REAL-TIME INTEGRATION OF ARROW BOARD MESSAGES INTO TRAVELER INFORMATION SYSTEMS EVALUATION

FINAL REPORT

JANUARY 21, 2020

ENTERPRISE TRANSPORTATION POOLED FUND STUDY TPF-5(359)

Prepared by:
Athey Creek Consultants

ENTERPRISE

Technical Report Documentation Page

1. Report No. ENT-2020-1	2. Government Accession No.	3. Recipients Catalog No.	
4. Title and Subtitle Real-Time Integration of Arrow Board Messages into Traveler Information Systems Evaluation		5. Report Date January 21, 2020 6. Performing Organization Code	
7. Author(s) Tina Roelofs, Jeremy Schroeder, and Carla Helgeson		8. Performing Organization Report No.	
9. Performing Organization Name and Address Athey Creek Consultants 2610 Lexington Terrace West Linn, OR 97068		10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No. 2019-0045	
12. Sponsoring Organization Name and Address ENTERPRISE Pooled Fund Study TPF-5 (359) Michigan DOT (Administering State) PO Box 30050 Lansing, MI 48909		13. Type of Report and Period Covered FINAL Report 14. Sponsoring Agency Code	
15. Supplementary Notes Final Report available at: http://enterprise.prog.org/Projects/2020/arrowboard_messages_into_travel_info_phase3-final_report.pdf			
16. Abstract In 2018, the Minnesota Department of Transportation (MnDOT) conducted a one year pilot project through a contract with a vendor (Street Smart) that installed a monitoring device on 20 arrow boards that provided arrow board status information (e.g. right arrow on, left arrow on) to the vendor's server. The arrow board status information from the server was then integrated with MnDOT's Advanced Traffic Management System (ATMS) and then their Road Condition Reporting System (RCRS). In 2019, the Iowa DOT had access to 5 equipped arrow boards with reporting capabilities (Street Smart, iCone, Ver-Mac) to provide real-time arrow board status information to the vendor's server. This project evaluated the deployments of the arrow board concept in these two ENTERPRISE member states (Minnesota and Iowa). In addition, an overview of the Regional Transportation Commission (RTC) of Southern Nevada real-time arrow board reporting system deployment is included as another perspective. Overall the data analysis for MnDOT and the information gathered from interviews from MnDOT and Iowa DOT indicate a benefit to the traveling public and Transportation Management Center (TMC) operators with additional information on the overall network with the location of lane closures provided by arrow board reporting systems.			
17. Key Words Arrow-board, traveler information, evaluation, ENTERPRISE		18. Distribution Statement No restrictions	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 44	22. Price

Acknowledgements

This Real-Time Integration of Arrow Board Messages into Traveler Information Systems Evaluation was prepared for the ENTERPRISE Transportation Pooled Fund TPF-5(359) program (enterprise.prog.org). The purpose of ENTERPRISE is to use the pooled resources of its North American members and the United States federal government to develop, evaluate, and deploy Intelligent Transportation Systems (ITS).

Project Champion

Michael Wroblewski, Michigan Department of Transportation, was the ENTERPRISE Project Champion for this effort. The Project Champion serves as the overall lead for the project.

ENTERPRISE Members

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

- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Michigan Department of Transportation
- Minnesota Department of Transportation
- Ontario Ministry of Transportation
- Pennsylvania Department of Transportation
- Texas Department of Transportation
- Wisconsin Department of Transportation

Project Participants

ENTERPRISE would like to acknowledge and thank the following individuals involved with integrating and deploying an arrow board reporting system(s) that greatly supported and enhanced this evaluation:

- Dan Rowe, Dave Tody, Garrett Schriener, and Kelly Braunig of the Minnesota Department of Transportation
- Neal Hawkins and Skylar Knickerbocker of the Iowa State University Center for Transportation Research and Education
- John Peñuelas and Julia Uravitch of the Regional Transportation Commission of Southern Nevada
- Jeff Anderson of Triton Traffic Technologies
- George Coffee, Mike Granger, and Adam O'Rourke of Street Smart
- Kristin Virshbo and Mary Crowe of Castle Rock Associates
- Ross Scheckler of iCone

Table of Contents

1.0 Introduction 1
2.0 Description of Deployments 4
2.1 Minnesota DOT 5
2.2 Iowa DOT 6
2.3 RTC of Southern Nevada 8
2.4 Deployment Variations 9
3.0 Evaluation Approach 11
3.1 Evaluation Intent 11
3.2 Evaluation Goals 11
3.3 Evaluation Objectives 11
4.0 Evaluation Data Sources, Collection, and Analysis 13
4.1 Minnesota DOT 13
4.2 Iowa DOT 17
5.0 Evaluation Findings 19
5.1 Minnesota DOT 19
5.2 Iowa DOT 28
6.0 Summary 31
Appendix A: MnDOT Matched Dataset: RCRS, Incident Feed, and ATMS 35

1.0 Introduction

Longer-duration construction and maintenance activities are typically manually entered into transportation agencies' Road Condition Reporting Systems (RCRS) and/or Advanced Traffic Management System (ATMS) to improve situational awareness of Traffic Management Center (TMC) operators and alert the traveling public. However, fast-changing and shorter-duration activities can be challenging and time consuming to enter and remove from a system and therefore these events are not always entered to make TMC operators or the traveling public aware of lane or shoulder closures.

The ENTERPRISE Pooled Fund Study has completed two efforts supporting transportation agencies integrating arrow board status information from the field into traveler information systems to alert TMC operators and travelers in real-time, for example, of a lane closure. Per direction from the ENTERPRISE Board, Phase 1 and Phase 2 were completed in 2017 in order to properly assess needs and potential solutions before deployment and evaluation of a real-time arrow board system at one or more ENTERPRISE agency sites.

- Phase 1, completed in February 2017, generated Model Concept of Operations and Model Requirements documents for a system to report in real-time arrow board status information to TMC staff and to the traveling public. This system was intended to improve traveler information dissemination and performance reporting without requiring agency staff time in the field or operator staff time at the TMC. These model systems engineering documents were developed for ENTERPRISE agencies to use and modify when implementing solutions to integrate active maintenance and work zone notifications into their current traveler information dissemination systems. These model documents were likewise expected to enable arrow board manufacturers and third-party integrators to develop systems that are flexible to meet the various needs of multiple agencies.

- Phase 2, completed in September 2017, generated an Evaluation Plan for examining the process, effectiveness, lessons learned, and benefits of real-time arrow board reporting systems once deployed. The Evaluation Plan was expected to guide future evaluations of one or more pilot deployments conducted by ENTERPRISE agencies.

Following the completion of Phase 2, in 2018 the Minnesota Department of Transportation (MnDOT) conducted a one year pilot project through a contract with a vendor (Street Smart) that installed a monitoring device on 20 arrow boards that provided arrow board status information (e.g. right arrow on, left arrow on) to the vendor's server. The arrow board status information from the server was then integrated with MnDOT's ATMS and then their RCRS. In 2019, the Iowa DOT had access to 5 equipped arrow boards with reporting capabilities (Street Smart, iCone, Ver-Mac) to provide real-time arrow board status information to the vendor's server. During this evaluation, Iowa DOT was in the process of upgrading their ATMS, therefore the arrow board integration to the ATMS was not included as part of this evaluation. However, Iowa anticipates integrating the arrow board messages after the ATMS upgrade is completed in 2020.

This project (Phase 3) uses the Evaluation Plan completed in Phase 2 to facilitate and evaluate deployments of the arrow board concept in these two ENTERPRISE member states (Minnesota and Iowa). In addition, an overview of the Regional Transportation Commission (RTC) of Southern Nevada real-time arrow board reporting system deployment is included as another perspective.

Evaluation Focus:

Real-time arrow board notification deployments in Iowa and Minnesota.

Potential benefits from the arrow board reporting system deployments that are examined as a part of this evaluation include:

- Detailed, consistent, and reliable real-time information about lane closures disseminated to travelers upstream of the closure through traveler information mediums.
- Improved situational awareness by TMC operators of real-time lane closures in the field.
- Increased archived data available for evaluation, performance management, and research to better understand work zone mobility impacts and exposure for reporting purposes, use for future work zone planning efforts, analysis of Transportation Management Plans (TMPs), and for performance-based specifications.
- Foundational technology for arrow boards to collect data regarding lane closure-related information that could be directly communicated by the arrow board to Connected and Automated Vehicles (CAVs).
- Improved quality of the device as a result of arrow board usage reports (e.g. the location can be more readily verified by field personnel).
- Real-time data about lane closures that could be integrated by third-party navigation apps (e.g. Google Maps, Waze), emergency dispatch, transit, or other systems that route travelers and workers through the transportation network.

Additional benefits are possible depending on how the systems are designed, which may include:

- Improved construction management opportunities, including the ability to verify contractor work status to document lane closure times for use on lane rental projects or enforce restricted hours or to cross check any lane closure updates that are required of the contractor.
- Opportunities for faster response time in the field for maintenance needs through arrow board system notifications (e.g., times when a trailer-mounted arrow board is hit by a passing vehicle or blown out of place by strong winds).

This evaluation document represents the final product of this Phase 3 effort, and contains the following sections:

2.0 Description of Deployments – description of real-time arrow board reporting system deployments in Minnesota, Iowa, and the RTC of Southern Nevada.
3.0 Evaluation Approach – details on the goals and objectives of this evaluation.
4.0 Evaluation Data Sources, Collection and Analysis – details on the data sources, collection approach, and data analysis approach in Minnesota and Iowa.

5.0 Evaluation Findings – quantitative and qualitative findings for each measure of effectiveness (MOE) organized by evaluation objective for Minnesota and qualitative findings for each objective for Iowa.

6.0 Summary – highlights key overall findings from the Minnesota and Iowa real-time arrow board reporting system deployments and, as applicable, the RTC of Southern Nevada.

2.0 Description of Deployments

This evaluation examines the technology solutions for two ENTERPRISE member states allowing for the real-time integration of arrow board status information messages from a third-party server to the ATMS and then to their RCRS in Minnesota and to a third-party server in Iowa. Iowa DOT was in the process of updating their ATMS at the time of this evaluation. Once the Iowa DOT ATMS is updated in 2020, it is anticipated the real-time arrow board data will be integrated into this system. In addition, this evaluation summarizes the real-time integration of arrow board status messages to a third-party server for the RTC of Southern Nevada as another perspective outside of the ENTERPRISE members.

In general, a real-time arrow board reporting system is comprised of two largely independent systems, as depicted in Figure 1: 1) arrow boards and 2) TMC systems that use the arrow board information for traveler information dissemination and data archives, i.e., the databases, RCRS, ATMS, and Advanced Traveler Information Systems (ATIS) used by transportation agencies to collect, process, disseminate, and store traffic data and information for use by the traveling public and agency stakeholders. Additionally, a third-party arrow board vendor server may assemble data from multiple arrow boards, conduct some processing, and create events as an intermediate step before the data is provided to TMC systems.

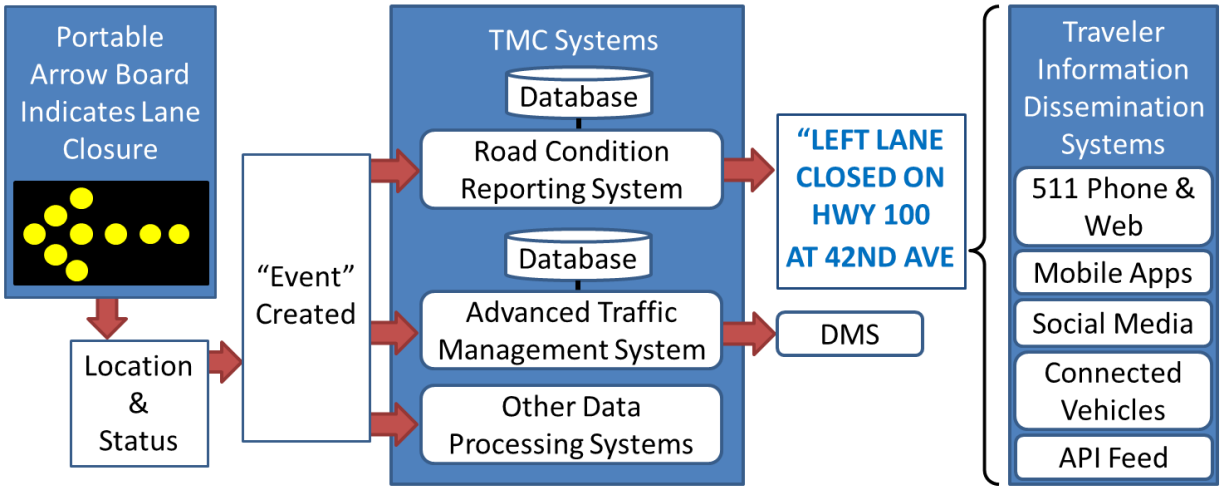

Figure 1: Portable arrow board flow of information to TMC Systems and Traveler Information Systems

Arrow board reporting systems from three vendors are included in this evaluation:

- Street Smart Rentals sells after-market devices that can be installed on arrow boards to collect data that are reported to a Smart Arrow Board (SmartAB) web-based system that can be viewed by users or polled by TMC systems to receive the arrow board data.
- iCone sells after-market devices that can be installed on arrow boards to collect data that are available on a web-based system that publishes arrow board information on Waze, allows users to view the data, and can be polled by TMC systems to receive the arrow board data.
- Ver-Mac is an original equipment provider that sells new arrow boards with fully integrated reporting capabilities.

Additionally, other vendors are known to offer or be developing products that are not included in this evaluation. For example, Wanco also sells new arrow boards with fully integrated reporting capabilities, and some manufactures (e.g. Ver-Mac,Wanco) may have plans to offer after-market devices that can be added to an older arrow board to provide reporting capabilities.

This evaluation examined the deployments in Minnesota and Iowa, as well as the RTC of Southern Nevada, to provide a broad view of ways that arrow board reporting systems have been developed and deployed and how they are being used. The Model Concept of Operations and Model Requirements documents developed in Phase 1 completed by ENTERPRISE were leveraged and modified for the one-year pilot deployment by MnDOT and an arrow board vendor (Street Smart) that developed a monitoring device for the arrow board. The data from the monitoring device was then integrated with MnDOT's ATMS and RCRS for automated provision of traveler information disseminated on MnDOT's traveler information website and mobile app. The arrow board deployments in Iowa included arrow board monitoring devices by Street Smart, iCone, and Ver-Mac. The devices used by the RTC of Southern Nevada are by iCone. The RTC of Southern Nevada followed a similar model to MnDOT but did not modify the ENTERPRISE model system engineering documents for their deployments. The Iowa and RTC of Southern Nevada deployments did not integrate into TMC systems; the data was provided via the vendor's server and redistributed by a third-party provider (Waze). Iowa DOT spent time developing a broader specification for procuring equipped arrow boards and other work zone technologies capable of providing data in a specific format as part of a more holistic vision for work zone technologies and data.

