TSMO Strategies and Automation in Work Zones

Image from built-in HD video camera

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16. Abstract
This research evaluated the Missouri Department of Transportation's (MoDOT's) use of Transportation Systems Management and Operations (TSMO) strategies in work zones, with an emphasis on Smart Work Zone (SWZ) technologies and automation. Project objectives included identifying available TSMO strategies, documenting examples of their use, implementing selected strategies in an active Missouri work zone, evaluating their effectiveness, and developing recommendations for future projects.
The work included a review of current practices and literature to assess MoDOT's work zone management, TSMO, and SWZ processes. Based on this review, selected strategies were recommended and implemented on a MoDOT construction project. Safety and operational evaluations were conducted using daily monitoring, performance data collection, and post-project analysis. An economic evaluation assessed the costs of the deployed strategies.

The project concluded with recommendations for SWZ Job Special Provisions and a refined list of TSMO strategies, documenting effective best practices, and guidance for integrating advanced work zone strategies into MoDOT's standard practices.

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Abstract

This research evaluated the Missouri Department of Transportation's (MoDOT's) use of Transportation Systems Management and Operations (TSMO) strategies in work zones, with an emphasis on Smart Work Zone (SWZ) technologies and automation. Project objectives included identifying available TSMO strategies, documenting examples of their use, implementing selected strategies in an active Missouri work zone, evaluating their effectiveness, and developing recommendations for future projects.

The work included a review of current practices and literature to assess MoDOT's work zone management, TSMO, and SWZ processes. Based on this review, selected strategies were recommended and implemented on a MoDOT construction project.

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The project concluded with recommendations for SWZ Job Special Provisions and a refined list of TSMO strategies, documenting effective best practices, and guidance for integrating advanced work zone strategies into MoDOT's standard practices.

Executive Summary

This project was conducted to quantify the effectiveness of Smart Work Zone (SWZ) deployments and to document best practices that support their successful, repeatable application across Missouri Department of Transportation (MoDOT) construction projects. The study focused on identifying proven SWZ deployment practices, developing recommendations for institutionalizing SWZ systems within MoDOT's standard procedures, and establishing guidance to better align construction project characteristics with appropriate SWZ solutions. Collectively, these efforts are intended to support consistent, effective, and scalable implementation of SWZ strategies statewide, while advancing work zone safety, improving operations, and addressing workforce constraints.

The findings of this research reinforce MoDOT's commitment to its Transportation Systems Management and Operations (TSMO) mission and the Show-Me Zero safety goal. Rather than developing new technologies, the project evaluated existing and proven SWZ strategies and emphasized how MoDOT can enhance their use through clearer guidance, standardized processes, and improved integration into project development and delivery. The results demonstrate that strengthening institutional practices and decision-making frameworks is critical to achieving reliable safety and mobility benefits from SWZ deployments.

A comprehensive set of recommendations was developed to improve MoDOT's SWZ program, spanning policy, guidance, design, operations, and training. Key recommendations include:

- Developing quick-reference tools to support decision-making when full data analysis is not feasible such as a flow chart for decision making.
- Updating and aligning existing guidance documents such as the Engineering Policy Guide and Work Zone Management Guidebook to better reflect MoDOT current practices.
- Publishing boilerplate Job Special Provisions and standard operating procedures for SWZ systems; and
- Establishing consistent conventions for device naming, performance monitoring, and system integration.

Additional recommendations emphasize regular review of tools and cost data, removal of outdated documents, expansion of SWZ design guidance, and incorporation of SWZ topics into statewide meetings and training to promote knowledge sharing and continuous improvement.

To support implementation, the recommendations were organized into a tiered approach based on relative effort and complexity. Tier One actions consist of "low hanging fruit" that can be implemented with minimal effort, such as piloting provided tools and templates, making targeted updates to existing guidance, and publishing standardized language and procedures. Tier Two actions involve moderate effort and planning, including periodic updates to analytical tools, expanded monitoring practices, and ongoing training and outreach. Tier Three actions represent larger initiatives requiring coordination across offices, additional funding, or external support, such as integrating portable smart work zone devices into MoDOT's Advanced Traffic

Management System (ATMS) and revising early project development protocols to ensure consideration of advanced work zone strategies.

