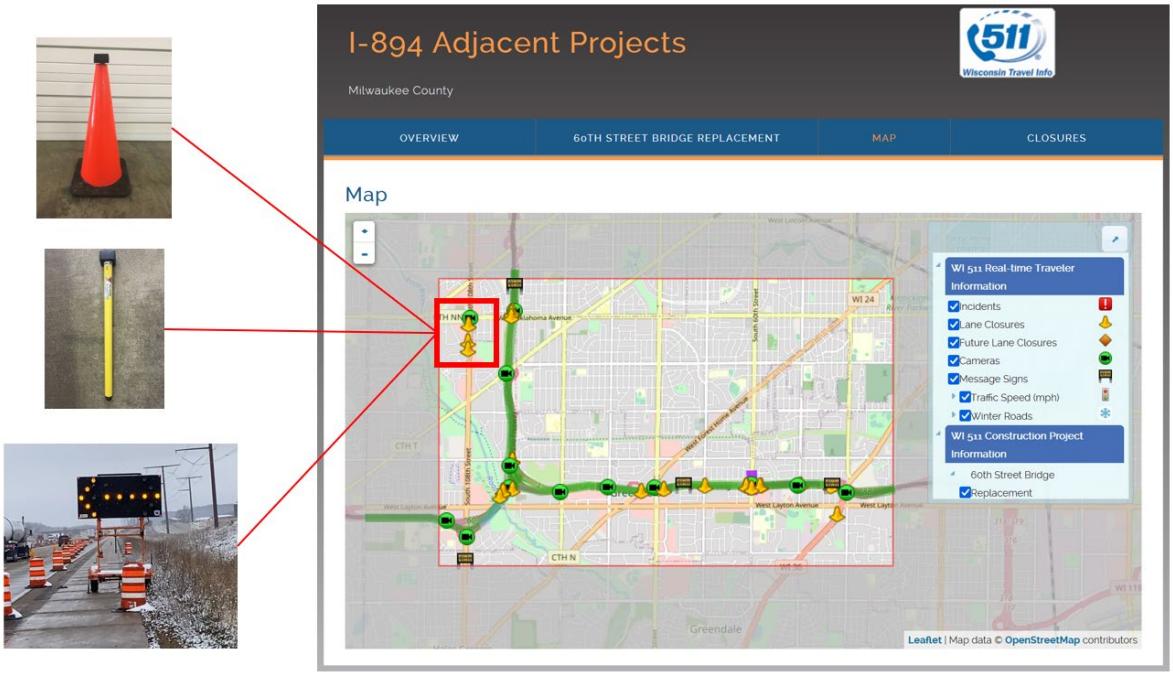
Extending the Wisconsin Work Zone Data Exchange (WZDx) to Local Roads Using Smart Work Zone ITS Devices



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Part 1 of 6: Introduction and Project Overview

Background

Work zones are necessary for the upkeep and improvement of our nation's roadway infrastructure, and every year thousands of hard-working men and women participate in street, highway, and bridge projects across the country. While these projects lead to important roadway safety and mobility improvements, they also create conditions that often result in crashes and excessive delay. As noted on the FWHA Work Zone Management Program website[1], work zone fatalities increased by 10.8% between 2020 and 2021, from 863 to 956 total fatalities. Of particular concern, after increasing by 21% over the previous period, the level of pedestrian and bicyclist work zone fatalities continued with a slight increase in 2021 relative to 2020, from 171 to 173. Whereas improving overall work zone safety will require a comprehensive approach, improving access to work zone data that incorporates real-time, field verified information using smart work zone technology represents a cornerstone of nearly all emerging strategies. Recognizing this need, the USDOT launched the Work Zone Data Exchange (WZDx) specification and in 2021 awarded $2.4M in demonstration grants to thirteen (13) states to develop public facing, WZDx compliant data feeds[2].

The Wisconsin Department of Transportation (WisDOT), as one of the thirteen demonstration grant recipients, has developed a new WZDx feed that conveys up-to-date, detailed information for all highway lane and road closures statewide, representing approximately 12,000 scheduled work zone events annually. However, the success of the Wisconsin WZDx effort is tempered by the fact that the data feed does not include work zones on the local road network. A limited number of local road closures that are associated with major improvement projects are currently entered manually into the Wisconsin 511 Construction Projects website[3]. All other local lane and road closures, including closures along locally maintained connecting highways[4], are not tracked at all through the system. These work zone events are inconsistently communicated to roadway users through various methods, leaving a large portion of work zones across Wisconsin unreported to roadway users and not documented for real-time and historic safety analysis.

While this can lead to unnecessary delay and safety issues, work zones on local roads also introduce additional factors that increase risks to vulnerable roads users (VRUs), such as pedestrians and bicyclists, and impact the efficient routing of emergency vehicles and first responders on the local road network. Rural local road closures introduce additional unique safety and mobility risks related to farm access and the safe and efficient movement of agricultural vehicles along the rural road network. Ensuring the equitable access to timely and accurate local road work zone event data in rural and under-resourced communities is therefore recognized as an important safety and mobility priority for Wisconsin and nationally.

The project proposed the use of connected work zone devices to incorporate real-time local road closure details into the Wisconsin WZDx and the Wisconsin 511 Traveler Information Systems. Connected work zone devices provides a strategic path to incorporate local lane closure information into the existing statewide data feed that is field verified and does not require the administrative overhead of a centralized lane closure scheduling system at the local level. The Stage 1 SMART Grant project expanded on the existing Wisconsin WZDx data model to incorporate local road work zone characteristics and prototype the capability on a select set of projects in Wisconsin using connected work zone devices purchased through

[1] FHWA Work Zone Facts and Statistics: https://ops.fhwa.dot.gov/Wz/resources/facts_stats.htm
[2] WZDx Demonstration Grants: https://ops.fhwa.dot.gov/wz/wzdx/demonstration_grants.htm
[3] 511 Wisconsin Construction Projects: https://projects.511wi.gov/
[4] Connecting highways are local streets and roads that carry state highway travel through cities and villages.

the grant. The Stage 1 SMART Grant project evaluated the ability to scale the proposed solution to all WisDOT improvement projects statewide with local road work zone components. Lastly, the project evaluated how to add local road work zones into the Wisconsin WZDx using connected work zone devices. The WisDOT Bureau of Traffic Operations (BTO) led the project with partners from the Wisconsin Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin – Madison, the Arcadis Group, and the Iowa County Highway Department.

The project had many different goals and desired outcomes for at-scale implementation which included addressing work zone safety and mobility concerns on the local road network by providing real-time, field verified work zone information to road users via the Wisconsin statewide WZDx. The grant also looked at equity and access to provide a way for all communities in Wisconsin to share local road work zone information to road users, including VRUs, through the Wisconsin statewide WZDx. WisDOT partnered with the Iowa County Highway Department, the WisDOT Northwest Region and Southwest Region offices and project staff.

The project looked at different technologies that could fall under coordinated automation, connected vehicles, intelligent sensor-based infrastructure, and systems integration. The technologies that were deployed during Stage 1 were connected arrow boards and connected location markers. The connected arrow boards provide information to drivers about lane closures and when they are active/not active and their GPS location. The connected location markers can provide information about the start/end of a work zone and can provide the GPS location. The Wisconsin Lane Closure System provided planned work zone event details to the WZDx for local road work zones that were part of a WisDOT improvement project and WisDOT local program project.

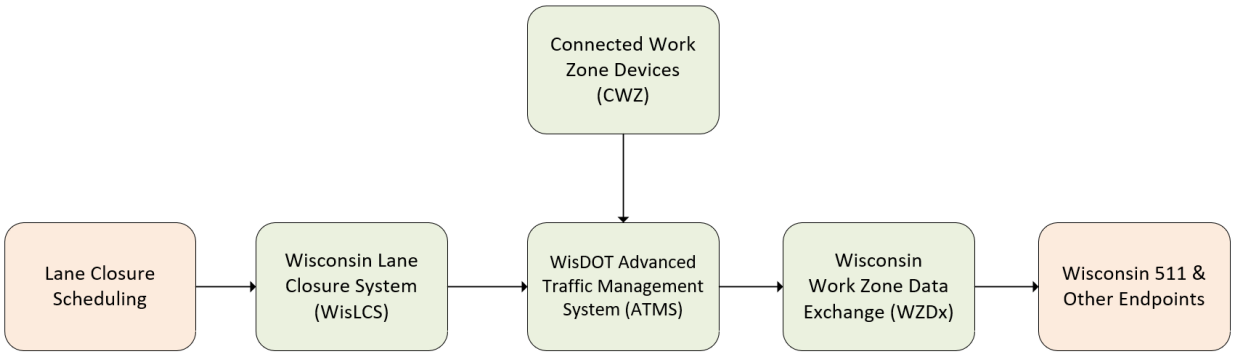
It should be noted that there were a few changes from when the SMART Grant was submitted to completion which are noted below and are discussed throughout the implementation plan:

- WisDOT had to select different projects to test the connected devices due to the timeline of the grant award and project start/end dates.
- WisDOT ran into issues with Wanco and was not able to test their connected devices due to shipping, lack of a WZDx compliant device feed and issues with the location markers.
- WisDOT was also not able to test the road-closure from the “markedlocationtype” in the WZDx feed as no manufacturer included the value in their WZDx feed at the time of the grant.
- To supplement the pilot site tests, the project team performed additional testing using a temporary connected work zone deployment outside of the WisDOT Southwest Region office.

Pilot Project Components

Over the course of the pilot project, several components of Wisconsin’s work zone data management system were upgraded to incorporate local road work zone event data. These components are part of an integrated work zone data architecture, illustrated below, that was developed for the highway work zone data management context under the FHWA 2020 Work Zone Data Exchange Demonstration Grant Program.

Figure 1: Work Zone Data Architecture



The key components of this architecture include:

1. Wisconsin Lane Closure System (WisLCS) – WisDOT's centralized work zone scheduling and approval system for all highway road and lane closures statewide. This system was upgraded to include support for standardized local road work zone lane types and local work zone roadway geometry.
2. WisDOT Advanced Traffic Management System (ATMS) – WisDOT's Statewide Traffic Management Center (TMC) system software for managing ITS roadway devices, supporting TMC control room activities, and providing traveler information. The ATMS was upgraded to manage local road work zone event data from the WisLCS and from Connected Work Zone Device pilot deployments.
3. Connected Work Zone Devices (CWZ) – Device feeds for connected arrow boards (CAB) and location markers were integrated into the ATMS to provide field verified work zone time and location attributes. These devices provided real-time data per the WZDx Device Feed specification.
4. Wisconsin Work Zone Data Exchange (WZDx) – Wisconsin's WZDx v4.2 compliant work zone data feed covering all approved highway closures statewide. The Wisconsin WZDx was upgraded to include local road work zone event details from the ATMS along with time and location field verification status values.

All upgrades were coordinated across the project team to maintain system interoperability and work zone event data standardization. It is important to note, however, that the underlying system architecture depicted above was not altered. This architecture was designed to support a scaled integration of CWZ devices across highway work zones in Wisconsin. The SMART Grant pilot project built upon this approach by testing its effectiveness and at-scale readiness for the local road work zone context. Details of the individual component upgrades are described more fully in the sections that follow.

