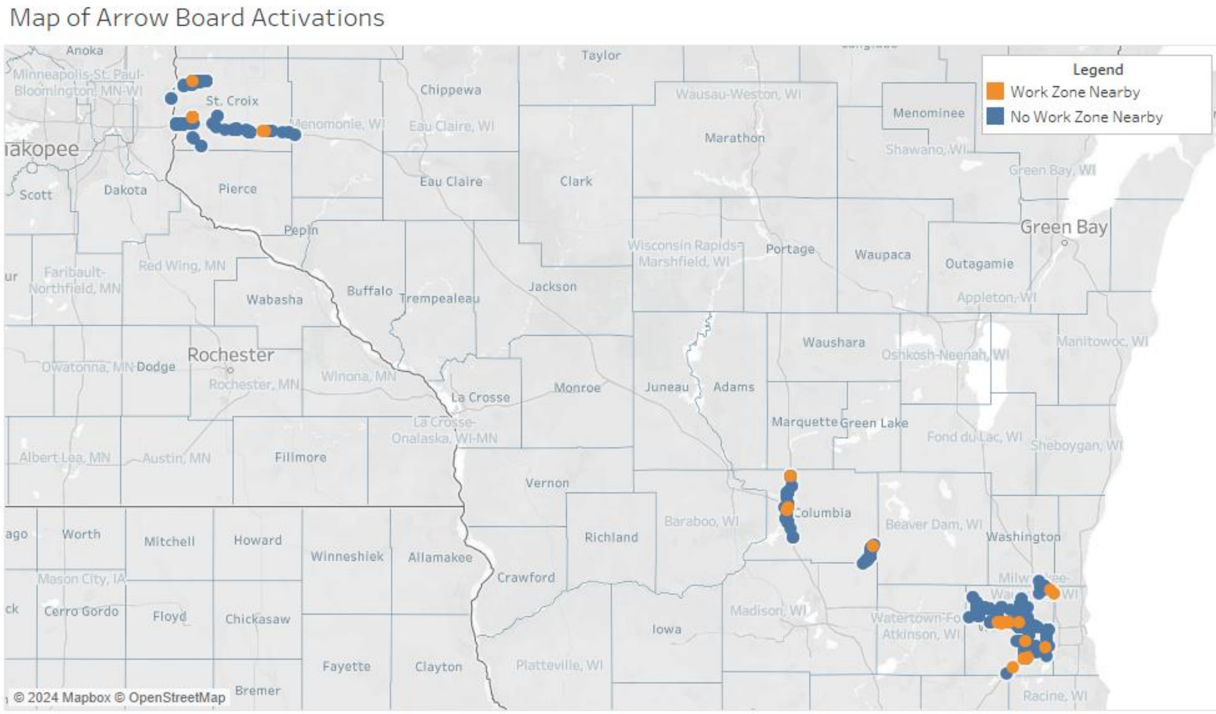


Figure 22. Map of arrow board and work zone spatial analysis in Wisconsin

Given the limited amount of ambiguity in Wisconsin, the locations near work zones were analyzed to determine the relative distance of each arrow board from a WZDx work zone. Figure 23 provides a distribution of the distance between the arrow boards and work zones in 5 ft bins. A majority of the sites had a work zone within 100 ft of the arrow board, though multiple locations did have distances of over 300 ft between the work zone and arrow board.

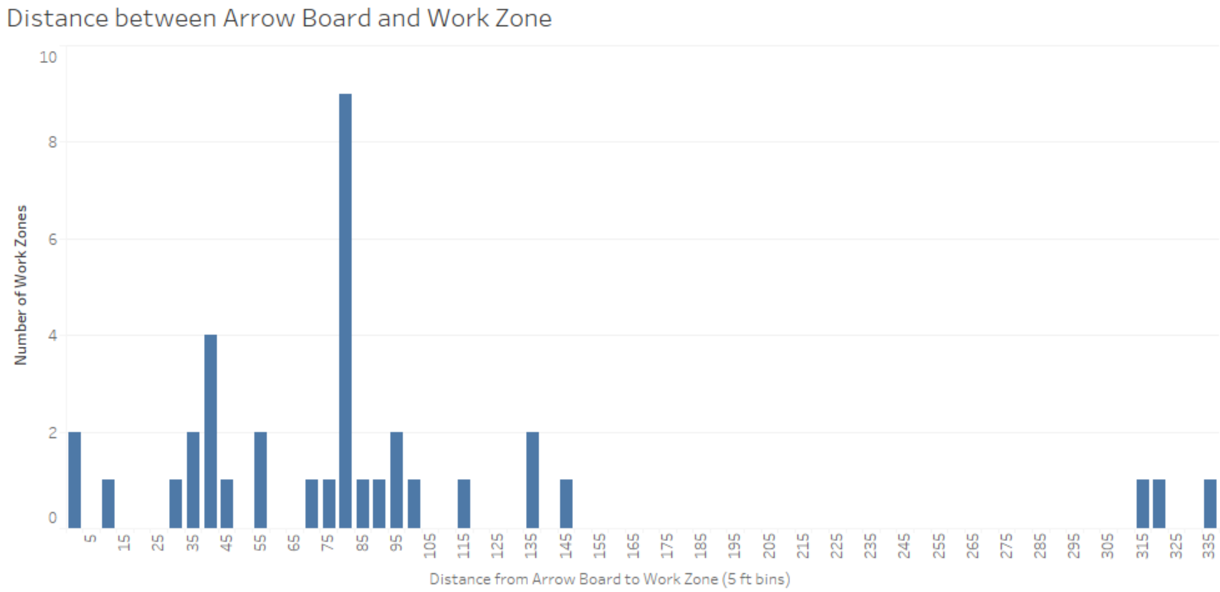
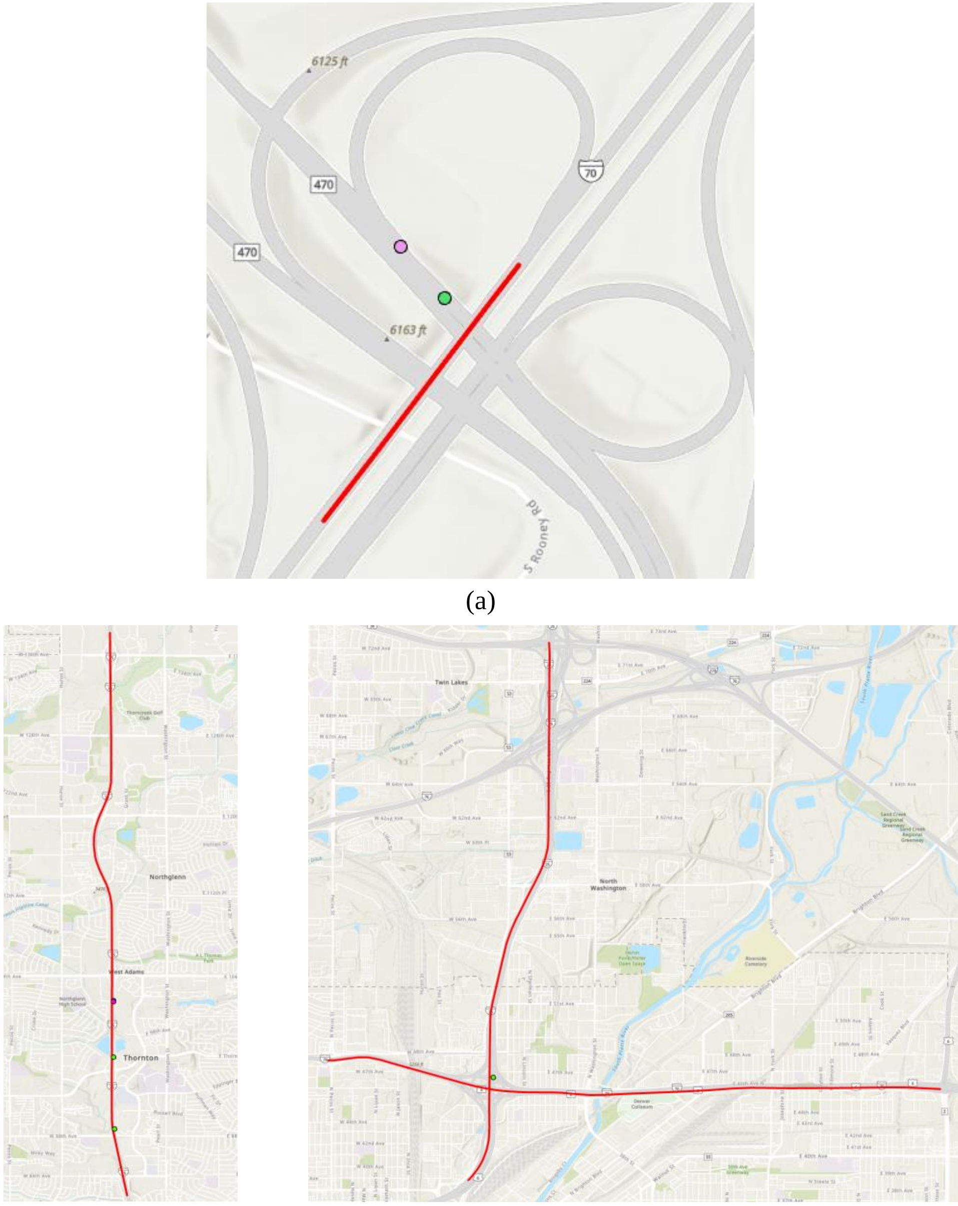


Figure 23. Distribution of distance between arrow boards and work zones in Wisconsin

When evaluating the data in Colorado, 66 unique activations of arrow boards were captured in the spatial analysis, with 10 activations having ambiguity. Figure 24 provides three examples of the types of integration found, with the points representing arrow boards associated with the given lines indicating the work zone extents. Figure 24a shows a work zone that at first appears to be incorrectly assigned to a single arrow board. After further analysis of the data, the arrow boards were placed before the ramp that was being closed leading to the work zone. The arrow boards for this work zone were turned on from 12:35 p.m. until 3:11 p.m. on December 8, 2023. The work zone data indicated a longer-duration impact from December 1, 2023, to March 7, 2023. Figure 24b represents a short-term work zone where the planned work zone data showed an impact from 10 p.m. to 6 a.m. the next morning. The arrow board data showed five activations, with three of the five activations appearing to be transitional activations (i.e., a caution pattern before the actual lane closure). The primary impacts based on the arrow board data were from 2:17 a.m. to 2:36 a.m. then from 3:50 a.m. to 4:09 a.m. The two activations were 0.8 miles and 2.4 miles from the estimated start of the work zone. Figure 24c represents a location with ambiguity that was related to two work zones on cross streets. This example highlights an area of concern where multiple work zones may be in close proximity and the arrow board is unable to automatically be assigned to a specific work zone.

