PILOTING SMART WORK ZONE TECHNOLOGIES TO PROVIDE REAL-TIME LANE CLOSURE INFORMATION TO IMPROVE OREGON HIGHWAY SAFETY AND MOBILITY

Final Report

PROJECT SPR 860

RESEARCH

Oregon Department of Transportation

PILOTING SMART WORK ZONE TECHNOLOGIES TO PROVIDE REAL-TIME LANE CLOSURE INFORMATION TO IMPROVE OREGON HIGHWAY SAFETY AND MOBILITY

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Abstract: This study presents the results and implementation strategies on the deployment of smart work zone equipment. A smart arrow board in combination with location beacons were tested towards understanding best practices, both informed by the test pilot and through a literature review, on the inclusion of such devices within work zones in Oregon. Furthermore, the deployment of these devices in an active work zone was also used as a case study on how these devices might be integrated into three primary categories: TripCheck, automation of the over-dimension permitting system from Oregon Department of Transportation's Commerce and Compliance Division, and the establishment of ODOT's work zone data exchange feed.

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Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH					**LENGTH**		
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	millimeters squared	mm^2	mm^2	millimeters squared	0.0016	square inches	in^2
ft^2	square feet	0.093	meters squared	m^2	m^2	meters squared	10.764	square feet	ft^2
yd^2	square yards	0.836	meters squared	m^2	m^2	meters squared	1.196	square yards	yd^2
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi^2	square miles	2.59	kilometers squared	km^2	km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	ml	ml	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft^3	cubic feet	0.028	meters cubed	m^3	m^3	meters cubed	35.315	cubic feet	ft^3
yd^3	cubic yards	0.765	meters cubed	m^3	m^3	meters cubed	1.308	cubic yards	yd^3
~NOTE: Volumes greater than 1000 L shall be shown in m^3.									
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	Fahrenheit	(F-32)/1.8	Celsius	°C	°C	Celsius	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

Continual maintenance on roadways is required for the safe and efficient transport of people and goods within Oregon. Construction and maintenance work zones are required for this to occur, however the presence of these areas along roadways produce hazardous environments for the workers and an increased risk for roadway users travelling through such corridors. The location of such work zones, to both inform drivers and indicate reductions in the roadway, which may require rerouting for over-dimension vehicles, is necessary towards ODOTs mission of a reliable transportation system. This project further has the ability to assist with ODOTs over-dimension permitting systems overhaul that will automatically permit and would require such real time lane closure information.

Although ODOT has an existing platform that indicates planned construction work there is still a need to have a real-time, dynamic process to feed lane closure information from work zones. Such a system would also need to be established that follows existing Federal Highway Administration (FHWA) work zone data exchange (WZDx) feed compliance which will support the future implementation of automated vehicles via a real-time updated, standardized feed. The smart work zone devices were identified and utilized within this study to address such limitations.

Considering the use cases, this research project piloted these systems that provide such real-time information, using existing smart work zone technologies which can provide real-time information about work zone status, with a particular focus on real-time lane closure information. The specific technology chosen for the piloting was initially understood by ODOT staff, where through Chapter two and the review of other smart work zone equipment the original equipment was found to meet the project goals. Specific technologies are anticipated to provide real-time lane closure data from work zones to support ODOT's Commerce and Compliance Division (CCD) project and other constraints. This comprehensive research, including the identified limitations on the piloted technologies will support the creation of work zone policies and technical standards that can guide statewide implementation.

1.1 KEY OBJECTIVES OF THIS STUDY

The main goals of this study are to:

- Demonstrate the ability for smart work zones devices to update TripCheck in Real Time.
- Discern the ability for the smart work zone devices to follow the FHWA WZDx-compliant feed including the architecture on the objects within the feed.
- Generate an understanding on how the information included in the smart work zone feed might be utilized within the ODOT automation of the Commerce and Compliance Division's over-dimension permitting system.
- Produce best practices and researchers' direction on the limitation of smart work zone systems, including options on how to best append further information of the

work zones into the feed and the possible formatting of the feed to provide critical information.

1.2 ORGANIZATION OF THIS RESEARCH REPORT

This research report is structured in the following way:

- Chapter 2.0 reviews the existing literature on smart work zones and their devices. This includes deployments of such systems across the U.S., vendors, funding agencies and the process towards integration of these systems into other DOT workflows.

- Chapter 3.0 investigates the current practices ODOT employs towards real-time lane closure information into the three primary categories of the project: TripCheck, the over-dimension permitting system and the Work Zone Data Exchange Feed.

- Chapter 4.0 demonstrates the existing smart work zone technologies that were considered for piloting in this project. This includes a description of the different transmission features of the devices specifically related to the datasets and feed types, attempting to find those that were already operating under the WZDx format.

- Chapter 5.0 presents the pilot preparation plan including some of the logistics and possible data collection processes leading towards an understanding on how the piloted technologies would be utilized within the three overarching categories of the project.

- Chapter 6.0 presents the research team's pilot of the smart work zone equipment at a live work zone within Eugene, Oregon. This includes the research team conducting a site visit with the work zone devices active, capturing how the feed from these devices was updating TripCheck, its display within the WZDx format, and how it might inform the real time lane closure component of the over-dimension permitting system.

- Chapter 7.0 describes the research team's evaluation process of the piloted technologies. The key variables extracted from the live data feed were utilized for the accuracy of their results, and the data collection algorithms used for doing this are also mentioned.

- Chapter 8.0 presents the research team's recommendations and guidelines for ODOT to consider when possible, integrating these systems into their workflow process for work zones.

- Chapter 9.0 provides a conclusion on the deployment and its outcomes. This includes further limitations the research team identified that should be considered.

2.0 LITERATURE REVIEW

This chapter presents a review of existing smart work zone devices with an emphasis on those devices that transmit real-time lane closure information. Investigations into past deployments of smart arrow boards (SAB) from other states, primarily used to transmit real-time lane closure information within work zones, were considered leading towards the identification of specific technologies to deploy in Oregon. In addition to this, the framework and policies that other state DOTs used to incorporate these technologies is presented here to enable ODOT to ensure an immediate and highly functional deployment. This includes a review of any subsequent manuals or technical standards that were developed to communicate data from the technology to both their TMC (Traffic Management Center) and general traveler information.

The documentation on SAB capability to transmit lane closure information to external sources were investigated for each agency. The transmission of the lane closure data will enable the research team to evaluate its use for ODOT's TripCheck platform, over-dimensioning permitting system, and ODOT's necessary compliance of the FHWA work zone data exchange (WZDx), for the eventually integration of CAV technologies and their reliance on in the field ITS technology feeds. This includes the review of a national effort to determine the implementation process and evaluation techniques for integrating ITS equipment to transmit location and real time travel information to TMCs and third-party applications.

This chapter is organized as follows: Section 2.1 discusses smart work zones, the typical systems that are deployed, the equipment related to such systems, vendors and finally a mention of the WZDx. Section 2.2 delves into the existing SAB technology including the two primary vendors that offer the technology and its integrated software platform. Section 2.3 investigates both SAB deployments from the ENTERPRISE project in the states of Iowa and Minnesota, and another initiative deployment within Nevada. Section 2.4 discusses the development and deployment of a joint project between numerous DOTs for the implementation SABs on work zone projects to transmit location and activation data for lane closures. Lastly, Section 2.5 briefly mentions other commonalities of state DOTs utilizing smart work zone systems but not particularly smart arrow boards or real-time lane closure systems.

2.1 SMART WORK ZONES

Smart work zone systems (SMZ) have seen an array of deployments across the Nation. These systems incorporate numerous ITS devices that work in tandem to make the work zone "smart" (FHWA, 2020). Smart work zones differ from typical work zones by analyzing, and using data collected in advance of and in the work zone to dynamically provide information to drivers and manage speeds and flows. Depending on the type of work zone there might be differing devices that will increase safety and travel reliability through the work zone. An example architecture for differing systems in shown in Figure 2.1. Many state DOTs have updated their Manual on Uniform Traffic Control Devices (MUTCD) or design manuals to include ITS devices for work zones, including schematics for optimal placement depending on the desired mitigation characteristic. (TxDOT, 2018; NOCoE, 2021). A national review of existing SMZ technologies and deployments was prepared for Arizona DOT (ADOT, 2019).

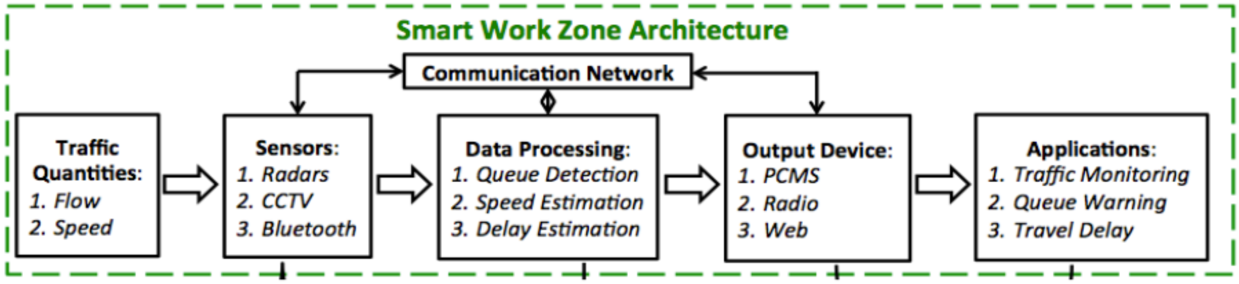

Figure 2.1: Smart Work Zone Overview (Li et al., 2016)

2.1.1 Smart work zone systems

In general, there are several categories of SMZ applications with their own combination of ITS equipment to make it distinct. Below is an overview of these categories and the anticipated ITS equipment incorporated:

- Dynamic Lane Merge Systems (DLMS) – DLMS offer variations in traffic merging behavior based on work zone and or traffic states. The key benefit is to promote the early or late lane merging of traffic, that can alter dynamically. The core ITS technology used for this are static/dynamic message boards, yellow LED warning beacons with static merge signs, and traffic sensors to dynamically adjust the warning beacon and message boards based on prevailing traffic conditions or may comprise of smart arrow boards that may alter their display of arrows. (H&I, 2021; Street Smart, 2022a).

    - Michigan DOT on I-94, which utilized five trailers equipped with flashing "Do Not Pass", and remote traffic microwave sensors (RTMS) to detect the traffics volumes and one script message board upstream of the five trailers indicating the merge was approaching (FHWA, 2004). The decision to promote a late merge is based on volume thresholds that are captured by the RTMS detectors.

    - Florida DOT operated a Simplified Dynamic Lane Merge System (SDLMS). The equipment utilized included RTMS for the traffic data, this also incorporated vehicle classification data at the merging points, which updated the Portable Changeable Message Sign (PCMS) (Li et al., 2016).

- Speed Management Systems (Variable Speed Limits (VSL); Dynamic Speed Limit (DSL)) – consider real-time traffic states to update the facilities current speed limit using cameras or RTMS, which may be grouped into one device or a combination of devices and may also have flashing yellow LED beacons present (H&I, 2019; Ver-Mac, 2022b). They may also alter the speeds based on if workers are present, which is considered an active workspace (Jura et al., 2018).

        - Utah DOT operated both VSL and portable VSL devices over the span of two years in differing work zone environments. One location was on I-80 where six PVSL were operated, spaced in 1-mile increments, to demonstrate the devices advantage by assessing vehicles' propensity to maintain the dynamic speeds, thus removing the previous necessity to move static reduces speed signs (Jura et al., 2018).

        - Other state DOTs that utilized VSL systems in work zones include Washington, Virginia, Ohio, and New Hampshire. This includes both regulatory and advisory VSLs within the work zone, where these are updated through the use of RTMS sensors within the work zone measuring speeds to update the VSL (FHWA, 2013).

    - Queue Warning Systems – (Queue Length Detectors; Automated Queue Warning; End-of-Queue Warning Systems) comprise of a series of sensors that are tracking the occupancy of traffic. If the occupancy reaches a certain threshold, information is transmitted to upstream ITS equipment to inform oncoming traffic of the dense traffic ahead. This is accomplished by RTMS sensors that transmit traffic data to various software which determine the state of traffic and update upstream PCMS (H&I, 2021b; Ver-Mac, 2018; Street Smart, 2022b; QLynx, 2022a; Enterprise, 2014).

        - I-35 Texas DOT, End-of-Queue warning system comprised of Bluetooth sensors for the travel time estimation, Wavetronix RTMS sensors for volume and vehicle classification, CCTVs and finally PCMS to relay the information to the travelers. (TxDOT, 2015).

        - I-57/I-64 Interchange Illinois, iCone portable traffic monitoring devices, which are equipped with radar detectors, GPS units and cellular communications, were deployed. This was then fed into the QLynx software and transmitted to CMS devices (FHWA, 2014).

    - Vehicle Entering Notification (Work Zone Access and Egress; Construction Access System) – A system that detects work zone vehicles entering the traffic stream and transmits this information to oncoming vehicular traffic. This system comprises of physical presence sensors and cameras to detect an approaching or exiting work zone truck that is attempting to enter the traffic stream to which information is sent to a PCMS or trucks entering sign with flashing lights to inform roadway user that there are trucks attempting to merge. (Street Smart, 2022c; Wanco, 2020).

    - Intrusion Detection Systems – The detection of the entry or potential entry of an unauthorized vehicle that enters the work zone closed to the public. The primary components of this system include the vehicle detection device (trigger mechanism) and the worker notification device. Once detected common ways to inform the workers include audio and visual alerts (Ozan, 2020). The Trigger mechanism might be a simple pneumatic hose, impact-tilt or more complex with vehicle trajectory estimation (Atro Optics, 2022; Intellicone, 2022; Zhu & Fan, 2020).

- Real-Time Traveler Information Systems – (Advanced Traveler Information Systems (ATIS)) provides current travel time or extent of delay, specific work zone or incident site information. Common detection equipment to capture the travel time estimations includes Bluetooth sensors with RFID capabilities, point to point travel time estimation from probe vehicles, CCTV and RTMS sensors. The distribution systems for the estimations include 511, through cellular devices, in-dash units or online, PCMS upstream of the work zone and highway advisory radios (ADOT, 2019).
    - From 2013-2014 MassDOT utilized real-time traveler information systems to update and reroute drivers around the year-long Callahan Tunnel Closure. Their system included a combination of portable cameras and portable changeable message signs, in-road sensors, as well as the utilization of probe vehicle data from alternative routes to give roadway users updated travel time estimations for various rerouting instances around this closure. What made this system unique is the variations in displayed route choices on the PCMS based on the observed travel times from the probe vehicles, which were calibrated before the construction began (MassDOT, 2015). A depiction for this is shown in Figure 2.

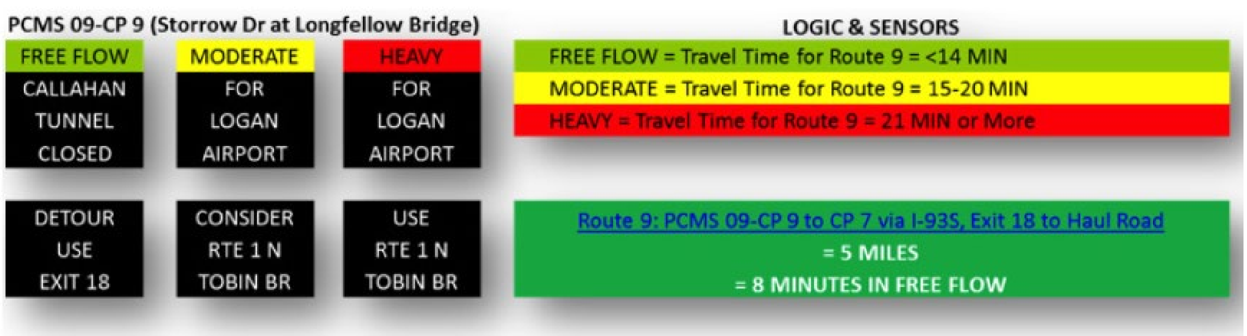

Figure 2.2: Mass DOT Callahan Tunnel Project PCMS messages based on observed travel times (MassDOT, 2015).

2.1.2 Smart work zone equipment

As mentioned, there are numerous systems that can be deployed to improve safety and operations within work zones. Each of these systems comprise of ITS equipment, that in many cases overlap. Indeed, not every deployment follows the same utilization of equipment to reach similar desired goals. It is up to the individual agency to decide which equipment should be incorporated as to meet a maximal benefit cost ratio or may be constrained by the vendors therein. For this a brief overview of existing ITS equipment that is often used in SMZ systems, is shown, broken down into several categories, with common devices for the systems shown in Figure 2.3.

Table 2.1: Overview of Smart Work Zone Components (Azimi et. al., 2021).