This pilot project also investigated the optimal balance between user configuration and automated discovery of connected work zone devices with respect to a range of local road work zone types and reporting scenarios. The objective was to develop a practical strategy to scale the reporting of local road work zone event data statewide.

The scale of deployment during Stage 1 was relatively small compared to the number of work zones occurring around the state. One connected arrow board (CAB) and eight (8) work zone location markers were purchased. These devices were deployed in three separate work zone locations around the state, in Columbia County, Dunn County and Iowa County. Below is the project specific information.

Project Information

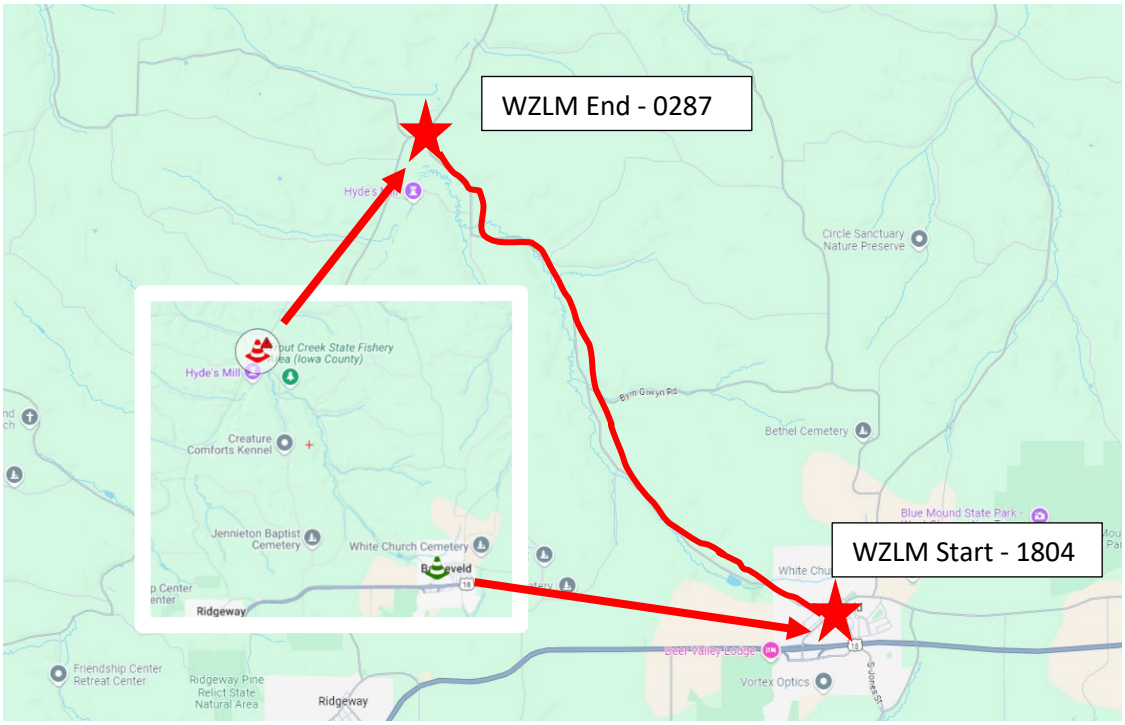
WisDOT piloted connected devices on different types of projects that include local roads. Below are the definitions for each of the different types of local roads that will be discussed for implementation:

1. WisDOT Improvement Project – a state highway project that impacts a local road.
2. WisDOT Local Program Project – a project that is on a local road but funded and administered by WisDOT.
3. Local Project – a project that is on a local road with no WisDOT involvement.

<u>Iowa County Highway Department: CTH T from Wood Street to CTH H</u>

The first project was located in Iowa County in the southwestern part of Wisconsin on CTH T from Wood Street to CTH H. The project was a full reconstruction with a full closure and detour route. This was also a local project so there was not a WisLCS closure event. The connected devices deployed from October 15, 2024 to November 25, 2024.

Figure 2: Iowa County Project Location



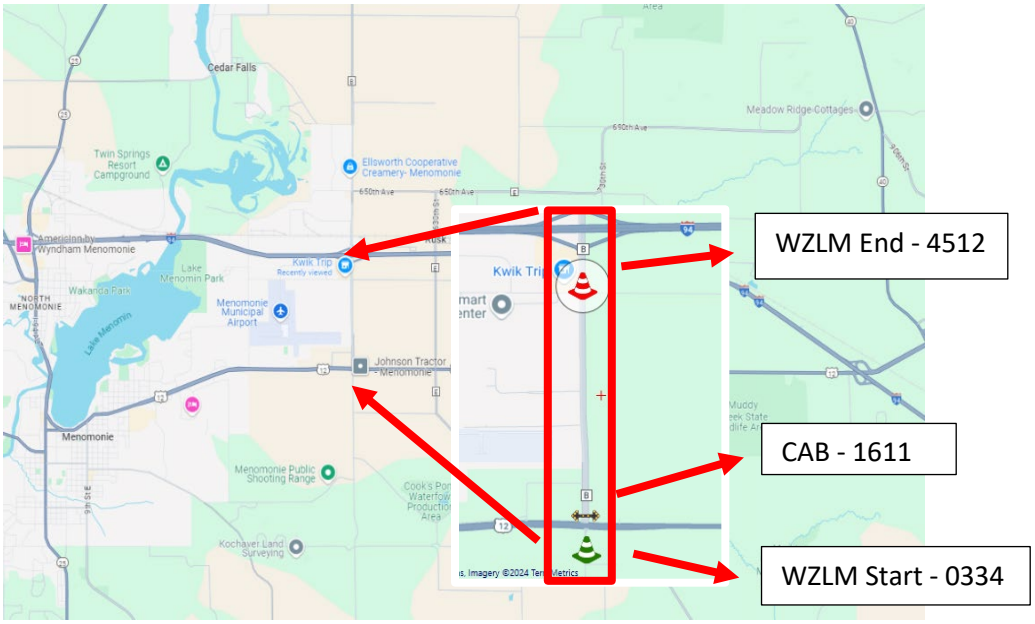
<u>WZLM Start- 1804</u>

WZLM End – 0287

WisDOT NW Region: CTH B from USH 12 to IH 94, Dunn County, Project ID: 7996-00-43

The second project was located in Dunn County in the northwestern part of Wisconsin on CTH B from USH 12 to IH 94 (Project ID: 7996-00-43). The project was a local road reconstruction with lane closures and had a WisLCS closure entry since it was a WisDOT Local Program Project. The connected devices deployed from October 10, 2024 to October 25, 2024.

Figure 3: Dunn County Project Location



Connected Arrow Board - 1611

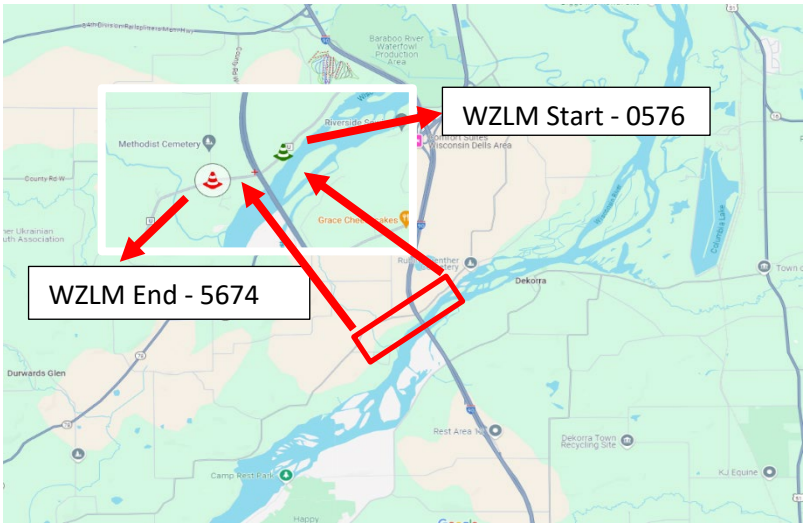
WZLM Start - 0334

WZLM End - 4512

WisDOT SW Region: IH 39/90/94, Wisconsin River Bridges/CTH U Overpass, Columbia County, Project ID 1010-10-82

The third project was located in Columbia County in the central part of Wisconsin on IH 39/90/94 at the Wisconsin River Bridge/CTH U Overpass (Project ID 1010-10-82). The project was a local road bridge reconstruction with full closure that was part of the overall WisDOT Wisconsin River Bridge project. Since this was a WisDOT Improvement Project there was a WisLCS closure entry. The connected devices deployed from October 10, 2024 to November 15, 2024 and again from January 28, 2025 to February 25, 2025.

Figure 4: Columbia County Project Location



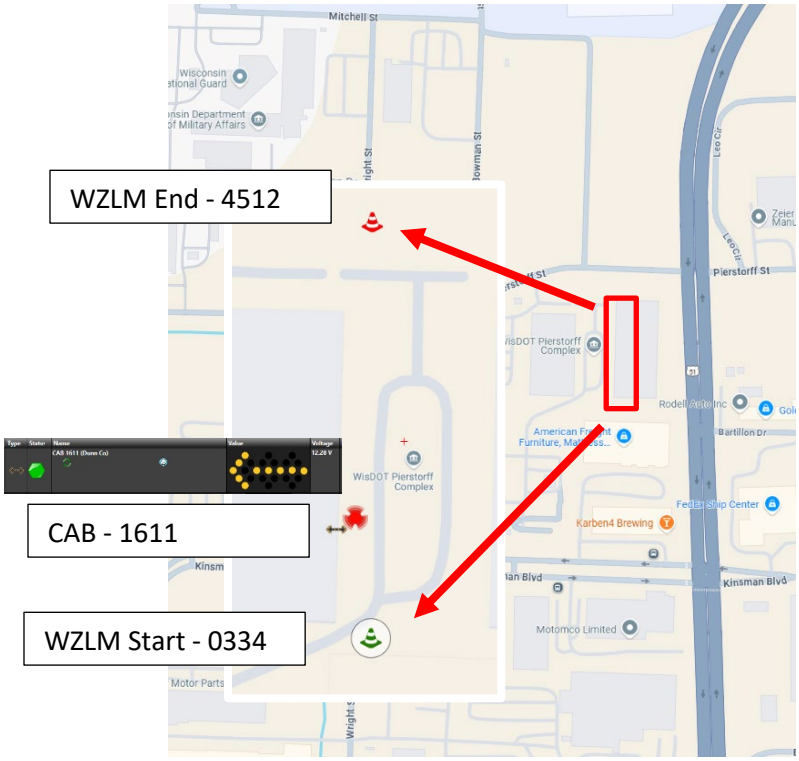
WZLM Start – 0576

WZLM End – 5674

WisDOT Sign Shop – Additional Testing

The project also completed additional testing at the WisDOT sign shop in Madison, WI. The other projects that were used for testing were completed in late November and early December, therefore we set up a "test" work zone to complete the final testing. The connected devices deployed from February 20, 2025 to March 14, 2025.