This section includes a description of the real-time arrow board deployments by MnDOT, Iowa DOT, and the RTC of Southern Nevada.

2.1 Minnesota DOT

MnDOT conducted a pilot project to deploy equipped arrow boards for integrating real-time notifications into its ATMS and RCRS. Specifically, the project deployed 20 arrow boards with status reporting capability (e.g. left arrow on, right arrow on) in the Twin Cities Metro District for a one-year test period from April 2018 to March 2019 using both permanent truck-mounted arrow boards and attenuator trailer mounted arrow board. These arrow boards were equipped on DOT-owned equipment that is deployed primarily in urban settings for shorter-duration maintenance activities that last several hours, including mobile work zones. MnDOT rented the arrow board reporting system device and technology from Street Smart. MnDOT staff cited the scheduling and coordination activities between MnDOT and Street Smart to set up and remove the arrow board devices was the biggest challenge. Each installation required an average of 3 hours per devices. Otherwise, the test period was uneventful.

The arrow board data was collected and aggregated by Street Smart. Specifically, data collection occurred at the arrow board onboard system. The onboard system passively monitored the arrow board status and provided this status when it was polled by the Street Smart SmartAB web-based system, which populated the arrow board information on a hosted/secure web-based application and interface. This application published the arrow board information to a real-time user interface designed to allow arrow board system users to monitor and manage the application and have full access to the data.

Additionally, the SmartAB system provided an incident feed file that was compliant with MnDOT's ATMS for integration to MnDOT servers through an external incident feed. When an arrow board was operational and reporting a status indicative of an active lane closure, the SmartAB system would update the external incident feed to reflect that.. Any time an arrow board was powered-down while retaining power to the onboard system, the onboard system logged the power down event, transmitted a message, and continued to send telemetry information. These events were available via the local onboard system log and SmartAB system reporting. However, when an arrow board was completely powered down with no power provided to the onboard system, its last known location and status were provided on the SmartAB interface.

The arrow board reporting system had data processing capabilities that determined the arrow board coordinate location, direction the arrow board is facing, arrow board status (left arrow, right arrow, or caution mode), and whether the arrow board unit is in the up or down position. Determination of the roadway or address took place at SmartAB and some information, e.g. arrow board in caution mode, was not passed on to MnDOT's ATMS.

Regarding integration, MnDOT incorporated the compliant incident file feed into its ATMS when an arrow board was in operational mode with a left or right arrow to indicate a lane closure. This was then transferred for integration into the ATMS and then the RCRS. Street Smart archived raw arrow board data, the incident feed provided to the ATMS, and arrow board location records in three separate datasets, and MnDOT archived the incident records that included arrow board-related lane closures from the Street Smart Incident feed. Castle Rock, MnDOT's traveler information vendor, does not archive data in its Minnesota RCRS deployment. However Castle Rock archived three weeks of RCRS data, as requested for this evaluation.

As a component of the pilot project, MnDOT also tested the arrow-board requirements that were developed during the pilot project. On September 27, 2018 one of the 20 MnDOT maintenance arrow boards equipped with a smart arrow board device was tested in real-time. Overall, the testing conducted was successful in demonstrating the integration (arrow board status to the vendor's server to the ATMS to the RCRS) of arrow board status information displayed in real-time on MnDOT's traveler information system. The system was tested for both a stationary lane closure and a mobile lane closure. In both cases it took 2 to 3 minutes for the event to display on MnDOT's traveler information website and app from the time the arrow board was turned on to indicate a lane closure. The 20 devices were removed from the arrow boards at the conclusion of the 1-year testing period, however MnDOT considers the pilot to have been successful and continues to explore options for deploying this capability in the future.

This evaluation includes a qualitative analysis through interviews and observations and a quantitative analysis of the data collected during a three-week period from the MnDOT one-year pilot deployment.

2.2 Iowa DOT

The Iowa DOT partnered with the Iowa State University Center for Transportation Research and Education (CTRE) to test and deploy three different arrow board status reporting systems beginning in spring of 2019.

- Specifically, two contractor-owned iCone arrow board reporting devices were used on trailer-mounted arrow boards. One of these operated on a single long-term work zone beginning in March 2019 and the other was used for various projects around the state.
- Two DOT-owned truck mounted attenuators (TMAs) were equipped with the Street Smart arrow board status reporting system in June 2019.
- One additional new Ver-Mac arrow board trailer was provided by Ver-Mac for testing in late 2019 that included fully integrated smart arrow board capabilities as part of the original equipment.

All of these real-time arrow board status reporting systems were used in conjunction with other work zone intelligent transportation system (ITS) products, such as iCone connected pins that can be used to complement the arrow board information by marking the end point of a work zone.

As part of a larger work zone data and technology effort, Iowa DOT and CTRE have worked with a consultant to develop an initial data communication protocol that is flexible for a variety of work zone technologies and applications such as one-way operations and connected pins. CTRE is receiving feedback from vendors to improve this specification for both near- and long-term use. CTRE is archiving all arrow board reporting system data every 5 minutes.

Iowa DOT intends to integrate the real-time arrow board reporting system data with their traveler information system, but this will not occur until late 2020 when a new ATMS is installed. In the meantime, CTRE is developing integration tools to merge data with context data and associated planned events in their traveler information system that will result in the generation of updated and more specific information to enhance existing planned event information. For example, general information such as "work zone at this location for 2 months with nightly lane closures" will be enhanced to indicate when the closure is active once the arrow board reporting system information is integrated to the ATMS and RCRS.

In August 2019, Iowa DOT updated their Smart Arrow Board Deployment Plan with two options for communications:

1) A JavaScript Object Notation (JSON) protocol where each manufacturer provides a feed of their arrow boards.
2) The DOT connects directly to the arrow board and pulls the data from the board at some frequency.

Iowa DOT found that most manufacturers they have talked to expect to pursue option 1. Iowa DOT still needs to develop specification criteria on the functionality (e.g. information pushed when the pattern changes, when the device moves x feet, and check in every x minutes) and plans to test devices from different manufacturers to put values to those requirements for their approved products list.

Since the deployment in Iowa was still in the testing phase, this evaluation includes a qualitative analysis provided through interviews and observations. However, it is important to note that Iowa will be conducting a separate evaluation once the testing period concludes in 2020 and the new ATMS is installed.

2.3 RTC of Southern Nevada

The RTC of Southern Nevada has been operating 12 iCone arrow board reporting systems on both contractor and city-owned trailer-mounted arrow boards as part of a pilot effort since late 2017. This pilot effort includes other technologies such as vehicle dash cameras and iCone pins. The arrow board reporting systems are used on both short- and long-duration work zones, including mobile operations, and help to track equipment and identify the beginning and end of work zones. In addition, iCone provides arrow board information to travelers via Waze, as depicted in Figure 2.

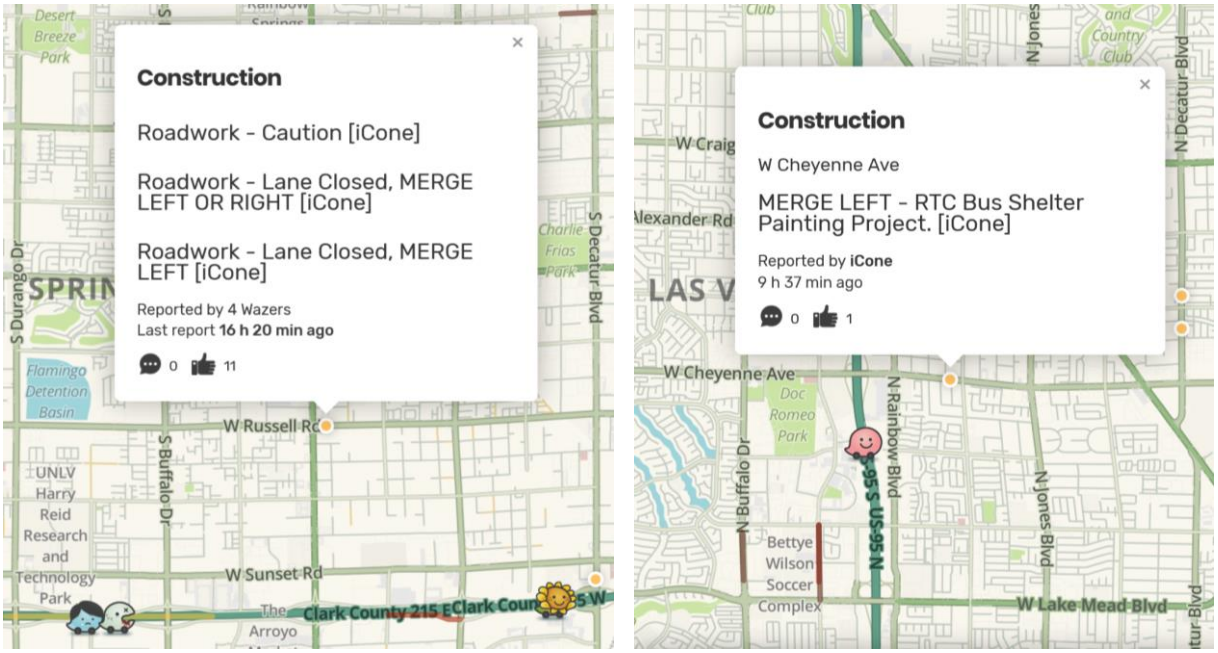

Figure 2. Example incidents in Waze generated from iCone Arrow Board Reporting Systems deployed in Las Vegas

The RTC of Southern Nevada is in the process of developing a generic specification for arrow board reporting systems to be included as part of construction contract bids in order to expand use. The RTC envisions the use of arrow board reporting system technology on every RTC-funded construction project, which involves about 400 arrow boards, as contractors and the public see the respective benefits for tracking equipment and real-time information, as well as future use cases. In the near term, RTC expects to deploy another 50-60 arrow boards reporting systems by the end of 2020.

Currently, arrow board data comes to the TMC and is provided to Waycare, a data integration, predictive, analytics GIS-based application. The RTC is in the early stages of importing iCone data into that system. RTC hopes to eventually use the arrow board data to identify locations where work zones affect traffic signals and make modifications, as an incremental step toward automation to assist in work zone planning and operations. Arrow board information is not integrated into a traveler information system as this is managed by Nevada DOT, not the RTC. While the RTC does not archive the arrow board data, the general specification for arrow board reporting systems notes an option to archive the data.

A dedicated staff member from Triton Traffic Technologies focuses on Arrow Board Reporting System equipment in the field to ensure construction zones show up on maps properly. There are no additional steps for RTC technicians to turn on the arrow board reporting system. The device tracks the arrow board location and sends an Extensible Markup Language (XML) feed to the iCone server. The iCone server sends one stream to RTC and a separate stream to Waze. RTC can see the status of all arrow board reporting systems on the iCone interface. Waze uses arrow board reporting system data to identify a generic construction event at the arrow board reporting system location that indicates it originates from iCone. In the future, RTC hopes Waze will provide this information to drivers as an audible alert and use a unique icon to differentiate arrow board reporting system events from other construction events.

2.4 Deployment Variations

Overall, deployments in Minnesota, Iowa, and the RTC of Southern Nevada are similar. All agencies find value in arrow board reporting systems in conjunction with other work zone ITS, on either portable truck-mounted arrow boards and/or arrow board trailers for long-term work zones and short-duration maintenance activities, including mobile work zones, on a variety of roadways. Deployment variations are summarized in Table 1 and inform the analysis of evaluation measures, alongside data availability. Key differences to note include the following:

- To date, only MnDOT fully integrated real-time arrow board reporting system information with their ATMS and RCRS for their pilot deployment. This functionality is expected to be added later for both Iowa DOT and the RTC of Southern Nevada. Currently a third-party traveler information provider (Waze) utilizes the smart arrow board status messages from Iowa and the RTC of Southern Nevada from the iCone servers.
- MnDOT deployed real-time arrow board reporting systems in mostly urban areas for short duration maintenance activities, while Iowa DOT primarily deployed on more rural corridors for nightly lane closures on longer work zone activities, and the RTC of Southern Nevada included mostly urban settings for both short-duration maintenance activities and longer work zone activities.

Table 1: Variations of arrow board reporting systems among Minnesota DOT, Iowa DOT, and the RTC of Southern Nevada

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	-	-
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

3.0 Evaluation Approach

This section presents a high-level overview of the evaluation intent, goals, and objectives that were detailed in the Evaluation Plan document previously developed in Phase 2 by ENTERPRISE and then modified and applied for this evaluation.

3.1 Evaluation Intent

The intent of this ENTERPRISE evaluation is to plan, execute, and report on a series of deployments that will help ENTERPRISE member agencies understand the potential for developed systems to integrate arrow board messages into traveler information systems in real-time. Specifically, there was an interest in an evaluation to determine whether the system can work in various situations (e.g. mobile lane closures). Evaluation findings may encourage additional agencies to deploy different approaches, which would further help industry professionals understand where, when, and why developed arrow board reporting systems experience issues, in order to invest in improvements where they are needed.

This evaluation follows a series of MOEs presented in the Evaluation Plan developed by ENTERPRISE in Phase 2 to evaluate the overall project objectives. The pilot arrow board reporting system deployments in Minnesota and Iowa do not meet all of the requirements or objectives that were originally documented in Phase 2, and as such this evaluation is flexible for the objectives and variations within each deployment to help ENTERPRISE member agencies understand the process, effectiveness, lessons learned, and benefits of various arrow board reporting systems.

3.2 Evaluation Goals

The overarching goal for evaluating arrow board reporting system deployments is to understand the potential of these systems to provide improved traveler information and to increase efficiency of DOT staff responsible for posting lane closure information to traveler information mechanisms. It is important to note that the deployments were expected to be "proof-of concept" level, and therefore this evaluation was intended to test the overall effectiveness and usefulness of the deployed systems.

Though each agency deployment differed such as the level of integration with TMC systems, the evaluation goals below were expected to be universal for all pilot deployments, regardless of the specific design selected, deployment setting, or level of integration with TMC systems.

- Goal #1: The equipped arrow board will be able to automatically collect and report sufficient information for determining its status and location.
- Goal #2: The arrow board reporting system will be able to process information collected at the arrow board to determine its current status and location.
- Goal #3: The arrow board current status and location information will be received by DOTs or a third-party vendor for providing improved real-time information.