Work Zone ITS	Description	Components	Function		
			Providing Information	Providing Warning	Controlling Traffic
Speed Advisory	Informs drivers of the speed of traffic in advance of the Work Zone (WZ) and helps them make better decisions to slow down sooner or divert to an alternate route.	Non-intrusive Detection, Portable Changeable Message Sign (PCMS), Communications	●	●	
Travel Time Estimation	Obtains real-time traffic data and predicts the current travel time on a section of the roadway downstream along the WZ.	Non-intrusive Detection, Video Camera, PCMS or Portable Hybrid Message Sign, Highway Advisory Radio/Websites/Telephone System, Communications	●		
Construction Vehicle Warning	Helps to identify that construction equipment is entering/exiting the work area and notify motorists.	Non-intrusive Detection, PCMS, Communications		●	
Excessive Speed Warning	Warns drivers if their speed is unsafe and alerts them that they are exceeding the advisory speed.	Non-intrusive Detection, Video Camera, PCMS or Portable Hybrid Message Sign, Communications		●	
Hazardous Condition Warning	Alerts drivers concerning the hazardous conditions in the WZ ahead and advises them of an appropriate action for the situation.	Non-intrusive Detection, Video Camera, PCMS, Communications		●	
Intrusion Detection	Monitors WZs and alerts both errant drivers and road workers when vehicles or construction equipment enter sensitive sections of the work area, such	Non-intrusive Detection, Alarm, PCMS, Communications		●	

	as areas in which personnel currently are working.				
Over-Dimension Warning	Identifies oversized loads when construction/maintenance causes temporary minimal width or height clearances for large vehicles using the roadway.	Non-intrusive Detection, Video Camera, Alarm, PCMS, Communications		●	
Stopped Traffic Warning	This warning is used to monitor the speed of vehicles within and upstream of WZs to alert drivers of traffic conditions ahead.	Non-intrusive Detection, PCMS, Communications		●	
Dynamic Lane Merge	Used to specify a definite merge point in the WZ with lane closure(s).	Non-intrusive Detection, PCMS, Communications			●
Portable Signal	Traffic signals and associated control equipment that can be transported easily and deployed in WZs to improve safety and mobility.	Non-intrusive Detection, Portable Traffic Signal, PCMS, Communications			●
Variable Speed Limit	Provides the ability to manage the speed of traffic approaching and traveling through WZs based upon either the current traffic conditions or the characteristics of the WZ.	PCMS, Portable Hybrid Message Sign, Communications	●		●
Temporary Ramp Metering	Regulates the flow of vehicles on the entrance ramp to the main lanes of the freeway where WZs are located.	Non-intrusive Detection, Portable Ramp Meter, Communications			●

.

In addition to this, Table 2.2 captures the known vendors who offer the equipment that make up the systems or sell the systems as a whole.

- Sensors – used to collect real-time data on existing traffic states
    - RTMS, Cameras, RFID and Bluetooth
- Communication – automation of devices incorporated to transfer the data collected
    - Wi-Fi, Dedicated short-range communications (DSRC), Satellite and Cloud
- Software – packages to interpret the data in real-time to make decisions that are transmitted to the equipment
    - JamLogic (Ver-Mac, 2022a), HS Connect (H&I 2022b), TrafficLynx (QLynx, 2022b)
- Devices – the equipment that disseminates information collected from the sensors to the roadway operator
- VMS, PCMS and SAB

Table 2.2: Known ITS equipment and vendors

Equipment / Vendor	**Smart Arrow Boards**	**Variable Speed Limit (VSL)**	**Live Data/Asset Tracking (Software/ RTTI)**	**Portable Changeable Message Signs (PCMS/VMS)**	**RTMS Sensors**	**Dynamic Lange Merge**
StreetSmart*	✓	✓	✓	✓	✓	✓
Ver-Mac	✓	✓	✓	✓	✓	✓
Hill & Smith	✓	✓	✓	✓	✓	✓
QLynx Technologies (Wanco & iCone)			✓	✓	✓	
Wavetronix					✓	
Speed-Mac					✓	
Houston Radars					✓	
***StreetSmart is rental/reseller company which offers all the other brands.**						

2.1.3 Work zone data exchange

The U.S. Department of Transportation Federal Highway Administration realized the need for a standardized data feed for work zones to have the capacity for systematic and universal safety studies and open sourced to be integrated into third-party applications, outlined in their work zone data initiative. This followed a similar initiative for archived transit data feeds, or the General Transit Feed Specification (GTFS), which allows for public transit agencies to publish their transit data for post analysis or for use in other third-party software applications. The same concept was desired to work zone data (WZDxS, 2022).

With the introduction of smart work zone equipment and capacity for real-time data, infrastructure owners and operators (IOO) could permit infrastructure to transmit dynamic and real-time work zone data to external third-party applications, which would improve mobility and safety around work zones. This also includes data sent to automated driving systems like Connected and autonomous vehicles, which will assist in their implementation as per the U.S. DOT's Data for Automated Vehicle Integration (DAVI) initiative (USDOT, 2022). The primary issue IOOs were facing was the lack of common data standards or specifications, which reduced the efficiency of third-party applications (WZDxS, 2022).

To combat this, a USDOT GitHub repository organization was created to assist in the registry of a WZDx compliant feed and subsequent archive (WZDxS, 2022). This includes a common GeoJSON JavaScript object notation described in (Butler et. al., 2016). As of now the exchange comprises over 100 organizations, both governmental and private entities, which also includes a working group to improve and assist in the development of this initiative. Currently, there are vendors of smart work zone technologies that are already following the WZDx protocols, for their product line, reducing the requirement for the agency to ensure their data is following the protocol but allowing the vendor to follow it (Ver-Mac, 2022c).

2.2 DESCRIPTION OF SMART ARROW BOARD

A smart arrow board has the same functionality as any other arrow board used on highway work zones; however, it has the capacity to transmit location-based variables in conjunction with its current display. This transmission is sent to the individual platform that is operating the device and can update third-party applications such as WAZE, INRIX, HERE and ODOT's TripCheck in real time as to the state of each individual smart arrow board deployed.

Existing SAB vendors that also include the software platform, include Ver-Mac and Hill and Smith. For both companies this also includes the option to utilize a device that can be attached to any existing arrow board and make it "Smart", a retrofit kit, by transmitting location and remote function to control the device (Ver-Mac, 2022a; H&I, 2022a). In the case of Ver-Mac the software platform that comes with the SAB or retrofit kit is known as Jamlogic. traffic stream characteristics that can be displayed such as speeds, within the platform. An example of the interface for the Jam Logic platform is shown in Figure 2.3.

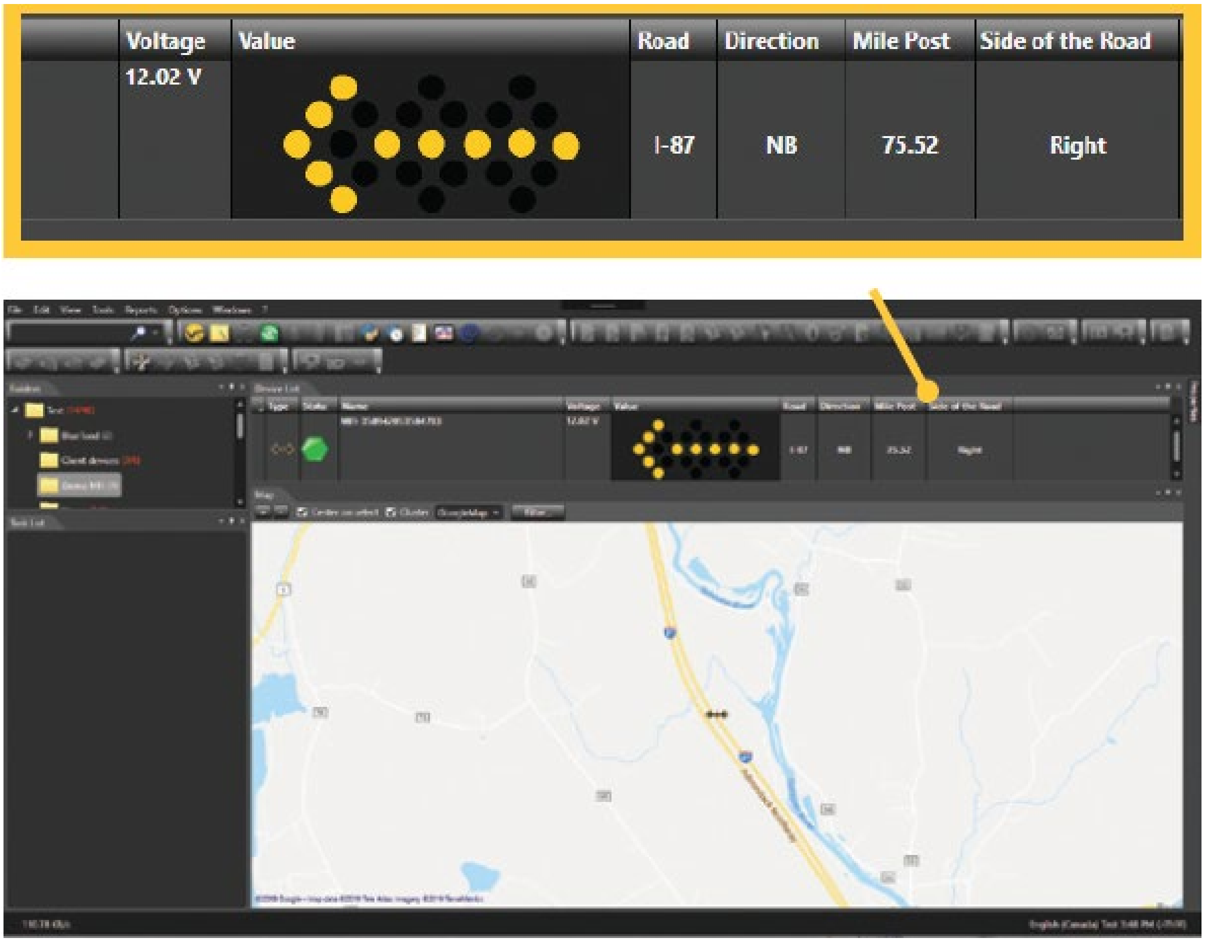

Figure 2.3: VER-MAC Jam Logic Smart Arrow Board Platform (Ver-Mac, 2022)

2.3 ENTERPRISE TRANSPORTATION POOLED FUND

With the desire to develop an integrated system that utilized existing arrow boards to transmit location and activation periods for work zones that required lane or shoulders closures, a project within the ENTERPRISE Transportation Pooled Fund TPF-5(231), investigated potential methodologies and implementation procedures to make this possible (ACC, 2017a-c). The project members for this initiative included the Michigan DOT, Kansas DOT, Minnesota DOT, Iowa DOT and Pennsylvania DOT. The solution was to utilize existing arrow boards to transmit location and operational characteristics of the roadway for use in TMCs and traveler information, primarily focusing on real time information on if the lanes were indeed closed and then if workers were present. This work was summarized into three documents including the Model Concept of Operations or Conops, Model Requirements and lastly an Evaluation Plan of this Implementation (ACC, 2017a-c).

The reporting systems anticipated from this effort include how the arrow boards reporting procedure would function to the TMC, shown in Figure 2.4 and then how this information might get to third-party applications for traveler information, Figure 2.5.

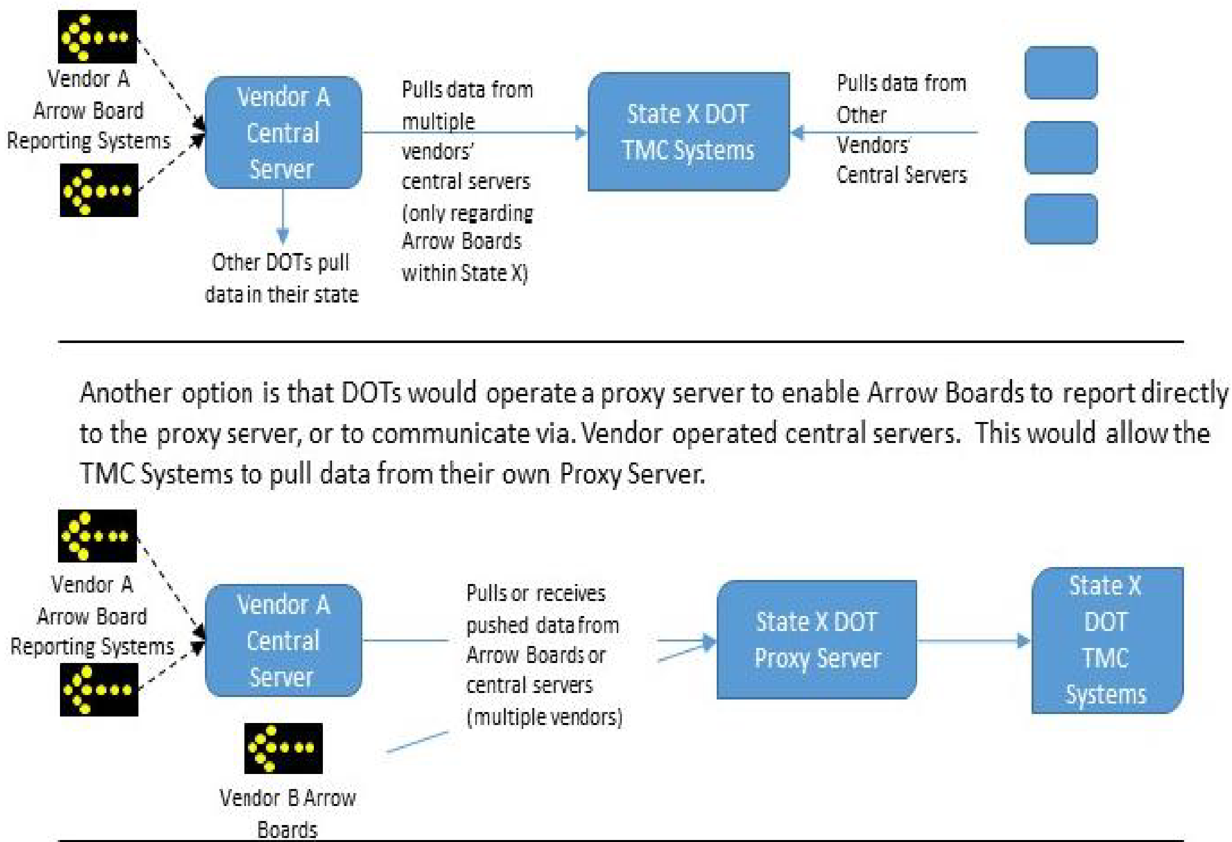

Figure 2.4: Arrow Board Reporting Systems (ACC, 2017a)

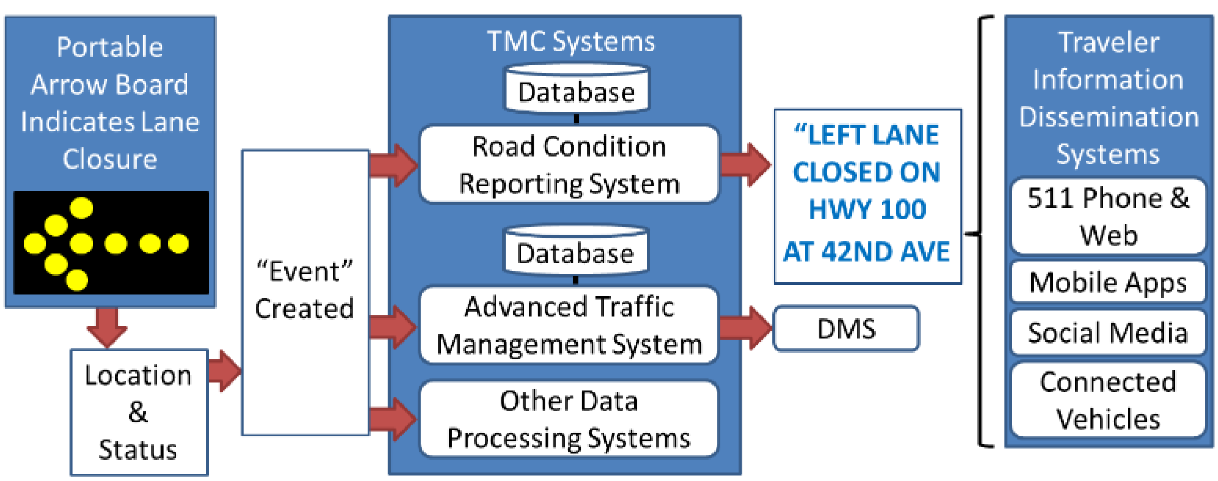

Figure 2.5: Proposed Traveler Information Reporting System (ACC, 2017a)

In addition to the prospected reporting systems, the project identified a set of challenges that would need to be overcome, either from the side of the state agency or from an existing technology standpoint (ACC, 2017a):

1. Details about the location and timing of lane closures is difficult and time consuming to assemble into traveler information systems, often resulting in general messages describing work zone impacts.

2. Traffic Management Center (TMC) staff often are not aware when lane closures begin, and therefore are not able to post messages on upstream DMS or take other actions.

3. The exact timing and locations of lane closures are often not known in advance, and field personnel performing the roadwork and closing the lanes have many other responsibilities such that manually reporting a lane closure is often not possible.

4. Travelers lack detailed information and are only given general information because known information is not accurate enough.

5. No off-the-shelf equipment or communications technology is currently available to automatically communicate lane closures to a central location.

6. Detailed records of the location, start and end time for lane closures are not always recorded, and this can impact the ability to do post work zone analysis.