The 10 ambiguous activations in Colorado were across 6 unique locations. The ambiguity at half of the locations was due to multiple work zones located along the same section of roadway. Upon evaluation of the work zone data, this appears due to either a shorter-term work zone being inputted along the same section as a longer-term work zone or a work zone extension where a new event was inputted as opposed to extending the current event. Two of the ambiguity issues were related to work zones present in opposite directions, while the final ambiguity issue was related to a cross street work zone, as described above.



(a)

(b) (c)

Figure 24. Example spatial integration in Colorado

Like in Wisconsin, the use of arrow boards in Colorado at locations beyond the work zones available in the WZDx has the potential to generate additional notifications of work zone activity. Figure 25 provides an overview of the number of minutes arrow boards were active in Colorado, while Figure 26 provides a map showing the locations with active arrow boards. The use of arrow boards was primarily around the Denver area, with some usage in other areas of the state. As Figure 25 shows, arrow boards that were spatially near a work zone represented only 1.2% of the time arrow boards were active in Colorado. The additional time arrow boards were active represent potential opportunities to enhance work zone data beyond the existing data provided by CDOT.

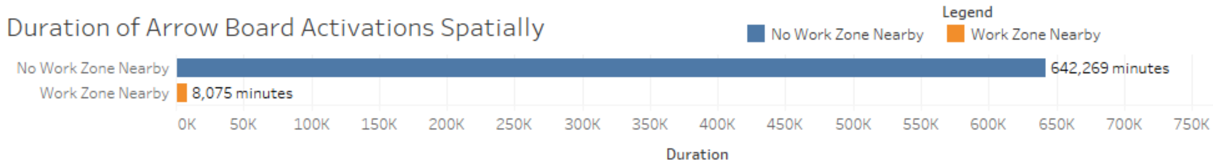


Figure 25. Minutes of arrow board activations in Colorado

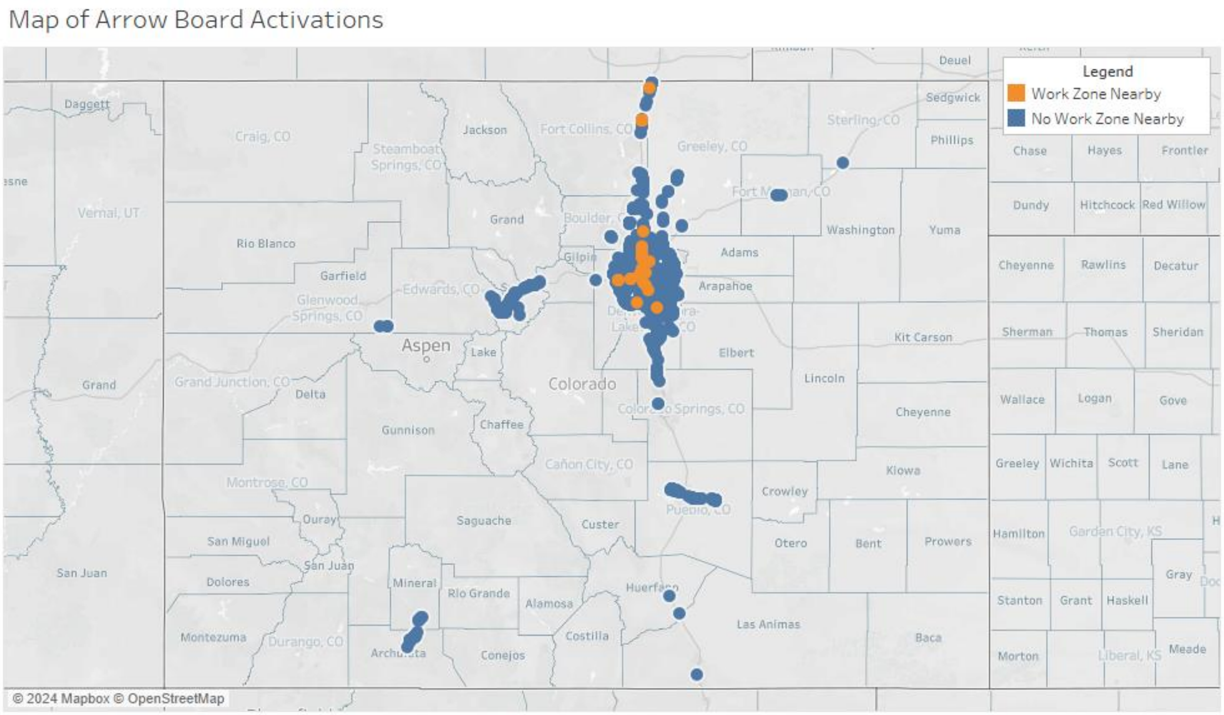


Figure 26. Map of arrow board and work zone spatial analysis in Colorado

The distances between arrow boards and WZDx work zones in Colorado were also compared, and a majority of arrow boards were found to be more than 400 ft from a WZDx work zone. Figure 27 provides a distribution of the distance between arrow boards and work zones in 5 ft bins. The data represent only a sample, but the figure shows that only 26.0% of arrow boards were within 100 ft of a work zone.

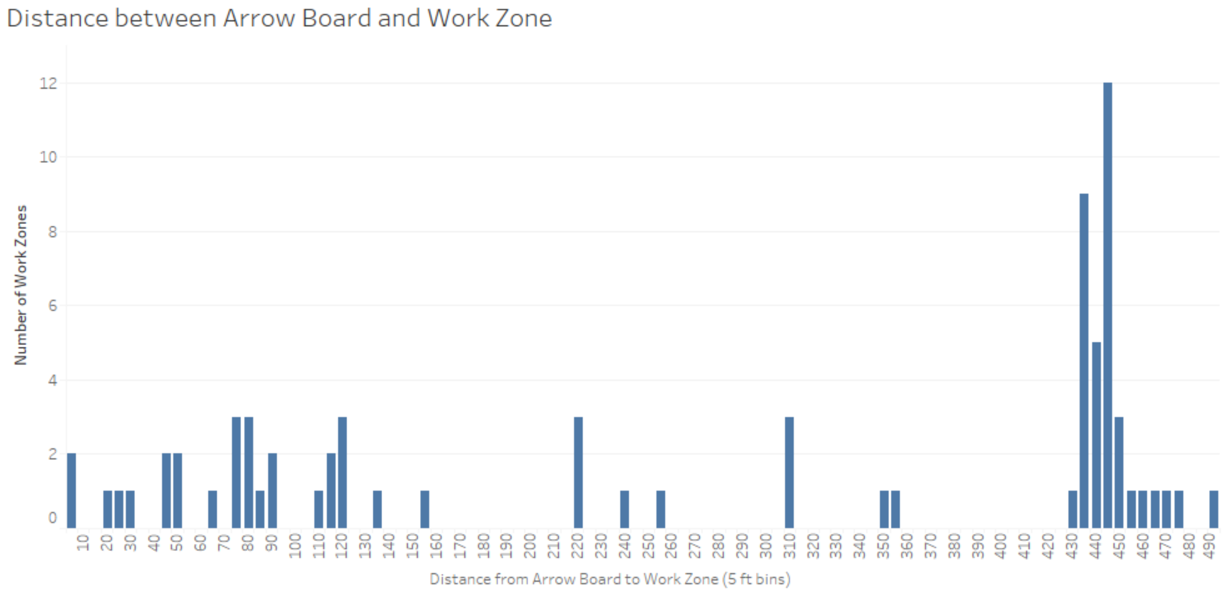


Figure 27. Distribution of distance between arrow boards and work zones in Colorado

Iowa was the final state that was analyzed, and a more extensive analysis was conducted due to the significant number of arrow board activations. In Iowa, a spatial analysis was utilized along with an additional route-based method utilizing the Iowa linear referencing system (LRS) network. The research team considers the route-based method to be a more precise method of integrating the arrow boards and work zones because each dataset is related to the road network independently. As part of the arrow board processing, arrow boards in Iowa were conflated to the LRS using a 150 ft search radius. The closest route to each arrow board was selected, which then provided a route and measure value for locating the arrow board within the network. As part of the arrow board aggregation, only the first route and measure value for each arrow board activation was retained, even though the activation could have been part of a moving operation. The work zone data also included route, from, and to measures, which allowed the work zone to be spatially located along the LRS network. With both datasets independently associated with the same network, the data were then integrated based on overlaps in the route and measure values. Using this method, the extents of the work zones were expanded, and the expanded boundaries were utilized in the analysis to identify any arrow boards 0.5 miles upstream or downstream of the roadway segment. A larger search distance could be used because this method looks only along the roadway; in contrast, the spatial analysis looks a set distance in any direction.