3.3 Evaluation Objectives

The following seven evaluation objectives were identified to assess the extent to which the developed arrow board status reporting system solutions in Iowa and Minnesota address the primary functions

presented in the Model Requirements previously developed by ENTERPRISE. The seven identified evaluation objectives are:

- **Objective #1: Arrow Board Data Collection Capabilities** – encompassing accuracy, reliability, completeness.
- **Objective #2: Arrow Board Data Communications Capabilities** – including timeliness and reliability.
- **Objective #3: Arrow Board Processing Capabilities** – focuses on the ability to process arrow board data to accurately determine the operational status, e.g., facing direction, roadway/milepost, status change, mobile work zone, activation/de-activation, maintenance needs.
- **Objective #4: Arrow Board-related Notifications Capabilities** – concentrates on the communication mechanisms to field and TMC staff through the vendor interface or DOT ATMS, including the configurability, functionality, and usefulness of different variations.
- **Objective #5: Integration with Existing TMC Systems for Reporting Capabilities** – includes creation of new reports, when warranted; identifying, updating, and closing existing, relevant reports; interfaces and displays of information within each of the integrated TMC systems, as applicable, compared to the current processes used to document and report lane closure information: ATMS, RCRS, and ATIS.
- **Objective #6: Traveler Information Impacts** – focuses on the changes to ATIS events based on availability of new arrow board information for the provision of additional, more specific information, and potential benefit to the traveling public. This is regardless of whether arrow board information is integrated with the ATIS or manually input to the ATIS by TMC staff who receive the arrow board information via other TMC Systems or interfaces.
- **Objective #7: Data Archiving Capabilities** – focuses on the availability and usefulness of archived, raw, and processed arrow board data.

4.0 Evaluation Data Sources, Collection, and Analysis

Data sources and collection of the data for the MnDOT and Iowa DOT real-time arrow board deployments for this evaluation are described in this section.

4.1 Minnesota DOT

This evaluation examined the capabilities described in the evaluation objectives described in the previous section by using the following quantitative and qualitative data sources for a comprehensive evaluation for the MnDOT real-time arrow board system deployments:

- **Quantitative Data Sources**
  - *Arrow board data* – raw and processed data generated by the arrow board reporting system that was archived by the vendor as three distinct datasets (Street Smart).
  - *ATMS data* – existing archives of events from MnDOT's ATMS.
  - *RCRS data* – existing archives of events from the RCRS provided by Castle Rock (MnDOT's traveler information vendor).

- **Qualitative Data Sources**
  - *Traveler information system interfaces* – observations of information available via the ATIS interfaces, i.e., website or mobile app.
  - *System integrator feedback* – interview with DOT staff responsible for integrating the arrow board reporting system information within the ATMS and interviews with the traveler information vendor (Castle Rock) responsible for integrating arrow board status information from the ATMS to the RCRS.
  - *DOT staff feedback* – interviews with DOT field staff, operator staff, traveler information staff, and traveler information managers that work directly with the arrow board reporting system in the field and at the MnDOT RTMC.

Specific details of data available and collection for the Minnesota evaluation are described below.

4.1.1 Quantitative Data Sources

The duration of the MnDOT pilot deployment for the real-time integration of arrow board message into their traveler information system was from April 2018 to March 2019. However, quantitative datasets to analyze the Minnesota deployment for this evaluation were provided for 18 of the 20 arrow boards with status reporting capability for the period of October 18, 2018 to November 7, 2018. This time period followed initial testing and integration activities during the pilot project, such that all known issues had previously identified and resolved. MnDOT staff noted that this time period was representative of typical maintenance activities.

The quantitative data analysis relied on archives of raw and processed arrow board data from Street Smart, as well as RCRS, and ATMS event data. The analysis examined the completeness and timeliness of data transmission and event generation. In general, the analysis leveraged Excel worksheet functions that are available to take a count of data elements in an event message and identify the time elapsed between

each transmission of arrow board data based on time stamps in different datasets. DOT staff corroborated all quantitative findings and provided additional context wherever possible.

The following summarizes the quantitative data sources analyzed for the MnDOT real-time arrow board notification deployments.

4.1.1.1 Arrow Board Data

Street Smart developed a self-contained monitoring unit that was installed on existing MnDOT arrow boards. The system collected and communicated arrow board data to Street Smart's SmartAB server. All data collected by Street Smart was archived. There was a lot of data collected by Street Smart that was not passed along to MnDOT (e.g. when arrow boards displayed caution for a shoulder closure). MnDOT requested that Street Smart share information only if the arrow board was active with the right or left arrow displayed. For this evaluation the following three data sets from Street Smart were provided.

- **Location Data**. Street Smart provided location data for each arrow board equipped with Street Smart's monitoring unit for the testing period. Data fields in the location data file for each device included: Valid, Time, Latitude, Longitude, Altitude, Speed, and Address. Street Smart collects location data for latitude and longitude once every 10 minutes if the device is stationary and every couple seconds if the unit is moving. Figure 3 below shows a sample of data provided in the Street Smart location data file. The location file included 175,249 records for 18 devices for the three-week evaluation period. This file was used internally by Street Smart in conjunction with other data sources to create the Incident Feed file described below that was integrated into MnDOT's ATMS.

	A	B	C	D	E	F	G
1							
2	Report type:	Route					
3							
4	Device:	212532					
5	Group:	Metro					
6	Period:	2018-10-18 00:00:00 - 2018-11-08 00:59:00					
7							
8	Valid	Time	Latitude	Longitude	Altitude	Speed	Address
9	TRUE	18/10/2018 00:00:33	45.218090	-93.378930	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
10	TRUE	18/10/2018 00:10:33	45.218080	-93.378940	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
11	TRUE	18/10/2018 00:20:33	45.218070	-93.378960	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
12	TRUE	18/10/2018 00:30:33	45.218060	-93.378960	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
13	TRUE	18/10/2018 00:40:33	45.218060	-93.378950	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
14	TRUE	18/10/2018 00:50:33	45.218070	-93.378960	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
15	TRUE	18/10/2018 01:00:33	45.218070	-93.378960	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
16	TRUE	18/10/2018 01:10:33	45.218070	-93.378960	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
17	TRUE	18/10/2018 01:17:57	0.000000	0.000000	0 m	0.0 kn	0.000000°, 0.000000°
18	TRUE	18/10/2018 01:17:57	0.000000	0.000000	0 m	0.0 kn	0.000000°, 0.000000°
19	TRUE	18/10/2018 02:01:12	45.217750	-93.379230	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
20	TRUE	18/10/2018 02:03:09	45.217920	-93.379010	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
21	TRUE	18/10/2018 02:13:09	45.217970	-93.378970	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
22	TRUE	18/10/2018 02:24:24	45.218290	-93.378840	0 m	6.1 kn	7th Avenue, Anoka, Minnesota, US
23	TRUE	18/10/2018 02:25:01	0.000000	0.000000	0 m	0.0 kn	0.000000°, 0.000000°
24	TRUE	18/10/2018 02:25:07	45.217780	-93.378820	0 m	0.0 kn	3439 7th Avenue, Anoka, Minnesota, US
25	TRUE	18/10/2018 02:26:19	45.217950	-93.378710	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
26	TRUE	18/10/2018 02:36:19	45.218030	-93.378780	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
27	TRUE	18/10/2018 02:46:19	45.218070	-93.378790	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
28	TRUE	18/10/2018 02:56:19	45.218060	-93.378810	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
29	TRUE	18/10/2018 03:06:19	45.218070	-93.378820	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US
30	TRUE	18/10/2018 03:16:19	45.218070	-93.378840	0 m	0.0 kn	7th Avenue, Anoka, Minnesota, US

212532 | 215333 | 204502 | 208500 | 217457 | 217420 | 207501 | 214521 | 205500 | 205502 | 217456 | 215456 | 203300 | 217694 | 2

Figure 3: Screenshot of Street Smart Arrow Board Location Dataset

- **Status Data.** The Street Smart status file provided data including the Unit #, Date, Orientation, and Board Status. Figure 4 below shows a screenshot of the Street Smart status data file. The status file included 145,303 records for the three-week evaluation period. This file was used internally by Street Smart in conjunction with other data sources to create the Incident Feed file described below that was integrated into MnDOT's ATMS.

	A	B	C	D
1	Unit #	Date	Orientation	Board Status
2	215456	10/18/2018 0:00	Board Up	Blank
3	205502	10/18/2018 0:00	Board Up	Caution
4	214521	10/18/2018 0:01	Board Up	Blank
5	215333	10/18/2018 0:01	Board Up	Left Arrow On
6	203300	10/18/2018 0:01	Board Up	Blank
7	214516	10/18/2018 0:01	Board Up	Blank
8	208500	10/18/2018 0:01	Board Up	Blank
9	215456	10/18/2018 0:01	Board Up	Blank
10	205502	10/18/2018 0:01	Board Up	Caution

Figure 4: Screenshot of Street Smart Status Dataset

- **Incident Feed.** Street Smart provided an arrow board incident feed for MnDOT to integrate into their ATMS. The incident feed included the following fields: Added or Removed, Date/Time, Unit, Status, Latitude, and Longitude. Figure 5 provides a screenshot of the Street Smart incident feed file. There were 688 records provided in the incident feed for the three-week evaluation period.

	A	B	C	E	F	G
1	Added or removed	Date / Time	Unit	Status	Lat	Long
745	Unit added to feed	Thu Oct 18 08:14:16 2018	217936	Left Arrow On	44.68815	-93.2931
746	Unit removed from feed	Thu Oct 18 08:18:59 2018	217936	Caution	44.67776	-93.2939
747	Unit added to feed	Thu Oct 18 08:28:25 2018	217936	Left Arrow On	44.64143	-93.297
748	Unit removed from feed	Thu Oct 18 08:42:33 2018	217936	Caution	44.64121	-93.2971
749	Unit added to feed	Thu Oct 18 09:17:53 2018	217936	Left Arrow On	44.64101	-93.2971
750	Unit removed from feed	Thu Oct 18 09:34:24 2018	217936	Caution	44.63903	-93.2975
751	Unit added to feed	Thu Oct 18 10:19:09 2018	217936	Left Arrow On	44.6388	-93.2975
752	Unit removed from feed	Thu Oct 18 10:38:03 2018	217936	Caution	44.63758	-93.2976
753	Unit added to feed	Thu Oct 18 11:13:22 2018	217936	Left Arrow On	44.63746	-93.2977
754	Unit removed from feed	Thu Oct 18 11:32:21 2018	217936	Blank	44.5951	-93.2985
755	Unit added to feed	Thu Oct 18 13:15:35 2018	217936	Right Arrow On	44.74347	-93.2774
756	Unit removed from feed	Thu Oct 18 14:41:10 2018	217936	Caution	44.71892	-93.2823

Figure 5: Screenshot of Street Smart Incident Feed Dataset

4.1.1.2 ATMS Data

MnDOT's ATMS integrated with Street Smart's incident feed described above, however, incident messages were only provided to MnDOT when the status from the arrow board monitoring device reported right arrow on or left arrow on. MnDOT's ATMS inserted additional records as the location

changed. There were 903 records provided for the three-week evaluation period from MnDOT's ATMS. Data stored by MnDOT's ATMS included the following:

- Event date (includes date and time)
- Description
- Road
- Direction
- Impact
- Camera name
- Lane type
- Detail
- Confirmed
- Cleared
- Latitude
- Longitude

Figure 6 below shows an excerpt of MnDOT's ATMS dataset.

	A	B	C	D	E	F	G	H	I	J	K	L
1	Eventdate	Description	Road	Direction	Impact	Cameraname	Lanetype	Detail	Confirmed	Cleared	Latitude	Longitude
2	10/18/2018 1:02 p.m.	Incident ROADWORK	I-35W	SB	....	C647	Mainline	ab_left	FALSE	TRUE	45.1794	-93.12153
3	10/18/2018 1:10 a.m.	Incident ROADWORK	I-94	EB	.....	C807	Mainline	ab_left	FALSE	TRUE	45.1385	-93.49509
4	10/18/2018 1:16 p.m.	Incident ROADWORK	I-35E	SB	....	C010	Mainline	ab_right	FALSE	TRUE	44.74347	-93.27744
5	10/18/2018 1:22 a.m.	Incident ROADWORK	I-94	EB	.....	C807	Mainline	ab_left	FALSE	TRUE	45.13803	-93.49473
6	10/18/2018 1:44 p.m.	Incident ROADWORK	I-35W	SB	....	C647	Mainline	ab_right	FALSE	TRUE	45.17944	-93.1216
7	10/18/2018 10:20 a.m.	Incident ROADWORK	I-35	SB	....	C599	Mainline	ab_left	FALSE	TRUE	44.6388	-93.29745
8	10/18/2018 10:30 a.m.	Incident ROADWORK	I-35	SB	....	C599	Mainline	ab_left	FALSE	TRUE	44.63776	-93.29761
9	10/18/2018 11:14 a.m.	Incident ROADWORK	I-35	SB	....	C599	Mainline	ab_left	FALSE	TRUE	44.63746	-93.29767
10	10/18/2018 11:16 a.m.	Incident ROADWORK	I-35	SB	....	C599	Mainline	ab_left	FALSE	TRUE	44.63671	-93.29778
11	10/18/2018 11:20 a.m.	Incident ROADWORK	I-35W	SB	....	C647	Mainline	ab_right	FALSE	TRUE	45.17941	-93.12155
12	10/18/2018 12:10 a.m.	Incident ROADWORK	I-94	EB	.....	C801	Mainline	ab_left	FALSE	TRUE	45.20092	-93.56716
13	10/18/2018 12:12 a.m.	Incident ROADWORK	I-94	EB	.....	C802	Mainline	ab_left	FALSE	TRUE	45.19378	-93.5503
14	10/18/2018 12:14 a.m.	Incident ROADWORK	I-94	EB	.....	C803	Mainline	ab_left	FALSE	TRUE	45.18689	-93.54111
15	10/18/2018 12:14 p.m.	Incident ROADWORK	T.H.55	EB	....	C329	Mainline	ab_left	FALSE	TRUE	44.98297	-93.4001
16	10/18/2018 12:16 a.m.	Incident ROADWORK	I-94	EB	.....	C803	Mainline	ab_left	FALSE	TRUE	45.18292	-93.53631
17	10/18/2018 12:18 a.m.	Incident ROADWORK	I-94	EB	.....	C804	Mainline	ab_left	FALSE	TRUE	45.17545	-93.52787
18	10/18/2018 12:20 a.m.	Incident ROADWORK	I-94	EB	.....	C805	Mainline	ab_left	FALSE	TRUE	45.16538	-93.52436
19	10/18/2018 12:20 p.m.	Incident ROADWORK	I-94	EB	....	C9450	Mainline	None	FALSE	TRUE	46.02114	-95.79968
20	10/18/2018 12:22 a.m.	Incident ROADWORK	I-94	EB	.....	C805	Mainline	ab_left	FALSE	TRUE	45.16157	-93.51875
21	10/18/2018 12:26 a.m.	Incident ROADWORK	I-94	EB	.....	C805	Mainline	ab_left	FALSE	TRUE	45.15563	-93.50999

Figure 6: Screenshot of MnDOT's ATMS Arrow Board Message Dataset

4.1.1.3 RCRS Data

MnDOT's RCRS incorporated MnDOT's ATMS data for display on MnDOT's traveler information website. Mobile app, and Twitter feed (@TwinCities511). The data fields for this evaluation period for MnDOT's RCRS provided by Castle Rock (MnDOT's traveler information vendor) are shown below. There were 148 RCRS records provided for the three-week evaluation period.