An additional opportunity for future research was identified related to the I-44 Strafford project, where previously assembled documentation could support further evaluation of driver response to speed feedback and queue warning systems as part of larger corridor construction efforts.

Overall, the recommendations presented in this report are intended to build upon MoDOT's already robust work zone tools and guidance. By streamlining and updating procedures, improving accessibility of decision-making resources, and standardizing advanced work zone practices, MoDOT will be better positioned to achieve consistent, repeatable safety outcomes, reduce the frequency and severity of work zone crashes, and effectively deploy SWZ solutions on future projects statewide.

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List of Abbreviations and Acronyms

AADT	Annual Average Daily Traffic
APS	Alert Processing System
ATMS	Advanced Traffic Management Systems
CCTV	Closed Circuit Television Cameras
CMF	Crash Modification Factor
CMS	Changeable Message Signs
CSV	Comma-Separated Values
DLM	Dynamic Late Merge
DOT	Department of Transportation
DSFS	Dynamic Speed Feedback Signs
EB	Eastbound
EOQ	End of Queue
EPG	Engineering Policy Guide
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
ITS	Intelligent Transportation System
JSP	Job Special Provisions
LED	Light Emitting Diode
LiDAR	Light Detection and Ranging
MM	Mile Marker
MoDOT	Missouri Department of Transportation
MOT	Maintenance of Traffic
PCMS	Portable Changeable Message Signs
PII	Personally Identifiable Information
RE	Resident Engineer
RFP	Request for Proposal
RTE	Route
RWA	Road Work Ahead
SD	Secure Digital
STIP	Statewide Transportation Improvement Program
SWZ	Smart Work Zone
TAC	Technical Advisory Committee
TIM	Traveler Information Map
TMC	Traffic Management Center
TMP	Transportation Management Plan
TMS	Transportation Management System
TRS	Transverse Rumble Strips
TSMO	Transportation Systems Management and Operations
TTI	Texas A and M Transportation Institute
TTC	Temporary Traffic Control
TTRS	Temporary Transverse Rumble Strips

WB..............................Westbound
WZITS..........................Work Zone Intelligent Transportation Systems

Chapter 1: Introduction

Managing traffic during construction is necessary to minimize traffic delays, maintain traveler and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents. Work zone management utilizing Transportation Systems Management and Operations (TSMO) to meet these needs is at the forefront of Department of Transportation (DOT) goals today. TSMO was intended to be a communication-driven, barrier-breaking method to increase mobility and safety in work zones. The common goal of the Show-Me Zero initiative has not changed, and these new methods are a step toward achieving these goals. As the Missouri Department of Transportation (MoDOT) continues to advance its TSMO Mission and Work Zone Management Priorities, the Department is working to identify implementable strategies that benefit both areas of workforce shortage and safety. Those successful strategies can then be incorporated into Missouri work zones. This project aimed to implement and evaluate available and proven TSMO work zone strategies, not to develop new solutions. The Department's goals for this research project include:

- Identification of available TSMO strategies and examples of their use.
- Demonstration of TSMO work zone strategies on a Missouri work zone.
- Determination of TSMO strategies' effectiveness.
- Creation of a final list of recommended strategies with construction-ready language for future projects.

1.1 Work Plan

The work plan included the following tasks that were performed as part of this project:

- Current Practice Review and Literature Search
- Technical Memorandum of Potential TSMO Strategies and Project Selection
    - Solutions Deployment Recommendations
- Safety Evaluation of TSMO and Automation on a MoDOT Construction Project
    - Daily Monitoring Plan and Performance Reporting
    - Post Project Evaluation Plan and Results
- Economic Evaluation of TSMO Strategies and Automation
- Creation of Job Special Provision (JSP) Recommendations and final list of recommended strategies.

1.2 Project Outcomes

This project aimed to quantify the effectiveness of Smart Work Zone (SWZ) deployments and document a variety of best practices. Key elements of the report objectives are summarized below.