The durations of arrow board activations are summarized in Figure 28, and a map showing all arrow board activations is presented in Figure 29. Figure 28 shows the duration arrow boards were active and whether they were near a verified or estimated work zone. This chart includes the results from both the spatial analysis and the route-based analysis and shows the best of both methods in terms of the associations between arrow boards and WZDx work zones. The results show that the arrow board activations near an estimated or verified work zone represented only around 31.1% of the time arrow boards were active in Iowa. If only activations on state roadways are considered, 60.1% of arrow board activations were near a work zone or verified work zone.

The spatial and route-based analysis methods are explored in further detail below, but 70% of both the estimated and verified nearby work zone activations were from the route-based analysis, which relates the data with greater confidence. The remaining 30% were from the spatial analysis, which may include arrow boards with ambiguity or other potential issues.

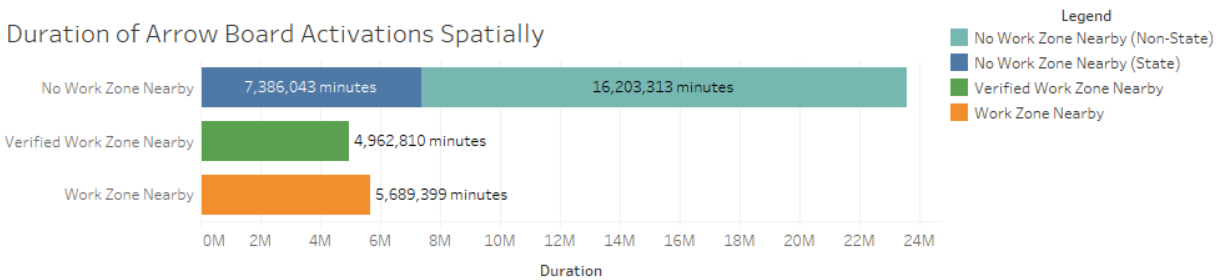


Figure 28. Minutes of arrow board activations in Iowa

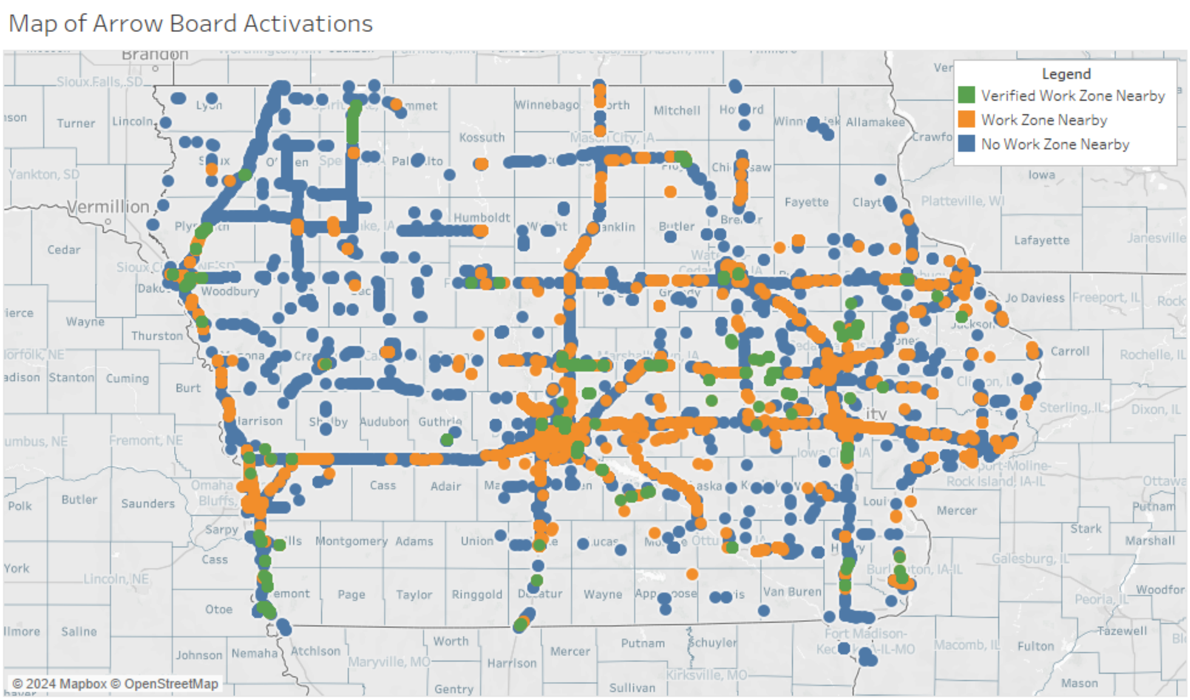


Figure 29. Map of arrow board and work zone spatial analysis in Iowa

For the spatial analysis, the distribution of distances between the arrow boards and work zones are compared in Figure 30. The results differed slightly from the HPMS-based analysis of arrow boards because a smaller percentage of work zones were within 50 ft of the arrow boards. It was found that 37.8% of the closest arrow boards were within 50 ft of a work zone, with 54.7% of arrow boards less than 100 ft from a work zone. The arrow boards may not be as close to the work zones in this analysis, but the amount of ambiguity decreased at greater search radiuses, as shown in Figure 31. Around 54.1% of arrow board activations were ambiguous at 500 ft, which decreased to 39.7% at a 25 ft search radius. Similar to the HPMS analysis of arrow boards, the number of arrow boards associated with work zones significantly decreased as the search radius decreased.