- Organization ID
- Contact ID
- Message Date
- Message Time
- UTC Offset
- Message Expiry Date
- Message Expiry Time
- Event-ID
- Update
- Status
- Priority
- Description Phrase
- Desc. (cont'd)
- Link Ownership
- Cross-Street Designator
- Route Designator
- Latitude
- Longitude
- Linear Reference
- Direction
- Alignment
- Update Date
- Update Time
- Valid Period Duration
- Start Date
- Start Time

A screenshot of key fields from the RCRS dataset provided by Castle Rock is provided in Figure 7.

Message Date	Message Time	Event-ID	Update	Priority	Description Phrase	Desc. (cont'd)	Route Designator	Latitude	Longitude
20181023	101402	CARSAB-869949	1	5	right lane closed		I-394	44970900	-93486140
20181023	112202	CARSAB-869957	2	3	mobile maintenance operations	left lane closed	I-94	45308605	-93822434
20181023	121202	CARSAB-869958	1	5	left lane closed		I-35W	45177612	-93118634
20181023	121602	CARSAB-869959	1	5	right lane closed		I-35W	45177614	-93118631
20181023	125412	CARSAB-869960	2	3	mobile maintenance operations	right lane closed	I-494	44862320	-93220776
20181023	130402	CARSAB-869961	1	5	right lane closed		MN 5	44871487	-93197438
20181023	135402	CARSAB-869963	1	5	left lane closed		I-35W	45177531	-93118739
20181023	204202	CARSAB-869967	1	5	left lane closed		US 169	45035121	-93400682
20181023	215802	CARSAB-869968	2	3	mobile maintenance operations	right lane closed	I-35E	45196520	-93029637
20181023	224402	CARSAB-869970	1	5	right lane closed		I-35	45243694	-93027281
20181024	83202	CARSAB-4	1	5	left lane closed		MN 55	44983926	-93315956
20181025	211002	CARSAB-37	2	3	mobile maintenance operations	left lane closed	I-494	44875483	-93032382

Figure 7: Screenshot of Key Fields from Castle Rock RCRS Arrow Board Message Dataset

Reasons as to why only a subset of events in the ATMS were ingested by the RCRS include:

- Records that did not have an "ab_left" or "ab_right" value in the Detail field were excluded from being imported into the RCRS.
- If the route name and geo-location of the event as reported in the ATMS didn't match the route name within a .25 mile margin or effort in the RCRS, RCRS would not import it, in order to avoid posting a potentially incorrect location description to the public.
- If no fields were updated in the ATMS that would result in an explicit change in the details of the RCRS report, the RCRS report would remain unchanged.

4.1.2 Qualitative Data Sources

Qualitative feedback was received from the Minnesota deployments following a year of testing. This included verification of quantitative findings. Question guides were developed by the evaluation team for Street Smart, Castle Rock, and MnDOT feedback to understand the types of information of interest to the evaluation, such as the level of effort for installation, accuracy and consistency of the reported arrow board data, and lessons learned. During the testing period, MnDOT's traveler information website and mobile app, and Twitter feed (@mndottraffic) were also observed to verify in real-time that arrow board status messages were displayed.

4.2 Iowa DOT

This evaluation examined the capabilities described in the evaluation objectives identified in the previous section by using the qualitative data sources for the Iowa DOT real-time arrow board system deployments. Quantitative data sources were not used as Iowa DOT was still in the testing phase of the deployments when this evaluation was completed. However, it is anticipated that an evaluation will be conducted by Iowa State University CTRE once deployments are integrated into their ATMS later in 2020.

4.2.1 Qualitative Data Sources

Throughout the course of this evaluation effort, CTRE was working closely with the Iowa DOT to test and deploy arrow board reporting systems. This evaluation relied on input and early findings of the deployment from CTRE staff who provided input to the evaluation about the deployment through phone interviews. Qualitative feedback was received about the Iowa deployment following several months of testing. Question guides were developed by the evaluation team to ensure certain information was gathered, such as the level of effort for installation, integration, accuracy, and consistency of the reported arrow board data and lessons learned.

5.0 Evaluation Findings

Each evaluation objective may relate to one or more measures of effectiveness, as outlined in the Evaluation Plan developed by ENTERPRISE in Phase 2. Note that analysis and presentation of evaluation findings may differ from what was proposed in the Evaluation Plan given the availability of data, how each agency measures success of a deployed arrow board reporting system, and how each arrow board reporting system was deployed. This evaluation attempts to capture as much detail and specific feedback as possible through a comprehensive series of MOEs for the MnDOT and Iowa DOT real-time arrow board status notification deployments.

5.1 Minnesota DOT

This section provides the evaluation results for each applicable MOE previously identified from the Phase 2 ENTERPRISE effort by evaluation objective. In addition, the datasets utilized from section 4.1.1 and a description of the analysis of data collected from 18 arrow board reporting devices during the test period from October 18 to November 7, 2018 is provided.

As mentioned earlier in this report, a requirements testing demonstration took place on Thursday, September 27, 2018 that provided the opportunity to verify the arrow board reporting system functions. Evaluation team staff were present for a field test in Minnesota. During this field test, the evaluation team documented the arrow board location and display status for several instances that the arrow board operational status changed in order to verify the arrow board data and functionality. Additionally, quantitative data findings were reviewed with DOT operator staff, DOT field staff, and vendor staff to verify the accuracy of the findings and to provide additional context and perspective. A summary report of this field test can be found at:
https://www.dot.state.mn.us/its/projects/2016-2020/arrowboard/summaryreport.docx.

Figure 8 illustrates the flow of the arrow board message records analyzed for this evaluation. Street Smart collected data (e.g. location, arrow board status) from the onboard devices on 18 arrow boards every 10 minutes or every couple seconds if the arrow board was moving. This data was then combined by Street Smart and fed into an incident feed of data for processing by MnDOT's ATMS. MnDOT requested only records when the arrow board was in use (left arrow on or right arrow on) be merged into the incident feed. However, MnDOT staff had access to view all data collected through the SmartAB web interface provided by Street Smart. Thousands of records were collected by Street Smart, however only 688 records were included in the incident feed for the evaluation period that was processed by MnDOT's ATMS and then by the RCRS. It is important to note that the Street Smart incident feed only adds and removes arrow boards, whereas MnDOT's ATMS inserts additional records as the location changes. As incomplete data was removed through each system a total of 141 records matched between Street Smart's Incident Feed, MnDOT's ATMS, and the RCRS. See Appendix A to review the data from key data fields of the matched dataset.

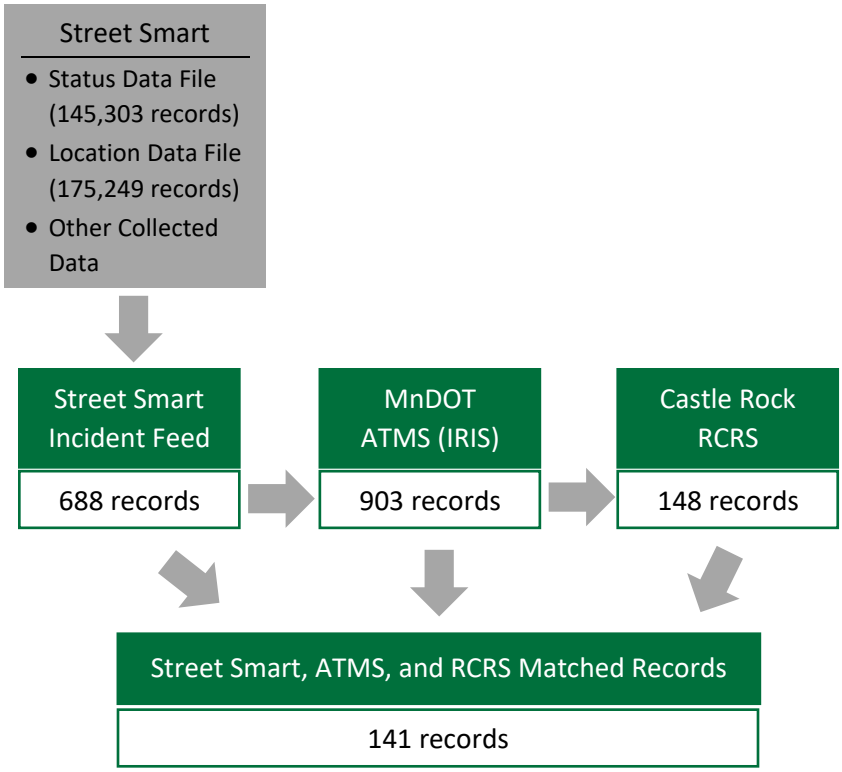

Figure 8: Data flow of MnDOT Real-Time Arrow Board Message Records for the Evaluation Period (October 18 to November 7 in 2018) from 18 arrow boards

5.1.1 Evaluation Objective #1: Arrow Board Data Collection Capabilities

Table 2 presents data collection capabilities of the arrow board monitoring devices installed by Street Smart on the MnDOT arrow boards. It is important to note that Street Smart archived all data collected for the duration of the one-year MnDOT pilot project. Street Smart provided one file with arrow board location data and one file with the status of the arrow board for the three-week period for this evaluation. Street Smart collected additional data, however for this evaluation the two files provided were analyzed to document the arrow board collection capabilities. These files were used along with other data collected by Street Smart to produce an incident feed for incorporation in MnDOT's ATMS. The incident feed included records of when the arrow board was active and indicating left arrow on or right arrow on as requested by MnDOT.

The table below indicates that 98.3% of the Street Smart status records (e.g. right arrow on, left arrow on) had complete board status information and 89.4% of Street Smart location records were complete. However, the number of incomplete location records is somewhat misleading. First, arrow boards continued to report location from inside a maintenance garage when given sufficient power, but reduced access to GPS inside the garage resulted in incomplete records. Second, many incomplete location records were immediately followed by a complete record to update the information that was previously lacking. Additional information on the datasets used and the analysis is described in the table below.

Table 2. Objective #1: Arrow Board Data Collection Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Percent of received arrow board status with complete data.		
Street Smart **Status Data** file fields used: • Board Status (e.g. right arrow on, left arrow on) Street Smart **Location Data** file fields used: • Latitude • Longitude	Compared the total number of records from the Status Data file to the number of incomplete records (board status field is "undefined"). • Total Records: 145,303 • Incomplete Records: 2,489 Compared the total number of records from the Location Data file to the number of incomplete ("0,0") latitude and longitude fields. • Total Records: 175,249 • Incomplete Records: 18,537	**98.3%** Street Smart status records with complete board status information. **89.4%** Street Smart complete location records.

5.1.2 Evaluation Objective #2: Arrow Board Data Communications Capabilities

Street Smart compiled information from its Status Data file, Location Data file, and other collected data and produced an incident feed for incorporation in MnDOT's ATMS. The incident feed contained only status information as desired by MnDOT (e.g. right arrow on, left arrow on). Table 3 below provides an analysis of the number of Street Smart Incident Feed records for incorporation into MnDOT's ATMS. In addition, the time delay in the message to go from the Street Smart incident feed to MnDOT's ATMS then to the RCRS and then to the traveling public interface was analyzed. The time delay was calculated using the 141 matched records between these systems. The records were matched by aligning the date, time, and status (e.g. RCRS "Right Lane Closed" matched to Street Smart "Left Arrow On" that matched to MnDOT's ATMS "ab_left").

There were 638 records received from Street Smart's Incident Feed over the three-week test period and 94.7% of these messages were complete. It took an average of 83 seconds for the 141 records to appear in the RCRS after being processed from Street Smart's Incident Feed. See the table below for additional details on the datasets used and analysis.

Table 3. Objective #2: Arrow Board Data Communications Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Number of arrow board messages received.		
Street Smart **Incident Feed** file fields used: • Latitude • Longitude	Compared the total number of records from the Street Smart Incident Feed file to the number of incomplete records (blank longitude and latitude) • Total Records: 638* • Incomplete Records: 34 ** There were 688 total records, but 10 records included data erroneously shifted into incorrect fields and 40 records recorded "timeout" for latitude and longitude by a device that may have been malfunctioning as it never recorded a latitude or longitude during the evaluation period. Therefore these 50 records were removed.*	**638 records** received from Street Smart's incident feed over the test period. **94.7%** Street Smart incident feed messages were complete.
MOE: Time delay in sending messages.		
RCRS Data file fields used: • Message Time • Message Date Street Smart **Incident Feed** file fields used: • Time • Date	There were 141 records that matched between Street Smart's Incident Feed, MnDOT's ATMS, the RCRS, and MnDOT's ATIS. These 141 records were compared for this analysis. Reviewed the difference between the RCRS Data file message time to the Street Smart Incident Feed file (time/date fields) and found the average. ATMS data does not indicate time in seconds. Therefore, it was not included in this analysis. • Average time between Street Smart Incident Feed and RCRS: 83 seconds.	**Average of 83 seconds for 141 records** to appear in RCRS after being processed from Street Smart's incident feed. NOTES: • The maximum time between messages was 459 seconds and the minimum time was 1 second. • In 59 records, it required more than the average amount of time to communicate between the RCRS and the Street Smart incident feed and in 82 records the time was at or below the average.

5.1.3 Evaluation Objective #3: Arrow Board Processing Capabilities

Street Smart provided the location of the arrow board with latitude and longitude. The ATMS incorporated this data. For the 141 matched records 87.2% were exact location matches or within 200 feet. Note that IRIS snaps a received arrow board location to the nearest node location that is coded as a road, so some location variability is expected. As a result, 200 feet is assumed to be within this expected variability. In

addition, there were 14 records that accurately characterized a mobile work zone. See the table below for additional details on the analysis.