The outcomes of this project are summarized in (ACC, 2020) where the deployments in Iowa, Minnesota, and another identified pilot program, not affiliated with the ENTERPRISE program, RTC of Southern Nevada are discussed. A summary of each of these deployments is presented in the follow sections. In general, the variations of these pilot programs are displayed in Table 2.2. The challenges identified are similar to the concerns ODOT has and desires to learn from this project. One major improvement from when the ENTERPRISE program was developed is the updated ITS equipment available that can cover the majority of the above challenges with a single piece of equipment One such ITS equipment now available is the retro fit kit found in Figure 2.8, with the capability of satisfying most of the above challenges and being able to simply attach to any existing arrows board giving it the communication capabilities of any current Smart Arrow Boards (SAB).

Table 2.3: Variations in connected arrow board deployments (ACC, 2020).

Variation	Minnesota DOT	Iowa DOT	RTC
Deployment timeline	April 2018–March 2019	Spring 2019 to present	Late 2017 to present
Arrow Board Reporting System Variations			
Arrow-board Type	Truck-mounted and attenuator trailer mounted	Truck-mounted and trailer	Trailer-mounted
Number, Brand of Devices	20 Street Smart	2 Street Smart, 2 iCone, 1 Ver-Mac	12 iCone
Arrow Board Owner	DOT owned	DOT and Contractor owned	Contractor owned
Reporting System Device Maintenance and Owner	Vendor	Vendor	Contractor
Communication Mechanism	To 3rd Party Server, to ATMS, and then RCRS	To 3rd Party Server, then Waze	To 3rd Party Server, then Waze
Connected Vehicle Capability	None	None	None
Deployment Setting Variations			
Area	Urban	Rural and Urban	Urban
Roadway Type	Freeway and Arterial	Freeway and Arterial	Freeway and Arterial
Work Zone Type	Stationary and Mobile	Stationary and Mobile	Stationary and Mobile
Lanes Closed	Single lane	Single lane	Single lane
Work Zone Duration	Short maintenance activities (minutes, hours)	Maintenance and longer duration work zones (hours, months)	Maintenance and longer duration work zones (hours, months)
TMC System Variations			
TMC System Integration	ATMS, RCRS	Planned for 2020	Underway
Level of Automation	Fully Automated	–	–
Staff Notification Recipients	Operator staff	–	–
Staff Notification Mechanism	TMC interface	Waze	Waze
Staff Notification Events	Activation	–	–

Variation	Minnesota DOT	Iowa DOT	RTC
Archive Database	Existing ATMS archive and vendor archive	CTRE archive and vendor archive NOTE: The new DOT ATMS will likely archive after it is installed.	Vendor archive

2.4 SMART ARROW BOARD DEPLOYMENTS

This section describes implementation and best practices of real time lane closure systems from other State DOTs, focusing on those that deployed SABs or retrofitted existing arrow boards to give it the capacity to transmit data from the ENTERPRISE program: Iowa and Minnesota. It mentions how each individual DOT was able to combat the major challenges presented from the ENTERPRISE program. The final section also describes an additional agency, that deployed SAB devices from a different vendor, Hill & Smith, which differs from those deployed within the ENTERPRISE program.

2.4.1 Iowa Department of Transportation & Iowa State University Center for Transportation Research and Education (CTRE)

The Iowa Department of Transportation has been utilizing general smart work zone technology and particularly SAB technology since their Adopt Smart Arrow Board Technology (AMES) initiative in 2019. The goal of this program was to utilize SABs to collect near real time data for the status of lane closures within work zones (IOWA DOT, 2019). From this Iowa DOT developed their own deployment plan to implement these devices for their work zones. This includes their key issues when dealing with work zones: inability to quickly and accurately update lane closures from work zones, which created inaccurate travel time estimates, and from a stakeholder perspective, Iowa DOT desired start and end times, location data for post analysis, and to comply with the Work Zone Data Exchange (WZDx) for reliable and accurate work zone data required for CV applications. Outside of placement standards that were already in place for regular arrow boards for work zones within the MUTCD, what is of important consideration is the development of general standards for these devices from both a communication and testing standpoint.

Within this deployment in 2019, Iowa DOT with the Iowa CTRE deployed several arrow board systems with different configurations (ACC, 2020):

- iCone retrofit kits attached to trailer mounted arrow boards
- DOT-owned truck mounted attenuators (TMAs) equipped with Street Smart arrow board kits
- Ver-Mac fully equipped smart arrow board

From this, Iowa developed specification standards the vendor must meet with their technology before being considered for any of their projects and are summarized in Iowa DOTs Specifications-Requirements (IOWA DOT, 2022b). The important component of this standard is the GPS and remote communications requirements which has further details for Iowa DOTs Communication Protocols (IOWA DOT, 2020). Lastly, Iowa DOT has a final Materials Approved Product List, from the vendors that past all of the previously mentioned standards and include Solar Technology, Inc., Wanco, Inc., iCone Products LLC, and Ver-Mac (IOWA DOT 2022a).

With the technical standards set and subsequent vendors tested, Iowa DOT has utilized SABs across their State and provide lane closure information to their TMCs, DOT staff and third-party applications, such as 511ia.org and WAZE, all not requiring any additional work from the construction workers. Lastly, Iowa DOT created a dashboard that tracks all of their deployed SAB in real time, currently upwards of 50 deployed. An image from this dashboard is displayed in Figure 2.7 with an image from Google Waze displaying the lane closure that was automatically transmitted from this particular SAB.

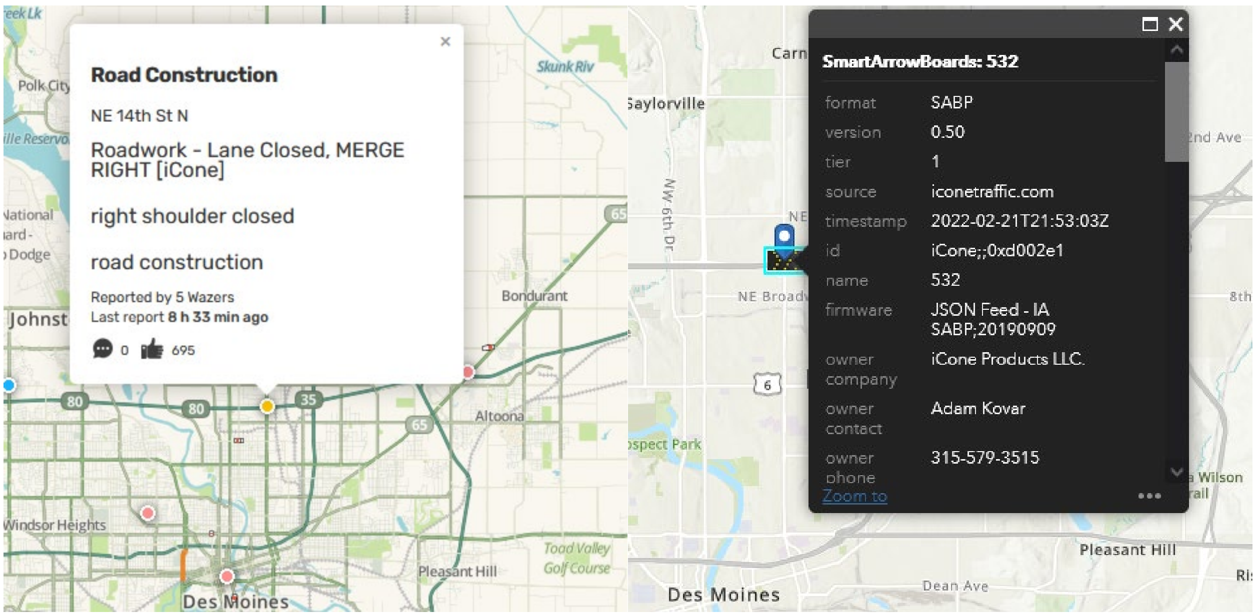

Figure 2.6: Google WAZE and Iowa DOTs ArcGIS Smart Arrow Board map transmission confirmation (Google WAZE 2022)

2.4.2 Minnesota Department of Transportation

Similar to IaDOT, Minnesota DOT (MnDOT) developed and operated their own ITS solution for real time work zone data transmission. They also investigated the use of updating arrow boards to SAB in order to transmit location, activation, and display information to both their TMCs and traveler information via 511or other third-party systems. Historically, MnDOT lane closure information was left as broad messages, where the lack of specific data meant traveler information was neither geographically specific nor operationally specific, thus broad messages were transmitted such as, “expect intermittent closures” (ACC, 2018). The outcomes of this project were to:

7. Disseminate real time lane closure information through existing traveler information mechanisms

8. Regional Transportation Management Center (RTMS) will be alerted in real-time of closures so they can **manually** post messages to dynamic message signs (DMS)

9. Improved performance reporting for post work zone evaluation from the accurate location and time data transmitted by the device.

From a systems overview standpoint, the MnDOT utilized the communication data from the smart arrow board and transmitted it to four major systems:

1. The Intelligent Roadway Information System (IRIS), Minnesota's version of ODOTs advanced system management program (ATMS).

2. Minnesota's Condition Acquisition and Reporting System (CARS), for road conditions

3. Minnesota's traveler information through 511 and the on-road DMS

4. IRIS data archive for performance evaluation (step 3 from the project outcome)

The transmission of data from the SAB to these systems are summarized in Figure 2.7.

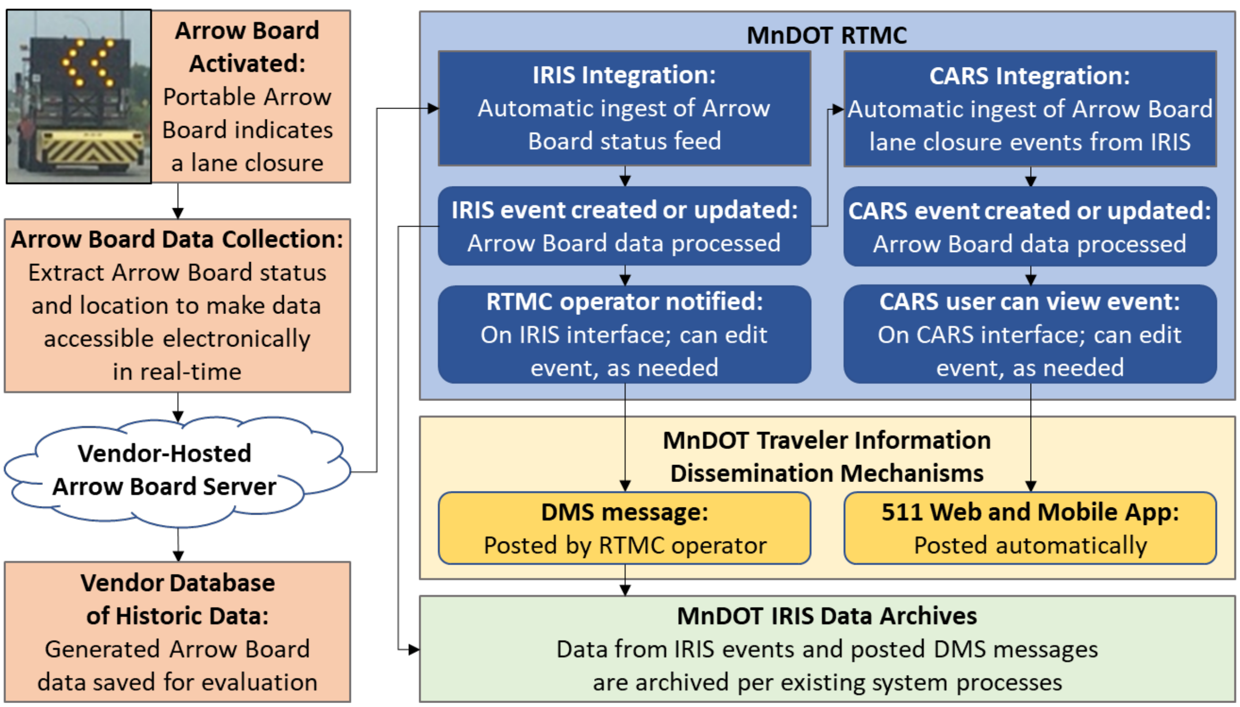

Figure 2.7: Minnesota SAB project system data transmission pipeline

This framework was subsequently tested in 2018 with the deployment of 20 connected arrow boards, both on truck-mounted arrow boards and an attenuator trailer over a one-year period. This was completed by utilizing a rented device from Street-Smart (possibly one of Ver-Macs SAB retrofit kits, unable to verify this) which could be attached to an existing arrow board and have the capacity to transmit location data and allows for remote operation of the arrow board. Figure 2.8 displays the retrofit kit attached to an existing arrow board from the project.

Figure 2.8: MnDOT arrow board retrofit kit (FHWA, 2020a)

With the equipped retrofit kit, the following parameters are made possible and such data automatically transmitted:

- Activation status
- Facing direction,
- Activated arrow direction,
- Location
- Time

During the project, MnDOT was also able to have these now connected arrow boards transmit real time lane closures information from the device to their 511 system and subsequent messages to their twitter feed automatically (FHWA, 2021). For these vendor-owned systems it included the vendor-based server which was rented on a per-month/per-device basis. This included the retrofit installation to existing arrow boards and other with a general cost shown in Table 2.3.

Table 2.4: Minnesota DOT cost of connected arrow board deployment

Cost Item	Hours of Staff Time	Annual Estimated Cost
20 Arrow Board Reporting Systems	-	$14,400 ($60/month/device)
MnDOT Maintenance Staff	1 hour/device/month	$1,200
Routine Maintenance of Arrow Board functions in IRIS	8 hours/year	$480
Routine Maintenance of Arrow Board functions in CARS	8 hours/year	$480
Total		$16,560

Although this projected demonstrated the capacity for these systems to depict real time lane closures status, it does not appear that WAZE is currently being updated for lane closures in the State of Minnesota compared to how frequent Iowa DOT updates google WAZE. If these devices are in use, they automatically update google WAZE, it can be deduced that Minnesota DOT is not deploying these systems currently or not on the same scale as Iowa DOT.

2.4.3 Regional Transportation Commission (RTC) Southern Nevada

The RTC Southern Nevada deployed twelve iCone retrofit kits on both their own city owned trailer mounted arrow boards, and also contractor owned since 2017 as part of a pilot program. In its current state the deployed equipment is able to update WAZE if there are lane closures or not. It operates in the same manner as Iowa DOT, as it utilized the same vendor, iCone (ACC, 2020). The information from the arrow board is displayed through iCone's interface, which did not require the RTC to develop their own platform or reporting system and is capable of tracking all devices deployed. This includes twenty-one other iCone traffic control devices deployed that have the ability to transmit location and other information from within the work zone (RTCSNV, 2019).

Figure 2.9: Hill & Smith HAAS Alert HA-5 (H&I, 2022)

In addition to this the RTC partnered with Hill & Smith Inc. to equip their work zone vehicles with HAAS alert systems that have V2X capabilities. The vehicle transponder, shown in Figure 2.9 This system transmits warnings to in-dash units of approaching vehicles that work zone vehicles were present and active. The HAAS alert system is also capable of transmitting this information through the HAAS Alert Safety Cloud which allows for third-party applications to be notified of their activation, location, and information (H&I, 2020).

2.5 OTHER STATE DOTS

From the review of other members apart of the ENTERPRISE shared pool fund including Texas DOT, Michigan DOT, Pennsylvania DOT and Kansas DOT, it appears the primary States that introduced these systems were Iowa and Minnesota DOT. These other States have their own Advanced Transportation Management Systems (ATMS) which distribute traveler and roadway condition information; however, it is not certain for the automation of such systems and the way in which lane closures are identified. In general, the framework for other State DOTs across the country includes a combination of on-road sensors and cameras that transmit this information to their own RTMCs which update other systems such as 511 or on-road DMS. Compared to the studies presented above these other states do not have the same automation capacity from the equipment that was deployed utilizing either smart arrow boards or retrofit kits on existing arrows.

3.0 ODOT CURRENT PRACTICES FOR REAL-TIME SMART WORK ZONES

This section delves into the state of practice of the three systems targeted for application of the identified technology in this project. Section 3.1 documents the current workflow ODOT employs for their Over-dimension Permitting System and its eventual adaptation to being automatic. Section 3.2 describes the existing use of TripCheck and how its data is generated and transmitted to this platform. Section 3.3 provides documentation on the FHWA WZDx feed with its requirements and association with the existing API that ODOT currently utilizes for their data transmission. Finally, Section 3.4 discusses the parameters that the selected technology would need to have in order to be incorporated into ODOTs existing systems whilst accomplishing the goals of this project.

3.1 OVER-DIMENSION PERMITTING SYSTEM

Oregon Department of Transportation Commerce and Compliance Division systems has an operational over-dimension permitting system to enable motor carriers to obtain permits to transport loads that fall outside of the Oregon Statutes Vehicle Limits. These limits identify several areas about the payload or the vehicle itself that require annual or single trip permits in order to operate on Oregon's roadways. In the context of vehicle weight, height and width limits, there may be routes that utilize undersized bridges or narrow roadways to which these larger loads are unable to be transported through (ODOT, 2022b). For the safety of the transporter and other roadway users there is a mechanism to ensure the safe travel of the over-sized vehicle, the over-dimension permitting system, which is housed under Oregon Trucking Online.