- Determine SWZ best practices for effective deployment.

- Recommend best practices for institutionalizing SWZ systems into MoDOT standard practices.
- Recommend best practices for matching construction projects with SWZ solutions.

Chapter 2: Current Practice Investigation and Literature Review

A current practice investigation and TSMO strategy literature review were essential steps in gaining a clear understanding of Missouri work zone processes to develop meaningful and effective solutions. The initial investigation guided the literature review and informed the development of the Technical Memorandum of Potential TSMO Strategies, ensuring that proposed approaches are well-supported and aligned with identified needs. This section discusses the current practice review and literature review outcomes.

2.1 Current Practice Investigation

A review of Missouri's existing TSMO services, systems, initiatives, and resources was conducted to evaluate their current application on MoDOT work zones. The review included assessments of smart work zone data availability and monitoring practices, Traffic Management Center (TMC) SWZ coordination, SWZ design processes, and traveler information dissemination methods.

To identify key work zone challenges and opportunities, outreach was conducted through virtual interviews with MoDOT personnel using a current practices questionnaire. This section presents the results of that assessment conducted in Fall of 2023.

2.1.1 Existing Policy and Procedures

Policy and procedure inquiry was made with a focus on SWZ design, coordination, and Public Information Outreach. MoDOT's policy and best practices for work zones was found in the Engineering Policy Guide (EPG) section 616.13 (now section 616.19) and 616.14 (now section 616.20). Information on capacity restrictions and cautionary zones, estimation of demand vs capacity and queue length are all provided here as well as links to the Work Zone Impact Analysis Spreadsheet. Section 616.19.6.3 on SWZ Strategy Selection provides an overview of eight smart work zone strategies that can be used on Missouri work zones to provide improved warning and real-time work zone traffic information to the traveling public.

Standalone documents from MoDOT were also consulted for this investigation including the Work Zone Management Guidebook from March 2021 and the Transportation Systems Management and Operations (TSMO) Program and Action Plan from January 2017. The Work Zone Management Guidebook acts as a supplement to section 616.19.6.3 of the EPG by providing additional discussion on applications, benefits, and diagrams on SWZ deployments. The Guidebook also provides TSMO Priority Index Maps for Major Routes and a walkthrough of how to assess work zone impacts using the Work Zone Impact Analysis Spreadsheet.

Since the conclusion of this assessment an updated TSMO Program and Action Plan was released in June 2024. That document was not a part of this initial investigation.

2.1.2 Existing Traffic Management Center (TMC) Operations

MoDOT operates three Traffic Management Centers (TMCs). Gateway Guide serves the greater St. Louis region, Kansas City Scout covers the Kansas City metropolitan area and portions of Missouri and Kansas statewide, and the Ozarks TMC in Springfield serves the Southwest District and the I-44 corridor in the Central District (Figure 2.1). All three TMC's Advanced Traffic Management Systems (ATMS) use TransCore's TranSuite software.

Figure 2.1 Map of TMC management areas

Temporary smart work zone devices such as Portable Changeable Message Signs (PCMS), sensors, and cameras are not currently integrated into the Gateway Guide or KC Scout TMC systems. While TMCs support queue and variable speed warnings using permanent Intelligent Transportation System (ITS) infrastructure, these systems are not work zone specific. The Ozarks TMC maintains a limited inventory of portable devices including PCMS, radar trailers, and closed-circuit television (CCTV) cameras; however, smart work zone deployments remain contractor-managed and are not integrated into the ATMS.

2.1.3 Existing Procedure – Questionnaire Responses

Information provided directly by DOT personnel that work in or with work zones provides greater insight than published policies or manuals, offering clarity on SWZ management practices, resource use, information sharing, and staff awareness. Similar to the policy review, the questionnaire addressed design, coordination, and Public Information Outreach, with additional sections on current priorities, successes, and challenges. The discovery questionnaire is included in Appendix A, and a summary of responses is provided below.