Table 4. Objective #3: Arrow Board Data Communications Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Percent of accurately identifying arrow board GPS location.		
Street Smart **Incident Feed** fields used: • Latitude • Longitude MnDOT **ATMS Data** fields used: • Latitude • Longitude	There were 141 records that matched between Street Smart's Incident Feed, MnDOT's ATMS, the RCRS, and MnDOT's ATIS. These 141 records were compared for this analysis. Compared the latitude and longitude from Street Smart Incident Feed and MnDOT's ATMS Data. • Total records: 141 • Exact location matches: 115 • Location matches within 200 ft*: 8 • Locations outside of 200 ft: 18 **Based on a latitude/longitude distance calculator*	**87.2% of 141 records** are exact location matches or within 200 ft.
MOE: Number of records accurately characterizing a mobile work zone.		
MnDOT **RCRS Data** field used: • Description Phrase	There were 141 records that matched between Street Smart's Incident Feed, MnDOT's ATMS, the RCRS, and MnDOT's ATIS. These 141 records were compared for this analysis. • Total records: 141 • Records describing mobile maintenance operations: 14	**14 mobile work zones** were identified in the 141 matched records.
MOE: Percentage that the closed lane of traffic is accurately identified when Arrow Board display is activated.		
Street Smart **Incident Feed** fields used: • Board Status MnDOT **ATMS Data** fields used: • Detail MnDOT **RCRS Data** fields used: • Description	There were 141 records that matched between Street Smart's Incident Feed, MnDOT's ATMS, the RCRS, and MnDOT's ATIS. These 141 records were compared for this analysis. • RCRS "Right Lane Closed" matched to Street Smart "Left Arrow On" that matched to MnDOT's ATMS "ab_left" • RCRS "Left Lane Closed" matched to Street Smart "Right Arrow On" that matched to MnDOT's ATM "ab_right"	**100% of 141** records are exact arrow-board status messages identifying the correct lane of traffic is closed.

5.1.4 Evaluation Objective #4: Arrow Board-related Notifications Capabilities

The purpose of this objective was to examine the ability of the TMC system to generate arrow-board notifications to field staff and TMC operators. However, for the MnDOT pilot test the focus was on integrating the data. The events did appear on the TMC RCRS interface, however TMC operators did not interact with the events and notifications were not provided to field staff. It is important to note that MnDOT RTMC managers and MnDOT Maintenance managers were also able to view the events through Street Smart's SmartAB web interface.

Table 5. Objective #4: Arrow Board-related Notifications Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Field staff time required to operate the arrow board reporting system.		
• MnDOT Field Staff	• Interview with MnDOT Field Staff.	No additional staff time was required to operate the arrow board reporting system in the field.

5.1.5 Evaluation Objective #5: Integration with Existing TMC Systems for Reporting Capabilities

For Objective #5 the purpose was to evaluate the ability of the arrow board reporting system information to be integrated with DOT-operated software solutions without the need to open external software systems or create new events, when warranted; to identify, update, and close existing, relevant events, when warranted; and to provide usable information on existing TMC interfaces and displays. The incident feed provided by Street Smart was incorporated into MnDOT's ATMS and then to the MnDOT RCRS. The ATMS interface provided the opportunity for RTMC operators to view and edit the real-time arrow board events. However, for this one-year test period RTMC operators only viewed the events; they did not modify the events or make any other changes because changes would either separate the event from the arrow board incident event to prevent real-time updates or be overwritten by the subsequent arrow board incident feed update.

Table 6. Objective #5: Integration with Existing TMC Systems for Reporting Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Extent of configurations, modifications, or integration actions required to integrate the arrow board information.		
• MnDOT System Integrator	• Interview with MnDOT ATMS integrator staff.	MnDOT staff reported that modifications within the ATMS to integrate the arrow board reporting system data required minimal effort since Street Smart provided the data in a compatible, pre-established format.
MOE: Operator ability to select and view arrow board information within the interface.		
• MnDOT RTMC Operators	• Interview with MnDOT RTMC Operators	RTMC Operators had the ability to select and view arrow board events, however for the one-year pilot operators only viewed the events.

Dataset	Analysis	MnDOT Evaluation Results
MOE: Operator satisfaction with capability of the system to automatically create system-generated new events.		
• MnDOT RTMC Operators	• Interview with MnDOT RTMC Operators	RTMC Operators only viewed the events during the one-year pilot, they did not make any modifications to the events. However, RTMC Operators indicated that the real-time arrow board events provided an additional source of information to understand the roadway network.
MOE: Operator satisfaction with capability of the system to automatically update existing events.		
• MnDOT RTMC Operators	• Interview with MnDOT RTMC Operators	RTMC Operators only viewed the events during the one-year pilot, they didn't make any modifications to the events. However, RTMC Operators indicated satisfaction with the automation of updating existing events that didn't require manual interaction.
MOE: Perceived benefits of added specificity in events that are automatically updated using arrow board information		
• MnDOT RTMC Operators • Evaluation Team	• Interview with MnDOT RTMC Operators	The new arrow board events were helpful to MnDOT operators, who noticed maintenance and snow removal activities that are normally not available and could be verified by operators using cameras.
MOE: Operator ability to view timely, accurate, and useful arrow board information from all active devices on the system interface, compared to previous information about lane closures.		
• MnDOT RTMC Operators • MnDOT Maintenance Managers	• Interview with MnDOT RTMC Operators • Interview with MnDOT Maintenance Managers	MnDOT previously did not enter short-term lane closure events into the RCRS. The real-time arrow board notifications alerted operators about locations to monitor.

5.1.6 Evaluation Objective #6: Traveler Information Impacts

Prior to the one-year pilot test conducted by MnDOT to integrate real-time lane closure of shorter-duration maintenance activities into the ATMS many of these event types were not reported. Therefore, before data was unavailable to compare these new events to. Traveler information impacts are documented in Objective #6. The average duration of arrow board events was 43.5 minutes for 335 events within the Street Smart Incident Feed. Four of 141 matched events occurred during the peak period, with an average duration of 8.3 minutes. See the table below for additional details.

Table 7. Objective #6: Traveler Information Impacts - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Number of new events created in TMC Systems using arrow board information.		
RCRS Data fields used: • Message Date • Message Time Street Smart **Incident Feed** fields used: • Date / Time MnDOT **ATMS Data** field used: • Event Date	The RCRS Data event date and time were first matched to the Street Smart Incident Feed data. The Street Smart Incident Feed updates once a minute which produced more records than the RCRS Data records. The records were then matched to MnDOT's ATMS data, creating 141 records. • Number of Street Smart Incident Feed Records: 638* • Number of MnDOT ATMS Records: 903 • Number of RCRS Records: 141** ** There were 688 total records, however 10 records included data erroneously shifted into incorrect fields and 40 records recorded "timeout" for latitude and longitude by a device that never recorded a latitude or longitude. The device may have been malfunctioning; therefore these 50 records were removed from the total.* ***7 records removed as they did not match with the ATMS or Incident Feed records.*	**141 new records** were created. Data was matched among the Street Smart Incident Feed, MnDOT ATMS Data, and the RCRS Data**.**
MOE: Duration of active lane closure events.		
Street Smart Incident Feed fields used: • Unit Number • Date / Time	The Street Smart Incident Feed file was sorted by unit number and then by date and time to calculate the time between adding and removing the unit, referred to as the minutes active. Number of events: 335 • Average minutes active: 43.5 minutes* **Maximum value of 469.93 minutes active and a minimum value of 1.18 minutes active.* There were 141 records that matched between Street Smart's Incident Feed, MnDOT's ATMS, the RCRS, and MnDOT's ATIS. These 141 records were reviewed for this analysis. • Number occurred during peak periods (Monday thru Friday 6AM to 9AM or 4PM to 7PM): 4 • Average minutes active: 8.3 minutes*	Average duration of arrow board events was **43.5 minutes for 335 events** within the Street Smart Incident Feed. **4 of 141** matched events occurred during the peak period, with an average duration of **8.3 minutes.**

Dataset	Analysis	MnDOT Evaluation Results
MOE: Perceived benefits of added details in events that are updated using Arrow Board information.		
• DOT traveler information staff and manager • Evaluation team	• Interview with MnDOT Traveler Information Staff and Manager • Evaluation Team Review	The new arrow board events were available for maintenance and snow removal activities that are normally not in 511 for travelers and believed to be beneficial.
MOE: Traveling public ability to view timely, accurate, and useful Arrow Board information from all active devices on the ATIS interface, compared to previous information about lane closures.		
• DOT traveler information staff and manager • Evaluation team	• Interview with MnDOT Traveler Information Staff and Manager • Evaluation Team Review	141 events were generated on 511 by 18 arrow boards during the 3-week evaluation. These events allowed for more timely traveler information with minimal delay. If we assume this 3-week time period to be representative of the 1-year test period, the 20 equipped arrow boards would generate an estimated 2,700 events over the 1-year test period.
MOE: Traveler Information staff satisfaction with information provided by Arrow Board system.		
• DOT traveler information staff and manager	• Interview with MnDOT Traveler Information Staff and Manager	MnDOT traveler information staff periodically viewed the arrow board events in the RCRS to understand the overall roadway network.
MOE: Traveler Information feedback from traveling public		
• DOT traveler information staff and manager	• Interview with MnDOT Traveler Information Staff and Manager	There was no feedback received by MnDOT from the public on the lane closure information reported on MnDOT's website and app from the pilot project.

5.1.7 Evaluation Objective #7: Data Archiving Capabilities

In this evaluation objective, the ability to store arrow-board related lane closure data for the purposes of research, performance management, evaluation, and transportation management planning were examined. Street Smart collected and archived all data from the monitoring device on each arrow board for the one-year pilot project. MnDOT's ATMS archived the ATMS data from Street Smart's incident feed. Although Castle Rock did not routinely archive any RCRS data in its Minnesota deployement, with

knowledge of this evaluation Castle Rock archived the arrow board event data for the three-week evaluation period. The table below indicates the amount of raw data archived for this evaluation over the testing and the ease of access to the data.

Table 8. Objective #7: Data Archiving Capabilities - MOE, Dataset Used, Analysis, and Evaluation Results

Dataset	Analysis	MnDOT Evaluation Results
MOE: Ability of system to store all raw and processed arrow board data with appropriate timestamps, operations and status changes, location, and other relevant data.		
• Street Smart **Status Data** file • Street Smart **Location Data** file • Street Smart **Incident Feed** file • MnDOT **ATMS Data** file • Castle Rock **RCRS Data** File	Street Smart and the MnDOT ATMS routinely stored all arrow board data. RCRS data was able to be archived and made available for a 3-week study period, as requested.	• **145,303 Street Smart Status Data records** • **175,249 Street Smart Location Data records** • **688 Street Smart Incident Feed records** • **903 ATMS Data records** • **148 RCRS Data records**
MOE: Ability of system to offer DOT staff relatively easy access to archived arrow board data.		
• Street Smart **Status Data** file • Street Smart **Location Data** file • Street Smart **Incident Feed** file • MnDOT **ATMS Data** file • Castle Rock **RCRS Data** File	Arrow board data from Street Smart, MnDOT, and Castle Rock was provided for a 3-week study period, as requested.	Received Street Smart, MnDOT ATMS, and Castle Rock RCRS data, as requested, with no noted issues in the data. Street Smart also provided a web interface to view all real-time and archived data collected throughout the one-year pilot project.

5.2 Iowa DOT

This section provides the evaluation results for each previously identified evaluation objective for the 5 arrow board devices tested by Iowa. This included two devices from iCone, two devices from Street Smart, and 1 device from VerMac. Results were gathered through phone interviews with the Iowa State University CTRE staff who worked closely with the Iowa DOT to test and deploy these arrow board reporting systems. Quantitative data sources were not used as Iowa DOT was still in the early testing phases of the deployments when this evaluation was completed. A separate evaluation will be completed by CTRE following the testing phase and integration of arrow board reporting system data with the new ATMS in 2020.

CTRE worked with the Iowa DOT during the development of a smart arrow board communication protocol and draft smart arrow board specification. Before finalizing the specification, the draft will be shared with arrow board manufacturers for input on the functional requirements. In addition, the communication protocol was developed to guide consistency in arrow board reporting deployments. The communications

protocol includes performance and some hardware requirements that complement the functional requirements in the draft smart arrow board specification.

5.2.1 Evaluation Objective #1: Arrow Board Data Collection Capabilities

This objective encompassed the accuracy, reliability, and completeness of collected arrow board data. The data collected to date by all three vendors that participated in the testing period for Iowa have produced complete records from general observations. Casual reviews of the data have not identified any time periods with missing data. However, it is important to note that review of the data during the testing period has focused more on individual data points to understand how it related to the work zone status, location, and planned event information. There have been a few times where a vendor's server was down for a week or two and CTRE has had to alert the vendor. It is anticipated additional reviews of the data for completeness will occur as the testing period moves forward.

5.2.2 Evaluation Objective #2: Arrow Board Data Communications Capabilities

This objective focused on the timeliness and reliability of data. During the testing period, latency of 7 to 8 minutes was observed for data from some vendors to be reported to CTRE. This was attributed to how the data was accessed by CTRE in the data interface. Data from one vendor must be downloaded from an FTP site while another vendor provides data on a server to be downloaded. Iowa DOT is in the process of finalizing a communication protocol for work zone devices, which includes arrow board reporting systems. The protocol will specify the format for transmitting data (e.g. Application Program Interface (API)) and result in reduced latency. It was observed that even with the latency, when CTRE received the data, the correct, original timestamp was reported with the event data.

In addition, CTRE tested the VerMac arrow board reporting system against the draft communications protocol. The test was valuable for validating the functionality of the draft protocol and confirming that the values to be included in the draft specification are realistic and attainable. The results of a test to identify a mobile work zone were favorable in that the data updated within two minutes when the arrow board moved by 500 feet or the pattern changed. However, it was noted that additional testing is needed to further refine the values, e.g. the 500-foot distance threshold, to include in the final specification.

5.2.3 Evaluation Objective #3: Arrow Board Processing Capabilities

Objective #3 focused on the ability to process arrow board data to accurately determine the operational status. The accuracy of the location and directionality had not been specifically noted during the testing period. However, CTRE assigned a reported arrow board event location to a linear reference that was then associated with the nearest 511 event. There were no known examples of provided arrow board information identifying the closure in the incorrect lane. Additional quality checks will be conducted to verify location and directionality.

In addition, CTRE tested mobile work zone applications by reviewing AVL data. The Automatic Vehicle Location (AVL) can verify location, but not information regarding which lane is closed. Although Iowa DOT is currently changing AVL providers, CTRE has developed a methodology that will be tested to detect and collect lane closure information using AVL data.