3.1.1 Current Practices Over-Dimension Permitting System

After determining that a load will indeed surpass the legal limits, motor carriers reach out to the ODOT Commerce and Compliance Division to receive one of two permits: an annual or single trip permit. The current permitting system is housed in a mainframe interface that uses COBOL which has its own limitations and no capacity for improvement. These permits have their own stipulations and in general cover the below areas:

- Annual – a continuous trip permit that grants vehicles whose dimensions surpass the legal limits to travel on pre-authorized and established routes. Alongside the permit, additional paper maps and attachments are provided to indicate any height, width, or weight restrictions along any route.

- Single Trip – those vehicles that are transporting loads in excess of annual permit allowances and may require a pilot vehicle. Similar to the annual permit, paper maps and attachments are provided to allow the purchasing agency to pre-plan their routes, considering the constraints of the route.

Upon receiving the permit and additional material, motor carriers must determine the route for their trips where their vehicles will not surpass any restrictions imposed by the route itself. The attachments that are included are as follows:

- Group Maps – displays a map of Oregon roadways with the associated highway group classification, which incorporates vehicle length and weights (ODOT, 2022c)

- Route Maps – 2-9 provide routes as a function of over width operations for bridges and tunnels (2), height restrictions (3), continuous operation variance permits (COVP) (4), annual triples routes (5), annual routes (6), length restrictions (7), weight restrictions (8) and annual routes for over width (9) (ODOT, 2022d).

- Other – extended documentation for variances outside of annual permits and specific purposes, primarily for single use trips (ODOT, 2022d).

In the case of single trip permits, after the motor carrier determines their route, a route request is sent in for approval to Oregon Trucking Online. Outside of this, for both single trips and annual trips, one major factor that can disable the movement of these over-dimension vehicles is unforeseen lane closures/road closures along their proposed routes. For this reason, OregonTruckingOnline.com has road restrictions portal that displays any existing or planned road closures, lane closures or reductions and is also displayed within ODOTs TripCheck platform, as demonstrated in Figure 2. This information combined with the attachments associated with the individual permits allows motor carriers to determine the best routes for their vehicles or in the case of single use proposed route (OTO, 2022).

An issue that may arise and could lead to better route choice decision making is the more real time approach to transmitted lane closures to the system. In its current state Oregon trucking online is informed by ongoing or pre-planned projects by ODOT, to which these lane closures are a static set value displayed. Examples include an off-ramp being closed for several days between the hours of 7 PM to 7 AM, or a bridge being intermittently restricted "1/2 hour after sunset to 1/2 before sunrise". This information is on the website and is also mailed to respective motor carries if they are on the GovDelivery email. Outside of this static system, it is desired to update these lane restrictions or closures through an automated means, which will assist in ODOTs eventual creation of its Automated Over-Dimension Permitting System.

3.1.2 Automation of ODOTs Over-Dimension Permitting System

Included as a priority in ODOT's Strategic Action Plan, the Over-Dimension Permit System Replacement Project is attempting to establish a web-based system to provide a more automated approach to the existing permit system. One of its primary features is automatic routing. Taking in the start and end destinations, the system would consider the dimensions of the vehicle and then all road restrictions in the system to provide an efficient route. This system would produce permits 24/7.

Outside of the system already having the static known routes from route and groups maps described above, the system would require restriction notices from contractors or resident engineers of construction projects in real time, which does not currently occur on ODOTs projects. Currently, the start and end times are not provided in real-time. The work of this project investigates options to provide real-time work zone information to improve the current practice. This necessitates the current study and the applicability to transmit real-time lane closure information to this eventual website.

3.2 UPDATING REAL-TIME WORK ZONE DATA TO ODOT TRIPCHECK

One of the primary tools ODOT utilizes to update traffic conditions, work zones and inclement weather maps, including construction project information is TripCheck (https://tripcheck.com/). Figure 3.1 shows the construction on OR-221 with mileage points and the estimated delay of under 20 minutes.

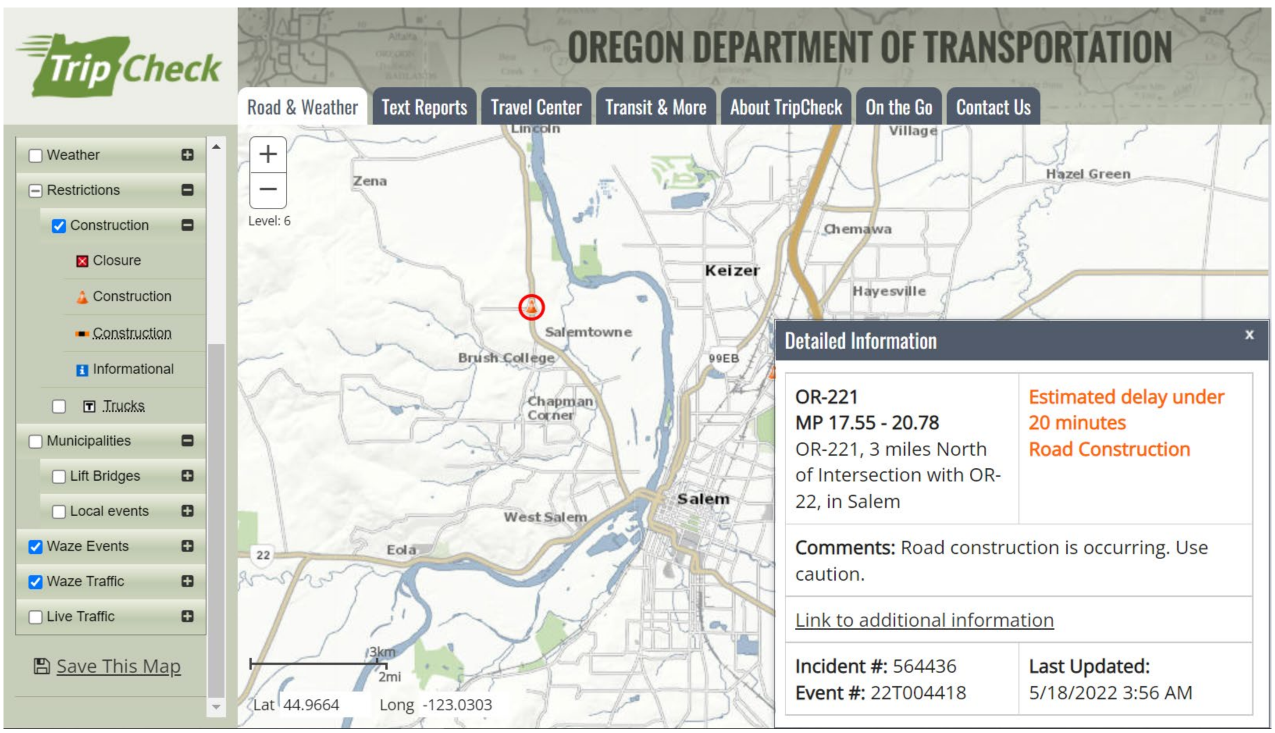

Figure 3.1: ODOT TripCheck providing construction project information

TripCheck provides an aerial feed for all of the major roadways in the State. The travel time and real-time traffic conditions are transmitted to the application through INRIX, which collects crowdsourced probe vehicle data. One of the stipulations for this dataset is the presence of vehicles capable of transmitting such information. This includes low volume routes, such as rural roads, that do not have a large enough penetration of connected vehicles to update theses estimations.

Similar to Oregon Trucking Online queries, they indicate the closures will occur between certain time periods, but do not have the capacity to update this information in real time as to when the work zone itself is indeed active or not.

Currently, ODOT works on testing TripCheck on about 12 construction projects to report real-time travel delays through work zones. The highway segments of construction projects are defined by hand within a map using the travel time administration software and are sent to probe data supplier INRIX to provide real-time delays. Then TripCheck updates the travel delays every 2 minutes. Currently defining construction work zones within a map is by hand, not in real-time as the construction starts. As the maintenance work zones are typically a shorter duration, another method is used to calculate the travel time.

ODOT TripCheck also provides truck restriction information shown Fig. 3.2. As there is no real-time lane closure information, this truck restriction information is not real-time.

Figure 3.2: ODOT TripCheck providing truck restrictions information

Similar to Oregon Trucking Online queries, they indicate the closures will occur between certain time periods, but do not have the capacity to update this information in real time as to when the work zone itself is indeed active or not.

3.3 REAL-TIME LANE IMPACTED DATA & ODOTS WZDX COMPLIANT DATA FEED

ODOT has created their own API that is housed under TripCheck to provide roadway work zone data to developers. The API makes ODOT's traveler information, including incidents, cameras, weather stations and others available. A full list of potential data feeds is mentioned in (ODOT, 2020). From ODOTs API, any developer can capture ODOTs data endpoints to produce integrated apps, that take in ODOTs data feeds. These data feeds come in two primary formats, XML and JSON.

ODOT recently updated its real time data portal with a new data set based on the FHWA WZDx work zone data exchange standard that was developed to support automated vehicles but is lacking the detailed lane impact data needed to fully support this standard. Outside of providing traveler information from ODOTs wide range of sensors and providing a feed for developers to utilize ODOTs data, the format in which their API was created and operates matches that which the ongoing FHWA WZDx initiative requires, either XML or JSON java scripts, as discussed in section 2.1.3. Although ODOTs existing API can transmit their data in the format of the FHWA WZDx, what is missing is on the data component side, primarily related to work zone data, and specifically lane closure or roadway restriction information in real time.

There is a required list of incoming data to be considered WZDx compliant, this includes the base WZDxFeed, RoadRestrictionFeed, and the SwzDeviceFeed. Each of these feeds are outlined on the USDOT GitHub page found in (USDOT ITS OTE, 2022a).

3.4 IMPLICATIONS OF CURRENT PRACTICES

3.4.1 Current ODOT Workflow

Based on the review of ODOTs current practices in relation to their over-dimension permitting system, TripCheck, and the work zone data exchange, the following observations were made that necessitate the use of technologies that provide real-time lane closure information.

Over-dimensioning system: The existing over-dimension permitting system is static and relies on semi-static work zone and road closure information before operators are given permits to transport. Providing real-time lane closure information to this existing system will not benefit the user nor the program. However, with the advent and current overhaul of this program, the existence of real-time lane closure information will directly assist in the permitting system. The idea for this integration is for the routes to be generated through TripCheck, which already houses the static routes which might disable particularly sized vehicles from traveling a given route. If the real-time lane closure information can be appended into trip check, then the over-dimension permitting system will be given this same information.

TripCheck: For TripCheck, it is understood that the information and data provided to TripCheck, and made available to third parties, is directly linked to the development of ODOTs existing API. This API allows for the transmission of their data to other applications and to their own systems namely TripCheck. For this reason, the potential device/devices need to have the capacity to transmit their data in a manner for ODOTs API to read from, possibly in a cloud-based environment.

ODOT WZDx feed: Based on the requirements to comply with the WZDx feed from the FHWA, the capacity to transmit data in this format is already available from ODOTs existing API. What needs to be established is the connection from the potential devices to ODOTs API and the subsequent transmission of the applicable data to the FHWAs WZDx feed. There are components of the WZDx feed that ODOT currently transmits, and from its own API this information is in the same format as what is required from the WZDx. There are however individual variables that ODOT does not currently possess data for, which would need to come from the vendors/device side. This data specifically related to real-time lane closures; once this information is generated, it could be sent to a cloud that ODOTs API could obtain to produce a feed that is formatted to meet the WZDx feeds requirements.

4.0 SELECTION OF DEVICES MEETING PROJECT GOALS

The purpose of this chapter is the identification and selection of suitable smart work zone technologies that can be piloted in Oregon to meet the project goals of piloting smart work zone technologies to obtain real-time work zone lane closure information. The selection of the devices for testing needs to meet the following project objectives: (1) pilot the selected smart work zone technologies to identify and recommend new ODOT policies and standards, (2) demonstrate methods to provide real-time, accurate work zone data to ODOT's TripCheck.com traveler information website, (3) demonstrate methods to provide high-fidelity real time work-zone lane closure data to the ODOT project of automated over-dimension permitting system, and (4) demonstrate methods to provide real time lane impacted data via ODOT's work zone data exchange compliant data feed.

Available smart work zone technologies discussed in Chapters 2 and 3 of this report were screened based on ODOT needs and considered input from the Technical Advisory Committee (TAC). Applicable devices were subsequently chosen based on outputs from the literature review in Chapter 2 and existing level of readiness to being incorporated into ODOTs existing architecture outlined in Chapter 3. The literature scan reviewed entire Smart Work Zone (SWZ) systems, that are multi-faceted and combine differing ITS components to accomplish a variety of goals. An example system is a Dynamic Lane Merge System (DLMS), which is comprised of remote traffic microwave sensors (RTMS) and Portable Changeable Message Boards (PCMS) to provide updates to traffic for early and late merging conditions. Other example systems are outlined in (Paracha & Ostroff, 2018) and from specific vendors (Hill & Smith, 2022; QLynx, 2022a; Ver-Mac 2022a). The ITS equipment that comprises these systems are also shared across different vendors as is outlined in Table 2.1 from Chapter 2.

The basis for the selection of the technology is similar to the ITS devices that comprise a DLMS as they have the required visual and physical indications of lane closures and the needed communication features. This system is intended to operate under the scenario of merging traffic, where there is a particular section of roadway that is closed or is attempting to manage heavy weaving sections. In the use case of a work zone with lane closures, which this project is specifically targeting, this existing system is the closest match. However, more advanced DLMS incorporate both RTMS and PCMS, where the density of traffic, captured by the RTMS, influences the message presented on the PCMS. This project's use case may not require such extensive interactions and a more simplified series of ITS equipment could satisfy its goals. As such, the substitution for an arrow board to be used as the indicator that a lane is closed within the work zone, so long as it can transmit its location and display, will satisfy the project constraints.

Based on this understanding, one of the identified vendors that offers this technology and also has a past relationship with ODOT, Ver-Mac, was contacted and their equipment was considered. This included two location beacons and a smart arrow board (SAB). These devices have the capacity to transmit their location, direction of travel and specific lane closed (inside or outside lane), and the SAB may also transmit its current display. All of this information is transmitted in a particular format, the FHWA based WZDx JSON format, which was another project requirement, and is described in Section 2.1.3 in Chapter 2 and ODOTs specific feed in Section 3.3 in Chapter 3.

4.1 DESCRIPTION OF SMART TECHNOLOGY

Two devices were identified that met the projects goals and include location beacons and the SAB from Ver-Mac, a depiction for both of these devices is shown in Figure 4.1 and 4.2. A detailed description of the Smart Arrow Board can be found in Section 2.2 in Chapter 2. The utilization of an arrow board over a PCMS is the distinction that arrow boards are almost exclusively used to indicate a lane closure. The Location Beacons operate in a similar manner to the SAB. The idea behind their use is to set a bounding box or envelop for the work zone itself with a designated start and end location that can be transmitted, this is shown in the right portion of Figure 4.2.

Figure 4.1: Ver-Mac Smart Arrow Board (Ver-Mac, 2022b)

Figure 4.2: Ver-Mac Location beacons (Ver-Mac 2022a)

In their current state both devices transmit their data feeds when an update occurs. This might be triggered by moving the location beacons or changing the pattern on the SAB. The data feeds are sent to Ver-Macs Jam Logic platform, whose UI is shown in Appendix A, Figure A.1, that allows for the user to observe the devices remotely, including their locations, side of road, direction, and other variables within the platform. A full list of the variables housed within the Jam Logic UI is found in Table A.1. This data feed is also accessible to external entities.

4.2 TRANSMISSION OF SMART WORK ZONE DATA

The prospect equipment has the capacity to transmit their data to third party applications in the form of a JavaScript Object Notation (JSON) URL. The output JSON URL is formatted in accordance with the Work Zone Data Exchange (WZDx) protocols housed under the US Department of Transportation (USDOT) Intelligent Transportation Systems Operational Data Environment (ITS ODE) GitHub (USDOT ITS ODE, 2022). The flowchart for the feed is shown in Appendix A.2. In addition to this, the individual objects and their links to the webpages associated with the FHWA GitHub are displayed in Tables A.2-A.12. One of the unique features of these devices is their ability to be automatically pushed to traffic information applications such as Waze. A short time after the devices is activated, they will automatically update Waze. In the event that the arrow board is present, and a start and end location beacon within close proximity, Waze will indicate there is a lane closure in that area.

5.0 PILOTING PREPARATION AND DATA COLLECTION PLAN FOR CASE STUDIES

With the selected technologies identified and base testing performed, the pilot preparation and data collection plans were considered. Section 5.1 looked into several aspects including potential projects and who to contact, ensuring the prospect project would provide an opportunity to test both the arrow board and locations beacons, and had enough spatial and directional changes as to test the broadcasted variables accuracy, specifically the output coordinates, roadway name and roadway direction.. Section 5.2 identified the procedures to collect data transmitted from the devices. This may include specific variables to track, methods to ensure accuracy and expected data formats.

5.1 PILOT PREPARATION PLAN

The purpose of this plan was to identify a suitable active work zone from existing ongoing ODOT projects. A key element for this process was to locate projects that required both lane closures on a multi-lane highway for merging scenarios, and on a two-lane highway to utilize the locations beacons for flagging operations. With assistance, one such project where both constraints were satisfied was identified. Located at OR 569 Green Hill Road, the Coburg Road project was an ongoing project that included repaving, concrete median barrier replacements, and bridge repairs along the OR569 beltway (ODOT, 2022a). This project also includes the replacement of curb ramps at some of the intersections adjacent to the beltway. An example of the project area is shown in Figure 5.1.