Figure 5: Test Location, WisDOT Sign Shop



Connected Arrow Board - 1611

WZLM Start – 0334

WZLM End - 4512

The stage 1 portion of the grant was successful with a lot of lessons learned that are discussed throughout the document. Based on the findings of Stage 1, WisDOT is recommending moving forward with a Stage 2 project that would achieve the desired statewide scale, which is described in detail below:

Table 1: Stage 2 Planned Work and Estimated Costs

Phase 1 - Year 1		**Cost**
Wisconsin DOT Improvement Projects with Local Road Impacts	**$**	**75,000.00**
• Update standards and policies to require connected devices and • WisLCS entry for all WisDOT Improvement Projects with Local Road Impacts • Testing and review of data quality for events in ATMS and WZDx • As noted in the implementation plan, there will be edge cases that WisDOT will determine how to handle in this phase. • Traning and outreach to WisDOT staff and others about the new standards and policies.		

Phase 1 - Year 1		**Cost**
Wisconsin Local Program Projects	**$**	**150,000.00**
• Update standards and policies to require connected devices and WisLCS entry for all WisDOT Improvement Projects with Local Road Impacts • Updates to both WisCLS and the ATMS to bring in local road geometry • As noted in the implementation plan, there will be edge cases that WisDOT will determine how to handle in this phase. • Testing and review of data quality for events in ATMS and WZDx • Training and outreach to WisDOT staff and others about the new standards and policies.		

Phase 1 - Year 2		**Cost**
Local Projects Testing	**$**	**365,000.00**
• Building local road closures in the ATMS without a WisLCS entry		
• Purchase Equipment for up to 10 local agencies to complete local road testing for the ATMS		
○ Connected Arrow Boards – 10 total x $6,000	$	60,000.00
○ Work Zone Start Markers – 10 total x $2,000	$	20,000.00
○ Work Zone End Markers – 10 total x $2,000	$	20,000.00
o Total Cost	***$***	***100,000.00***
• Training and outreach to local agencies.		
• Testing and review of data quality for events in ATMS and WZDx as well as archiving the data.		

Phase 2 - Year 3	Cost
Local Projects Roll-Out Statewide	**$ 3,930,000.00**
• Purchase equipment for local agencies. Wisconsin is comprised of 72 counties, 1,253 towns, 190 cities, and 411 villages which is a total of 1,926 local governments who would need connected devices. The plan would be to provide connected devices to a 25% of the local governments. The department would anticipate a competitive bid with the total number of devices that would be purchased.	
○ Connected Arrow Boards – 480 total x $5,000	$ 2,400,000.00
○ Work Zone Start Markers – 480 total x $1,500	$ 720,000.00
○ Work Zone End Markers – 480 total x $1,500	$ 720,000.00
○ ***Total Cost***	***$ 3,840,000.00***
• Training and outreach to local agencies.	
• Testing and review of data quality for events in ATMS and WZDx as well as archiving the data.	

Phase 1 and 2	Cost
Work Zone Quality Assurance Engineer	**$ 600,000.00**
• On-site engineer to perform data quality, check the ATMS and WisLCS, link devices to WisLCS entry if not automatically associated, document issues and identity process improvements.	

Stage 2 Total	$ 5,120,000.00

WisDOT ATMS Updates

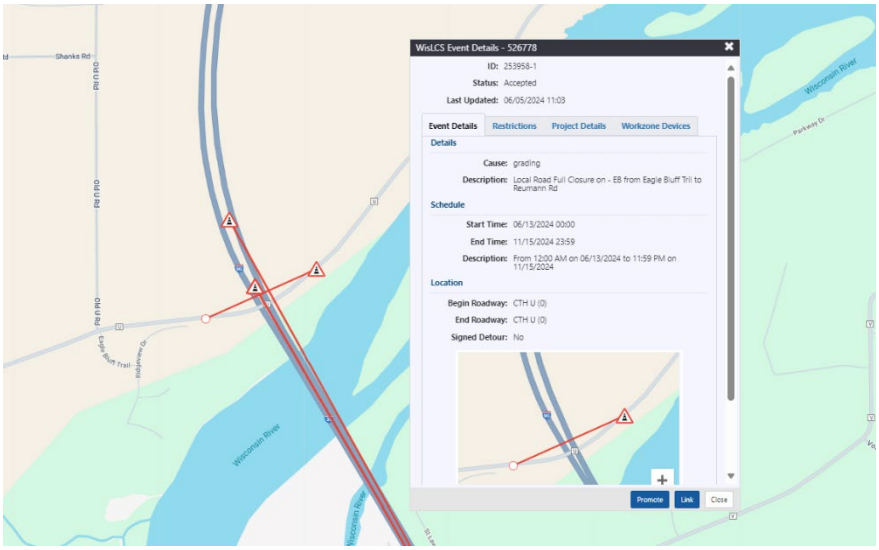
Throughout the project there were a number of ATMS updates that were completed. Some of the updates were completed under a different task order and some were completed with the grant, but the department thought it would be good to discuss all the efforts as one since they are directly related to each other.

To support the use of connected work zone devices, a simplified workflow was designed to automate the process of associating a connected work zone device to a work zone. The project team has tested manual device association with work zone events; however, an automated workflow will be necessary to support a full-scale implementation as the operational needs for manual association would be immense. Development is completed for the association process of connected devices within the ATMS. During Stage 1, this process automation process was tested and was successful for the limited testing that was completed.

Additionally, the underlying assumption is that some form of base mapping is required to associate events and devices when there is not a WisLCS entry, and the development effort completed so far is beginning to highlight the mapping data needs that would be required for a statewide implementation in Stage 2.

Figure 5 below shows the WisLCS event, but the device mapping where it does not follow the roadway. This was updated in the ATMS and if there is a WisLCS event, the ATMS will use the underlying mapping from LCS but if there is not a WisLCS event, the ATMS will need to map the connected devices.

Figure 6: ATMS Event Information



Automatic Device Association

As part of a different task order, the department added functionality to automatically associate connected devices with work zone events in the ATMS instead of having a manual intervention by the traffic management center operators. Below is the logic for how the device association works:

- On an interval (e.g. every 60 seconds), the software will perform the following for every connected device in the system:
    1. Remove all automatic associations for the device (manual associations are not affected).
    2. If the device is not recently updated, do not associate this device with an event—skip the remaining steps.
    3. Check every work zone road event in the system to determine which meet the criteria for being associated: the event must be nearby the device (physical location) and the overall event must have started (based on planned dates) and not finished (approximately—the system will still associate if the dates are close, based on configuration).
    4. If there is only one event that meets the criteria for being associated, associate the device with that event.

Verify Work Zone Events Using Devices

Logic was also added through the project to verify and modify (to improve accuracy) work zone events in the outgoing WZDx Work Zone Feed using real-time information from connected work zone devices that are deployed in the work zone.

When a WZDx Work Zone Feed is requested, the software will loop through every work zone road event in the system, get all recently updated (not stale) field devices associated with it, and for the active occurrence of the event, performs the following to modify the occurrence in the feed based on device type:

- Arrow Board: If the arrow board is “off” (blank), verify that the event has ended (set “end date verified” field and set occurrence end date to the timestamp when the arrow board was turned off).If the arrow board is “on” (displaying a pattern), verify that the event has started (set “start date verified” field and set occurrence start date to the timestamp when the arrow board was turned on).
- Flashing Beacon: If the beacon is currently flashing, verify that the event has started (set “start

date verified" field and set occurrence start date to the timestamp when the beacon started flashing).

- Location Marker: Use the "work zone start" and/or "work zone end" marker to verify the start and/or end location of the occurrence (set "is location verified" fields) and update the event path based on the locations of the marker.

Improve WZDx Work Zone Feed

As part of a different task order, the representation of events in the outgoing WZDx Work Zone Feed was improved by splitting recurrent events into their occurrences and connecting the occurrences using the "related road events" capability defined in the WZDx specification.

WisDOT Work Zone Data Exchange Updates

As noted, the Wisconsin WZDx provides standardized work zone event data from WisDOT's WisLCS and ATMS systems, both of which have traditionally been oriented toward highway events. The Stage 1 SMART Grant project therefore included software updates to prepare these systems to manage local road work zone event data, particularly with respect to WZDx local road lane types. The WZDx JavaScript Object Notation (JSON) record shown below is taken from a local road closure (#250575) that was created within the project team's test environment to demonstrate end-to-end interoperability of local road work zone event data flows through the WisLCS, ATMS, and WZDx components.

The newly added local road work zone "two-way-center-turn-lane," "parking," "bike-lane," and "sidewalk" lane types have been captured alongside the existing "general" lane type that is used for both highway and local road contexts. As a test closure, this example was not associated with actual CWZ devices in the field and as such, the "is_end_date_verified," "is_end_position_verified," "is_start_date_verified," and "is_start_position_verified" boolean values are set to false.

An important part of the pilot evaluation, as described below, focused on enhancing capabilities within the ATMS to set these values to true based on real-time local road work zone CWZ device status updates. The WisLCS and ATMS already included basic capabilities to manage local road work zone geometry which was used largely without modification in the pilot evaluation. Examples of local road geometry are provided in the later in this report.

Figure 7: WZDx Feed with Local Road Attributes

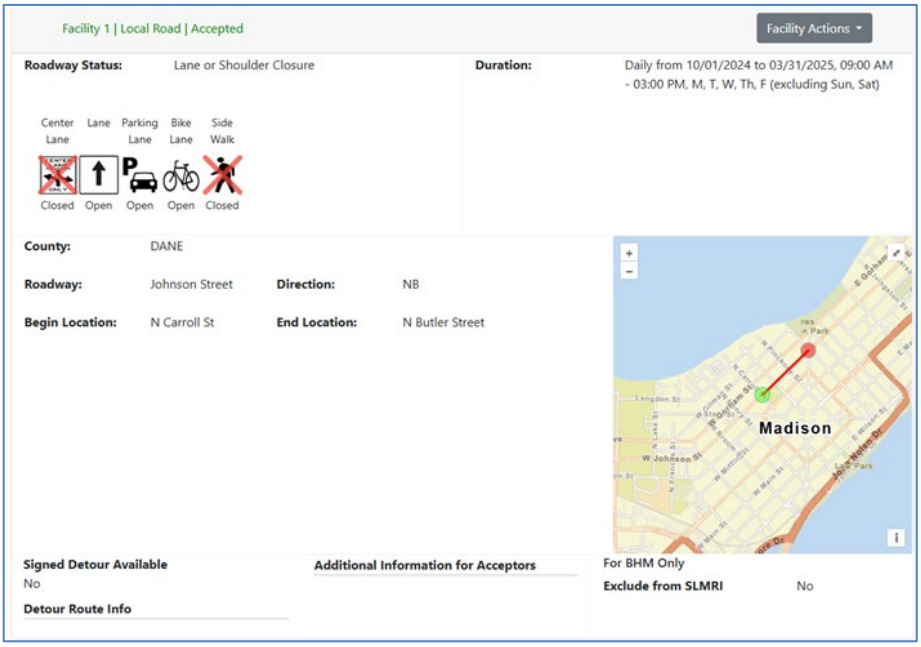

```
{
  "core_details": {
    "creation_date": "2025-01-24T15:55:10.083+00:00",
    "Datasource": "ATMS",
    "description": "Local Road Various Lanes Closed on Johnson Street NB from N Carroll St to N Butler
Street",
    "direction": "northbound",
    "event_type": "work-zone",
    "name": "ExtEvent-Johnson Street NB-NB-20241001",
    "related_road_events": [
      {
        "id": "7b5c9ed3-81ea-5a56-a318-e4cced0676af",
        "type": "first-occurrence"
      }
    ],
    "road_names": [
      "Johnson Street NB"
    ],
    "update_date": "2025-01-24T15:55:10.083+00:00"
  },
  "end_date": "2025-02-21T21:00:00+00:00",
  "is_end_date_verified": false,
  "is_end_position_verified": false,
  "is_start_date_verified": false,
  "is_start_position_verified": false,
  "lanes": [
    {
      "order": 1,
      "restrictions": [],
      "status": "closed",
      "type": "two-way-center-turn-lane"
    },
    {
      "order": 2,
      "restrictions": [],
      "status": "open",
      "type": "general"
    },
    {
      "order": 3,
      "restrictions": [],
      "status": "open",
      "type": "parking"
    },
    {
      "order": 4,
      "restrictions": [],
      "status": "open",
      "type": "bike-lane"
    },
    {
      "order": 5,
      "restrictions": [],
      "status": "closed",
      "type": "sidewalk"
    }
```