5.2.4 Evaluation Objective #4: Arrow Board-related Notifications Capabilities

The arrow board reporting system data was integrated by the iCone system with Waze. DOT staff have the capability to review the reported data from the iCone arrow boards through the Waze application. Notifications to TMC staff will be made available with all vendor data through Iowa DOT's ATMS when the update is complete in 2020.

The arrow board reporting system notifications are desired by TMC staff as it provides another source of information on the overall network. This solution is also desired by field staff because it does not take extra time to operate and there is no training required to operate the arrow board reporting system.

5.2.5 Evaluation Objective #5: Integration with Existing TMC Systems for Reporting Capabilities

Iowa DOT was in the process of updating their ATMS. During the testing period the arrow board reporting system was not integrated with any existing TMC systems. It is anticipated that once the ATMS is updated in 2020 the arrow board reporting system will be included as an input to the ATMS.

5.2.6 Evaluation Objective #6: Traveler Information Impacts

This objective focused on changes to ATIS events based on the availability of new arrow board information. During the testing period quality checks were conducted by reviewing and matching events from the arrow board system and finding the nearest 511 event entered as planned event information. Additional testing will be conducted to determine changes to ATIS events based on arrow board information.

5.2.7 Evaluation Objective #7: Data Archiving Capabilities

During the testing period, CTRE archived all data gathered from the arrow board reporting system deployments. Each vendor's data was archived into a separate database for the testing period. However, development of a more robust system that would pull all vendor information into one database is desired. It is anticipated that once the new Iowa DOT ATMS is installed that archiving will occur at the DOT. The goal is for arrow board information to be one of the data inputs into the new ATMS.

6.0 Summary

This section provides key highlights from the evaluation results of arrow board reporting system deployments by MnDOT, Iowa DOT, and the RTC of Southern Nevada.

There were similarities and differences among the three states with their arrow board reporting system deployments as show in Table 9 below. Notable differences included the following:

- To date, only MnDOT fully integrated real-time arrow board reporting system information with their ATMS and RCRS for their pilot deployment. This functionality is expected to be added later for both Iowa DOT and the RTC of Southern Nevada. Currently, a third-party traveler information provider (Waze) utilizes the smart arrow board status messages from Iowa and the RTC of Southern Nevada from the iCone servers.
- MnDOT deployed real-time arrow board reporting systems in mostly urban areas for short duration maintenance activities, while Iowa DOT primarily deployed arrow board reporting systems on rural corridors for nightly lane closures on longer work zone activities, and the RTC of Southern Nevada included mostly urban settings for both short-duration maintenance activities and longer work zone activities.

Table 10 provides key findings from each objective that was analyzed for this evaluation.

Table 9: Variations of arrow board reporting systems among Minnesota DOT, Iowa DOT, and the RTC of Southern Nevada

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	-	-
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

Table 10: Key findings by each objective analyzed for MnDOT and Iowa DOT arrow board reporting system deployments

Evaluation Objective #1: Arrow Board Data Collection Capabilities – encompassing accuracy, reliability, completeness.	
MnDOT Results	98.3 percent of the 145,303 Street Smart status records (e.g. right arrow on, left arrow on) had complete board status information and 89.4 percent of the 175,249 Street Smart location records were complete. However, the number of incomplete location records is somewhat misleading. First, arrow boards continued to report location from inside a maintenance garage, but insufficient power reduced access to GPS and resulted in incomplete records. Second, many incomplete location records were immediately followed by a complete record to update the information that was previously lacking.
Iowa DOT Results	The data collected to date by all three vendors that participated in the testing period for Iowa have produced complete records from general observations. Casual reviews of the data have not identified any time periods with missing data
Evaluation Objective #2: Arrow Board Data Communications Capabilities – including timeliness and reliability.	
MnDOT Results	There were 638 records received from Street Smart's Incident Feed over the three-week test period and 94.7 percent of these messages were complete. It took an average of 83 seconds for the 141 records to appear in the RCRS after being processed from Street Smart's Incident Feed.
Iowa DOT Results	During the testing period latency of 7 to 8 minutes was observed for some data to be reported to CTRE from each vendor. However, once an API is utilized to transmit the data, the latency will be reduced.
Evaluation Objective #3: Arrow Board Processing Capabilities – focuses on the ability to process arrow board data to accurately determine the operational status, e.g., facing direction, roadway/milepost, status change, mobile work zone, activation/de-activation, maintenance needs.	
MnDOT Results	For the 141 matched records 87.2 percent were exact location matches or within 200 feet. Note that IRIS (MnDOT's ATMS) snaps a received arrow board location to the nearest node location that is coded as a road, so some location variability is expected. As a result, 200 feet is assumed to be within this expected variability. In addition, there were 14 records that accurately characterized a mobile work zone.
Iowa DOT Results	For the testing period the accuracy of the location and directionality was not noted, however, additional quality checks are being conducted to verify location and directionality.
Evaluation Objective #4: Arrow Board-related Notifications Capabilities – concentrates on the communication mechanisms to field and TMC staff through the vendor interface or DOT ATMS, including the configurability, functionality, and usefulness of different variations.	
MnDOT Results	For the MnDOT pilot test the focus was on integrating the data. The events did appear on the TMC RCRS interface, however TMC operators did not interact with the events and notifications were not provided to field staff.
Iowa DOT Results	The arrow board reporting system data was integrated by the iCone system with Waze. DOT staff have the capability to review the reported data from the iCone arrow boards through the Waze application. Notifications to TMC staff will be made available with all vendor data through Iowa DOT's ATMS when the update is complete in 2020.

Evaluation Objective #5: Integration with Existing TMC Systems for Reporting Capabilities – includes creation of new reports, when warranted; identifying, updating, and closing existing, relevant reports; interfaces and displays of information within each of the integrated TMC systems, as applicable, compared to the current processes used to document and report lane closure information: ATMS; RCRS; and ATIS.	
MnDOT Results	For the one-year test period RTMC operators only viewed the events; they did not modify the events or make any other changes because changes would either separate the event from the arrow board incident event to prevent real-time updates or be overwritten by the subsequent arrow board incident feed update.
Iowa DOT Results	Iowa DOT was in the process of updating their ATMS. During the testing period the arrow board reporting system was not integrated with any existing TMC systems. It is anticipated that once the ATMS is updated in 2020 the arrow board reporting system will be included as an input to the ATMS.
Evaluation Objective #6: Traveler Information Impacts – focuses on the changes to ATIS events based on availability of new arrow board information for the provision of additional, more specific information, and potential benefit to the traveling public. This is regardless of whether arrow board information is integrated with the ATIS or manually input to the ATIS by TMC staff who receive the arrow board information via other TMC Systems or interfaces.	
MnDOT Results	The average duration of arrow board events was 43.5 minutes for 335 events within the Street Smart Incident Feed. Four of 141 matched events occurred during the peak period, with an average duration of 8.3 minutes.
Iowa DOT Results	During the testing period quality checks were conducted by reviewing and matching events from the arrow board system and finding the nearest 511 event entered as planned event information.
Evaluation Objective #7: Data Archiving Capabilities – focuses on the availability and usefulness of archived, raw, and processed arrow board data.	
MnDOT Results	Street Smart collected and archived all data from the monitoring device on each arrow board for the one-year pilot project. MnDOT's ATMS archived the ATMS data from Street Smart's incident feed. Although Castle Rock did not routinely archive any RCRS data in its Minnesota deployment, with knowledge of this evaluation Castle Rock archived the arrow board event data for the three-week evaluation period, as requested.
Iowa DOT Results	During the testing period, CTRE archived all data gathered from the arrow board reporting system deployments. It is anticipated that once the new Iowa DOT ATMS is installed, archiving will occur at the DOT.

Overall the data analysis for MnDOT and the information gathered from interviews from MnDOT and Iowa DOT indicate a benefit to the traveling public and TMC operators with additional information on the overall network with the location of lane closures provided by arrow board reporting systems.

Appendix A: MnDOT Matched Dataset: RCRS, Incident Feed, and ATMS

Key data fields used in matching data from Castle Rock's RCRS Data, Street Smart's Incident Feed, and MnDOT's ATMS Data.

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181018	111402	CARSAB-869859	right lane closed		44983042	-93400103	Thu Oct 18 12:13:37 2018	214521	Left Arrow On	44.98297	-93.4001	10/18/2018 12:14 p.m.	ab_left	44.98297	-93.4001
20181018	115202	CARSAB-869863	left lane closed		45177559	-93118703	Thu Oct 18 12:50:48 2018	203300	Right Arrow On	45.17941	-93.1216	10/18/2018 12:52 p.m.	ab_right	45.17941	-93.12156
20181018	115802	CARSAB-869864	left lane closed		45177564	-93118696	Thu Oct 18 12:57:49 2018	203300	Right Arrow On	45.1794	-93.1215	10/18/2018 12:58 p.m.	ab_right	45.1794	-93.12153
20181018	121602	CARSAB-869867	left lane closed		44743319	-93277259	Thu Oct 18 13:15:35 2018	217936	Right Arrow On	44.74347	-93.2774	10/18/2018 1:16 p.m.	ab_right	44.74347	-93.27744
20181018	124402	CARSAB-869868	left lane closed		45177561	-93118700	Thu Oct 18 13:42:19 2018	203300	Right Arrow On	45.17944	-93.1216	10/18/2018 1:44 p.m.	ab_right	45.17944	-93.1216
20181018	183402	CARSAB-869871	right lane closed		44973169	-93088415	Thu Oct 18 19:33:58 2018	215333	Left Arrow On	44.97316	-93.0909	10/18/2018 7:34 p.m.	ab_left	44.97316	-93.09086
20181018	195002	CARSAB-869872	right lane closed		45010212	-93154224	Thu Oct 18 20:48:39 2018	215333	Left Arrow On	45.01049	-93.1544	10/18/2018 8:50 p.m.	ab_left	45.0105	-93.15423
20181019	11212	CARSAB-869874	right lane closed		45010212	-93154174	Fri Oct 19 02:10:48 2018	215333	Left Arrow On	45.0105	-93.1542	10/19/2018 2:12 a.m.	ab_left	45.0105	-93.15418
20181019	65412	CARSAB-869875	left lane closed		44973110	-93088414	Fri Oct 19 07:53:40 2018	215333	Right Arrow On	44.9731	-93.0911	10/19/2018 7:54 a.m.	ab_right	44.9731	-93.09108
20181019	82202	CARSAB-869876	right lane closed		45010116	-93160132	Fri Oct 19 09:20:29 2018	215333	Left Arrow On	45.01007	-93.1601	10/19/2018 9:22 a.m.	ab_left	45.01007	-93.16013
20181019	94002	CARSAB-869878	right lane closed		44897972	-93219990	Fri Oct 19 10:38:20 2018	207501	Left Arrow On	44.89791	-93.22	10/19/2018 10:40 a.m.	ab_left	44.89791	-93.21997
20181019	121602	CARSAB-869881	right lane closed		44898325	-93214500	Fri Oct 19 13:14:47 2018	207501	Left Arrow On	44.89839	-93.2145	10/19/2018 1:16 p.m.	ab_left	44.89839	-93.2145
20181019	125612	CARSAB-869883	right lane closed		44897399	-93223403	Fri Oct 19 13:55:04 2018	207501	Left Arrow On	44.89749	-93.2234	10/19/2018 1:56 p.m.	ab_left	44.89749	-93.22344
20181019	131602	CARSAB-869884	right lane closed		44897446	-93233960	Fri Oct 19 14:14:02 2018	207501	Left Arrow On	44.89743	-93.234	10/19/2018 2:16 p.m.	ab_left	44.89743	-93.23396
20181020	61802	CARSAB-869888	mobile maintenance operations	left lane closed	44865786	-93422546	Sat Oct 20 07:15:32 2018	214521	Right Arrow On	44.8668	-93.4194	10/20/2018 7:18 a.m.	ab_right	44.86592	-93.42259
20181020	71602	CARSAB-869889	mobile maintenance operations	left lane closed	44861286	-93472754	Sat Oct 20 08:12:22 2018	214521	Right Arrow On	44.85887	-93.4778	10/20/2018 8:16 a.m.	ab_right	44.86131	-93.47276
20181020	74402	CARSAB-869890	right lane closed		44867388	-93417985	Sat Oct 20 08:43:09 2018	214521	Left Arrow On	44.8676	-93.4183	10/20/2018 8:44 a.m.	ab_left	44.8676	-93.41827