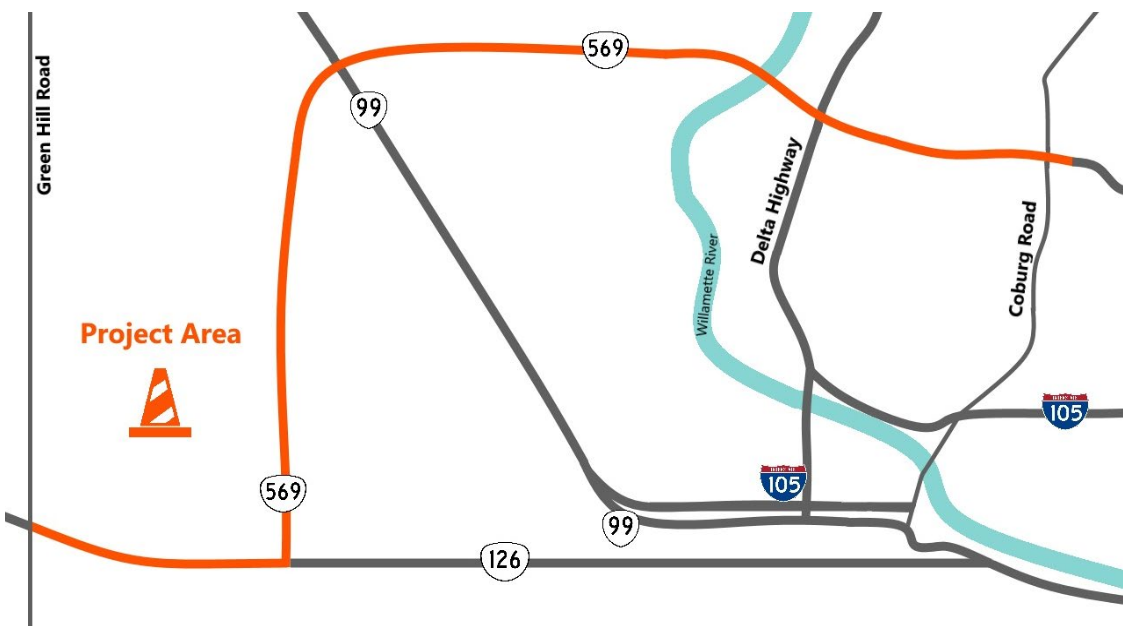

Figure 5.1: OR569 Green Hill Road – Coburg Road Project (ODOT, 2022a)

The research team contacted the resident engineer on this project for plans to deploy the equipment during the bridge repair work. As the repair work occurred at multiple bridges along OR569 requiring lane closures in both directions, the research team had ample locations to test the accuracy of both the smart arrow board and the location beacons. Moreover, a unique aspect of this project is the lane closures occurring on two separate classifications of roadways. As seen in Figure 5.1, the section of roadway east of US-99 is a divided multi-lane highway with a median barrier. The western segment of OR569 turns into an undivided two-lane highway. This gave the research team an opportunity to deploy the smart arrow board on the segments where lane merging occurred on the multi-lane section, specifically when conducting bridge repairs were being conducted and the location beacons were placed on the eastern side of US-99 where flagging operations were ongoing during repaving.

As part of this plan, ODOT personnel were required to assist in the movement of the smart work zone technologies to the work zone itself. Discussions with the resident engineer for this project led to an agreement for the contracted crew to transport and utilize both the smart arrow board and the location beacons for the project as they would any other devices. The contractors understood that the smart work zone equipment functioned in the same manner as any other arrow board, however it transmitted its location and displayed variables to the research team for data collection means. This process was estimated to last for several weeks during the bridge repair work by the consultants.

5.2 DATA COLLECTION PLAN

The primary characteristics that needed to be captured were the raw data being transmitted from the devices, both the start and end location beacons and the smart arrow board. To capture and display the data feeds, which were broadcasted in the WZDx JSON format, two methods were developed. The first method utilizes a quickly developed JavaScript that reads in the GeoJSON URL and exports the current contents of the devices into a text file to be post-processed. The organization and variables within this text file are mentioned in section A.2. The second method developed relies on the use of ArcGIS online. ArcGIS online has the capacity to take in a GeoJSON URL and display it on a variety of maps, which include fully interactable and sharable online maps. An example of displaying the smart work zone equipment within ArcGIS online is shown in Figure 5.2.

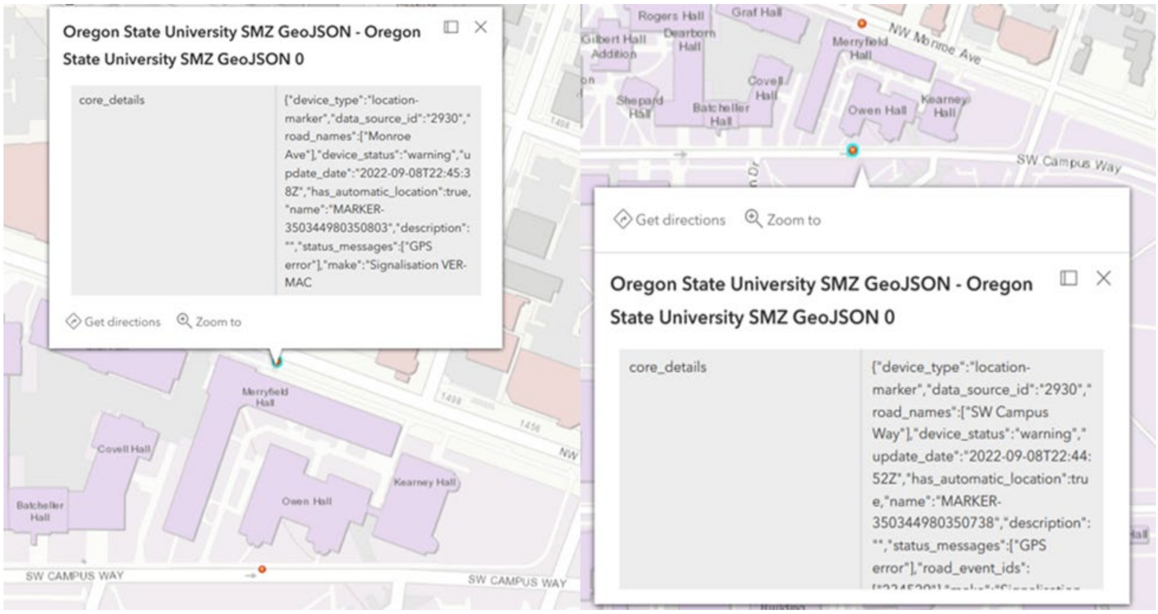

Figure 5.2: Example ArcGIS view of sample data produced from the smart work zone devices

Figure 5.2 displays an actual deployment of the location beacons on the Oregon State University campus, where the northern dot (highlighted) is displaying the GeoJSON elements. The southern or lower dot is the end location beacon on the opposite side of Owens Hall. The location beacons specifically have a line within the GeoJSON feed which dictates if the beacon is the start or end beacon. The combination of these methods demonstrated the devices' ability and accuracy to transmit its locations and displays, whereas the integration to ArcGIS may be seen as a possible future example of having these devices eventually populate TripCheck. To be more specific they will be transmitting their location, side of road, name of road and other variables just like the arrow board. The feed itself will have the information tabulated to both location beacons and the smart arrow board. This constitutes method one. For method two, the data feed was imported into ArcGIS to provide a map, or visual display of the devices to provide an example of what it might look like within TripCheck.

Some of the anticipated variables to track are:

- Timestamp
- Coordinates
- Roadway name
- Side of road (Location Beacons only)
- Travel direction
- Pattern (ArrowBoard)

The procedures for running the developed java script were used, during the deployment to populate the datasets for further analysis. To pull this data, the JavaScript was run in Microsoft Visual Studio analysis, which queries the devices and downloads the parameters of the devices into a text file. The collection of these text files over the duration of the deployment constituted the data collection process. With this information, and the distribution of the data following the WZDx guidelines, the project will have satisfied the constraints for the scope of work. This includes operating over the WZDx based smart work zone device commination protocols, storing, and collected transmitted datasets which might eventually assist with the over-dimension-permitting process as this data feed is streamed in real time, and lastly through a georeferenced depiction of the devices within the ArcGIS platform, providing an example of how it may be viewed if integrated into TripCheck in the future.

As the data feed from the Smart Arrow Board and the location beacons are being broadcasted in the WZDx JSON format, the research team accessed the data feed remotely through the provided Vermac-Jamlogic url:

https://svr1.jamlogic.com/workzonefeed/public/Oregon_State_University

With the WZDx broadcasted data feed, connected, and automated vehicles can receive real-time lane closure data to guide their operations. Moreover, when the devices are activated, they also transmit a signal to Google Waze indicating that there is construction ahead.

We anticipate that the data collection will last for more than two weeks. The duration for the data collection will be based on several location changes of the arrow board and location beacons. This will depend on the scheduled work for the construction crews. A month worth of data would most likely encompass all of the possible configurations that might occur on roadways. This would include changes in the device's location at different sections of the work zone and on different sides of the road. We will store all the data collected during the pilot testing on the ODOT construct project and will process the data into text format. The collected data will then be used to prepare three data examples. (1) real-time work-zone lane closure data to the ODOT project of automated over-dimension permitting system; (2) real-time work zone data to ODOT TripCheck; and (3) real time lane impacted data via ODOT's work zone data exchange compliant data feed to fully support the US DOT work zone data exchange standard.

6.0 PILOTING TESTING SMART WORK ZONE TECHNOLOGIES IN MULTIPLE OREGON WORK ZONES AND REAL-TIME DATA COLLECTION

The plan of implementation developed in Chapter 5 of this report was conducted on an active work zone within Eugene, Oregon along W 11th Avenue between Beltline Road and Terry Street and is displayed in Figure 6.1. The work zone, 1-mile in length, was utilized for typical resurfacing where the outcomes of this testing can be realized for any work zone within Oregon. The strategy to satisfy the constraints of the work plan was employed and an overview of the data collection efforts presented through this case study. Following this, a discussion specifically towards the three primary subtasks:

- Real-time work-zone lane closure data to the ODOT project of automated over-dimension permitting system.
- Real-time work zone data to ODOT TripCheck and other navigation tools.
- Real time lane impacted data via ODOTs work zone data exchange.

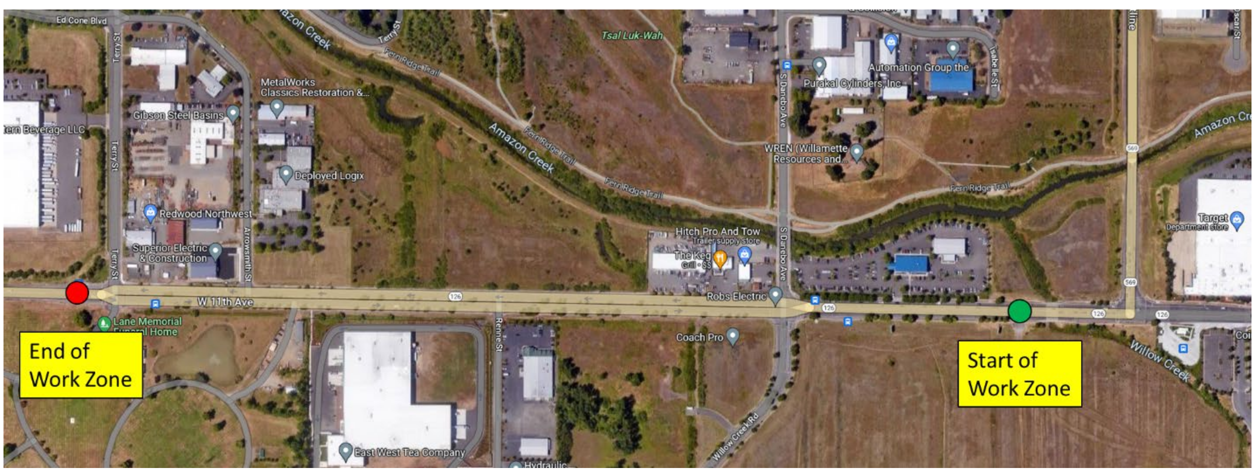

Figure 6.1: Location of Work Zone Test Site

6.1 CASE STUDY IMPLEMENTATION

The research team, with the assistance of ODOT personnel, tested the smart work zone equipment within a resurfacing work zone located in Eugene, Oregon. The team also had a site visit to observe the devices, their interactions with vehicular traffic and subsequent real time cross-verification of the data feed to be transmitted and displayed. Examples of the smart work zone devices deployed at the work zone are shown in Figures 6.2 and 6.3.

(a) (b)

Figure 6.2: Location Beacon Deployments Onsite: Start-of-Workzone (a), and End-of-Workzone (b)

Figure 6.3: Smart Arrow Board Deployment

6.1.1 Real-Time Work-Zone Lane Closure Data to the ODOT Project of Automated Over-Dimension Permitting

Following the current timeline for the Oregon Over-Dimension Permit System Replacement Project; current milestones of that project include permit transaction management and system connectivity through the identification of a third-party vendor who will develop the system.

More information on that project in particular can be found at: https://www.oregon.gov/odot/mct/pages/oregon-od-permit-project.aspx.

The general understanding of how the results of this project will be eventually implemented into the future web infrastructure of the automated over-dimension permitting system will be the data feed that is transmitted from the devices in real time. However, the current feed does not indicate which side of the road is closed and the number of lanes, although there are variables within the feed that could be post-populated: "road-direction", as an example. This would require external calculations against the data-feed if desired to be fully automated, or personnel could also simply enter the direction and number of lanes affected by the construction work, however this would not be automated.

Other agencies across the country that utilize similar technologies also have variables within their data feeds for number of lanes closed, or the lane number itself and if it is closed, with further discussion of this in section 6.1.3. In regard to the application of this projects outcomes towards the automation of the over-dimension permitting system, it is understood that the data type of the feed itself, a GeoJSON, suffices as an easily accessible input into the future system, with external modifications on specific lane closure information being populated by personnel.

For specific use in the automation of the over-dimension permitting system, additional consideration or external processing might be needed outside of the information that could be updated within section 6.1.2. For instance, even if the feed is post-processed to add in number of lanes closed, which lanes are closed and their directions, for the over-dimension permitting, it might be best to take this information and determine a binary response to indicate if particular classifications of vehicles would be able to pass that location. Although there will be lane restriction information, some dimensions of the available lanes might be needed also, which can be added into the feed. Examples of this extra data that could be added come from OregonTruckingOnline. Within this ODOT platform there is a section under Road Restrictions, that provide the road, mile point range, city, width and or height restriction, and time these restrictions will exist.

6.1.2 Real- Time Work Zone Data to ODOT TripCheck and Other Navigation Tools

The second area of interest is the ability for other applications to read in the GeoJSON feed emitted by the smart arrow board and location beacons. Outside of the inhouse methods of displaying this information, such as through python scripts to display the information of these devices on maps within a local computer environment, Google WAZE and also ODOT's TripCheck were able to display the existence of the work zone and its devices in real time.

Examples of TripCheck populated with the live Ver-Mac GeoJSON feed during the site visit are displayed in Figures 6.4-6.7. What was observed, however, was as usual the devices would populate Google WAZE. TripCheck on the other hand was not directly being informed by the feed but indirectly receiving information through the Google Waze channel. Despite this, there is an opportunity for ODOT to specifically receive the data feed and decide to add additional components to this feed before being transmitted to TripCheck. There are, however, drawbacks to only utilizing the informed feed from Google Waze.

The information provided by Waze only interprets the location beacons and if they are the start or end location beacon to which it depicts the ‘ENTERING A WORK ZONE – STAY ALERT” and “YOU ARE LEAVING THE WORK AREA" messages shown in Figures 6.4 and 6.5. Outside of this, the same problem as mentioned in the previous section still stands; there is no indication of which lanes are closed or even the direction that is closed from the base feed. This can of course be adapted, and additional variables added to include such information, either automatically or from manual inputs from personnel.