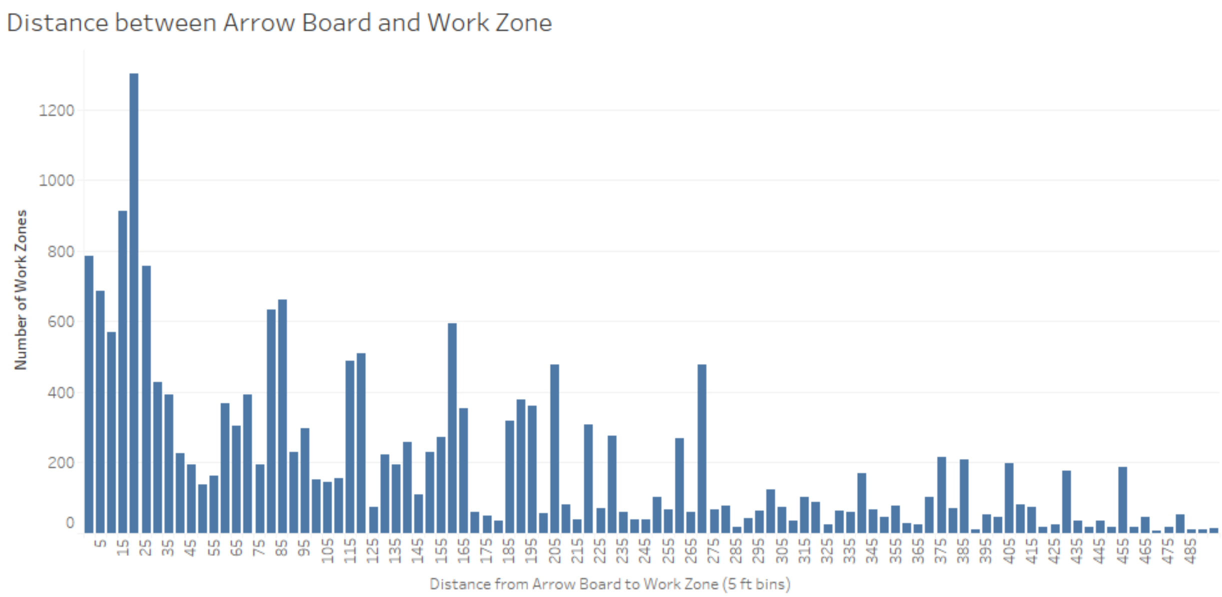


Figure 30. Distribution of distance between arrow boards and work zones in Iowa

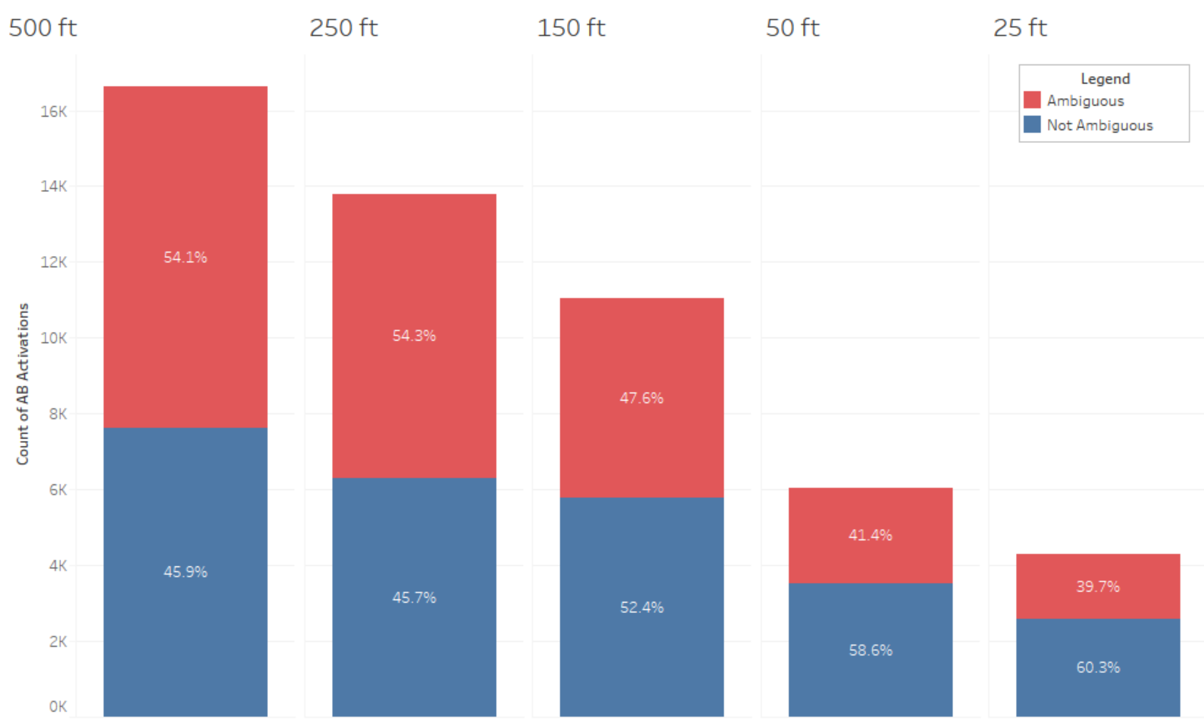


Figure 31. Ambiguity of arrow board activations and work zones in Iowa

The route-based method of integrating arrow boards with work zones provides multiple benefits relative to a simple spatial analysis. One benefit is the ability to have more control in identifying the roadway a work zone is located along. As shown in the HPMS analysis of arrow boards, a smaller search radius can be used to precisely locate an arrow board along a roadway. A significant challenge with the spatial analysis, however, is that any search radius is applied in all directions regardless of whether the arrow board is on the routes in range. This requires a smaller search radius to be applied to reduce the potential for locating an arrow board on a completely different roadway. For the route-based method, another benefit is that a distance upstream or downstream of the work zone can be applied that will only identify devices along the given route, reducing the potential for locating an arrow board on a different roadway than the work zone. For this analysis, 0.5 miles was used to identify arrow boards upstream or downstream of the work zone.

Figure 32 provides a summary of the number of work zones (not accounting for recurring events) and the number of minutes an activated arrow board was associated with a work zone using the route-based method. The orange line represents work zones that were associated using the process developed by the Iowa DOT, while the blue line represents potential opportunities for the Iowa DOT to associate additional arrow boards with existing work zones. Figure 33 shows the same data as Figure 32 but as a percentage of the total number of work zones or minutes for a given month.

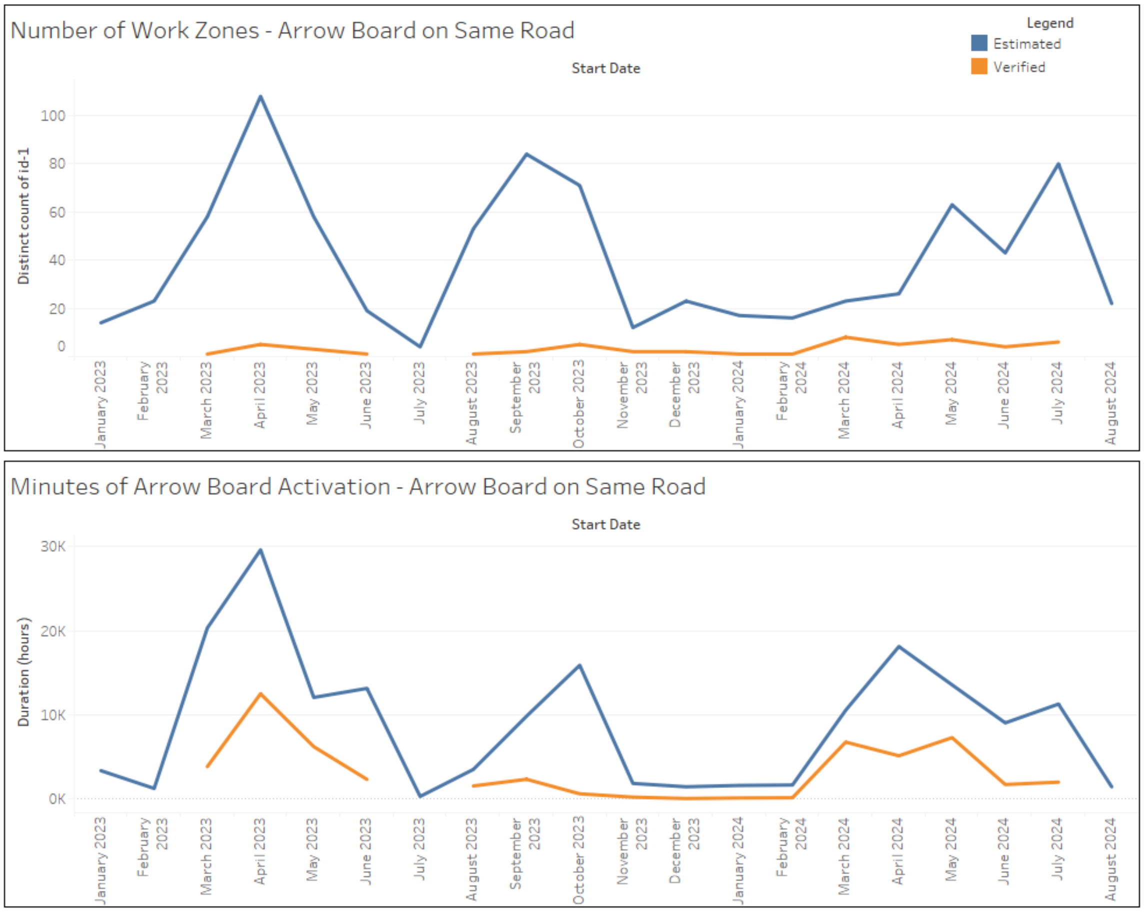


Figure 32. Work zones with arrow boards on the same road and WZDx status

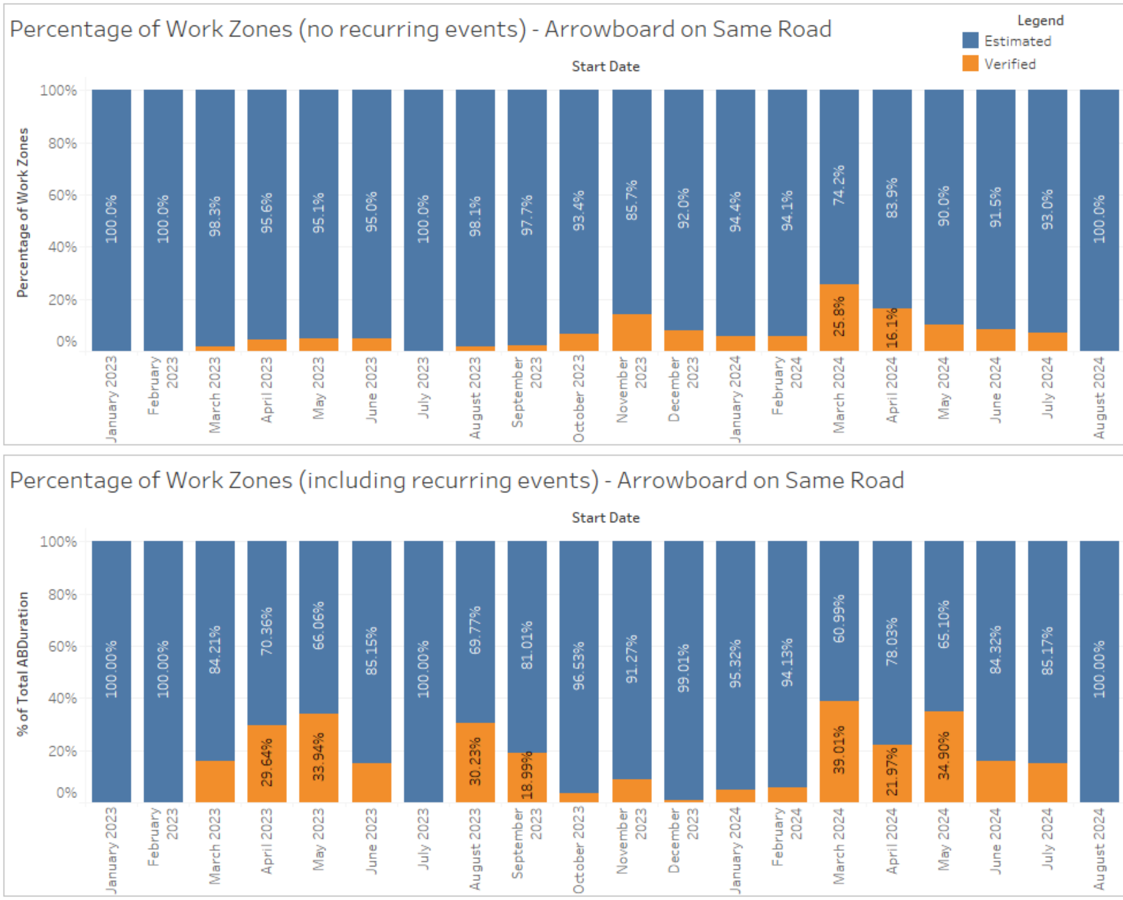


Figure 33. Percentage of work zones with arrow boards on the same road and WZDx status

Using only the route-based method for analysis, Figure 34 shows a comparison of the arrow boards associated with a verified work zone versus those associated with an estimated work zone. The top chart shows that the number of hours where an active arrow board is near a work zone but not being used is over three times the number of active arrow board hours near verified work zones. This amount of time represents missed opportunities for enhancing work zone data by associating arrow boards with work zones. As described in an earlier section, TMC operators noted that they focus on longer-duration work zones when associating arrow boards with work zones, which can also be seen in the average lengths of arrow board durations shown in Figure 34. The average duration of arrow board activations near an estimated work zone was 1.6 hours less than the duration of arrow board activations near a verified work zone. The upper whisker and 75th percentile durations were also lower for estimated work zones.