WisDOT Lane Closure System Updates

The Wisconsin Lane Closure System (WisLCS), WisDOT's central lane closure scheduling software, serves as the source system for planned highway closures statewide. Although the WisLCS was designed primary for highway events, the WisLCS has also included basic capabilities for tracking local road closures associated with existing highway projects. To support the full WZDx specification for local road work zone events, the WisLCS was updated to incorporate four additional WZDx lane types: sidewalk, bike-lane, parking, two-way-center-turn-lane. The new lane types were also incorporated into an internal web service API that supports work zone event data interoperability between the WisLCS and ATMS. The WisLCS already included an ability to define local road closure geometry in terms of a WZDx conforming GeoJSON multistring object which was considered sufficient for the Stage 1 pilot project.

The figure below shows a fictional local road closure that incorporates the new local road lane types is given below. This example corresponds to the WZDx record (#250575) from the WisLCS test environment shown earlier in this section.

Figure 8: WisLCS Entry with New Local Road Lane Types



Unlike highways, local roads in the LCS are not managed with respect to formal linear referencing system (LRS) geometry. Instead, road names and roadway geometry are entered as free text and using a drawing tool to generate the GeoJSON multistring.

Part 2 of 6: Proof-of-Concept or Prototype Evaluation Findings

The connected work zone devices were be deployed October through the end of November and then again in January for additional testing. Below are the performance measures that were evaluated as part of the SMART Grant. Each evaluation question is answered in more detail on the following pages.

Evaluation Question	Performance Measure	Performance Measure Target
1. Were the pilot deployments successful?	Pilot work zone event data available in the WZDx and field verified.	1. Basic work zone event data is captured in the WZDx 2. Time and position attributes are verified per connected devices 3. Bike-path and side-walk impacts are included, where applicable
2. How successful was the pilot at automatically assigned connected devices to corresponding work zone events in the ATMS?	Number of successful automated assignments in the ATMS.	1. Less than 20% unassigned 2. Less than 10% assigned incorrectly
3. How reliable was the connected device integration?	Connect device status availability in the ATMS.	1. Real-time connected device statuses available 90% of the time during planned operational hours
4. How accurate was the connected device integration data quality for WZDx event reporting?	Comparison of time and positional attributes to ground truth observations.	1. WZDx verified start times within 5 minutes of true work zone start time 2. WZDx verified end times within 5 minutes of true work zone end time 3. WZDx verified start position within 0.1 miles of true work zone start position 4. WZDx verified end position within 0.1 miles of true work zone end position
5. What were the minimum data / integration requirements to be successful for each scenario?	Number of devices required to meet WZDx reporting requirements.	1. One arrow board for worker presence 2. One arrow board and two location markers for time and position field verification
6. What were the key challenges by field staff in the setup, configuration, and maintenance of connected devices for purposes of this project?	Ease of implementation (simple, moderate, challenging).	1. Minimal user reported issues 2. Challenges 3. Questions from field staff
7. Was it easy to procure the devices?	Ease of procurement (simple, moderate, challenging).	1. Comparable to procurement of traditional work zone traffic control devices for similar work zones.
8. How much did the workload increase for field staff and ATMS staff?	% scale, 0-100% increase in workload to support the connected device integration.	1. Less than 5% increase in workload reported by field staff 2. Less than 5% increase in workload reported by TMC staff

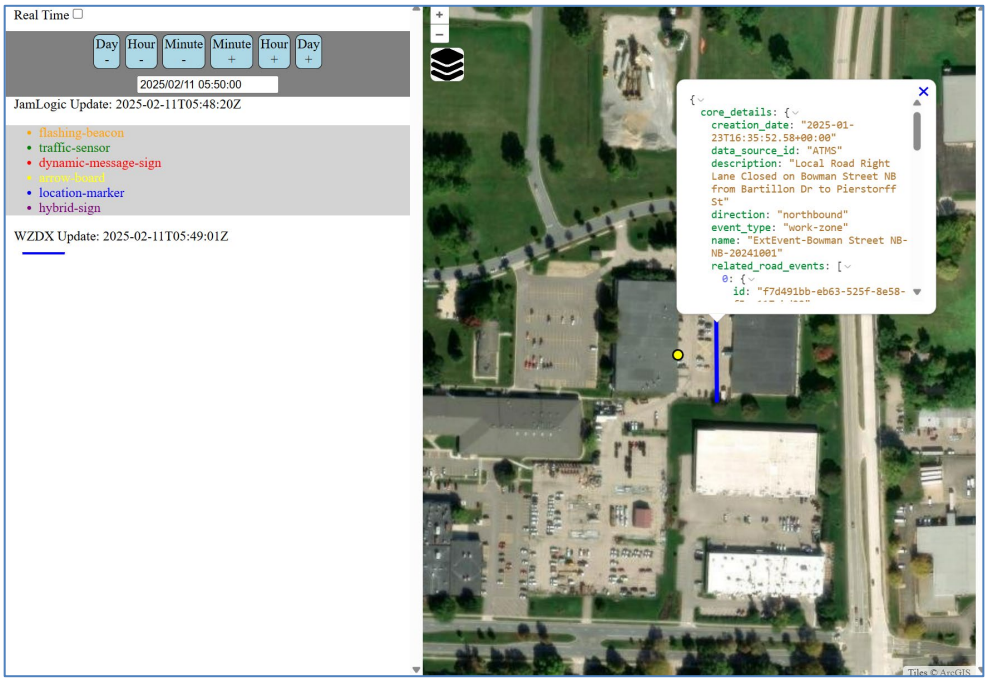
The following data collection activities were performed by the project team to support evaluation:

Pilot Site Data Archiving

- Connected work zone device status (CAB and location markers) from the Ver-Mac WZDx Device Feed was archived for all pilot sites at 60-second intervals over the duration of the pilot.
- Work Zone Data Exchange snapshots from the WisDOT production and test ATMS endpoints were archived at 60-second intervals over the duration of the pilot.
- Snapshots of the internal "LCS API" were archived at 60-second intervals over the duration of the pilot. The LCS API supports interoperability between the WisLCS and ATMS.

The Wisconsin SMART WZDx Project Dashboard (https://transportal.cee.wisc.edu/services/smart-pilot/device-history/), a map-based utility, was developed for the project team to view real-time and archived status information from the ATMS WZDx and Ver-Mac device feeds. This utility allows a user to select a point in time to view the GeoJSON contents along with mapped device locations and work zone multi-string geometries.

Figure 9: Map-based utility showing a snapshot of the WZDx geometry and GeoJSON attributes for the SW Region office deployment.



Project Team Pilot Site Visits

The project team conducted several pilot site visits to inspect the devices, take GPS measurements, and evaluate the effects of moving and power-cycling the devices:

Table 2: Project Site Visit Summary

Location	Date	Field Tests and Observations
Dunn County	10/16/2024	Power-cycled, moved, and changed the orientation of the location markers. Power-cycled the CAB. Recorded independent GPS locations for all three devices. Observed and recorded real-time impacts through the Ver-Mac device feed.
Columbia County	10/30/2025	Power-cycled, moved, and changed the orientation of the location markers. Recorded independent GPS locations for all three devices. Observed and recorded real-time impacts through the Ver-Mac device feed.
Columbia County	11/06/2025	Power-cycled and moved the location markers. Recorded independent GPS locations for both devices. Observed and recorded real-time impacts through the Ver-Mac device feed.
Iowa County	11/13/2024	Power-cycled and moved the location markers. Recorded independent GPS locations for both devices. Observed and recorded real-time impacts through the Ver-Mac device feed.
Iowa County	11/22/2024	Power-cycled and moved the location markers. Recorded independent GPS locations for both devices. Observed and recorded real-time impacts through the Ver-Mac device feed.
Dane County	2/19/2025, 2/20/2025	Additional CAB and location marker testing at the WisDOT SW Regional office. Power-cycled and moved the location markers. Power-cycled the CAB.

Several observations to note from the pilot site visits:

- The Iowa County end-location marker had intermittent cell service and was not available in the Ver-Mac device feed for most of the 11/13/2024 and 11/22/2024 site visits. This was attributed to the location of the marker with respect to the cell tower. The project team also experienced poor to no-cellular connectivity from that location.
- During the 11/6/2024 site visit to Columbia County, the start marker 0576 was found lying on its side. Nevertheless, the location marker continued to report its location.

- The project team met with Ver-Mac on 11/4/2025 to better understand how location marker values are updated in the device feed. Per that meeting, a standard operating procedure for moving the location markers (described above) was developed and applied during subsequent pilot tests.

Evaluation Question #1: Were the pilot deployments successful?