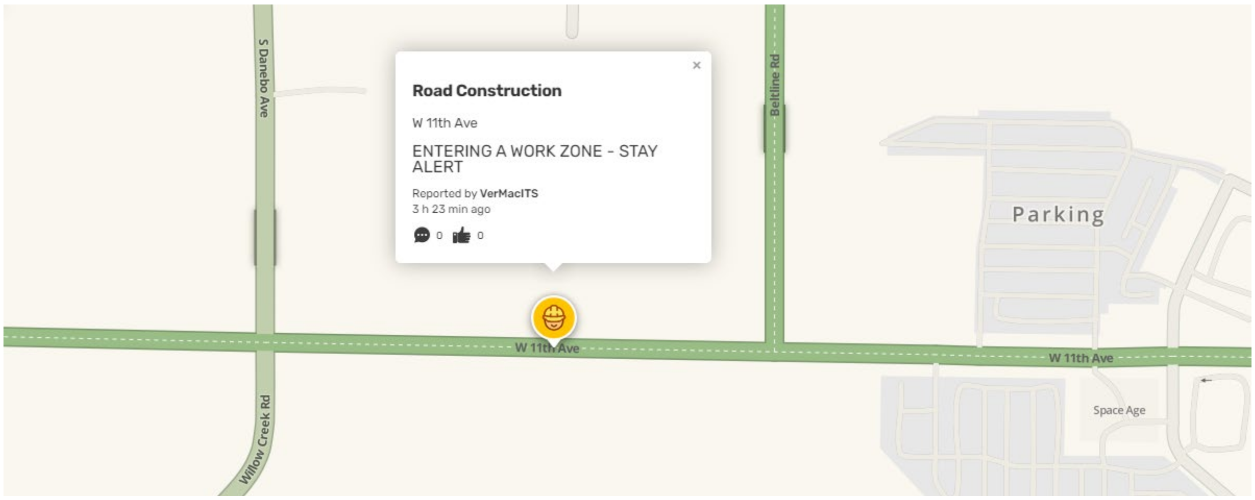

Figure 6.4: Ver-Mac data feed populating Google Waze from the Start-of-Workzone Location Beacon

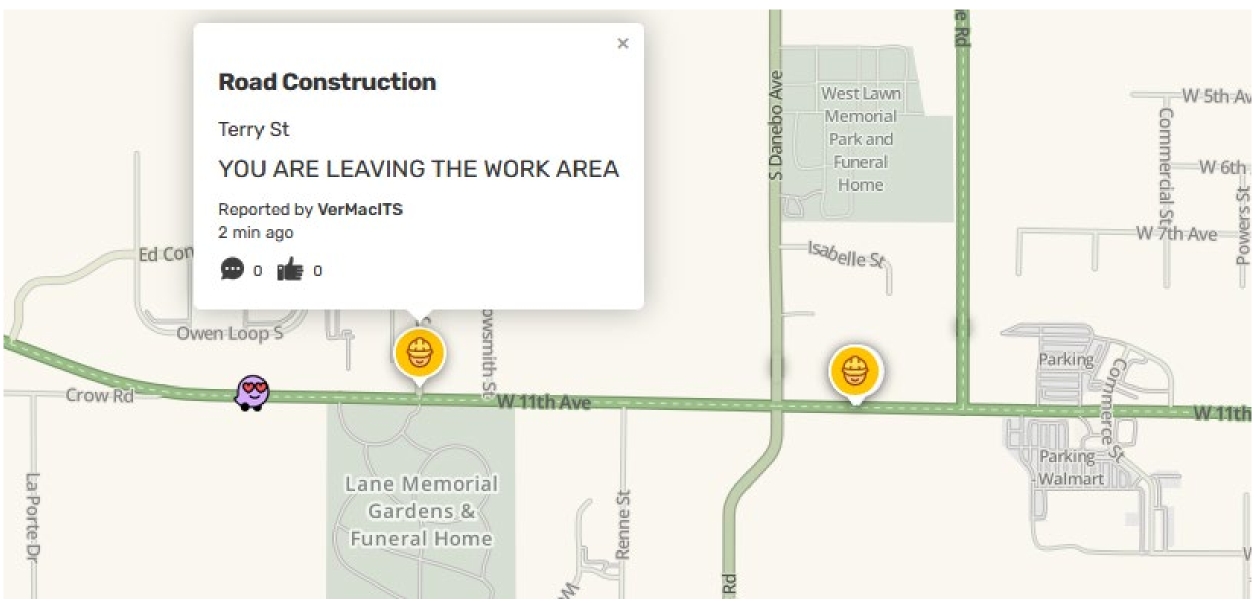

Figure 6.5: Ver-Mac data feed populating Google Waze from the End-of-Workzone Location Beacon

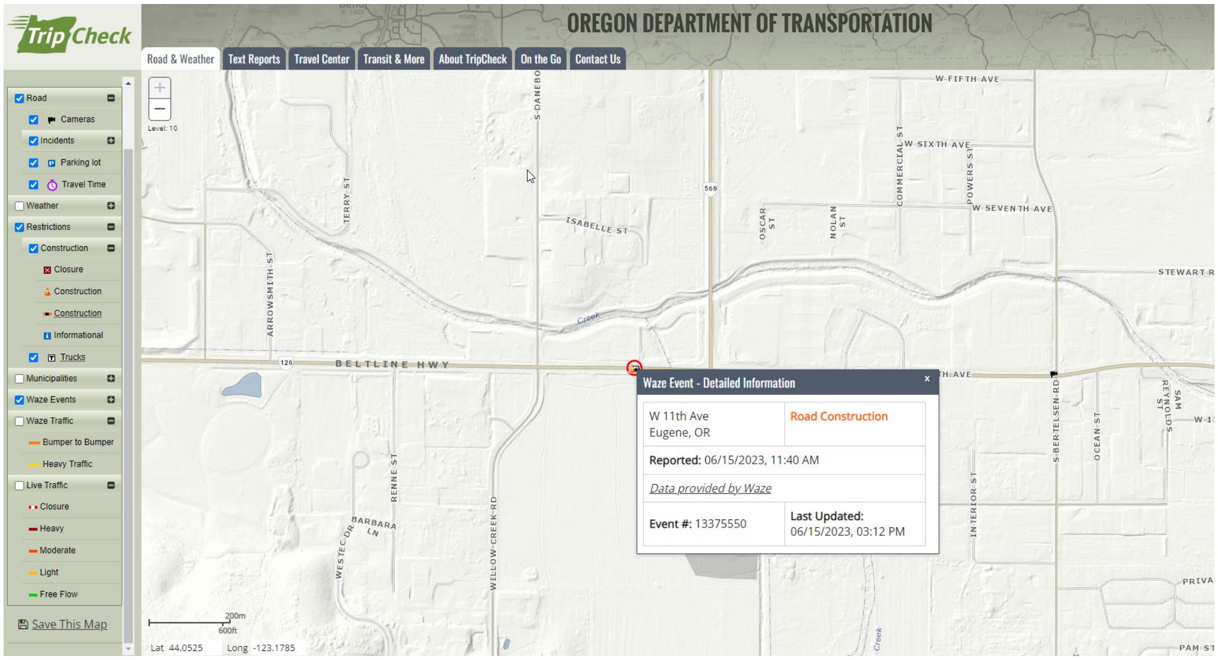

Figure 6.6: TripCheck Informed through Google Waze

By comparing the work zone information provided by ODOT TripCheck's Waze event layer in Figure 6.6 and the restriction construction layer, ODOT TripCheck's construction layer does not provide the real-time work zone information, shown in Figure 6.7. Despite this, the layer provided through Waze again only displays the location through a processed version of Waze.. Despite these drawbacks it is still demonstrating the first step towards the full integration of the smart work zone equipment into TripCheck.

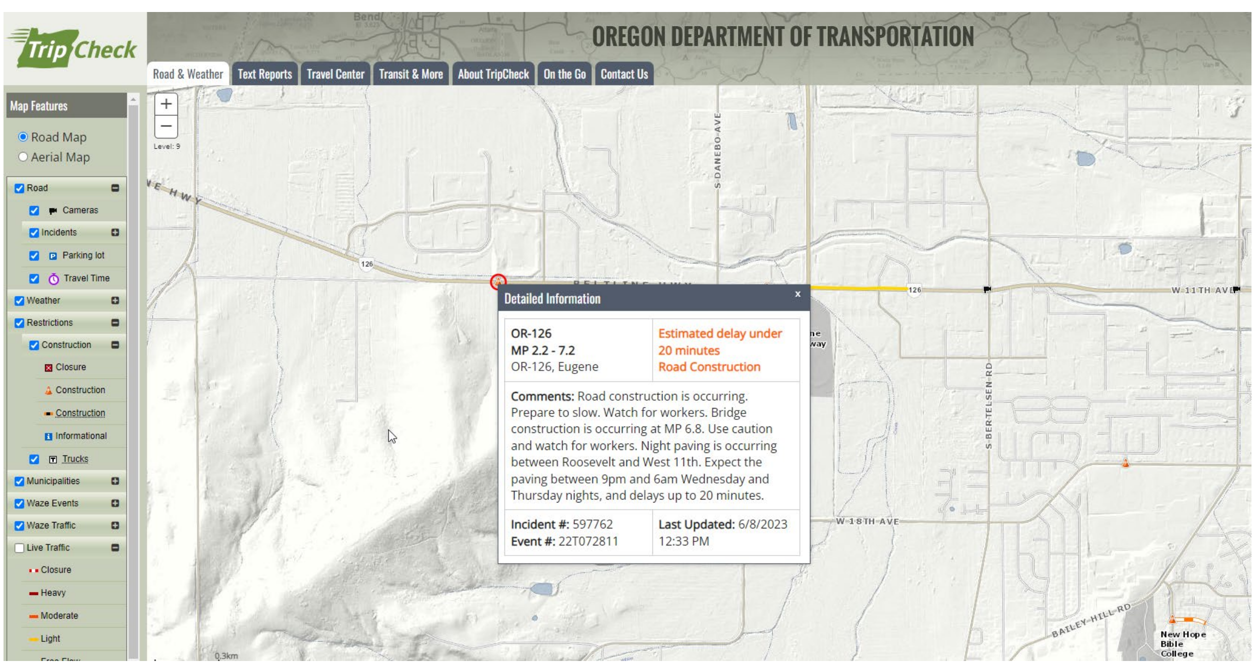

Figure 6.7: TripCheck Static Construction Event layer

Lastly, with the above depictions of the feed being transmitted into a navigational app such as Waze and its subsequent population into TripCheck, one of the possible depictions it might have at a later time with full integration into TripCheck is shown in Figure 6.8. In this case, the work zone start location beacon is the green cone, the arrow board displayed at the bi-directional arrow and lastly the end of work zone depicted as the red cone. Although visually it provides the start, end, and full length of the work zone, it is still missing the key attributes about the work zone, namely the direction and number of lanes closed.

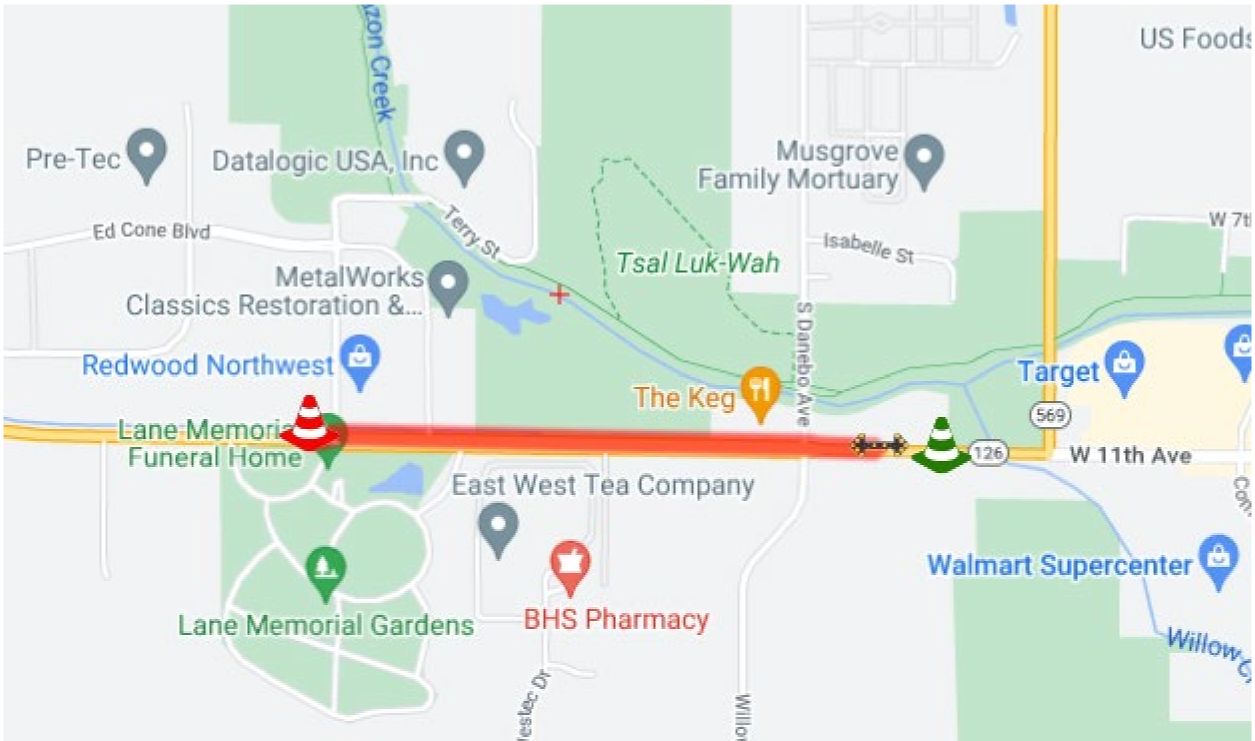

Figure 6.8: Map Visualization within Ver-Mac Jam Logic Software

6.1.3 Real-time Lane Impacted data via ODOTs Work Zone Data Exchange

One of the major drawbacks that was observed during the deployment and data collection efforts was the lack of any variables that could track both which side of the road the lane closure was on, and the number of lanes closed. The default feed, although having a variable that could be populated with the side of road closed, has no variables for the number of lanes.

With this realization, the research team investigated other agencies that are following the WZDx data feed format for their work zones and proposed to consider the approach from those feeds to fully accomplish the goal of transmitting real-time lane closure information. Figures 6.9 and 6.10 are snapshots from other state agencies' feeds on how they specifically transmit the lane closure information which might be considered to append to the test feed operated over within this project:

A list of all of the feeds can be found at: https://datahub.transportation.gov/Roadways-and-Bridges/Work-Zone-Data-Exchange-WZDx-Feed-Registry/69qe-yiui. (USDOT, 2024)

- Massachusetts DOT - https://wzdx.massdot-swzm.com/massdot_wzdx_v3.1.geojson (USDOT, 2024)


```
"direction": "westbound",
"vehicle_impact": "some-lanes-closed",
"relationship": {
  "parents": [
    "2401"
  ]
},
"lanes": [
  {
    "order": 1,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 2,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 3,
    "type": "lane",
    "status": "open"
  }
],
"beginning_milepost": 109.83,
"ending_milepost": 106.15,
"event_status": "active",
"reduced_speed_limit": 50,
"creation_date": "2021-06-25T12:32:57Z",
"update_date": "2021-07-09T13:38:43Z"
```

```
"direction": "eastbound",
"vehicle_impact": "some-lanes-closed",
"relationship": {
  "parents": [
    "2401"
  ]
},
"lanes": [
  {
    "order": 1,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 2,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 3,
    "type": "lane",
    "status": "open"
  }
],
"beginning_milepost": 106.18,
"ending_milepost": 109.84,
"event_status": "active",
"reduced_speed_limit": 50,
"creation_date": "2021-06-25T12:31:12Z",
"update_date": "2021-07-09T13:38:02Z"
```


Figure 6.9: Example Lane Closure Massachusetts WZDx Data Feed

- Texas DOT - https://wzdx.massdot-swzm.com/massdot_wzdx_v3.1.geojson (USDOT, 2024)

```
"lanes": [
  {
    "lane_edge_reference": "left",
    "lane_number": 1,
    "lane_status": "open",
    "lane_type": "left-lane"
  },
  {
    "lane_edge_reference": "left",
    "lane_number": 2,
    "lane_status": "open",
    "lane_type": "middle-lane"
  },
  {
    "lane_edge_reference": "left",
    "lane_number": 3,
    "lane_status": "open",
    "lane_type": "right-lane"
  }
]
```

```
  "lanes": [
    {
      "lane_edge_reference": "left",
      "lane_number": 1,
      "lane_status": "closed",
      "lane_type": "unknown"
    },
    {
      "lane_edge_reference": "left",
      "lane_number": 2,
      "lane_status": "open",
      "lane_type": "unknown"
    },
    {
      "lane_edge_reference": "left",
      "lane_number": 3,
      "lane_status": "open",
      "lane_type": "left-lane"
    },
    {
      "lane_edge_reference": "left",
      "lane_number": 4,
      "lane_status": "open",
      "lane_type": "right-lane"
    },
    {
      "lane_edge_reference": "left",
      "lane_number": 5,
      "lane_status": "open",
      "lane_type": "unknown"
    }
  ]
},
```


Figure 6.10: Example Lane Closure TxDOT WZDx Data Feed

Using MassDOT and TxDOT as examples, it can be observed that the structure within their lane value is different, and it is understood the order within MassDOT is the order going away from the outside lane. The configuration of the two feeds demonstrates an important component to be considered when leveraging the smart work zone equipment and the production of automated lane closure information. Both feeds designate what is occurring to each lane, not just an entire segment. In the case of TxDOT they also use lane edge referencing, which could possibly be used in conjunction with different pattern configurations to infer the lanes that are closed. The reasoning behind choosing these two is that their feeds are in an easily visualizable format whereas the others are not, however they are still in the same format when operated over within software programs.

From the research team's observations, the majority of the other state agencies follow the same description as MassDOT: Order, type, and states for the individual event. Another observation is that the feeds being transmitted from the other state agencies include all of their operating smart work zone equipment and in some cases reach upwards of 3,000 work zone events being transmitted in real time. TxDOT's lane information is unique against the other DOT feeds providing a different perspective to consider where they utilized the lane_edge_reference and then a similar approach where instead of order they use number.