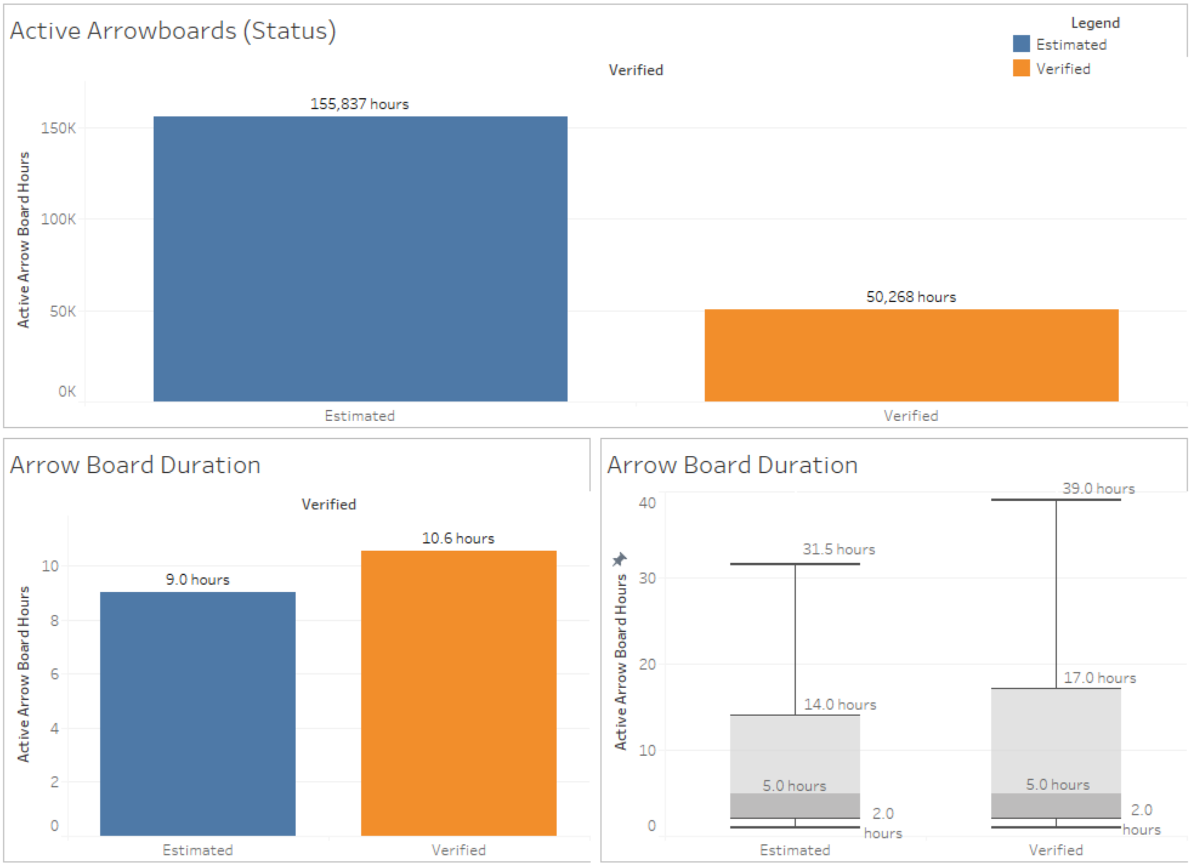


Figure 34. Summary of potential benefits of integration based on proximity

Another benefit of integrating connected arrow boards is the ability to verify the start times and start locations of work zones. To document this benefit, the estimated start times and locations of work zones were compared to the actual start times and locations reported by connected arrow boards. To compare the start times, only work zones and arrow boards that had start times within 1 day of each other were considered. This was done to eliminate work zones with long durations and extents due to alternating lane closures for activities such as patching, which may span multiple counties. The remaining work zones represented actual work zones and arrow board activations that are comparable, but these only represented 12% of the total work zone and arrow board combinations.

For verified work zones, the arrow boards were activated on average 290 minutes after the reported start time. For estimated work zones, the arrow boards were activated on average 139 minutes after the reported start time. Figure 35 provides a distribution of the differences in start times, with a positive value indicating that the arrow board was activated after the work zone start time and a negative value indicating that the arrow board was activated before the work zone start time. Both the unverified and verified work zones had a majority of activations after the work zone start time. The unverified work zones had the most activation events within 60 minutes of the reported start time of the work zone. The verified work zones had a fairly flat distribution of start time differences, likely due to the lower number of verified work zones.

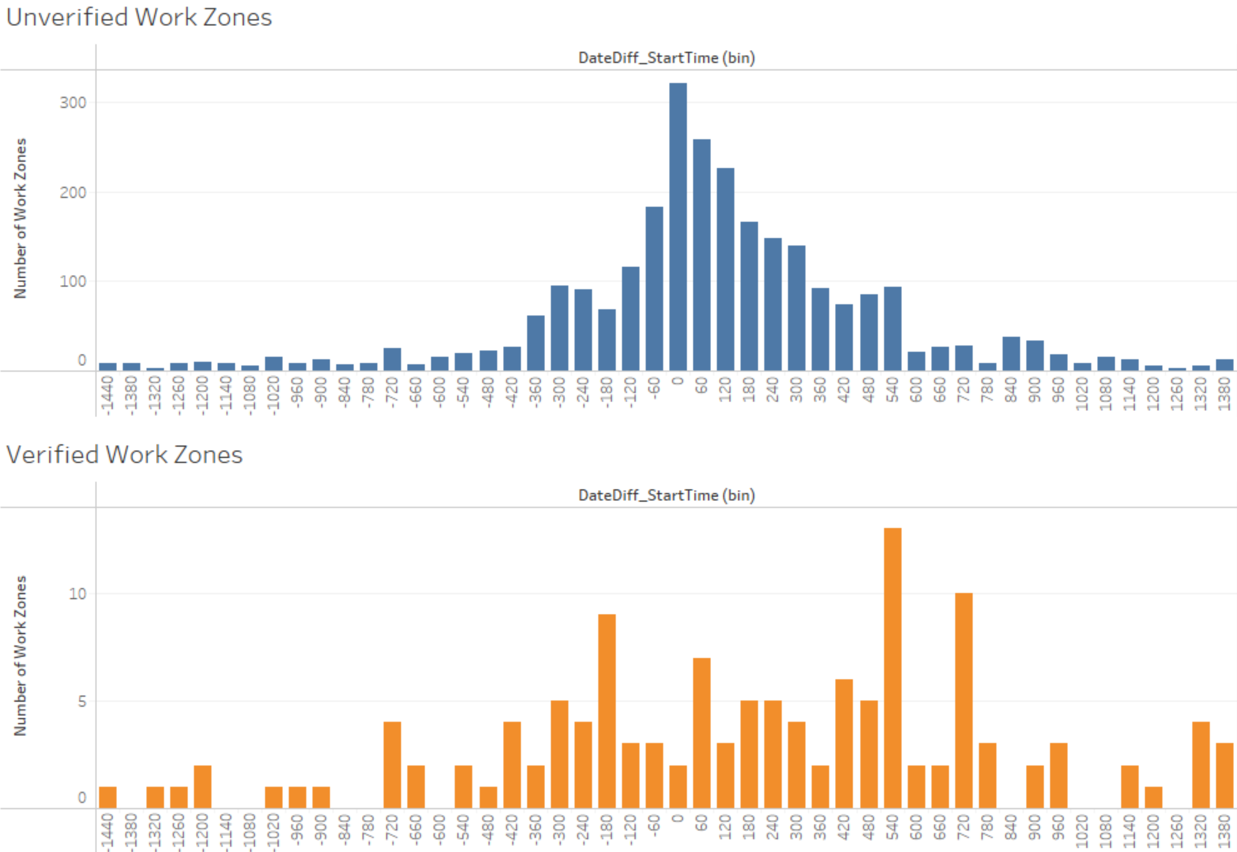


Figure 35. Distribution in the difference between work zone and arrow board start times in Iowa

Figure 36 provides a summary of the differences between the start locations of the work zones and the arrow board locations. A positive value indicates that the arrow board was located after the work zone start location, while a negative value indicates that the arrow board was located before or upstream of the work zone start location. Both charts in Figure 36 show a distribution in which the arrow boards are in close proximity to the estimated start location but skew in the positive direction, indicating that the arrow boards are placed after the estimated start location. Overall, the arrow boards were placed on average 0.51 miles after the estimated start location for unverified work zones and 0.99 miles after the estimated start location for verified work zones.