1. *Basic work zone event data is captured in the WZDx*

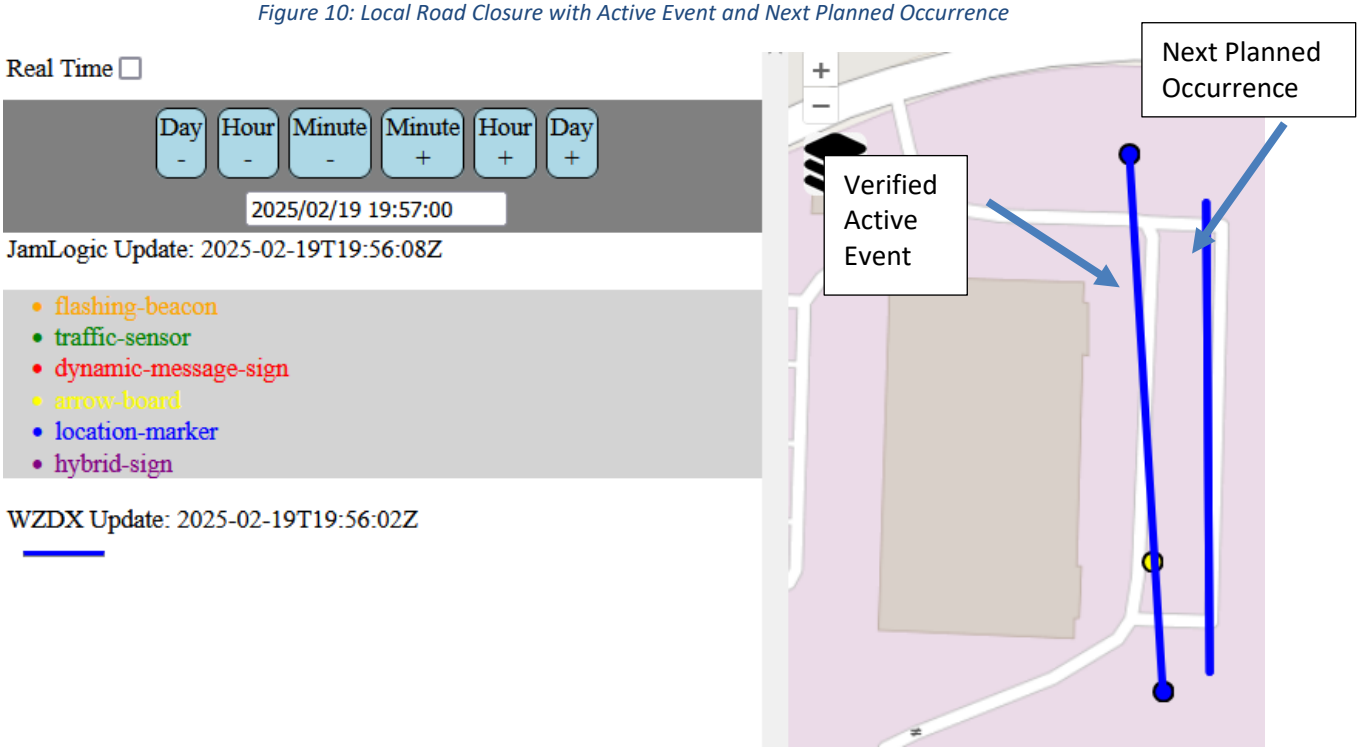
Yes, basic local road work zone attributes from the Wisconsin Lane Closure System, including local road lane types, status, and geometry, were successfully included in the WZDx feed.

2. *Time and position attributes are verified per connected devices*

CWZ logic in the ATMS was not available in time to provide time and location field verification during the formal pilot deployments. However, this capability was subsequently demonstrated through an additional deployment on location at the WisDOT Southwest Regional office. During the additional testing, the start date of the WZDx event was updated appropriately and marked as verified when the arrow board was turned on. Likewise, the start and end positions were changed to verified and the event geometry was updated automatically when a start and end marker were associated with the same work zone. Through these automatic updates it is reasonable to say a user of the WZDx feed could infer that the work zone is active given the verified fields.

The figures below are taken from the Project Dashboard, which shows a local road closure that has an active event (the left linework) and its next occurrence (the right linework). The active event was successfully associated with two location markers and an arrow board, and its geometry was automatically adjusted to match the two location markers. The next occurrence on the right has not yet been associated to the location markers and is therefore still displayed based on the original WisLCS geometry.

Figure 10: Local Road Closure with Active Event and Next Planned Occurrence



The GeoJSON content in the following figure demonstrates how the CWZ device assignments translate to WZDx field verification of the closure time and location attributes. The active work zone event on the left

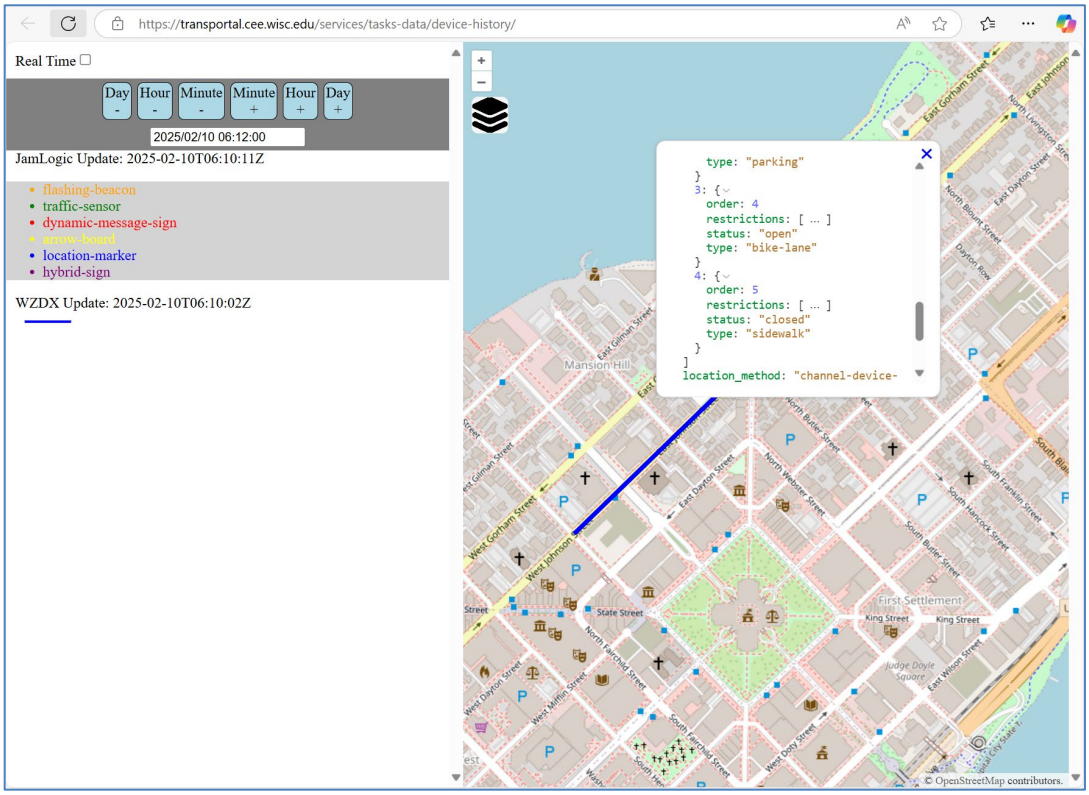
panel, which has been associated to the location markers and arrow board, has the start date, start position, and end position verification elements set to true. The future event on the right, on the other hand, has not yet been associated to the field devices, and the corresponding date and position verification elements are still set to false.

Figure 11: Active WZ Event vs Future WZ Event

3. Bike-path and side-walk impacts are included, where applicable

Yes, local work zone lane attributes from the WisLCS for bike-lane, sidewalk, parking lane, and two-way-center-turn-lane were successfully included in the WZDx feed, as demonstrated previously for the WisLCS test closure #250575. The WZDx multi-string geometry and lane level attributes for this closure as captured in the Project Dashboard (https://transportal.cee.wisc.edu/services/smart-pilot/device-history/) are shown below:

Figure 12: Local Road WZ Attributes



The overall deployment of connected devices was successful, but there were a number of lessons learned which are listed below:

- Connected Location Markers
    a. A Location Marker, as represented in the WZDx device feed, cannot be used to verify the start date of a work zone event because the WZDx specification does not provide a way to represent “on” or “off”.
    b. Additional location markers may be used to mark the location of a full closure using the “markedlocationtype” – road-closure option which would then provide the start time of the full closure. At the time of the grant, the manufacturer’s location markers did not have the option this option, so it is recommended that manufacturers start including this option in the WZDx device feed.

Figure 13: "MarkedLocationType" WZDx Feed

MarkedLocationType Enumerated Type

The `MarkedLocationType` enumerated type describes options for what a MarkedLocation can mark, such as the start or end of a road event.

Values

Value	Description
`afad`	An automatic flagger assistance device.
`delineator`	A generic delineation point in a work zone. This value can be used for most types of marked locations that don't match any of the other values.
`flagger`	A human who is directing traffic.
`lane-shift`	A lane shift.
`lane-closure`	One or more lanes are closed.
`personal-device`	A connected device that is worn or carried by an individual worker in a work zone.
`ramp-closure`	The start of a closed ramp onto or off a main road or highway.
`road-closure`	The start of a closed road.
`road-event-start`	The start point of a road event.
`road-event-end`	The end point of a road event.
`work-truck-with-lights-flashing`	A work truck with lights flashing, actively engaged in construction or maintenance activity on the roadway.
`work-zone-start`	The start point of a work zone.
`work-zone-end`	The end point of a work zone.
`temporary-traffic-signal` (DEPRECATED)	A temporary traffic signal. *This property will be removed in a future release; use TrafficSignal instead.*

c. It was observed that there is an unknown update time for the location markers depending on different factors. As such, after meeting with Vermac, a standard operating procedure was developed to reliably communicate local road work zone start and end locations:
    i. Power down the start / end location marker.
    ii. Move the start / end location marker to the new location in the work zone.
    iii. Power up the start / end location marker.
    iv. In contrast, failing to follow this procedure was observed to lead to erroneous locations and uncertain update frequencies in the device feed. Whereas this procedure, when followed, was found to be reliable, it represents an additional training step for work zone personnel and may not be applicable for all device manufacturers.

- In order for a work zone to be accurately mapped without a WisLCS entry, there would need to be a minimum of three devices in each required direction for local projects.
- It was difficult to reliably map local projects without a WisLCS entry, so in the future the Department would require WisLCS entries for every WisDOT Improvement Project and WisDOT Local Program project. We would require a minimum of three devices to accurately map and verify the work zone is present.

Evaluation Question #2: How successful was the pilot at automatically assigning connected devices to corresponding work zone events in the ATMS?

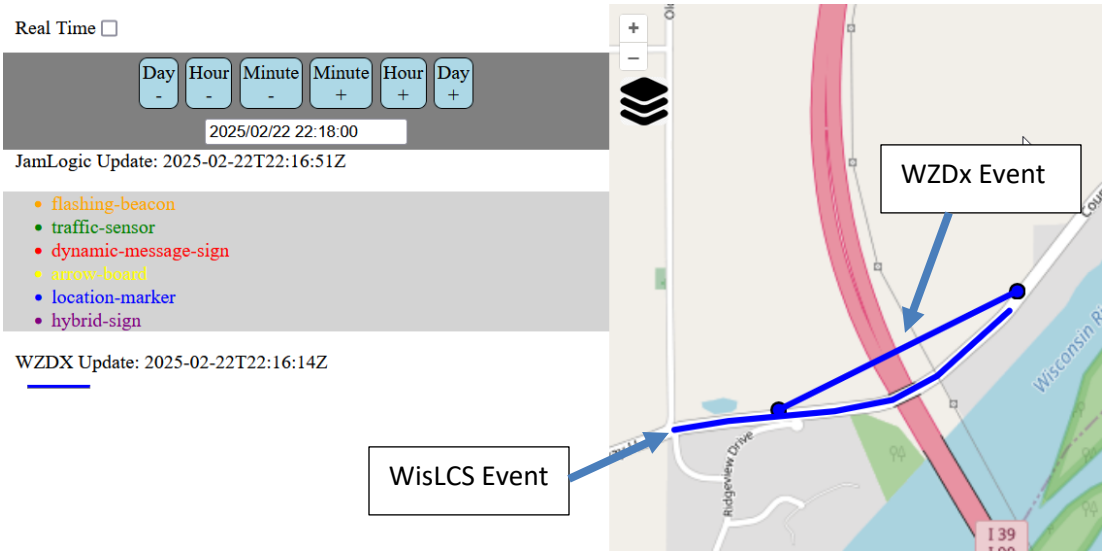
1. *Less than 20% unassigned*
2. *Less than 10% assigned incorrectly*

The feature to automatically assign connected devices to work zone events in the ATMS was not in place during the initial testing of the pilot with real-world construction projects. WisDOT did complete additional testing at the WisDOT SW Region sign shop where this process was successfully demonstrated. Therefore, the project team is confident that had the feature been available in ATMS, the pilot would have been successful and will be moving forward.