A final thought from the research team in regard to the other State agencies and their data feeds; it is understood that numerous agencies are indeed utilizing the same type of feed from the exact same vendors, however, the strategy for the automatic population of those feeds is unknown outside of the basic structure matching that of the WZDx format. Using TxDOT's feed in Figure 6.10, it is not certain what technology is used that can automatically indicate that lane one is closed, or even if this information is automatically updated. To the research team's best knowledge, this specific location within the TxDOT's feed is pre-arranged, where if the smart work zone device became active, this location was already pre-set to indicate that the left lane, lane number 1, would be closed and the others still operating. If there is a system that provides automation of this information, including the specific lane that is closed, it would be incredibly valuable. With the default data produced from the devices tested herein, (shown in Tables A.2-A.12.) specific lane closure information would not be obtainable in an automatic fashion and further investigation or communication with the vendors from these other agencies towards depicting this lane information in real time would be highly recommended.

7.0 EVALUATION OF PILOTED TECHNOLOGIES AND DATA ANALYSIS

With an understanding of the limitations on the type of data that is transmitted from the devices, a review on the accuracy of their output variables during the pilot is displayed. Also, as mentioned in Chapter 5, the data collection method employed during the pilot was to enact a JavaScript that would write out the GeoJSON feed to local files. The files saved for the entire duration of the pilot are in a single zip-file for data records. Moreover, an adapted python script was created that can query the GeoJSON data feed at any time interval automatically and store this locally as well. Furthermore, the data collection efforts utilized the developed algorithms to pull from the data feed manually twice a day during the pilot. Following this, the devices were queried sporadically over the span of a month to retrieve additional data although they were not deployed during this time.

7.1 TECHNOLOGY EVALUATION

As the evaluation of the devices are constrained by the data they are emitting, the evaluation crosschecked these variables against what was observed visually during the on-site visit and those that could be semi-validated. The primary variables that can be tested included:

- Road_names
- Milepost
- Pattern (only for the arrow board)
- Coordinates

There was an additional variable mentioned in the previous section, road_direction, where this variable was never populated from the data feed during the storage or the deployment stages of the project.

7.1.1 Road Names

During the deployments, all three devices were able to relay that their current road location was on W 11th Ave, however when they were turned off and transported to their storage locations the data feed still portrayed the devices were on W 11th Ave. The primary cause of this is within the devices ability to transmit a portion of its feed always even if turned off. All of the devices tested continued to transmit their locations at all times even if turned off so long as there is power left in the device.

For both devices there was an option within the JamLogic software to pull the current voltage within the devices, if this is not at zero the devices will always transmit their location within the feed, even if turned off for the location beacons and not displaying any pattern for the arrow board. An example of the JamLogic interface and the voltage reading for all of the devices is shown in Figure 7.1. It is the teams' understanding that the road name variable in particular will only be re-calculated when the devices are turned on and then the device specific hertz will update the road name variable. In general, when the devices were fully deployed, they displayed the correct road name with 100% accuracy.

7.1.2 Milepost

The milepost variables for all three devices during the deployment were not accurate where each depicted different values for the milepost, namely: 54.43 for the arrow board, 1.0 for the work-zone-end location beacon and no milepost reading for the work zone start location beacon. A possibility on the difference in the mile-markers could be an error on the part of where the devices are retrieving their mile marker reference compared to the roadway itself. Those discrepancies may be caused by the base data the devices are using to compare their coordinates. With this and additional feed readings from where the arrow board was specifically stored prior to the deployment, the feed was transmitting the correct milepost with the associated roadway that was in proximity. As for the work-zone-start location beacon, the research team is uncertain of why there was never a milepost value transmitted during the storage or deployment phases.

7.1.3 Smart Arrow Board Pattern

From visual observations, the arrow boards operated with a right-chevron-sequential pattern the entire deployment. This was observed during the site visit, and verified through the stored data feed. The research team also performed some preliminary tests where the arrow board was being stored prior to the deployment and confirmed that the different display values for the arrow board transmitted with 100% accuracy within the JamLogic interface and within the live feed.

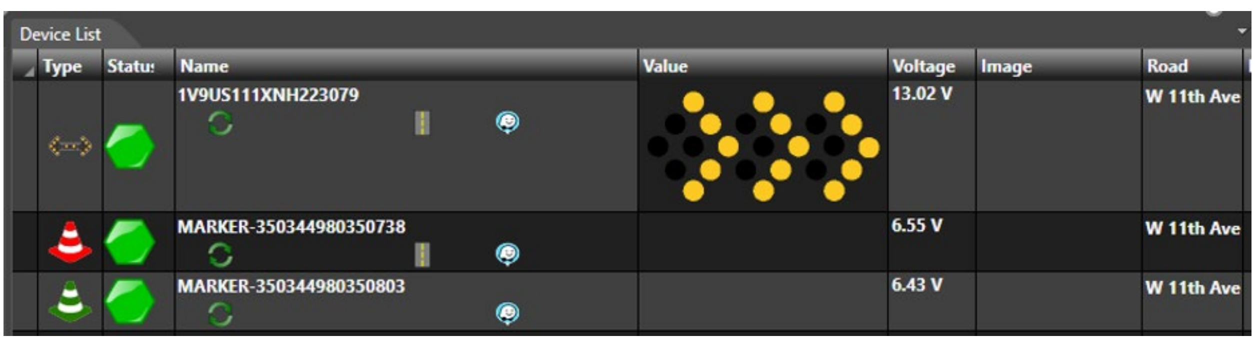

Figure 7.1: JamLogic Interface Readings

7.1.4 Coordinates

Visual cross-checks for the SAB location within the Jam Logic interface were examined and compared against the corresponding coordinates from Google Waze. Following this, the output coordinate readings from the SAB data feed were also collected and compared, to which no coordinate errors were found. As for the work-zone-end and -start coordinates from the location beacons, there was never an instance where the work-zone-end location beacon switched readings to be at the front of the work zone or vice-versa. All readings during the pilot from the location beacons indicated the work-zone-end location beacon were always downstream of the work-zone-start. Following this the same visual inspection that was conducted with the arrow board was done with the location beacons and no errors were found.

7.2 DATA COLLECTION ALGORITHMS

As mentioned in Chapter 6, an initial JavaScript, shown in Figure 7.2, was created and manually utilized to write the GeoJSON feed to local files. Later on, the research team created an automated python script, shown in Figure 7.3, that can query the feed at any time interval desired and write out the file to a local computer while the computer remains active.

7.2.1 Java Manual Algorithm

```
const http = require('https'); // or 'https' for https:// URLs
const fs = require('fs');

const file = fs.createWriteStream("file.txt");
const request =
http.get("https://svr1.jamlogic.com/workzonefeed/public/Oregon_State_University",
function(response) {

   response.pipe(file);

   // after download completed close filestream
   file.on("finish", () => {
       file.close();
       console.log("Download Completed");
   });
});
```

Figure 7.2: Manual Java Script for Data Retrieval

The above Java script will write out a text file titled "file.txt" when executed, in the case of this project it was executed within the IDE, Visual Studio Code.

7.2.2 Python Automated Algorithm

```
import requests
import json
import datetime
import time
import schedule

def run_script():
    current_time = datetime.datetime.now()
    # Format the time as a string
    time_string = current_time.strftime("%Y-%m-%d_%H-%M")  # Example: 2023-08-
29_15-30-45
    # Create the filename with the time included
    output_filename = f"output_{time_string}.json"  # Example: output_2023-08-
29_15-30-45.txt
    r =
requests.get(https://svr1.jamlogic.com/workzonefeed/public/Oregon_State_Universit
y)
    data = r.json()

    with open(output_filename, 'w') as json_file:
        json.dump(data, json_file, indent=4)

schedule.every().hour.do(run_script)
# if every 30 min
# schedule.every(30).minutes.do(run_script)
while True:
    schedule.run_pending()
    time.sleep(1)
```

Figure 7.3: Automated Python Script for Data Retrieval

The following python-based script requires certain packages from python: requests, json, datetime, time and schedule, to which it will write out a json file at specific intervals to a local folder, where the title of the file is associated with the current time and day that it is written. For instance:

- Output_06-13_2006.json
- Output_06-28_0147.json

These outputs would be the month of June (06), days (13 and 28), and times (20:06 and 01:47). The script in this case would write out the current information from the data feed every hour and can be altered to minutes or any time increment desired. The only drawback here is that the file is stored locally. It is the research team's understanding, however, that ODOT will be able to simply retrieve the information from the feed in real time and relay it through TripCheck automatically pending this project.

8.0 GUIDELINES AND RECOMMENDATIONS ON ODOT POLICIES AND STANDARDS

After conducting the required steps to test and validating the mechanisms of the technologies in this project – from initial testing of the smart arrow board and location beacons to deploying these devices on an active work zone, the research team has identified key opportunities for ODOT to consider towards the possible investment of such systems into their existing workflow. This chapter describes the implications of using the smart arrow board and beacons in three implementation scenarios for ODOT and describes remaining tasks that would fully incorporate these devices at scale within ODOT.

8.1 IMPLICATIONS FOR OREGON'S OVER-DIMENSTION PERMIT SYSTEM REPLACEMENT PROJECT

Currently, ODOT's Commerce and Compliance Division (CCD) is in the stages of securing a particular vendor to generate a web-based application that will eventually have the capacity to distribute over-dimension permits, those permits currently planning to be consolidated, automatically and in real time. The anticipated vendor is ProMiles, and their existing basic framework for the app is shown in Figure 8.1, to which the state permitting and routing systems would need to provide the information of the lane closures. The final connection is the State Permitting and Routing Systems, and is assumed these would be updated in some facet of time in relation to both real-time and expected future lane closures from work zones.

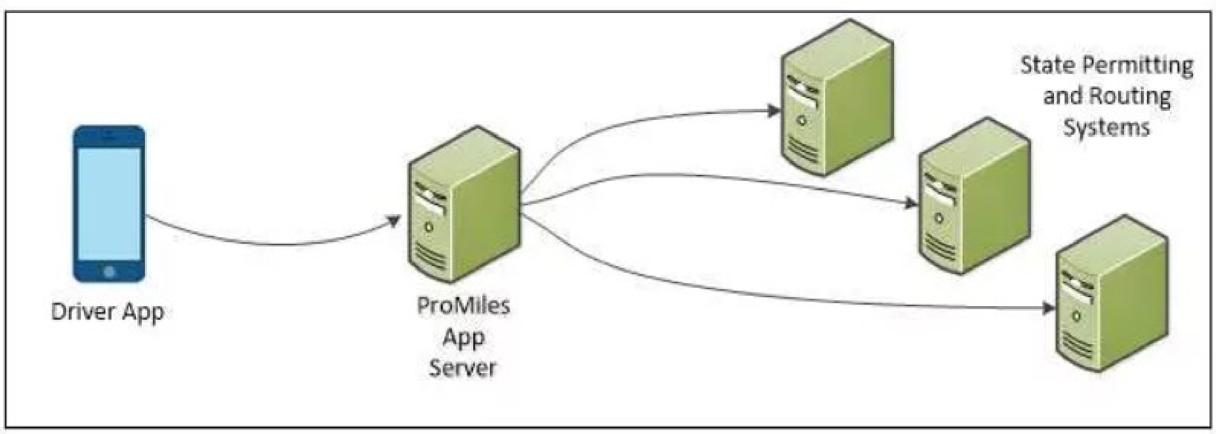

Figure 8.1: ProMiles Architecture

However, one of the constraints of this envisioned system is its inability to incorporate real time impacts of disruptions towards current and future planned routes, including those caused by work zones. From the previous sections it was identified that the data feed being transmitted from the work zone devices can be read in through simple python scripts or through other processes. One recommendation from the research team are the potential solutions for the secured vendor of the over-dimension replacement project with the constraints needed to also include this potential incoming data stream to the automated permitting, and routing produced from this application.

While static preplanned maps exist, the base application can provide routes given the constraints of the vehicle and the roadway under normal conditions. However, whether the software has the ability to produce automatic routing that considers work zone status, subsequent lane closures or even height and width restrictions is unknown.

Moreover, the information provided from the data-feed does not currently display which lanes are closed, however it is understood that when an arrow-board is deployed there is a lane closure on that segment of roadway. One possible alternative is to proactively create additional information within the GeoJSON feed so that when the work zone becomes active it is understood which exact lanes are closed. An example of this is shown in Figure 8.2, displaying a feed from the Work Zone Data Exchange Feed Registry, specifically MassDOT's live data feed: (https://datahub.transportation.gov/Roadways-and-Bridges/Work-Zone-Data-Exchange-WZDx-Feed-Registry/69qe-yiui) (USDOT, 2024). This of course is important for this use case, as certain routes may become unavailable if lane restrictions exist.


```
"direction": "westbound",
"vehicle_impact": "some-lanes-closed",
"relationship": {
  "parents": [
    "2401"
  ]
},
"lanes": [
  {
    "order": 1,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 2,
    "type": "lane",
    "status": "open"
  },
  {
    "order": 3,
    "type": "lane",
    "status": "open"
  }
],
"beginning_milepost": 109.83,
"ending_milepost": 106.15,
"event_status": "active",
"reduced_speed_limit": 50,
"creation_date": "2021-06-25T12:32:57Z",
"update_date": "2021-07-09T13:38:43Z"
```


Figure 8.2: Example WZDx Lane Closure Feed, MassDOT (USDOT, 2024)

An example of a potential solution for generating an automated response that would fill in the open or closed status with particular lanes would be a combination on the display of the arrow board with an understanding on the lane direction. For instance, a left sequencing chevron would indicate lane order 3 is closed, or a right sequencing chevron would indicate lane order 1 is closed and this information could be appended or even update the GeoJSON feed produced by the equipment, this may also include lane width restrictions as well. There are different approaches to this, however this was an initial idea by the research team. With this said, it would be more beneficial to simply have a pre-set message that is related to the specific work zone that would be conducted where all of the attributes exist in the same format as the WZDx, demonstrated in Appendix A to which when the devices are activated all of this information would be relayed.

8.2 IMPLICATIONS FOR TRIPCHECK

From the previous sections demonstrating the deployment of the smart work zone devices, it is clear that TripCheck already has the capability to portray the existence of a work zone through Google Waze. The devices come equipped to relay information directly to Google Waze and TripCheck gets updated on the existence of a work zone. However, specific information about the work zone, lane closures and even the side of the road the work zone is on are not appended through this approach, only an indication that there is an active work zone. For the latter, the research team has considered some possibilities for an automated approach to display the number of lanes closed, and which lanes (NB/SB/EB/WB).

Although these methods, which would require post processing of the live data feed, may be able to depict this information, it would not always be accurate and it would be more prudent for ODOT to consider having pre-recorded information of the particular work zone and its closures, to which when the feed goes live it is understood that pre-recorded information becomes activated. Using the above feed in Figure 8.2, ODOT personnel could indicate when the work zone becomes activated, lane order 3 would become closed, from this other information such as the milepost would be automatically updated. It is the research team's perspective that there are certain attributes that would be unrealistic to be automated, for the goal of the project, automated indication that there is a work zone and it being active is currently satisfied with the current devices.

8.3 IMPLICATIONS FOR ODOT WORK ZONE DATA EXCHANGE COMPLIANT FEED

The intention of utilizing the smart work zone devices, the smart arrow board, and location beacons, was to lay the foundation for a live data feed that would be transmitted in compliance with the FHWA WZDx. As it currently stands, the feed produced by these devices are transmitted in the format of the WZDx. If ODOT plans to append information to this feed for the above mentioned reasons, that information would need to follow the general outline of variables and objects presented in Appendix A, section A.2, and examples of other state agencies WZDx data feeds can be found at https://datahub.transportation.gov/Roadways-and-Bridges/Work-Zone-Data-Exchange-WZDx-Feed-Registry/69qe-yiui (USDOT, 2024), where there is slight variations in the reporting of certain variable and objects. These variations are likely a result of data variables used in legacy systems in those states; and ODOT is recommended to consider their own system requirement while defining the feed. Furthermore, the most recent conversation on each of these variables and objects that should be considered from the feed can be found at https://public.huddle.com/b/ldlyDW/index.html (Deshmukh-Towery, 2021).

9.0 CONCLUSION AND LIMITATIONS

With consideration for the key objectives established in section 1.1, the following statements underline the outcomes from the conducted research:

- The smart work zone devices deployed were able to provide TripCheck with real-time work zone information indirectly through Google Waze. However, further work is required for TripCheck to directly utilize the data feed from these devices.

- The architecture of the data feed followed the WZDx format and would be directly accessible in TripCheck's current WZDx API, thus satisfying the WZDx data format requirements.

- Descriptions on the possible configurations on how the existing data feed would be utilized for use within the automation of the Commerce and Compliance Division's over-dimension permitting system were discussed. Identifying the need for more specific lane closure information, such as lane restrictions, to provide real-time data into their automated system. It was also understood that automating the permitting system would not necessarily result in real-time processing, as the automatic retrieval of the permit is unlikely to coincide with the trip occurring on the same day.

- Final recommendations and possible avenues for adapting the base data feed, given some of the more specific information that could be appended, including possible automated decision trees based on GPS and pattern displays of the smart work zone technologies. Another identified possibility could be static binary filing of work zone variables such as lane numbers closed, and width restrictions, that pre-recorded and appended to the feed once it becomes active. Both of these options would require further research.