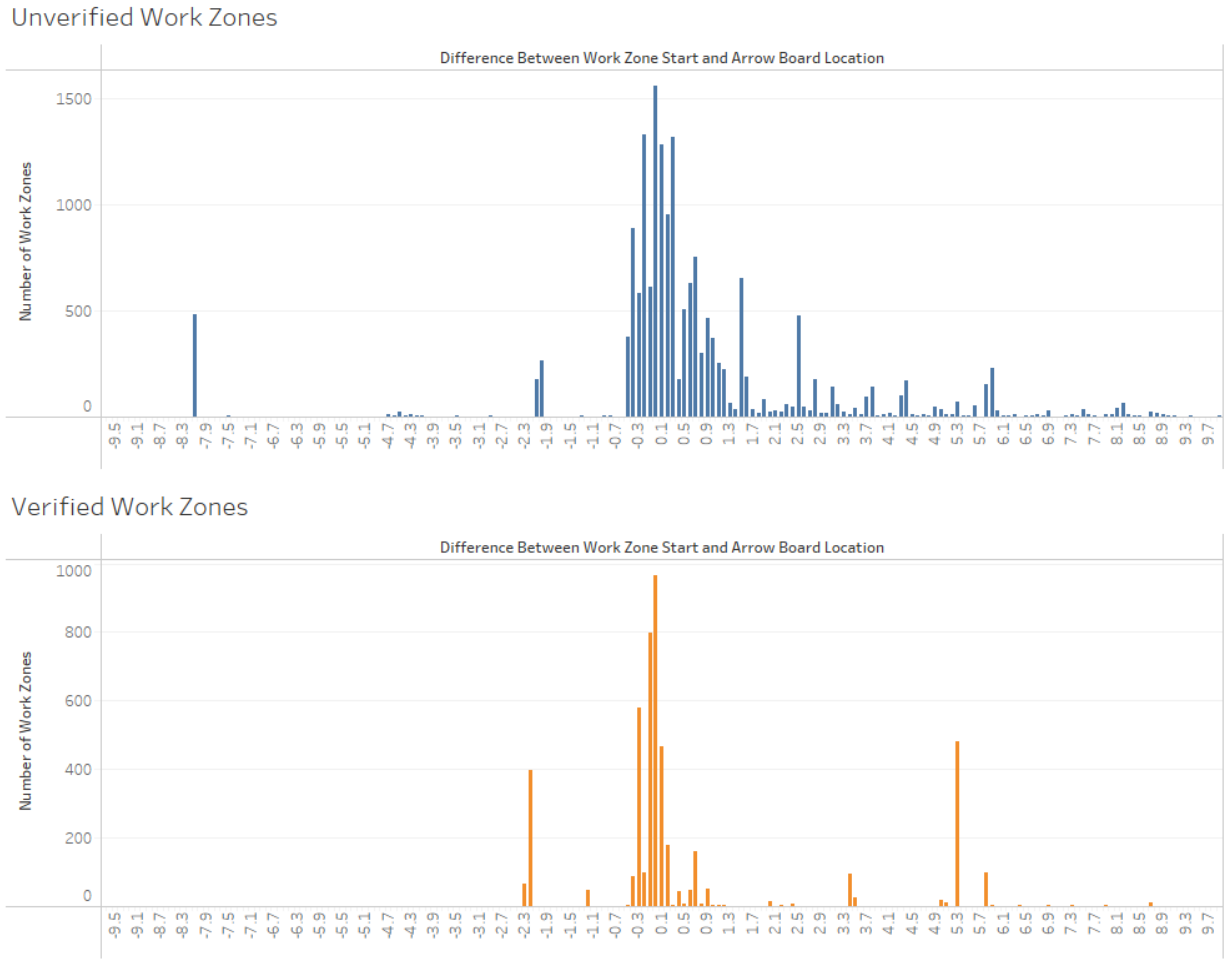


Figure 36. Distribution of start location differences between work zones and arrow boards in Iowa

CONCLUSIONS

In a continuously connected world, it is expected that work zones will become increasingly connected with new devices, allowing for a digital representation of work zone traffic control. This influx of data can offer agencies a better understanding of where work zones are located at any given time and the ability to then communicate that to motorists, vehicles, and mapping companies. The challenge agencies face is how to most effectively utilize these new data sources and incorporate the information into their business process. This research represents a starting point in the development of guidance for utilizing cTTCDs.

Through the literature review and agency interviews, it was documented that a number of devices are available or are coming to market that can be used to locate elements of work zone traffic control. One of the most common types of devices discussed was connected arrow boards, which have a low barrier of entry for agencies. In the interviews, all agencies noted that they desired automated methods for associating arrow boards or other cTTCDs with work zones. Some agencies, such as WisDOT and CDOT, are developing automated methods, while agencies such as the Iowa DOT have a system in place but require arrow boards to be associated with work zones manually.

One of the benefits of the data processing conducted for this research was the ability to summarize work zone deployments using historical connected arrow board data. With the archived arrow board data, a database of arrow board activations was developed showing the location, start time, and end time of a given work zone. The data also included the begin and end locations of arrow boards that were part of a moving operation, but only the begin location was utilized for this research. The archived data allowed for the creation of a historical database of work zones for examining metrics such as the duration of lane closures or the number of lane closures, which are not easily quantifiable with existing work zone databases.

The focus of the research was on evaluating connected arrow boards and exploring ways to integrate them into a traffic management or similar system. The analysis was not dependent on a specific traffic management system but instead simply compared the reported information on planned work zones with the arrow board data provided by manufacturers. If an agency wants to simply display arrow board data in its system, then the WZDx device feed or the Iowa DOT-developed SABP can be used to bring manufacturer-provided data in through a standardized data feed.

One of the primary methods of analysis was to utilize the compiled work zone data to compare the methods of integration used by different states. Iowa, Wisconsin, and Colorado were selected based on the relative ease of access to their data and the inclusion of verified work zones in their WZDx feeds. Unfortunately, due to the timing of the analysis, no verified work zones were reported in the WZDx feeds for Wisconsin or Colorado during the analysis period, which did not allow for an evaluation of the automated processes these states were developing. The verified work zones were evaluated in Iowa using a manual process for associating arrow boards with work zones. The Iowa DOT also utilized an alerting system that would notify operators if an arrow board was near a work zone. The alerting system was not implemented until early 2024, which aligned with a significant increase in the reported number of verified work zones starting in February 2024. Some work zones were being verified prior to the notifications, but the notifications appeared to have increased the awareness of operators to associate arrow boards with work zones. In discussions with the operators receiving the alerts, the operators noted that they associate arrow boards with longer-term work zones because doing so updates the location and does not require adding/removing the arrow board over time. Arrow board alerts that were associated with short duration or recurring work zones were not always acted on because of the significant amount of time required to add or remove the association between the arrow boards and the work zones and because different arrow boards may be used on the same project or the same arrow board may be used on multiple projects on a given day.

For a broad view of how arrow boards can be integrated, arrow board data were summarized across 18 states, including Arizona, California, Colorado, Connecticut, Florida, Illinois, Iowa, Maryland, Massachusetts, Michigan, New Jersey, New York, North Carolina, Pennsylvania, Texas, Virginia, Washington, and Wisconsin. The states were selected based on the number of arrow boards activations within each state as well as their membership in the SWZDI pooled fund. The analysis provides a broad perspective and accounts for various types of roadway configurations and work zones utilizing arrow boards, from moving operations to static lane closures. In total, 498,358 arrow board activations were captured between January 2023 and August 2024.

As part of the broad analysis, ambiguity was a concern that was evaluated by relating all arrow board activations to the roadway network. As the search radius around each arrow board decreased, the percentage of locations that were unambiguously associated with a single roadway increased, with 86.6% of locations being unambiguous at a search radius of 25 ft. The decrease in search radius also increased the number of arrow boards that were not associated with a roadway. This suggests that agencies must strike a balance between selecting a search radius that is too high, which causes ambiguity, or too small, which eliminates potential work zones. In total, 62% of arrow board activations had the closest roadway within 50 ft of the roadway, with a majority of arrow board activations within close proximity to a roadway and two-thirds of the closest activations being less than 25 ft. When accounting for the type of road, the highest percentage of activations less than 50 ft from a road were on Interstates (73.3%), followed by US routes (64.3%), state routes (61.8%), local roads (45.1%), and county roads (34.2%). These results indicate that different approaches may be necessary for local and county roads as opposed to state-maintained roadways. The broad analysis highlighted some of the factors that agencies must consider to avoid ambiguity in an automated system.

To explore the methods of integrating arrow boards and work zones, two approaches were applied. The first approach, which was used on the Wisconsin, Colorado, and Iowa data, used a spatial analysis to simply relate arrow boards to work zones within 500 ft. The method is simple but not precise because arrow boards on other roads could be associated with the work zone in question. The second method, which used a route-based methodology, was used on only the Iowa data. The route-based methodology related the arrow boards and work zones independently to the roadway network and then identified overlaps based on the route and measure data from the network. This method was considered more precise because a smaller search radius could be used to associate devices with the network. A search distance could then be applied upstream or downstream that only considered records on the same route.

For the spatial analysis, 36 unique activations of arrow boards were captured in Wisconsin, along with 66 unique activations in Colorado. Only 1 of the activations in Wisconsin had ambiguity, while 10 of the activations in Colorado had ambiguity. A majority of the ambiguity across both states was due to multiple planned work zones located along the same roadway. Issues like these can easily be resolved by applying quality control to the planned work zone data to ensure that only a single work zone is represented by a given location and time. The remaining ambiguity was due to divided roadways and cross streets, which represent common situations that would need to be addressed by an automated process.