There were several lessons learned with regards to automatically assigning connected devices to work zone events in the ATMS and are listed below:

- If there is a WisLCS event, the ATMS will keep the WisLCS geometry and update the start/end location coordinates. If there is not a WisLCS event, the ATMS will need to know the roadway geometry, which is not a feature right now but would be developed in Stage 2. The figure below shows the planned WisLCS event following the roadway geometry and the straight line is the verified location, so you can see there is not the underlying mapping associated with it. This was fixed with an update to the ATMS and if there is a WisLCS Event, the ATMS will use the WisLCS mapping instead of creating the roadway geometry.

Figure 14: Comparison of WisLCS Event and WZDx Event



- In order for the ATMS to automatically assign the connected devices to a WisCLS entry, there will need to be a minimum of three devices marking the start/end of the work zone and then the impact with an arrow board or other location marker.

Evaluation Question #3: How reliable was the connected device integration?

The project team was unable to measure device integration within the ATMS at the time of the local road work zone pilot deployments. As such, reliability measurements were obtained by reviewing archived device status records obtained from the manufacturer's WZDx device feed. Device status records were archived at 60-second intervals over the course of the pilot deployment. Device *availability* was taken as the percentage of time over the deployment period for which a status update was available in the archive. *Lag* was taken as the difference in seconds between the feed update and the update time of the individual devices.

The feeds from the devices were reliable and current with the exception of one device in the Iowa County project where the cellular connection was intermittent. The statistics of the device availability and the update time of the device relative to the feed update time are given below. The feed evaluation excludes dates for which site visits were conducted as the devices were temporarily moved and powered on and off.

Table 3: Device Reliability

Dunn County			
Device	**Availability***	**Median Lag** (sec)**	**Standard Deviation Lag** (sec)**
Connected Arrow 1611	100%	1777	1058
WZ Start Marker 0334	99.9%	399	255
WZ End Marker 4512	100%	400	255
Columbia County			
Device	**Availability***	**Median Lag** (sec)**	**Standard Deviation Lag** (sec)**
WZ Start Marker 0576	95.5%	95	172
WZ End Marker 5674	99.9%	114	197
Iowa County			
Device	**Availability***	**Median Lag** (sec)**	**Standard Deviation Lag** (sec)**
WZ Start Marker 1804	99.9%	402	255
WZ End Marker 0287	23.7%	444	406

*Percentage of 1 minute feed records over the time of the respective project for which the given device was present in the feed
**Lag as the difference in time (seconds) between the feed update time and the device update time

Since ATMS integration is also based on retrieving device status updates from the manufacturers' WZDx device feeds, the archiving process itself served as a successful demonstration of that approach. As such, the project team felt that reliability taken as a measure of device feed status over the duration of the project provided an accurate measure for this evaluation question.

One of the lessons learned with reliability of the devices is the location of the devices. Devices in rural areas may experience connection issues, so that needs to be factored in when associating a connected device with a work zone.

Evaluation Question #4: How accurate was the connected device integration data quality for WZDx event reporting?

1. *WZDx verified start times within 5 minutes of true work zone start time*
2. *WZDx verified end times within 5 minutes of true work zone end time*

Yes, field tests show that (for Ver-Mac devices), an Arrow Board (which is used to verify work zone start and end time) is updated in Ver-Mac's WZDx device feed immediately when it changes from blank (off) to displaying a pattern (on) or vice versa. The ATMS polls the WZDx device feed on a configurable interval—next time it polls after the change is made on the device feed (turning it off or on), then the event start or end time will be verified.

3. *WZDx verified start position within 0.1 miles of true work zone start position*

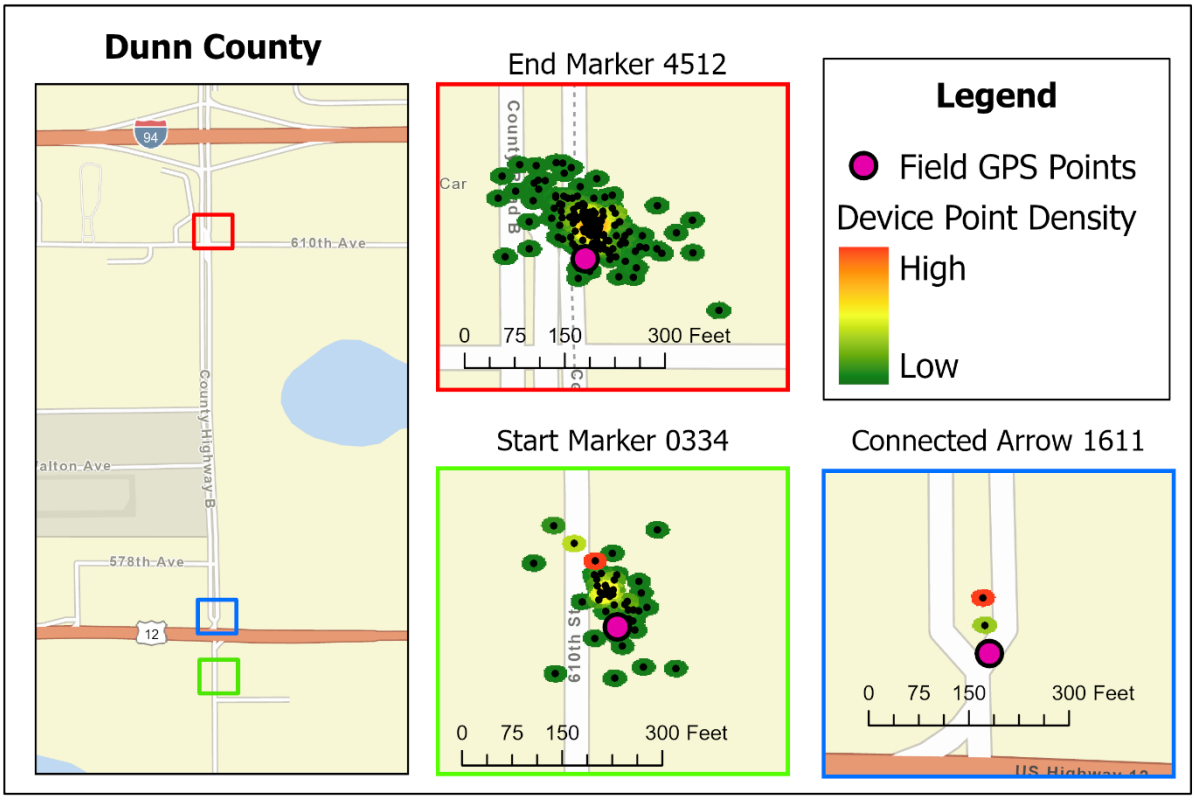
Yes, field tests show that the coordinates from the device feed are within 0.1 miles.

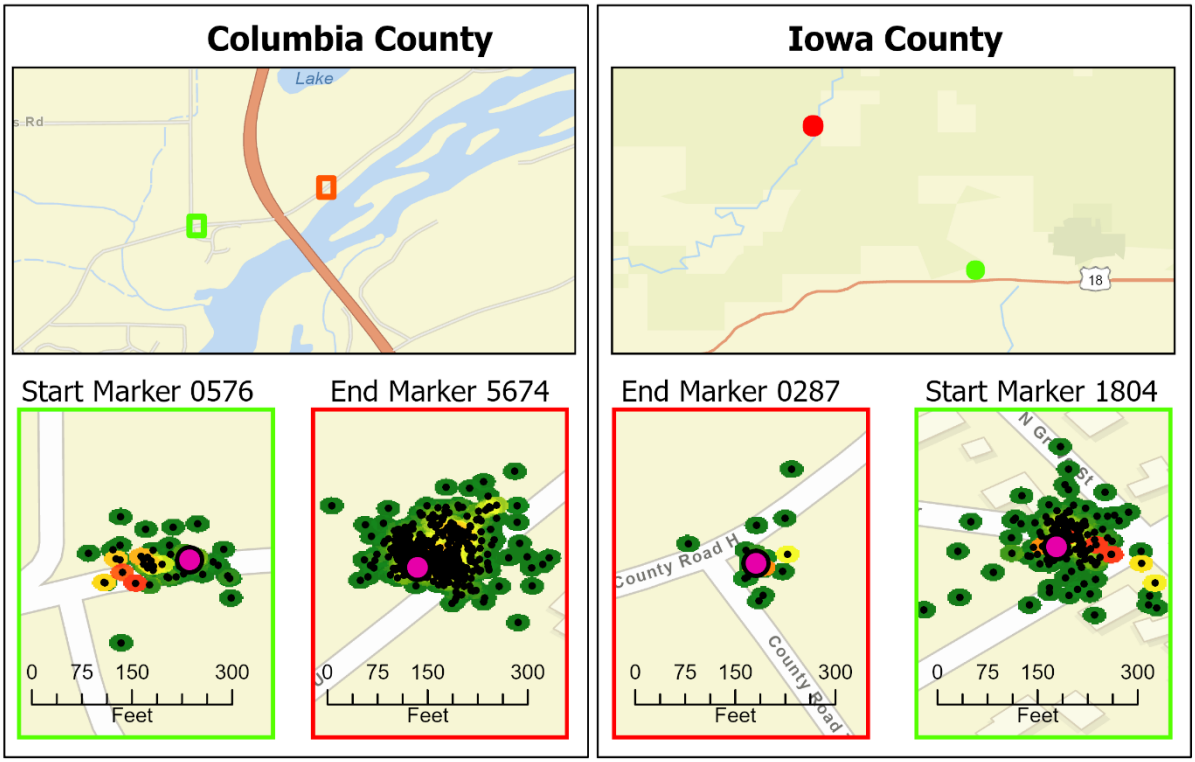
4. *WZDx verified end position within 0.1 miles of true work zone end position*

Yes, field tests show that the coordinates from the device feed are within 0.1 miles.

In general, the device location was reliable to within a few hundred feet of field verified locations but with some notable float in the locations of the start and end markers. The pink dot on the maps below indicate the locations field verified using a handheld GPS device and the color gradient shows a relative point density heatmap with green to red as low to high respectively. The device locations according to the feed were consistently within 200 feet of the field verified location but no greater level of accuracy should be assumed. Ver-Mac mentioned a smoothing capability whereby the location of a device indicated in the feed would stabilize by using an aggregation of the coordinates provided by the device and excluding outliers. However, there was no discernable evidence of location stabilization as the coordinates were similarly disperse during the beginning and ending week(s) of the project. The position of the connected arrow board in Dunn County – the only site for which one was available – was more consistent than the positions of the location markers. This could be due to a difference in the device or location processing/smoothing methods applied by the vendor.