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181020	80202	CARSAB-869891	left lane closed		44951631	-93168637	Sat Oct 20 09:01:45 2018	215333	Right Arrow On	44.95204	-93.1686	10/20/2018 9:02 a.m.	ab_right	44.95204	-93.16861
20181020	92402	CARSAB-869892	left lane closed		44861762	-93461563	Sat Oct 20 10:22:35 2018	214521	Right Arrow On	44.862	-93.4616	10/20/2018 10:24 a.m.	ab_right	44.862	-93.46159
20181020	103002	CARSAB-869893	left lane closed		44913499	-93503667	Sat Oct 20 11:29:17 2018	214521	Right Arrow On	44.91349	-93.5037	10/20/2018 11:30 a.m.	ab_right	44.91349	-93.50366
20181020	111002	CARSAB-869894	left lane closed		44919436	-93483396	Sat Oct 20 12:09:36 2018	214521	Right Arrow On	44.91955	-93.4834	10/20/2018 12:10 p.m.	ab_right	44.91955	-93.48343
20181021	103202	CARSAB-869896	left lane closed		45091473	-93445852	Sun Oct 21 11:31:38 2018	205502	Right Arrow On	45.09266	-93.4446	10/21/2018 11:32 a.m.	ab_right	45.09266	-93.44461
20181022	70202	CARSAB-869899	left lane closed		45130143	-93433685	Mon Oct 22 08:01:10 2018	205502	Right Arrow On	45.12903	-93.4336	10/22/2018 8:02 a.m.	ab_right	45.12903	-93.43364
20181022	80202	CARSAB-869901	left lane closed		44995624	-93438005	Mon Oct 22 09:01:54 2018	214521	Right Arrow On	44.99574	-93.4378	10/22/2018 9:02 a.m.	ab_right	44.99574	-93.43781
20181022	80602	CARSAB-869903	right lane closed		44952350	-93070230	Mon Oct 22 09:04:31 2018	215333	Left Arrow On	44.95219	-93.0703	10/22/2018 9:06 a.m.	ab_left	44.95219	-93.07034
20181022	83802	CARSAB-869904	right lane closed		44977997	-93245245	Mon Oct 22 09:36:03 2018	203300	Left Arrow On	44.97796	-93.245	10/22/2018 9:38 a.m.	ab_left	44.97796	-93.24503
20181022	84612	CARSAB-869905	mobile maintenance operations	left lane closed	45108255	-93467027	Mon Oct 22 09:43:14 2018	205502	Right Arrow On	45.10294	-93.4579	10/22/2018 9:46 a.m.	ab_right	45.10838	-93.46689
20181022	84612	CARSAB-869906	left lane closed		45627937	-94579234	Mon Oct 22 09:45:59 2018	214151	Right Arrow On	45.62606	-94.5804	10/22/2018 9:46 a.m.	ab_right	45.62606	-94.58043
20181022	93602	CARSAB-869907	left lane closed		44983014	-93372958	Mon Oct 22 10:34:15 2018	214521	Right Arrow On	44.98304	-93.373	10/22/2018 10:36 a.m.	ab_right	44.98304	-93.37296
20181022	105802	CARSAB-869908	right lane closed		44997179	-93439895	Mon Oct 22 11:57:13 2018	214521	Left Arrow On	44.99714	-93.44	10/22/2018 11:58 a.m.	ab_left	44.99714	-93.43996
20181022	123202	CARSAB-869909	right lane closed		45789629	-95084585	Mon Oct 22 13:30:50 2018	214151	Left Arrow On	45.79059	-95.0837	10/22/2018 1:32 p.m.	ab_left	45.79059	-95.08368
20181022	125602	CARSAB-869910	right lane closed		44864538	-93205679	Mon Oct 22 13:54:18 2018	207501	Left Arrow On	44.86452	-93.2057	10/22/2018 1:56 p.m.	ab_left	44.86452	-93.20566
20181022	132602	CARSAB-869911	right lane closed		44965411	-93280579	Mon Oct 22 14:22:29 2018	203300	Left Arrow On	44.96695	-93.2881	10/22/2018 2:26 p.m.	ab_left	44.96547	-93.28061
20181022	133202	CARSAB-869912	left lane closed		45719500	-94950014	Mon Oct 22 14:30:55 2018	214151	Right Arrow On	45.71905	-94.9503	10/22/2018 2:32 p.m.	ab_right	45.71905	-94.95032
20181022	133802	CARSAB-869913	right lane closed		44884150	-93246780	Mon Oct 22 14:34:32 2018	207501	Left Arrow On	44.88319	-93.2449	10/22/2018 2:38 p.m.	ab_left	44.88414	-93.24489
20181022	135202	CARSAB-869915	right lane closed		44876011	-93163977	Mon Oct 22 14:51:20 2018	207501	Left Arrow On	44.8761	-93.1707	10/22/2018 2:52 p.m.	ab_left	44.8761	-93.17072
20181022	135602	CARSAB-869914	mobile maintenance operations	left lane closed	45664418	-94751361	Mon Oct 22 14:48:23 2018	214151	Right Arrow On	45.66635	-94.81	10/22/2018 2:56 p.m.	ab_right	45.66373	-94.75139

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181022	185202	CARSAB-869916	right lane closed		44973209	-93088415	Mon Oct 22 19:51:36 2018	215333	Left Arrow On	44.9732	-93.0909	10/22/2018 7:52 p.m.	ab_left	44.9732	-93.09088
20181022	194202	CARSAB-869917	right lane closed		45010199	-93155404	Mon Oct 22 20:40:11 2018	215333	Left Arrow On	45.01062	-93.1434	10/22/2018 8:42 p.m.	ab_left	45.01049	-93.15541
20181022	201002	CARSAB-869918	right lane closed		45010109	-93160382	Mon Oct 22 21:08:42 2018	215333	Left Arrow On	45.01046	-93.1604	10/22/2018 9:10 p.m.	ab_left	45.01046	-93.1604
20181022	204002	CARSAB-869919	mobile maintenance operations	left lane closed	45129913	-93389095	Mon Oct 22 21:32:44 2018	205502	Right Arrow On	45.13204	-93.4439	10/22/2018 9:40 p.m.	ab_right	45.12998	-93.38909
20181022	225002	CARSAB-869920	left lane closed		45075684	-93327428	Mon Oct 22 23:47:30 2018	205502	Right Arrow On	45.07605	-93.3483	10/22/2018 11:50 p.m.	ab_right	45.07574	-93.32742
20181023	4402	CARSAB-869922	left lane closed		45070268	-93304849	Tue Oct 23 01:43:15 2018	205502	Right Arrow On	45.07031	-93.3048	10/23/2018 1:44 a.m.	ab_right	45.07031	-93.30483
20181023	12412	CARSAB-869923	left lane closed		45070265	-93304835	Tue Oct 23 02:23:56 2018	205502	Right Arrow On	45.0703	-93.3048	10/23/2018 2:24 a.m.	ab_right	45.0703	-93.30482
20181023	13602	CARSAB-869924	left lane closed		45070265	-93304835	Tue Oct 23 02:35:54 2018	205502	Right Arrow On	45.0703	-93.3048	10/23/2018 2:36 a.m.	ab_right	45.0703	-93.30482
20181023	15602	CARSAB-869927	left lane closed		45070262	-93304822	Tue Oct 23 02:55:02 2018	205502	Right Arrow On	45.07029	-93.3048	10/23/2018 2:56 a.m.	ab_right	45.07029	-93.30481
20181023	20602	CARSAB-869930	left lane closed		45070262	-93304822	Tue Oct 23 03:05:48 2018	205502	Right Arrow On	45.07029	-93.3048	10/23/2018 3:06 a.m.	ab_right	45.07029	-93.30481
20181023	21202	CARSAB-869931	left lane closed		45070262	-93304822	Tue Oct 23 03:11:46 2018	205502	Right Arrow On	45.07029	-93.3048	10/23/2018 3:12 a.m.	ab_right	45.07029	-93.30481
20181023	81802	CARSAB-869936	left lane closed		45106810	-93188204	Tue Oct 23 09:16:48 2018	208500	Right Arrow On	45.10681	-93.1882	10/23/2018 9:18 a.m.	ab_right	45.10681	-93.18818
20181023	82402	CARSAB-869937	left lane closed		44891668	-93006939	Tue Oct 23 09:23:10 2018	215333	Right Arrow On	44.89173	-93.0066	10/23/2018 9:24 a.m.	ab_right	44.89173	-93.00663
20181023	83002	CARSAB-869938	mobile maintenance operations	left lane closed	44929370	-93023620	Tue Oct 23 09:25:33 2018	215333	Right Arrow On	44.90254	-93.0105	10/23/2018 9:30 a.m.	ab_right	44.92935	-93.02366
20181023	83002	CARSAB-869939	left lane closed		44999905	-93442291	Tue Oct 23 09:28:32 2018	214521	Right Arrow On	44.99999	-93.4421	10/23/2018 9:30 a.m.	ab_right	44.99999	-93.44207
20181023	83602	CARSAB-869940	left lane closed		45417808	-94073657	Tue Oct 23 09:34:28 2018	214151	Right Arrow On	45.41805	-94.0735	10/23/2018 9:36 a.m.	ab_right	45.41805	-94.07348
20181023	92202	CARSAB-869943	right lane closed		44862816	-93209423	Tue Oct 23 10:20:18 2018	207501	Left Arrow On	44.86337	-93.2115	10/23/2018 10:22 a.m.	ab_left	44.86337	-93.21148
20181023	92602	CARSAB-869944	left lane closed		45167056	-93290498	Tue Oct 23 10:25:19 2018	205502	Right Arrow On	45.1672	-93.2903	10/23/2018 10:26 a.m.	ab_right	45.1672	-93.2903
20181023	93002	CARSAB-869945	right lane closed		44862535	-93213660	Tue Oct 23 10:29:46 2018	207501	Left Arrow On	44.8614	-93.2135	10/23/2018 10:30 a.m.	ab_left	44.8614	-93.2135
20181023	94002	CARSAB-869946	right lane closed		44862816	-93209423	Tue Oct 23 10:39:14 2018	207501	Left Arrow On	44.86217	-93.2102	10/23/2018 10:40 a.m.	ab_left	44.86217	-93.21018

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181023	94202	CARSAB-869947	right lane closed		44980611	-93244232	Tue Oct 23 10:40:14 2018	203300	Left Arrow On	44.98071	-93.2447	10/23/2018 10:42 a.m.	ab_left	44.98071	-93.24466
20181023	101402	CARSAB-869949	right lane closed		44970900	-93486140	Tue Oct 23 11:12:43 2018	214521	Left Arrow On	44.9709	-93.4861	10/23/2018 11:14 a.m.	ab_left	44.9709	-93.48614
20181023	112202	CARSAB-869957	mobile maintenance operations	left lane closed	45308605	-93822434	Tue Oct 23 12:19:07 2018	214151	Right Arrow On	45.30446	-93.8169	10/23/2018 12:22 p.m.	ab_right	45.30876	-93.82218
20181023	125412	CARSAB-869960	mobile maintenance operations	right lane closed	44862320	-93220776	Tue Oct 23 13:50:57 2018	207501	Left Arrow On	44.862	-93.2258	10/23/2018 1:54 p.m.	ab_left	44.86205	-93.22076
20181023	130402	CARSAB-869961	right lane closed		44871487	-93197438	Tue Oct 23 14:02:47 2018	207501	Left Arrow On	44.87144	-93.1973	10/23/2018 2:04 p.m.	ab_left	44.87144	-93.1973
20181023	204202	CARSAB-869967	left lane closed		45035121	-93400682	Tue Oct 23 21:40:53 2018	205502	Right Arrow On	45.03512	-93.4009	10/23/2018 9:42 p.m.	ab_right	45.03512	-93.40088
20181023	215802	CARSAB-869968	mobile maintenance operations	right lane closed	45196520	-93029637	Tue Oct 23 22:54:59 2018	215333	Left Arrow On	45.18333	-93.0296	10/23/2018 10:58 p.m.	ab_left	45.19652	-93.02962
20181023	224402	CARSAB-869970	right lane closed		45243694	-93027281	Tue Oct 23 23:43:44 2018	215333	Left Arrow On	45.24379	-93.0279	10/23/2018 11:44 p.m.	ab_left	45.24379	-93.02792
20181025	210612	CARSAB-38	mobile maintenance operations	left lane closed	44874812	-93054840	Thu Oct 25 22:03:26 2018	205502	Right Arrow On	44.87521	-93.0745	10/25/2018 10:06 p.m.	ab_right	44.87468	-93.05484
20181025	211002	CARSAB-37	mobile maintenance operations	left lane closed	44875483	-93032382	Thu Oct 25 22:03:35 2018	215333	Right Arrow On	44.87486	-93.0769	10/25/2018 10:10 p.m.	ab_right	44.87435	-93.03742
20181026	11202	CARSAB-39	left lane closed		45072695	-93286124	Fri Oct 26 02:10:05 2018	203300	Right Arrow On	45.07269	-93.2862	10/26/2018 2:12 a.m.	ab_right	45.07269	-93.28617
20181026	12202	CARSAB-40	left lane closed		45072705	-93286127	Fri Oct 26 02:21:49 2018	203300	Right Arrow On	45.0727	-93.2862	10/26/2018 2:22 a.m.	ab_right	45.0727	-93.28617
20181026	13002	CARSAB-41	left lane closed		45072705	-93286127	Fri Oct 26 02:28:52 2018	203300	Right Arrow On	45.0727	-93.2862	10/26/2018 2:30 a.m.	ab_right	45.0727	-93.28617
20181026	14202	CARSAB-42	left lane closed		45072705	-93286127	Fri Oct 26 02:40:38 2018	203300	Right Arrow On	45.0727	-93.2862	10/26/2018 2:42 a.m.	ab_right	45.0727	-93.28617
20181027	72212	CARSAB-45	right lane closed		45021157	-93283312	Sat Oct 27 08:21:31 2018	203300	Left Arrow On	45.02168	-93.2811	10/27/2018 8:22 a.m.	ab_left	45.02168	-93.2811
20181027	80202	CARSAB-46	right lane closed		44961594	-93212040	Sat Oct 27 09:01:25 2018	203300	Left Arrow On	44.96177	-93.2118	10/27/2018 9:02 a.m.	ab_left	44.96177	-93.21182
20181027	130602	CARSAB-47	right lane closed		44973529	-93088417	Sat Oct 27 14:04:18 2018	215333	Left Arrow On	44.97346	-93.0907	10/27/2018 2:06 p.m.	ab_left	44.97352	-93.09067
20181027	132812	CARSAB-48	right lane closed		45042915	-93061096	Sat Oct 27 14:27:05 2018	215333	Left Arrow On	45.04297	-93.0616	10/27/2018 2:28 p.m.	ab_left	45.04297	-93.06155