In terms of the potential benefits of arrow board integration, the arrow board activations near a work zone in Wisconsin represented only 11.3% of the total time arrow boards were active. In Colorado, the arrow board activations near a work zone represented only 1.2% of the total time arrow boards were active. Both of these numbers indicate that there are likely thousands of hours of arrow board activations on local, county, or other roadways that are not being utilized for alerting. Methods for utilizing these data should be explored. The number of hours resulting from such limited arrow board deployments also show the potential benefits that a larger-scale deployment can have in both of these states.

In Iowa, the results showed that the arrow board activations near an estimated or verified work zone represented only around 31.1% of the total time arrow boards were active. The results were based on both the spatial and route-based analyses, but over 70% of the activations were based on the route-based analysis. The high percentage of arrow boards associated with work zones indicates the potential value of the route-based approach compared to the potential issues with a spatially based analysis. The spatial analysis did yield slightly different results compared to the broad analysis, where only 37.8% of the closest arrow boards were within 50 ft of a work zone and 54.7% of the closest arrow boards were less than 100 ft from a work zone. These results indicate that although a road may be near an arrow board, if the arrow board is not precisely located in that road, there may be an issue with a smaller search radius.

The route-based method of integrating arrow boards with work zones provides multiple benefits relative to a simple spatial analysis. The first benefit is the ability to have more control in identifying the roadway a work zone is located along. The second benefit is the ability to search upstream and downstream of a work zone but only consider devices on the given roadway. For this analysis, 0.5 miles was used to identify arrow boards upstream or downstream of the work zones. This method resulted in the identification of a higher percentage of verified work zones than unverified work zones with an arrow board nearby. Similar to the WZDx analysis, increases in the percentage of verified work zones were found starting in early 2024. With the route-based analysis, the results showed that the number of hours where an active arrow board is near a work zone but not being used is still over three times the number of active arrow board hours near verified work zones.

Based on this research, there are multiple considerations for an agency integrating connected devices into a traffic management system:

- Leading agencies are pushing for automated methods of associating cTTCDs with work zones. In the absence of automated methods, alerts such as those used by the Iowa DOT do show an increase in the number of verified work zones.
- Ambiguity is a concern for automatically associating devices with work zones. Larger search radiuses lead to higher ambiguity, while smaller search radiuses may not capture all work zones near an arrow board. The research team ultimately used a 50 ft search radius, which limited the amount of ambiguity for the closest route.
- A route-based method of integration allows for a smaller search radius for arrow boards and does not introduce as many ambiguity issues as a spatial analysis. The route-based method also allows for searching along a route using larger distances.
- Over half of the ambiguity identified in Wisconsin and Colorado was due to duplicate planned work zones in the WZDx. This issue can easily be resolved by agencies through the implementation of quality checks on the planned work zone data to avoid overlaps in work zones spatially and temporally.
- The connected arrow board data alone can be beneficial for agencies for historical usage. The clustered arrow board data can be used to report the duration, frequency, and number of work zones deployed in a given state.
- County and local roadways may need to utilize different methods of associating arrow boards with work zones because less than half of the arrow board activations were within 50 ft of those roads.

The use of cTTCDs such as connected arrow boards is expected to continue to increase, which will result in the need for additional research to continue to explore how this information can be utilized for real-time and historical analysis. The potential for automating the process of associating arrow boards and work zones still faces implementation challenges, but these can be overcome with continued evaluation and deployment of cTTCDs.

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APPENDIX A. INTERVIEW QUESTIONS

Background

Improving the accuracy of work zone data is a multilayered problem that a number of agencies have been working to address over the last several years. Connected temporary traffic control devices (cTTCDs) such as connected arrow boards and other connected devices have the capabilities to improve the accuracy of work zone data without the need for a contractor or agency employee to manually enter the information. The objective of this project is to evaluate and develop methods for integrating cTTCD data within transportation agency operations via an advanced traffic management system (ATMS) or similar system. The research team is currently working to document the existing types of cTTCDs in terms of the state of the practice for agency use, including the purpose and need for tying this information to an ATMS or similar system.

Survey Questions

Related to Connected Temporary Traffic Control

1. Does your agency currently deploy any connected temporary traffic control devices such as connected arrow boards, connected cones/pins, etc. (i.e., any device intending to improve work zone location attributes)?

    a. What types of devices are being deployed?

2. How are you currently receiving data from any connected temporary traffic control (i.e., WZDx Device Feed, other data feeds, email notifications, etc.)?

3. Is the data integrated into any other systems such as the ATMS/511?

    a. If not, do you plan on integrating the data into any other systems.

4. How do you associate devices to work zones (i.e., manual reports, automatic association to work zone, etc.)?

    a. If not currently done, how do you envision data being associated to work zones?

5. If relying on manual reports, who is responsible for notifying you which device is associated to the work zone (contractor, device manufacturer, construction engineer, operators, etc)?

6. Does the device update any attributes for the work zone (i.e., update start location, end location, start time, etc.)

7. How do you envision connected temporary traffic control devices to be used in work zones (i.e., only begin/end locations, indicating all equipment, indicating points of interest, etc.)

8. Would you be able to provide work zone and connected temporary traffic control device data for analysis as part of this project?

Related to Smart Work Zones and Advanced Traffic Management Systems (ATMS)

1. Does your agency deploy smart work zones including sensors, portable dynamic/changeable message signs, cameras, queue alerting, etc.?

2. How many smart work zones are deployed each year?

3. Are alerts such as queue, zipper merge, travel times for smart work zones generated by the ATMS/DOT or other systems outside the DOT?

4. Does the data from the smart work zone integrate into your ATMS?

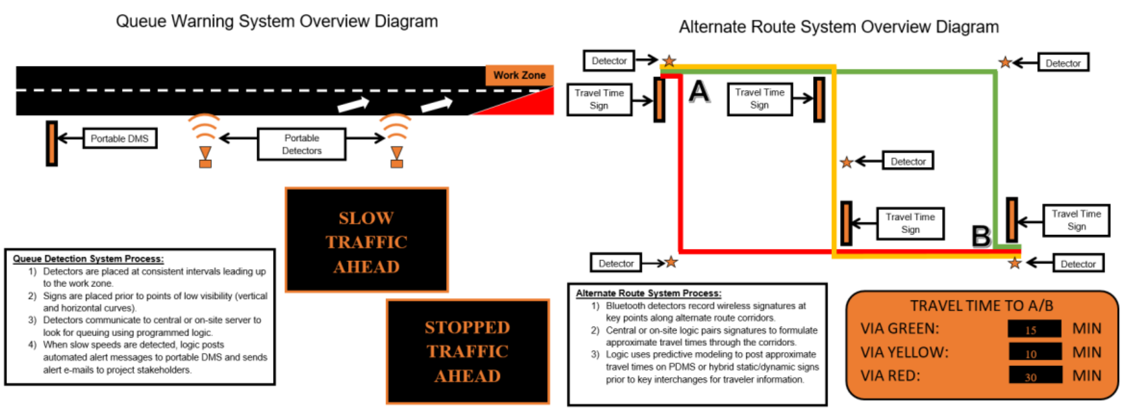
    a. What benefits does integrating smart work zones into the ATMS provide your agency?

    b. What additional challenges exist when integrating smart work zones into the ATMS?

APPENDIX B. SMART WORK ZONE AND ATMS LITERATURE REVIEW AND AGENCY INTERVIEW SUMMARY

Literature Review on the Integration of Smart Work Zones in Advanced Traffic Management Systems (ATMS)

Smart work zones have been around since the late 1990s and typically include the deployment of sensors, dynamic message signs, cameras, or other technologies to collect data or provide information to the public. The goal of these systems is to provide accurate, real-time information to drivers to improve safety and mobility throughout the work zone. Figure 37 shows an example queue warning system designed to alert motorists that they need to be aware of slow/stopped traffic ahead in addition to a travel time message so that drivers can select a suitable alternative route or avoid the work zone when it is under excessive delay. Various types of smart work zone systems have been identified by the Federal Highway Administration (FHWA), including real-time traveler information, queue warning systems, dynamic late merge control, variable speed limits, and vehicle entering/exiting systems (Ullman et al. 2014).



Source: Iowa DOT Traffic Critical Project Program

Figure 37. Iowa DOT standard smart work zone layouts

Most smart work zone systems are typically self-contained, with the data reported primarily using dynamic message signs or other signs deployed as part of the system. Brown and Edara (2022) conducted a survey of state departments of transportation (DOTs) and found that only 31% of the DOTs surveyed store work zone data in a central server automatically, indicating that a large percentage of agencies are using self-contained systems. Kimley-Horn and United Civil Group (2019) reviewed four DOT smart work zone systems and noted that only one explicitly featured integration with an advanced traffic management system (ATMS). Some reasons for not including smart work zone systems in ATMS include the challenges of integrating devices, such as allowing the transmittal of data through firewalls (Brown and Edara 2022), as well as the general complexity of managing external devices from multiple contractors. The ease with which vendors can provide a comprehensive system to achieve the goals of a smart work zone system can be appealing for many agencies due to other complexities related to identifying and procuring systems. Ullman et al. (2014) noted that self-contained systems are intended to operate independently for smaller projects that do not necessarily need to integrate with other intelligent transportation system (ITS) devices. Self-contained systems also typically rely on the expertise of the vendor deploying the system. This type of expertise may not be available within each DOT, which may also limit the ability of agencies to integrate devices within the ATMS.