Figure 15: Device Location Information





Evaluation Question #5: What were the minimum data / integration requirements to be successful for each scenario?

Based on the pilot deployments, the following CWZ integration requirements are proposed for at-scale implementation:

- WisDOT Improvement Project – a state highway project that impacts a local road.
    a. All WisDOT improvement projects will continue to require a Lane Closure System entry to provide estimated geometry and schedule attributes. The lane closure system will also be required for local road specific lane details, such as “bike-lane” and “sidewalk” status.
    b. Connected work zone devices will additionally be required on all Improvement projects to provide verified location and time attributes:
        i. Two location markers will be required per direction to provide field verification and geometric correction to the start and end locations. The location markers should have appropriate “work-zone-start” and “work-zone-end” location type settings.
        ii. Lane closures will require one connected arrow board (CAB) per roadway direction to provide field verification and timestamp correction to the work zone start and end times.
        iii. Full roadway closures will require a third location marker per direction to provide field verification and timestamp correction to the work zone start and end times. The location marker should have the “road-event-start” location type setting.

- WisDOT Local Program Project – a project that is on a local road but funded and administered by WisDOT
    a. All WisDOT Local Program projects will be required to have a Lane Closure System entry that will provide estimated geometry and schedule attributes. The lane closure system will also be required for local road specific lane details, such as “bike-lane” and “sidewalk” status.
    b. Connected work zone devices will additionally be required on all Local Program projects to provide verified location and time attributes:
        i. Two location markers will be required per direction to provide field verification and geometric correction to the start and end locations. The location markers should have appropriate “work-zone-start” and “work-zone-end” location type settings.
        ii. Lane closures will require one connected arrow board (CAB) per roadway direction to provide field verification and timestamp correction to the work zone start and end times.
        iii. Full roadway closures will require a third location marker per roadway direction to provide field verification and timestamp correction to the work zone start and end times. The location markers should have the “road-event-start” location type setting.

- Local Project – a project that is on a local road with no WisDOT involvement
    a. Local projects will NOT have a Lane Closure System entry.
    b. Local road closures without a Lane Closure System entry must include two location markers per direction and either a CAB or road-event-start location marker to be recognized as a valid work zone.
- The Stage 1 SMART project did not cover requirements to include “work presence” attributes in the WZDx.

Evaluation Question #6: What were the key challenges by field staff in the setup, configuration, and maintenance of connected devices for purposes of this project?

1. *Minimal user reported issues*
    a. BTO staff deployed the devices in the field and did not have any major issues with the connected work zone start/end location markers.
    b. TOPS Lab completed testing of the devices by turning them on and off as well as moving them around and did not have any major issues.
    c. There were not any issues with the connected arrow board, it was straight forward for set up.
2. *Challenges*
    a. There were initial challenges on learning how the connected work zone start/end location markers work with regards to turning them on and off and making sure they were connected to GPS.
    b. The work zone start/end location devices just have small push button that you are supposed to push and then a series of lights inside the Type C warning light will illuminate which can be challenging to see. It would be recommended to create a switch to turn the devices on and off to make it more clear for the user in setting up the devices.
    c. The devices are also still relatively new so there will be a period of time where users will be learning how they operate and how to use them.
    d. One of the other challenges is when you are in the field, deploying the markers, you do not get instant feedback like you would with the arrow board. When the arrow board is turned on, you see the pattern on the board, but when you turn the location markers on, you do not know if they are on/off or connected to any signal.
3. *Questions from field staff*
    a. We only coordinated with field staff with regards to the placement of the connected devices to ensure they were not going to be in the way of any work activity. So, we did not have any questions from field staff during the pilot. WisDOT would expect more questions when connected devices are fully implemented.

For future implementation, it is recommended a standard operating procedure (SOP) be created on how they should be set up.

Evaluation Question #7: Was it easy to procure the devices?

1. *Comparable to procurement of traditional work zone traffic control devices for similar work zones.*

For the purpose of the SMART Grant, the procurement process was very challenging. WisDOT was hoping to use our statewide devices contract to purchase devices from, but all the devices we wanted to pilot were not on the contract. Since the devices were not on the contract, we had to work through purchasing and were told we could amend the current devices contract to get quotes from manufacturers to add the required devices to the contract. We reached out for a number of quotes and heard back from Wanco and Vermac. After we received quotes, we were able to move forward with procurement of the connected devices. We ran into shipping issues with Wanco and the devices were delivered after the pilot projects were completed. We did not end up procuring the Wanco connected devices. WisDOT still has them at the sign shop for further testing to help Wanco get a WZDx compliant feed.

With full implementation, the department should not run into any procurement issues. The connected work zone devices have been tested and added to the departments approved products list. Locals and contractors will be able to purchase connected work zone devices that are on the departments approved product list, therefore the ease of procurement should be simple.

Evaluation Question #8: How much did the workload increase for field staff and ATMS staff?

1. *Less than 5% increase in workload reported by field staff*

   At this time there was no increase in workload for field staff. Adding the additional connected work zone devices would be lumped in with their daily/weekly checks of temporary traffic control.

2. *Less than 5% increase in workload reported by TMC staff*

   At this time, there was not any increase in workload for the ATMS staff. There could possibly be once it is fully rolled out, but that increase would likely be below 5%. WisDOT will have a better idea once it is fully scaled and we can verify devices are matching; this may require some increased workload depending on the data status. It is recommended a quality assurance engineer be hired to help assist the TMC staff to ensure the workload does not increase by more than 5%.

Part 3 of 6: Anticipated Costs and Benefits of At-Scale Implementation

Benefits

There are many benefits that will be addressed with at scale implementation which include:

1. Providing work zone information on local roads through connected devices. Currently Wisconsin does not have a cost-effective or scalable solution to provide information to motorists about road closures, lane closures, etc. on local roads. Wisconsin State Highway information is provided to make work zones safer for the traveling public and workers. Local agencies currently may not have the resources to provide this information and then share it with the public.
2. Providing work zone information to vulnerable road users, such as bicyclists and pedestrians. Currently no data is being shared to tell VRU's about sidewalk or bike lanes that are closed.
3. Providing work zone information to emergency vehicles. Routing emergency vehicles in and around local road work zones is often a critical factor in the overall response time for traffic crashes and other emergency events. Currently there is no reliable, statewide source of real-time, local road work zone data available to emergency service providers.
4. Putting work zones on the map. This is a federal initiative to inform the traveling public about where work zones are to help them better navigate in and around work zones.
5. Safer for workers and traveling public. Providing real-time information about where work zones are could make travel on public roadways safter for everyone.

Costs

There will be extensive cost components to build out the ATMS to include local roads as well as update the Wisconsin WZDx feed. There will also be costs for updates to the Wisconsin Lane Closure System to at a minimum include local road closure entries for all WisDOT improvement projects, including local program projects. The proposed estimated cost for a Stage 2 grant is about $5.2 million which includes procurement of devices, development, testing and QAQC. The detailed Stage 2 cost breakdown is included in Table 4.

In order to support local roads, it was originally believed that it was required to map out every local road in ATMS. This is a time consuming, lengthy and expensive process. Alternate mapping will be looked into in Stage 2 to dramatically reduce the cost of creating a base map for local roads in ATMS. It cannot be assumed that all local roads will have mapping data with the same attributes, so a third-party provider will be the most suitable for a Stage 2 implementation. Additionally, while for the purposes of the Stage 1 evaluation the decision was made to configure local roads in the ATMS, this would not be a viable long-term solution as the ATMS base mapping was not designed to support the volume of roads and data needed to represent a statewide road network down to the local level. This local road mapping was never done in the pilot and we were still able to draw local road start and endpoints of work zones, but unable to draw work zone's complete roadway geometry.

Additional operational costs will be needed to maintain the systems. Data models tend to evolve over time, and integration efforts are not always trivial. There may also be ongoing licensing costs for third-party mapping data. However, these ongoing costs pale in comparison to the additional staffing that would be needed to support this type of effort without a systematic process. The ongoing costs would represent less than a single full-time resource, who would not be able to provide nearly as much verifiable work zone

data to the public.

The Wisconsin Lane Closure System has already been updated to support pilot capabilities for local road closures associated with highway construction projects. Additional development will be required to support a more generalized and user-friendly capability for all state improvement project-related local road closures, including stand-alone Local Program projects that are not tied to highway construction and may require new roles and scheduling workflows within the system. It is also anticipated that the underlying location model for the WisLCS would be upgraded to incorporate WisDOT's new all roads network that provides a combined representation of the state and local road systems. These updates are estimated to take 12-18 months for planning, design, and systems programming.

As discussed earlier, the project would likely roll out the at-scale implementation in two phases. Phase 1 would be to require connected devices and WisLCS entries for all WisDOT Improvement Projects with local road impacts and all Wisconsin local program projects. The total number of projects impacted is to be determined based on the number of LET projects in a year and the number of impacts to local roads each of those projects have. Stage 1 costs for connected work zone devices would be minimal as WisDOT would require the devices to be included in the project plans as BID items which the department would pay for. Phase 1 would also include testing and building out the ATMS for local projects that do not have a WisLCS entry. There would be costs associated with development as well as procurement of connected devices for up to 10 local agencies for testing. Phase 1 would be expected to be completed over two years.

Phase 2 would likely cost more as the purchase of connected devices would occur for a set number of local agencies so their work zones can be displayed in 511 WI and in Wisconsin's WZDx feed. To get a larger picture, there are 585 municipal governments and 1,265 town governments in Wisconsin along with 72 counties. The overall cost of the devices would be determined based on the number of devices purchased and how the local governments are selected. The intent is to purchase a connected arrow board, one work zone start and one work zone end location marker for 25% of the local agencies. As part of Phase 2, there would be extensive training and outreach to the locals as well as additional testing and QAQC.

The department is also proposing to have a Work Zone Quality Assurance Engineer on-site to perform data quality, check the ATMS and WisLCS, link devices to WisLCS entry if not automatically associated, document issues and identity process improvements. This engineer would be for the life of the grant, so cover Phase 1 and Phase 2 for three years.

Part 4 of 6: Challenges & Lessons Learned

There were many challenges and lessons learned throughout the Stage 1 grant process and are identified below and throughout the implementation plan. Several challenges have occurred with regards to procurement of devices, project selection and coordination, testing of the devices as well as the development of the IT systems. The Wisconsin SMART grant project plan has required upgrades to multiple traffic management systems that are connected through interoperability interfaces. Coordinating updates across multiple systems is always a challenge for complex, distributed IT environments, but has been especially challenging given the external timeframe constraints of the SMART Grant project schedule.