The objective of this study was to identify and pilot specific smart work zone technologies that have the ability to transmit real-time work zone and lane closure information. With the requirement for these systems to have their feed be under the Work Zone Data Exchange format, the eventual goal was to demonstrate how these systems could be integrated into ODOTs TripCheck and the Commerce and Compliance Division's ongoing overhaul of the over-dimension permitting system. With this goal the research team performed a review of current literature on the deployment of such systems across other state agencies in the U.S., including their work-flow processes, technologies used, and configuration of how their feed functions. Once this review was completed, the research team purchased and tested smart work zone technologies, specifically a smart arrow board and location beacons.

With the assistance of ODOT personnel, the research team was able to locate a resurfacing project within Eugene, Oregon, where the devices were tested in real time. The outcomes of this pilot included an evaluation of the limitations and possible future directions that these devices have in relation to their ability to capture real time lane closure information. This includes possible adaptations and extensions to the base data feed that transmits in the FHWA WZDx format, the identified current process for the devices to update TripCheck, and avenues for the systems to provide real-time information to the future the automated over-dimension permitting system.. Although the pilot was able to satisfy the constraints of this project and meet the general goal of providing real-time lane closure information, the research team identified some critical gaps that would need to be considered for incorporating such devices into their existing workflow. These critical gaps are as follows:

- Currently TripCheck receives information from these devices indirectly from Google Waze. Thus, adding anything to the base feed would not be transmitted if TripCheck is only receiving information this way. The process for TripCheck to receive the feed from the devices is the first step.

- Specific lane closure information – If an ODOT goal is to know the location of a work zone and its mile marker extent, without any other information, the devices can currently do this. However, any further information, such as the number of lanes closed or any lane restrictions, such as height or width, needs another developed process. The two possible approaches for this are described above in this chapter.

- The automation of the over dimensions permitting system and integration into the software purchased from the commerce and compliance division (CCD) – This component comes down to the needs of the CCD. If the planned flowchart is to utilize data from TripCheck to inform their systems, then the first critical gap would satisfy their needs. If they need more information in real-time such as lane restrictions, not just closures, the above specific lane closure information development would need to be created.

Considering the recommendations of the research team on how to effectively integrate these devices, limitations were identified in both the study and the smart work zone equipment in general. As documented within Chapter 8, there is an array of different configurations that the feed itself may take-on, including further information about the specific work zone itself. While this information can certainly be appended to a static feed, the process of having an automated process that can generate finite information about a particular work zone is still an area of future research. The primary limitation of the study is indeed the inability for the smart work zones devices to automatically transmit the exact lane closed while being operated outside of external intervention from personnel. This exact limitation is described in Chapter 8. Lastly, the research team can see an area of future research to establish a methodology to automatically provide this information, and would also see ODOT considering key, additional, variables that should be added to the base WZDx feed.

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APPENDIX A: JAM LOGIC UI AND VARIABLES, AND WORK ZONE DATA EXCHANGE VARIABLES AND OBJECTS

A.1 JAM LOGIC UI

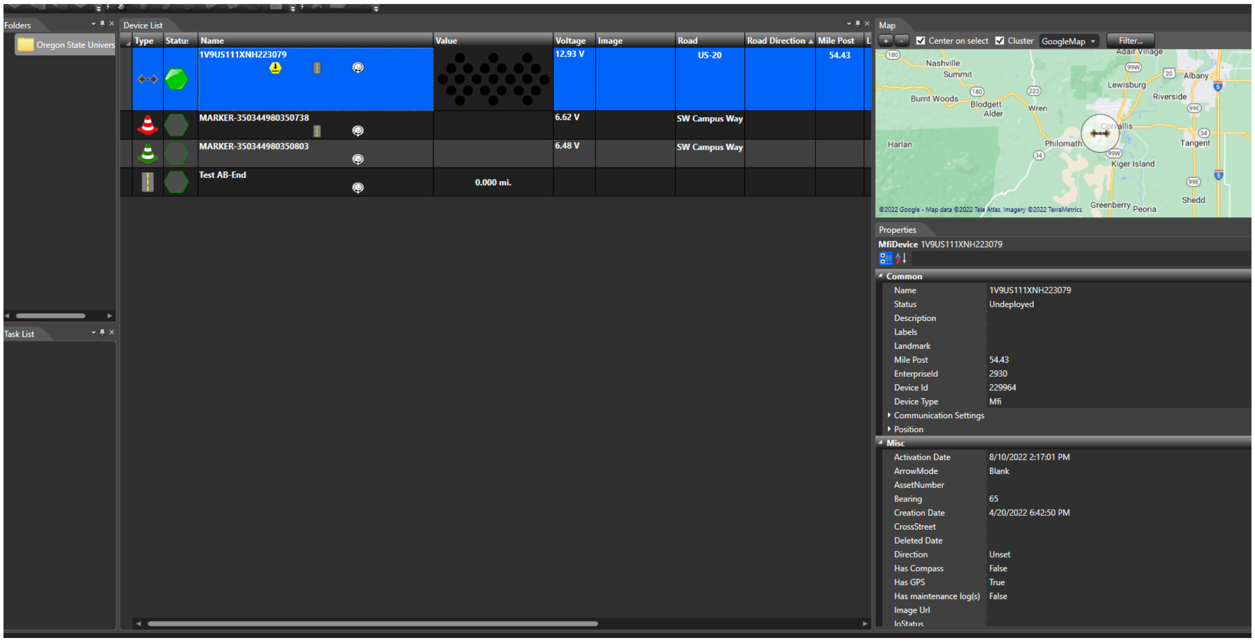

Figure A.1: Jam Logic User Interface

Table A.1: Ver-Mac Jam Logic Variables

Variable	Description	Associated Device
CrossStreet		SAB, Location Beacon
Current	Battery	SAB, Location Beacon
Current	Line	SAB, Location Beacon
Current	Solar	SAB, Location Beacon
Direction	Bearing	SAB, Location Beacon
FailedPushCount		SAB, Location Beacon
GpsComplement	Fix	SAB, Location Beacon
GpsComplement	Hdop	SAB, Location Beacon
GpsComplement	NumberOfSatellite	SAB, Location Beacon
HeartBeat		SAB, Location Beacon
Illumination	Photocell	SAB

Variable	Description	Associated Device
Interface		SAB, Location Beacon
Io		SAB, Location Beacon
Landmark		SAB, Location Beacon
MilePost		SAB, Location Beacon
ParentFolder		SAB, Location Beacon
Position		SAB, Location Beacon
Road		SAB, Location Beacon
SideOfTheRoad		SAB, Location Beacon
SignalStrength	RadioRssi	SAB, Location Beacon
SignalStrength	Rsrp	SAB, Location Beacon
SignalStrength	Rssi	SAB, Location Beacon
Temperature	Ambient	SAB
Temperature	Cabinet	SAB
Temperature	SignHousing	SAB
TrafficDirection		Location Beacon
TravelTimeState		SAB, Location Beacon
Voltage	Battery	SAB, Location Beacon
Voltage	Line	SAB, Location Beacon
Voltage	Solar	SAB, Location Beacon
Voltage	Source	SAB, Location Beacon

A.2 WORK ZONE DATA EXCHANGE FORMATTED SMART ARROW BOARD AND LOCATION BEACON DATA FEED FRAMEWORK:

- SwzDevice Feed [SwzDeviceFeed]
    - feed_info [Feed-info]
        - publisher
        - version
        - license
        - data_sources [FeedDataSource]
            - data_source_id
            - organization_name
            - update_date
        - update_date
        - update_frequency
        - contact_name
        - contact_email
    - features [FeildDeviceFeature]
        - id
        - type
        - properties
            - ArrowBoard [ArrowBoard]
                - core_details [FieldDeviceCoreDetails]
                    - device_type [FieldDeviceType]
                    - data_source_id
                    - road_names
                    - device_status [FieldDeviceStatus]
                    - update_date
                    - has_automatic_location

            - name
            - description
            - status_messages
            - road_event_ids
            - milepost
            - make
            - model
            - serial_number
            - firmware_version
        - pattern [ArrowBoardPattern]
        - is_moving
        - is_in_transport
    - LocationMarker [LocationMarker]
        - core_details [FieldDeviceCoreDetails]
            - See above under ArrowBoard
        - marked_locations [MarkedLocation]
            - type [MarkedLocationType]
- Geometry
    - type
    - coordinates

Hyperlinks imbedded into the tables operate in two functions: The header of the table provides a link to the GitHub web page associated with the Object. The hyperlinks imbedded within the table itself and not in the header provide a link to the associated table located within this document.

Table A.2 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: SwzDeviceFeed Object

SwzDeviceFeed Object			
Name	**Type**	**Description**	**Our Feed**
feed_info	[FeedInfo] Object	Information about the data feed.	See Feed-Info Table
type	String	The GeoJSON object type. For WZDx, this must be the string FeatureCollection.	"FeatureCollection"
features	Array;[FieldDevice Feature]	An array of GeoJSON Feature objects which each represent a field device deployed in a smart work zone	See FieldDeviceFeature Object Table

Table A.3 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: Feed-info Object

Feed-info Object			
Name	**Type**	**Description**	**Our Feed**
publisher	String	The organization responsible for publishing the feed.	"Ver-Mac inc."
version	String	The WZDx specification version used to create the data feed in major.minor format. Note this mandates that all data in a WZDx	4.0

Feed-info Object			
Name	**Type**	**Description**	**Our Feed**
		feed complies to a single version of WZDx.	
license	String; uri;	The URL of the license that applies to the data in the WZDx feed.	"https://creativecommons.org/publicdomain/zero/1.0/"
data_sources	Array;[FeedDataSource]	A list of specific data sources for the road event data in the feed.	See FieldInfo Object Table
update_date	String; date-time	The UTC date and time when the GeoJSON file (representing the instance of the feed) was generated.	"2022-08-01T20:53:21Z"
update_frequency	integer	The frequency in seconds at which the data feed is updated	1
contact_name	string	The name of the individual or group responsible for the data feed.	"Ver-Mac Support"
contact_email	Stinrg; email	The email address of the	"support@ver-mac.com"

Feed-info Object			
Name	**Type**	**Description**	**Our Feed**
		individual or group responsible for the data feed.	

Table A.4 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: FieldDeviceFeature Object

FieldDeviceFeature Object			
Name	**Type**	**Description**	**Our Feed**
id	String	A unique identifier issued by the data feed provider to identify the field device. It is recommended that this identifier is a Universally Unique IDentifier (UUID) as defined in RFC 4122.	"2005be59-d875-4910-ade2-13c30a6d4a38"
type	String; feature	The GeoJSON object type. This MUST be the string Feature.	"Feature"
properties	One of: ArrowBoard, Camera, DynamicMessageSign, FlashingBeacon, HybridSign, LocationMarker, TrafficSensor	The specific details of the field device.	See ArrowBoard and LocationMarker Tables
geometry	GeoJSON Geometry object with `type` of Point.	The geometry of the field device, indicating its location. The Geometry object's `type` property MUST be Point.	"type": "Point", "coordinates": [-123.29439544677734, 44.55388259887695]

Table A.5 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: ArrowBoard Object

ArrowBoard Object			
Name	**Type**	**Description**	**Our Feed**
core_details	[FieldDeviceCoreDetails]	The core details of the field device that are shared by all types of field devices, not specific to arrow boards.	See FieldDeviceCoreDetails Object Table
pattern	[ArrowBoardPattern]	The current pattern displayed on the arrow board. Note this includes `blank`, which indicates that nothing is shown on the arrow board.	“blank”
is_moving	Boolean	A yes/no value indicating if the arrow board is actively moving (not statically placed) as part of a mobile work zone operation.	false
is_in_transport_position	Boolean	A yes/no value indicating if the arrow board is in the stowed/transport position (`true`) or deployed/upright position (`false`).	true

Table A.6 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: FieldDeviceCoreDetails Object

FieldDeviceCoreDetails Object			
Name	**Type**	**Description**	**Our Feed**
device_type	[FieldDeviceType]	The type of field device.	"arrow-board"

FieldDeviceCoreDetails Object			
Name	**Type**	**Description**	**Our Feed**
data_source_id	String	Identifies the data source from which the field device data originates.	"2930"
road_names	Array; [String]	A list of publicly known names of the road on which the device is located. This may include the road number designated by a jurisdiction such as a county, state or interstate (e.g. I-5, VT 133).	"US-20"
device_status	[FieldDeviceStatus]	The operational status of the field device. The value of this property indicates if the device is ok or in an error or warning state.	"ok"
update_date	String; date-time	The UTC time and date when the field device information was updated.	"2022-08-01T20:00:17Z"
has_automatic_location	Boolean	A yes/no value indicating if the field device location (parent FieldDeviceFeature's geometry) is determined automatically from an onboard GPS (true) or manually set/overidden (false).	true
name	String	A human-readable name for the field device.	"1V9US111XNH223079"
description	String	A description of the field device.	“”

FieldDeviceCoreDetails Object			
Name	**Type**	**Description**	**Our Feed**
status_messages	Array; [String]	A list of messages associated with the device's status, if applicable. Used to provide additional information about the status such as specific warning or error messages.	"Not Deployed"
road_event_ids	Array; [String]	A list of one or more IDs of a RoadEventFeature that the device is associated with.	"234529"
milepost	Number	The linear distance measured against a milepost marker along a roadway where the device is located.	54.43
make	String	The make or manufacturer of the device.	"Signalisation VER-MAC Inc."
model	String	The model of the device.	"SmartArrow"
serial_number	String	The serial number of the device.	"356043110595196"
firmware_version	String	The version of firmware the device is using to operate.	"4.002"

Table A.7 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: FieldDeviceType Object

FieldDeviceType Object	
Value	**Description**
arrow-board	An electronic, connected arrow board which can display an arrow pattern to direct traffic.
camera	A camera device deployed in the field, capable of capturing still images.
dynamic-message-sign	An electronic traffic sign deployed on the roadway, used to provide information to travelers.

FieldDeviceType Object	
Value	**Description**
flashing-beacon	A flashing beacon light of any form, used to indicate caution and capture driver attention.
hybrid-sign	A message sign that contains both static text (e.g. on an aluminium board) along with a variable electronic message sign, used to provide information to travelers.
location-marker	Any GPS-enabled ITS device that is placed at a point on a roadway to mark a location (often the beginning or end of a road event).
traffic-sensor	A device deployed on a roadway which captures traffic metrics such as speed, volume, or occupancy.

Table A.8 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: FieldDeviceStatus Object

FieldDeviceStatus Object	
Value	**Description**
`ok`	The device is turned on and working without issue.
`warning`	The device is functional but is impaired or impacted in a way that is not critical to operation.
`error`	The device is impaired such that it is not able to perform one or more necessary functions.
`unknown`	The device's operational status is not known.

Table A.9 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: ArrowBoardPattern Object

ArrowBoardPattern Object	
Possible Values	**Description**
`blank`	No pattern; the board is not displaying anything.
`right-arrow-static`	Merge right represented by an arrow pattern (e.g. -->) that does not flash or move.
`right-arrow-flashing`	Merge right represented by an arrow pattern (e.g. -->) that flashes on/off.
`right-arrow-sequential`	Merge right represented by an arrow pattern (e.g. -->) that is displayed in a progressing sequence (e.g. > -> --> or - -- -->).
`right-chevron-static`	Merge right represented by a pattern of chevrons (e.g. >>>) that does not flash or move.
`right-chevron-flashing`	Merge right represented by a pattern of chevrons (e.g. >>>) that flashes on/off.
`right-chevron-sequential`	Merge right represented by a pattern of chevrons that is displayed in a progressing sequence.
`left-arrow-static`	Merge left represented by an arrow pattern (e.g. <--) that does not flash or move.
`left-arrow-flashing`	Merge left represented by an arrow pattern (e.g. <--) that flashes on/off.

ArrowBoardPattern Object	
Possible Values	**Description**
`left-arrow-sequential`	Merge left represented by an arrow pattern (e.g. <--) that is displayed in a progressing sequence (e.g. < <- <-- or - -- <--).
`left-chevron-static`	Merge left represented by a pattern of chevrons (e.g. <<<) that does not flash or move.
`left-chevron-flashing`	Merge left represented by a pattern of chevrons (e.g. <<<) that flashes on/off.
`left-chevron-sequential`	Merge left represented by a pattern of chevrons that is displayed in a progressing sequence.
`bidirectional-arrow-static`	Split (merge left or right) represented by arrows pointing both left and right (e.g. <-->) that does not flash or move.
`bidirectional-arrow-flashing`	Split (merge left or right) represented by arrows pointing both left and right (e.g. <-->) that flashes on/off.
`line-flashing`	A flashing line or bar (e.g. ---), indicating warning/caution, not a merge.
`diamonds-alternating`	An alternating display of two diamond shapes (e.g. ◇ ◇), indicating warning/caution, not a merge.
`four-corners-flashing`	Four dots on the corners of the board which flash, indiciating warning/caution, not a merge.
`unknown`	The arrow board pattern is not known.

Table A.10 Smart Arrow Board and Location Beacon Data Feed Variables and Objects: MarkedLocationType Object

MarkedLocationType Object	
Value	**Description**
`afad`	An automatic flagger assistance device.
`flagger`	A human who is directing traffic.
`lane-shift`	A lane shift.
`lane-closure`	One or more lanes are closed.
`temporary-traffic-signal`	A temporary traffic signal.
`road-event-start`	The start point of a road event.
`road-event-end`	The end point of a road event.
`work-zone-start`	The start point of a work zone.
`work-zone-end`	The end point of a work zone.