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181029	63402	CARSAB-49	right lane closed		45020646	-93283101	Mon Oct 29 07:32:21 2018	203300	Left Arrow On	45.021	-93.2812	10/29/2018 7:34 a.m.	ab_left	45.021	-93.28122
20181029	80202	CARSAB-50	right lane closed		44966102	-93248659	Mon Oct 29 08:59:29 2018	203300	Left Arrow On	44.9628	-93.2499	10/29/2018 9:02 a.m.	ab_left	44.96278	-93.2499
20181029	85402	CARSAB-53	right lane closed		44971870	-93493220	Mon Oct 29 09:53:24 2018	214521	Left Arrow On	44.97187	-93.4932	10/29/2018 9:54 a.m.	ab_left	44.97187	-93.49322
20181029	91402	CARSAB-55	right lane closed		44973600	-93495910	Mon Oct 29 10:12:24 2018	214521	Left Arrow On	44.9736	-93.4959	10/29/2018 10:14 a.m.	ab_left	44.9736	-93.49591
20181029	95602	CARSAB-56	right lane closed		44794315	-93221797	Mon Oct 29 10:54:42 2018	207501	Left Arrow On	44.79432	-93.2224	10/29/2018 10:56 a.m.	ab_left	44.79432	-93.2224
20181029	115602	CARSAB-58	right lane closed		44965818	-93247612	Mon Oct 29 12:54:33 2018	203300	Left Arrow On	44.96273	-93.2498	10/29/2018 12:56 p.m.	ab_left	44.96273	-93.24984
20181029	115602	CARSAB-61	right lane closed		44971350	-93491770	Mon Oct 29 12:54:52 2018	214521	Left Arrow On	44.97135	-93.4918	10/29/2018 12:56 p.m.	ab_left	44.97135	-93.49177
20181029	122002	CARSAB-65	right lane closed		44862353	-93219688	Mon Oct 29 13:18:41 2018	207501	Left Arrow On	44.86239	-93.2197	10/29/2018 1:20 p.m.	ab_left	44.86239	-93.21969
20181029	122612	CARSAB-66	left lane closed		44965672	-93460082	Mon Oct 29 13:25:11 2018	214521	Right Arrow On	44.96567	-93.4602	10/29/2018 1:26 p.m.	ab_right	44.96567	-93.46017
20181030	230602	CARSAB-113	right lane closed		45204512	-93389997	Wed Oct 31 00:05:27 2018	205502	Left Arrow On	45.20447	-93.3898	10/31/2018 12:06 a.m.	ab_left	45.20447	-93.38983
20181030	232402	CARSAB-115	right lane closed		45204512	-93389997	Wed Oct 31 00:22:06 2018	205502	Left Arrow On	45.20447	-93.3898	10/31/2018 12:24 a.m.	ab_left	45.20447	-93.38983
20181030	233002	CARSAB-116	right lane closed		45204512	-93389997	Wed Oct 31 00:28:01 2018	205502	Left Arrow On	45.20447	-93.3898	10/31/2018 12:30 a.m.	ab_left	45.20447	-93.38983
20181031	202	CARSAB-119	right lane closed		45204512	-93389997	Wed Oct 31 01:00:01 2018	205502	Left Arrow On	45.20447	-93.3898	10/31/2018 1:02 a.m.	ab_left	45.20447	-93.38983
20181031	1202	CARSAB-121	right lane closed		45204883	-93385470	Wed Oct 31 01:11:51 2018	205502	Left Arrow On	45.20488	-93.3855	10/31/2018 1:12 a.m.	ab_left	45.20488	-93.38547
20181031	1802	CARSAB-122	right lane closed		45204882	-93385430	Wed Oct 31 01:16:36 2018	205502	Left Arrow On	45.20488	-93.3855	10/31/2018 1:18 a.m.	ab_left	45.20489	-93.38543
20181031	3202	CARSAB-125	right lane closed		45204882	-93385442	Wed Oct 31 01:30:49 2018	205502	Left Arrow On	45.20492	-93.3854	10/31/2018 1:32 a.m.	ab_left	45.20492	-93.38544
20181031	15212	CARSAB-126	right lane closed		45204810	-93382427	Wed Oct 31 02:51:31 2018	205502	Left Arrow On	45.20474	-93.3824	10/31/2018 2:52 a.m.	ab_left	45.20474	-93.38243
20181031	15402	CARSAB-127	right lane closed		45204810	-93382427	Wed Oct 31 02:53:53 2018	205502	Left Arrow On	45.20475	-93.3824	10/31/2018 2:54 a.m.	ab_left	45.20475	-93.38243
20181031	20402	CARSAB-128	right lane closed		45204811	-93382448	Wed Oct 31 03:03:22 2018	205502	Left Arrow On	45.20477	-93.3825	10/31/2018 3:04 a.m.	ab_left	45.20477	-93.38245
20181031	20602	CARSAB-129	right lane closed		45204811	-93382448	Wed Oct 31 03:05:44 2018	205502	Left Arrow On	45.20477	-93.3825	10/31/2018 3:06 a.m.	ab_left	45.20477	-93.38245
20181031	20802	CARSAB-130	right lane closed		45010068	-93165629	Wed Oct 31 03:06:28 2018	215333	Left Arrow On	45.01041	-93.1656	10/31/2018 3:08 a.m.	ab_left	45.01041	-93.16564

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181031	21002	CARSAB-131	right lane closed		45204810	-93382438	Wed Oct 31 03:09:18 2018	205502	Left Arrow On	45.20477	-93.3824	10/31/2018 3:10 a.m.	ab_left	45.20477	-93.38244
20181031	22402	CARSAB-133	right lane closed		45204811	-93382448	Wed Oct 31 03:23:32 2018	205502	Left Arrow On	45.20476	-93.3825	10/31/2018 3:24 a.m.	ab_left	45.20476	-93.38245
20181031	190612	CARSAB-138	right lane closed		45021314	-93283384	Wed Oct 31 20:04:09 2018	203300	Left Arrow On	45.02182	-93.2812	10/31/2018 8:06 p.m.	ab_left	45.02182	-93.28117
20181031	191402	CARSAB-139	left lane closed		44706282	-93284967	Wed Oct 31 20:13:08 2018	217936	Right Arrow On	44.70602	-93.2821	10/31/2018 8:14 p.m.	ab_right	44.70602	-93.28211
20181031	192002	CARSAB-140	left lane closed		44973599	-93088418	Wed Oct 31 20:19:25 2018	215333	Right Arrow On	44.97359	-93.0908	10/31/2018 8:20 p.m.	ab_right	44.97359	-93.09082
20181031	204212	CARSAB-141	right lane closed		44960696	-93210609	Wed Oct 31 21:40:25 2018	203300	Left Arrow On	44.96087	-93.2104	10/31/2018 9:42 p.m.	ab_left	44.96087	-93.21039
20181031	211602	CARSAB-142	left lane closed		44730145	-93282872	Wed Oct 31 22:15:56 2018	217936	Right Arrow On	44.73013	-93.283	10/31/2018 10:16 p.m.	ab_right	44.73013	-93.28304
20181031	213002	CARSAB-144	left lane closed		44957517	-93459652	Wed Oct 31 22:29:52 2018	205500	Right Arrow On	44.95751	-93.4599	10/31/2018 10:30 p.m.	ab_right	44.95751	-93.45989
20181031	213002	CARSAB-143	left lane closed		44960797	-93459835	Wed Oct 31 22:29:50 2018	214521	Right Arrow On	44.96079	-93.4601	10/31/2018 10:30 p.m.	ab_right	44.96079	-93.46011
20181031	214412	CARSAB-145	right lane closed		45007562	-93112339	Wed Oct 31 22:42:08 2018	215333	Left Arrow On	45.00751	-93.1124	10/31/2018 10:44 p.m.	ab_left	45.0075	-93.11235
20181031	222402	CARSAB-146	right lane closed		44664764	-93293870	Wed Oct 31 23:22:03 2018	217936	Left Arrow On	44.66476	-93.2943	10/31/2018 11:24 p.m.	ab_left	44.66476	-93.29426
20181101	10402	CARSAB-147	right lane closed		45007735	-93113838	Thu Nov 01 02:02:27 2018	203300	Left Arrow On	45.00767	-93.1139	11/01/2018 2:04 a.m.	ab_left	45.00767	-93.11386
20181101	11412	CARSAB-148	right lane closed		44775252	-93287476	Thu Nov 01 02:12:57 2018	217936	Left Arrow On	44.7752	-93.2875	11/01/2018 2:14 a.m.	ab_left	44.7752	-93.28746
20181101	14202	CARSAB-149	left lane closed		44950053	-93103503	Thu Nov 01 02:40:06 2018	203300	Right Arrow On	44.95048	-93.1033	11/01/2018 2:42 a.m.	ab_right	44.95048	-93.10325
20181101	21802	CARSAB-150	left lane closed		44959464	-93200830	Thu Nov 01 03:17:51 2018	215333	Right Arrow On	44.95951	-93.2008	11/01/2018 3:18 a.m.	ab_right	44.95951	-93.2008
20181101	24202	CARSAB-151	right lane closed		45124822	-93213355	Thu Nov 01 03:41:05 2018	203300	Left Arrow On	45.12503	-93.2131	11/01/2018 3:42 a.m.	ab_left	45.12503	-93.21311
20181101	31202	CARSAB-152	right lane closed		45131086	-93225269	Thu Nov 01 04:11:33 2018	203300	Left Arrow On	45.13102	-93.2253	11/01/2018 4:12 a.m.	ab_left	45.13102	-93.22532
20181101	81212	CARSAB-156	left lane closed		44983728	-93380946	Thu Nov 01 09:11:35 2018	215456	Right Arrow On	44.98389	-93.3809	11/01/2018 9:12 a.m.	ab_right	44.98389	-93.38088
20181101	81402	CARSAB-157	right lane closed		45010124	-93159831	Thu Nov 01 09:13:28 2018	215333	Left Arrow On	45.01011	-93.1598	11/01/2018 9:14 a.m.	ab_left	45.01011	-93.15983
20181101	83212	CARSAB-158	mobile maintenance operations	left lane closed	45130391	-93417590	Thu Nov 01 09:29:35 2018	205502	Right Arrow On	45.1303	-93.4275	11/01/2018 9:32 a.m.	ab_right	45.13041	-93.41759

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181101	85802	CARSAB-159	right lane closed		44964541	-93283975	Thu Nov 01 09:57:01 2018	215456	Left Arrow On	44.96436	-93.2839	11/01/2018 9:58 a.m.	ab_left	44.96436	-93.2839
20181101	91402	CARSAB-161	right lane closed		45122648	-93315127	Thu Nov 01 10:13:33 2018	205502	Left Arrow On	45.12303	-93.3151	11/01/2018 10:14 a.m.	ab_left	45.12303	-93.31508
20181101	95802	CARSAB-162	left lane closed		45099203	-93453807	Thu Nov 01 10:58:01 2018	205502	Right Arrow On	45.09932	-93.4536	11/01/2018 10:58 a.m.	ab_right	45.09932	-93.45361
20181101	193802	CARSAB-167	mobile maintenance operations	left lane closed	44973033	-93403831	Thu Nov 01 20:34:54 2018	214521	Right Arrow On	44.97408	-93.3904	11/01/2018 8:38 p.m.	ab_right	44.97319	-93.40385
20181101	205802	CARSAB-168	right lane closed		44930017	-93024153	Thu Nov 01 21:57:26 2018	215333	Left Arrow On	44.93005	-93.0241	11/01/2018 9:58 p.m.	ab_left	44.93005	-93.02407
20181102	5402	CARSAB-169	right lane closed		44951670	-93122447	Fri Nov 02 01:53:27 2018	215333	Left Arrow On	44.95156	-93.1225	11/02/2018 1:54 a.m.	ab_left	44.95156	-93.12245
20181102	114402	CARSAB-170	left lane closed		45011684	-93460150	Fri Nov 02 12:42:40 2018	205500	Right Arrow On	45.00928	-93.4614	11/02/2018 12:44 p.m.	ab_right	45.00928	-93.46141
20181102	124602	CARSAB-172	left lane closed		44988121	-93420560	Fri Nov 02 13:45:46 2018	205500	Right Arrow On	44.9876	-93.4208	11/02/2018 1:46 p.m.	ab_right	44.9876	-93.42082
20181105	85402	CARSAB-174	right lane closed		45126580	-93485138	Mon Nov 05 08:53:14 2018	205502	Left Arrow On	45.12604	-93.4869	11/05/2018 8:54 a.m.	ab_left	45.12604	-93.48689
20181105	91402	CARSAB-175	left lane closed		44951665	-93124816	Mon Nov 05 09:11:41 2018	215333	Right Arrow On	44.95181	-93.1242	11/05/2018 9:14 a.m.	ab_right	44.95182	-93.12482
20181105	92402	CARSAB-176	left lane closed		45199693	-93552474	Mon Nov 05 09:22:55 2018	215456	Right Arrow On	45.19968	-93.5526	11/05/2018 9:24 a.m.	ab_right	45.19968	-93.55255
20181105	103202	CARSAB-180	left lane closed		44992455	-93236975	Mon Nov 05 10:30:37 2018	203300	Right Arrow On	44.99236	-93.2372	11/05/2018 10:32 a.m.	ab_right	44.99236	-93.23719
20181105	122402	CARSAB-183	left lane closed		45069514	-93292531	Mon Nov 05 12:22:38 2018	215456	Right Arrow On	45.06989	-93.2925	11/05/2018 12:24 p.m.	ab_right	45.06989	-93.29253
20181105	130412	CARSAB-184	left lane closed		45045850	-93326604	Mon Nov 05 13:03:42 2018	215456	Right Arrow On	45.04587	-93.3267	11/05/2018 1:04 p.m.	ab_right	45.04587	-93.32665
20181106	204202	CARSAB-185	left lane closed		45130143	-93433682	Tue Nov 06 20:41:20 2018	205502	Right Arrow On	45.12911	-93.4336	11/06/2018 8:42 p.m.	ab_right	45.12911	-93.43364
20181106	205402	CARSAB-186	left lane closed		44841480	-93298187	Tue Nov 06 20:52:04 2018	217936	Right Arrow On	44.84148	-93.2983	11/06/2018 8:54 p.m.	ab_right	44.84148	-93.29833
20181106	220602	CARSAB-188	mobile maintenance operations	left lane closed	45204999	-93391184	Tue Nov 06 22:03:32 2018	205502	Right Arrow On	45.20502	-93.3891	11/06/2018 10:06 p.m.	ab_right	45.20508	-93.39118
20181106	221602	CARSAB-189	left lane closed		45205089	-93396121	Tue Nov 06 22:14:17 2018	205502	Right Arrow On	45.20514	-93.3958	11/06/2018 10:16 p.m.	ab_right	45.20514	-93.39612
20181106	223402	CARSAB-190	left lane closed		45206183	-93402494	Tue Nov 06 22:32:07 2018	205502	Right Arrow On	45.20626	-93.4024	11/06/2018 10:34 p.m.	ab_right	45.20626	-93.40244
20181106	223602	CARSAB-191	left lane closed		44970280	-93460318	Tue Nov 06 22:34:15 2018	214521	Right Arrow On	44.97028	-93.4608	11/06/2018 10:36 p.m.	ab_right	44.97028	-93.46076

RCRS Data							Street Smart Incident Feed Data					ATMS Data			
Message Date	Message Time*	Event-ID	Description Phrase	Desc. (cont'd)	Latitude	Longitude	Date / Time	Unit	Status	Latitude	Longitude	Event Date	Detail	Latitude	Longitude
20181106	223602	CARSAB-192	left lane closed		44970366	-93460317	Tue Nov 06 22:34:33 2018	205500	Right Arrow On	44.97038	-93.4608	11/06/2018 10:36 p.m.	ab_right	44.97038	-93.46077
20181106	224602	CARSAB-193	left lane closed		44970355	-93460318	Tue Nov 06 22:44:11 2018	205500	Right Arrow On	44.97037	-93.4608	11/06/2018 10:46 p.m.	ab_right	44.97037	-93.46079
20181107	12802	CARSAB-195	left lane closed		44749813	-93284644	Wed Nov 07 01:27:17 2018	217936	Right Arrow On	44.74976	-93.2848	11/07/2018 1:28 a.m.	ab_right	44.74976	-93.28484
20181107	100402	CARSAB-196	right lane closed		44973918	-93390811	Wed Nov 07 10:03:56 2018	214521	Left Arrow On	44.97381	-93.3908	11/07/2018 10:04 a.m.	ab_left	44.97381	-93.39082
20181107	141602	CARSAB-197	right lane closed		44998213	-93089371	Wed Nov 07 14:15:16 2018	215333	Left Arrow On	44.99821	-93.0901	11/07/2018 2:16 p.m.	ab_left	44.99821	-93.09006

** RCRS Data time required adding one hour to account for Daylight Saving Time for a portion of the study period.*