1. Procurement of devices has been a challenge since starting the procurement process. In Wisconsin there is a traffic control devices contract with many different work zone traffic control devices on them, including connected devices. There is also an approved products list (APL), so contractors know what is allowed on our state highway system in terms of traffic control devices. The plan when applying for the grant was to add additional connected work zone devices to the WisDOT APL and then update the traffic control devices contract to add the additional devices to the contract so WisDOT could purchase them at a reduced rate. This process was not very straightforward, and there was a lack of response from the vendors. It took about 4 months to work through this process with our internal contracting department and the two vendors, Wanco and Vermac, to supply the quote. A lesson learned from this process is to make sure the correct people are at the table and have regular check in meetings to keep everyone on task to keep the process moving along.

2. There were also challenges with shipping of the devices. Wanco took too long to deliver the devices, so we were unable to complete any field testing of the devices. It was determined that after internal testing of the Wanco devices, the department would return the devices since we could not use the devices for the SMART Grant testing. At this point, WisDOT is still trying to test the Wanco devices. WisDOT ran into issues with the Wanco WZDx feed as well as issues with the work zone start and end location markers. WisDOT ended up having to return the batteries to get new ones and are still waiting for the batteries as well as the work zone location markers to be included in the WZDx feed.

3. One issue identified during the evaluation of vendor feeds was a lack of commonality in the approach to implementation. A number of vendors' WZDx-compliant data feeds were evaluated, however, despite them all adhering to the standard data model, each feed has a different approach to authentication which required slight modification to ingest. Standards-based feeds imply the feeds can be plug-and-play, however without a common approach (or set of approaches) to authentication mechanisms, multiple means need to be supported to allow any WZDx device feed from being ingested without any additional development effort.

4. The work zone device feed provides location, but no bearing or other means to identify the orientation of the device relative to the direction of travel. This makes it more difficult to associate a device with a work zone. There is also the issue of devices that may be in close proximity to multiple work zones, which may result in the system not being able to automatically associate a device with a work zone. At this stage, these challenges can be addressed by user intervention to deal with ambiguous cases, however this is undesirable for a full-scale implementation as the resource implications would be significant. A refined algorithm to associate devices with work zones would be a task in the early part of a Stage 2 grant.

5. Another challenge encountered was in the project selection process. When originally applying for the grant, projects were identified, but those were no longer candidate projects because of the timeline of

the procurement of the devices and award of the grant from USDOT. It was challenging to find projects that fit the needs of the project, specifically a lane closure on a local roadway. A lot of projects with construction on local roads close the road down and detour traffic. It took a lot of communication with the regions to find a candidate project that had a lane closure in order to prototype a lane closure with a connected arrow board. There was also a need to find two other projects to pilot the connected devices on, both full closure projects. One identified was a WisDOT project that had a local road impact that lasted a few years so this would work for the pilot project as the closure would be up long-term. The other project was a little more challenging since the plan was to work with the Columbia County Highway department, but most of their projects were ending in August and the grant project team needed more time for the procurement and piloting of the devices. Another county that had a work zone with a full closure through December 1, 2024 was then identified, that would allow for the complete and extensive testing if needed.

6. There was a lack of guidance and standard operating procedures for how to use the connected devices. The Vermac connected work zone start and end location markers were a little challenging to work with at first. There was a push button to turn the devices on and then to turn the devices off you had to hold the button in. When the device was turned on, there were a number if lights embedded within the Type C warning light that would illuminate to show that there was a signal, battery life, etc. The light was hard to see in daylight conditions and there were not very good instructions on how to troubleshoot if you did not see the device online. The figure below shows the SOP for the Vermac devices.

Figure 16: Connected Work Zone Start and End Location Marker How-to-Guide

Workzone Location Sensors LED Behavior

LED icon	Name	Color	Behavior
	Error	Red	On if there is a modem or GPS error. Blinks a half-second on/off for USB error.
	Button pushed	Green	Turns on when someone pushes the button with the pin. Push 1 second to have the device push a communication once a minute for 5 minutes to JamLogic.
	Modem	Yellow	Blinks a on/off for a quarter second when connected. Blinks every second when connected to cellular. Solid when connected to JamLogic. Error if off and Error LED on.
	Battery # 3	Green	Battery level >6.5V Blinks a half-second on/off at the end of a USB transfer.
	Battery # 2	Green	Battery level >6.4V Blinks a half-second on/off at the end of a USB transfer.
	Battery # 1	Green	Battery level >6.0V Blinks a half-second on/off at the end of a USB transfer.
No icon. Bottom right of the orange lens.	System in operation	Red	Always on.

When initializing battery LED turns on in the pattern 1-2-3-2-1…

The additional pictures below show the LED lights within the Type C warning light. The first picture shows the yellow, green and red LED which corresponds to the Figure above. When the device is initially turned on, all of the lights will illuminate and once the device is connected to the cloud, only the yellow LED will remain on along with the green LED signifying the battery power, as shown in the second picture. The last picture is showing a device that is not working due to a broken seal and water

leaking into the device.

Connected Device LED Lights



A recommendation would be to have an on/off switch to clearly identify the devices being on and off and provide a better seal to ensure water does not enter the device.

7. There were also edge cases that were identified throughout the process that we did not foresee being a problem. Some closures may not be as straightforward as initially thought for the auto association of connected devices. Below are a couple scenarios that the department will have to consider in the at-scale implementation:
   - The first is having multiple closures in the same locations and associating connected devices to the correct closure.
   - Associating devices to the correct closure when work zone events are stacked vertically, such as connected devices on a county road bridge closure (overpass) over an interstate work zone (underpass).
   - Closures that are located at intersections within a work zone and how to accurately assign the connected devices.

8. As part of the grant, the department wanted to test the marked location of a full closure. Unfortunately, no manufacturers had the ability to add the “road closed” “marked location type” status to their connected devices, so this will be a test that is completed in Stage 2.

9. There needs to be a protocol for what happens when devices lose connection. For the Iowa County Project, we lost connection to the location markers numerous times. The Columbia County project also lost connection, but only when the temperatures dropped below 0 degrees. In this scenario, it was determined that if there was a WisLCS entry for the lane closure/closure, the closure would be reverted back to the WisLCS entry as a planned/estimated event.

10. As we went through the different iterations of associating the connected devices with a work zone event, it was determined there would be a requirement for the minimum number of connected devices to accurately create a WZDx verified event. Refer to evaluation question #5 for detailed information on connected device requirement.

11. Currently the WZDx specification does not require a refresh rate for the devices in the field. WisDOT has added specifications beyond the WZDx specifications to ensure devices are updated when their state changes (e.g. they are turned on or off), moved or have loss of communication.

12. WisDOT is requiring one statewide WZDx device feed per manufacturer to simplify having to ingest multiple feeds from each individual work zones. We also require that all the connected devices in a work zone are from the same manufacturer so the device feed is the same.

13. As with any new device roll out, there needs to be proper training to the person deploying the connected devices as well as the staff putting them in plans and inspecting the devices in the field. As part of the Stage 2 grant, training and outreach will be a big component to ensure the connected devices are accurately deployed and used.

14. A noticeable dispersion of reported GPS locations for the start and end location markers was observed over the duration of each pilot work zone deployment. Since the ATMS adjusts the work zone geometry based on the field verified start and end locations, this will contribute to instability in the work zone representations over time if left unaddressed. This can also lead to ambiguity at local road intersections such as in the Barneveld (Iowa County) case depicted in the dispersion plots. It is unclear whether this can be effectively addressed through WisDOT's vendor specifications and may need to be handled algorithmically within the ATMS.

Part 5 of 6: Deployment Readiness

Key obstacles to scaling this project include the need for manual intervention when the device cannot be unambiguously associated with a work zone, and the need for additional manual roadway configuration. It should be noted that the department does not know how large of a problem manual intervention will be without at-scale testing. The ATMS may be able to associate devices automatically most of the time, but we won't know until at-scale implementation.

During Stage 1, the project team collected data allowing for the determination of what roadway mapping needs are required for a statewide implementation. The current approach allowed the existing ATMS mapping to be used. However, the effort to configure a statewide base map with the current approach is significant and the effort would be better expended identifying an improved approach to providing mapping data to provide geographic context when associating devices to work zones when a WisLCS event is not available.

Additionally, the Stage 1 implementation primarily relied on work zone entries existing within WisLCS. By analyzing and comparing the device data with associated work zones, the project team may be able to identify a minimum set of device data that would allow for the extrapolation of a work zone without any existing WisLCS entry. This would be essential for a Stage 2 implementation since local projects will not have a WisLCS entry.

As in the case of ATMS, determining the local road mapping needs within WisLCS is also an important outcome of the pilot project. Whereas highway closure geometries are automatically generated from the underlying highway network model in the WisLCS, local road closure geometries are manually drawn by users against a base map representation. As noted, an important component of the project is to determine the appropriate balance between manual entry and automatic discovery based on connected devices. It is also anticipated that certain local road projects, such as those associated with state improvement projects, may require a higher level of detail and accuracy. In order to scale and improve the quality of local road lane closure data over time, it is expected that the underlying location systems in the WisLCS and ATMS will be upgraded from their current highway linear referencing system (LRS) networks to WisDOT's newer all roads network LRS.

Based on the outcome of the Stage 1 Grant, the Department is ready to start updating policies and procedures to require WisDOT Improvement Projects with Local Road impacts to enter a WisLCS entry and start the planning, development, training and outreach for WisDOT Local Program projects to enter closures into the WisLCS. The statewide implementation on all local projects will take 2-3 years for development, but the planning is ready to be started. As noted, this will also provide critical data and experience to prepare for non-WisDOT local road closures that will not have a WisLCS entry. The project team is also ready to start testing logic for creating/extrapolating an event from devices without an LCS entry.

Part 6 of 6: Wrap-Up

Throughout the Stage 1 Grant, the department learned a lot about connected work zone devices as well as the capabilities and limitations of the ATMS and Lane Closure System. There were a number of lessons learned throughout the project which were discussed in great detail, which will help provide information to other states interested in deploying connected devices to provide real-time information about work zones.

The grant looked at how to address real-world issues surrounding work zone data which included determining how to provide work zone information not only on state highways managed by WisDOT, but also on all local roads outside the department's jurisdiction. Currently Wisconsin does not provide any information to motorists about road closures, lane closures, etc. on local roads, but since completing the Stage 1 Grant, WisDOT has identified a plan to make work zones safer for the traveling public and workers by incorporating all work zones through connected devices into the Wisconsin WZDx Work Zone Feed.

The grant also looked at how to provide information about sidewalk and bike lane closures to vulnerable road users, such as bicyclists and pedestrians through attributes added to the WisLCS. WisLCS entries are now able to provide this information for a WisDOT Improvement Project with Local Road impacts and will be expanded in Stage 2 to Wisconsin Local program projects.

It is the intent that an at-scale implementation would cover the entire state of Wisconsin through a phased approach. Buy-in would be required by the locals to start using connected work zone devices to provide reliable real-time information about work zones under their jurisdiction. The at-scale implementation would not be accomplished all at once, but our long-term goal is for all work zones to be included in the Wisconsin WZDx Work Zone Feed.

Currently, the project has not been discussed in any conference presentations, academic articles or media stories published. The intent would be to share the success at future conferences in 2025 and beyond.