Deeter et al. (2015) identified various areas where traffic management centers (TMCs) can be involved in work zones and where the resources available in the TMC can support various stages of the work zone. The applicable aspect of the TMC for the purposes of this report is Stage 3, which involves active work zone operations. The researchers identified three strategies for utilizing the TMC during active operations. For example, Strategy 6A identifies the use of real-time traffic data and cameras to monitor stopped traffic or the status of the queuing system approaching a work zone. With the integration of smart work zone sensors and cameras, the TMC can more actively monitor traffic through the work zone and identify if the queue system is operating correctly or if additional resources are needed. Strategy 7B also identifies the potential use of existing resources in the TMC for potential smart work zone applications such as computing travel times. Existing data sources could potentially be used to more broadly report travel times across work zones without the additional resources required to procure individual smart work zone systems.

To support the Arizona DOT (ADOT), Kimley-Horn and United Civil Group (2019) identified the benefits of integrating smart work zone systems into ADOT systems, including the ability to collect and disseminate information more efficiently through the TMC. Other benefits included the ability to share work zone information publicly through 511, the ability to manage variable message signs, and access to real-time camera feeds.

When smart work zone systems are integrated into an ATMS, several capabilities can become available for work zones. For example, Deeter et al. (2015) noted multiple data archiving functions within the TMC, including functions for traffic data, traffic cameras, dynamic message sign logs, and incidents. Having information archived in a single system or a handful of systems can be more effective than having multiple self-contained smart work zone systems provided by a vendor, which may not store and archive data uniformly. The TMC operators' familiarity with the use of various smart work zone devices is an additional capability that can provide expertise in utilizing these devices.

The Minnesota DOT (MnDOT) has developed a toolbox that puts together guidelines for deploying smart work zone systems (MnDOT 2020). As part of the toolbox, MnDOT identifies the ability to utilize the TMC for smart work zone deployments, including for end of queue warnings, travel time notifications, and temporary ramp metering. The document mentions that some permanent devices may be impacted by construction but that contractor-supplied equipment could be utilized as well.

Smart Work Zone and Advanced Traffic Management System Questions

A secondary focus of the present project was to provide information about the benefits of incorporating smart work zone devices/systems into an ATMS. A portion of each interview was used to discuss whether smart work zone systems were integrated into the agency's ATMS, with the corresponding questions from Appendix A used to facilitate the discussion. Table 4 provides an overall summary of the current deployment and integration available in each of the state DOTs. Further details are provided under each state summary below.

Table 4. Smart work zone integration and ATMS—overall interview summary

	Colorado DOT	Iowa DOT	MnDOT	Washington State DOT	Wisconsin DOT
Smart Work Zones Per Year	5–10	30–40	5–10	3–4	<10
Devices Integrated into ATMS	No	Yes	Yes	No	No
Logic for Smart Work Zone System	From vendor	Based on ATMS	Based on ATMS	From vendor	From vendor
Utilizing WZDx Device Feed for Integration in ATMS		N/A	N/A	Viewed as possible method of integration	Viewed as possible method of integration

Colorado DOT

The Colorado DOT (CDOT) has been deploying smart work zones since 2012 but has been limited in its ability to connect these to other systems. A full specification for a smart work zone system was developed for a project in 2017/2018, which included various connected devices including sensors, camera, dynamic message signs, and so on. The smart work zone efforts have since been expanded into a specification for devices and a specification for software. The device specification is scalable based on the number of devices needed for the size of the project. The software specification is used when systems are needed to manage multiple devices in a work zone and outlines the logic for managing speed and other relevant systems.

The current deployment of smart work zone systems is managed through third-party software systems and does not currently integrate into the ATMS. This is a notable challenge because it is difficult to aggregate and compare data across the state due to the fact that the information must be exported out of each system for each work zone. CDOT is exploring how these devices can be integrated into its systems.

Iowa DOT

Iowa DOT has a Traffic Critical Project (TCP) program that is used to deploy smart work zone systems, including various sensors, dynamic message signs (DMS), and cameras. All of the devices are required to be integrated into the ATMS and are deployed as part of a statewide contract. Additionally, other work zones that are deploying DMS are required, as part of the Iowa DOT specification, to integrate the DMS with the ATMS to ensure that they are available to be updated by the TMC. The TCP program has been successful since its inception in 2014, with 30 to 40 smart work zones deployed each year. The logic for queue warnings, travel time notifications, and other alerting systems are generated by the ATMS. Using the logic within the ATMS allows the Iowa DOT to have full control and ensure that similar logic is being used for the various projects across the state.

One of the major benefits identified by the Iowa DOT is the ability to access all of the data from a central platform. All sensors, DMS, and cameras are accessible through the ATMS and do not require access to any other system. The Iowa DOT has worked hard to minimize the workload for TMC operators, which has included minimizing the number of other systems they must login into for access. Having all of the devices and logic from the smart work zone in one platform provides better situational awareness for the operators and other Iowa DOT staff because they can quickly and easily understand any impacts due to the work zone or other events. The DMS and cameras are also able to be used for traffic incident management due to the TMC operators' ability to use and access the devices as part of the ATMS. The central repository of information also makes it easier to access data for historical analysis. All data are available in a single platform and consistent format.

The Iowa DOT noted its appreciation that smart work zones were not siloed outside of the TMC during the initial stages of implementation. Requirements were put in place early for devices such as DMS that required contractors to integrate them into the ATMS. The Iowa DOT's opinion is that doing the hard work up front makes it easier on the backend for TMC operators and others.

A final benefit noted by the Iowa DOT is the control over the logic used by smart work zone systems. Because the logic is part of a single ATMS, the Iowa DOT can ensure consistency in the message logic across work zones. The goal is that regardless of where the queue warning system is in the state, drivers know what type of impacts can be expected. If needed, the Iowa DOT can also adjust the logic to account for special situations without the need to coordinate with a third party on the modifications.

The integration of smart work zone systems does not come without challenges. Communication is a key component of the TCP program. The communication starts with coordinating the needs of each district and the status of each work zone. Throughout the construction season, weekly calls are scheduled with the Iowa DOT, TMC operators, the smart work zone equipment provider, the ATMS system contractor, the Iowa DOT ITS maintenance contractor, Iowa State University, and the TCP program consultant manager. The call is used for regular communication and for ensuring that all groups are aware of any needs throughout the construction season. The partnerships forged during these coordination calls are critical for the successful deployment and implementation of smart work zone systems.

The Iowa DOT also noted the dedication of both contractors and staff during the deployment of the systems. There have been multiple times where an exception could have been applied but the Iowa DOT persisted with integrating the devices for the benefit of users on the backend. The Iowa DOT also expressed gratitude for the partnerships with contractors through organizations such as the American Traffic Safety Services Association (ATSSA) and its commitment to supporting these programs to improve safety.

MnDOT

MnDOT uses a variety of devices for its smart work zone system, including sensors, portable DMS, and cameras. A statewide contract is utilized for deploying the smart work zone devices, and all devices are integrated into the ATMS. The number of deployments each year is dependent on the types and needs of projects and has ranged from five to eight deployments over the last two years. The projects have primarily been located in the metropolitan district but will also include other districts. Most of the deployments are utilizing queue detection and travel time notifications, but some deployments utilize the zipper merge. For the zipper merge, signs will activate when volumes exceed a defined value per lane. All logic for the smart work zones is managed through the ATMS.

MnDOT mentioned three notable benefits of integrating smart work zones into the ATMS. The first benefit is the amount of data MnDOT receives from the work zones, which allows the state to do additional analysis. The work zone devices are like any other sensor or DMS in the ATMS, which allows MnDOT to access historical or real-time data. The second benefit is the ability of operators to utilize devices such as DMS and cameras like any other permanent device in the TMC. If additional DMS are deployed, those DMS can be utilized for traffic incident management if a crash or other situation occurs. Cameras can be used to replace permanent cameras that are removed or to provide supplemental cameras to the work zone, which allows operators additional situational awareness of what is occurring in the work zone. Finally, with all of the logic being driven by the ATMS, MnDOT has more control over the logic thresholds and when systems activate than if these decisions were coordinated with a third party. Changes to the logic for a given work zone can be made dynamically if needed based on the conditions of the work zone to ensure that the work zone is operating as desired. As a note, MnDOT uses an ATMS developed in-house named IRIS.

The deployment of smart work zones and their integration into the ATMS has been fairly easy to manage. There are challenges with ensuring that devices are deployed correctly and calibrated for their locations. Communication is critical, both with the contractor deploying the equipment and with field staff. As a work zone transitions between different stages, resulting in changes such as lane shifts, this transition can impact devices. Communication with various parties is critical to ensure that the ATMS is updated and is not receiving bad data from the devices. This can cause the logic to generate messages based on incorrect information.

Washington State DOT

Smart work zones are utilized in Washington State through a special contract provision. For example, if queueing is expected at a work zone, then the Washington State DOT (WSDOT) will be able to utilize this information to deploy queue detection systems from a selected listed of approved vendors. These systems are not integrated into the ATMS but use third-party systems for the integration of devices and the deployment of logic such as queue warnings, travel time notifications, and zipper merges. The expectation is that the devices would be integrated into the ATMS, but the current deployment has not gotten to that point. Part of this integration will involve the updating of specifications to require contractors to provide the data necessary for these systems to be integrated into the ATMS. The logical next step WSDOT sees is the integration of these devices through a WZDx device feed into the ATMS system. This would provide the ability for WSDOT to see the devices and how the system is operating separate from the systems provided by third parties.

Wisconsin DOT

The Wisconsin DOT (WisDOT) utilizes smart work zone systems that are managed as part of their respective projects and that are utilized through a third-party system. Each work zone is within its own silo, which does not allow information across work zones to be viewed easily in a single system. A possible solution that has been identified by WisDOT is to utilize the WZDx and require device feeds as part of smart work zone deployments. This would allow the devices to be integrated into the ATMS for viewing purposes to provide better situational awareness.