2.1.3.1 SWZ Planning

SWZ use is primarily determined by project managers and teams, with Central Office support typically limited to higher-impact projects. SWZs are most commonly implemented on larger projects requiring a Transportation Management Plan (TMP) and are incorporated into TMPs, plans, or specifications. For design-build projects, SWZs may be addressed through general Request for Proposal (RFP) language allowing consultants to propose solutions, though this is not consistent across projects. Overall experience with SWZs is limited, and they are often considered late in the project development process, after budgets are established, underscoring the need for earlier coordination.

2.1.3.2 SWZ Design

SWZ design details are often informed by lessons learned from prior projects, particularly design-build efforts where consultants propose project-specific SWZ strategies. These proposals are evaluated for best value, with Maintenance of Traffic (MOT) frequently scored separately when SWZ requirements are defined in the RFP. An in-house tool supports early SWZ consideration and has been used effectively in select districts, including Kansas City and the Southwest Region, to evaluate traffic impacts and mitigation strategies on high-volume corridors. There are no standard SWZ plans, and development varies by project, with consultants or internal staff, including SCOUT, providing support as needed.

2.1.3.3 SWZ Design Feedback – Post Construction

Post-construction feedback on SWZ effectiveness is generally informal and inconsistent due to limited formal processes. Lessons learned are typically captured through core team discussions and, for design-build projects lessons learned documents used to inform future proposals. While teams often monitor performance during construction and adjust as needed, respondents noted that more structured post-project reviews could improve knowledge sharing and future implementation.

2.1.3.4 Project Coordination

Districts coordinate during planning and project development to minimize work zone conflicts, including communication with adjacent districts to reduce overlapping impacts. Coordination is achieved through team and project status meetings, resource management discussions, Statewide Transportation Improvement Program (STIP) reviews, and work zone tracking in systems such as Transportation Management System (TMS) database and district work zone maps. Some districts, including St. Louis, also conduct regular multi-department coordination calls and annual reviews, with similar coordination occurring statewide during peak construction seasons.

2.1.3.5 Closure Coordination

Maintenance and construction activities are sometimes coordinated to share work zones and leverage closures, though this occurs inconsistently. When coordination is successful, maintenance tasks such as drainage cleaning, pavement repair, mowing, and barrier or sign replacement can be completed concurrently. However, the high volume of projects often limits these opportunities. Ongoing coordination efforts aim to improve collaboration, but ownership and liability issues must be addressed early to allow shared work zones prior to project letting.

2.1.3.6 Coordination Communication

Coordination practices vary by district, ranging from informal communication during routine updates to structured, proactive approaches. For example, the St. Louis District conducts annual meetings with a multiyear project outlook and weekly coordination calls to address overlaps and communication needs. Interstate projects are supported by weekly statewide internal coordination calls from May to September to discuss projects during the Statewide Work Zone Management of Traffic (Interstate Corridor) Meeting, with additional meetings for larger projects. Overall, coordination typically occurs through the core team well before construction to identify and manage potential conflicts.

2.1.3.7 Traveler Communication

MoDOT uses multiple communication methods to inform the public and freight carriers about work zone impacts, with enhanced coordination for higher-impact projects. Major projects often include direct coordination with MoDOT's Motor Carrier Services group to reach trucking and oversize/overweight permit holders. Districts provide weekly impact lists and update the Traveler Information Map (TIM) with work zone data also shared through the Work Zone Data Exchange and third-party navigation apps. Additional Public Information Outreach includes project websites, public meetings, social media, media releases, door hangers, and on-road message signs, with select projects using enhanced strategies such as direct coordination with mapping companies.

2.1.3.8 Level of Communication

Decisions regarding the level and type of coordination and communication are primarily made by the districts based on public impact factors such as project size, complexity, duration, and anticipated traffic effects. Larger or longer-duration projects typically require more extensive Public Information Outreach, with local events also influencing communication needs. Central Office provides guidance as needed, while senior leadership is more directly involved in higher-impact projects.

2.1.3.9 Challenge Areas

The responses highlight several key challenges related to work zone data and coordination, including inconsistent and duplicative data entry processes across districts, particularly in areas like St. Louis where information must be entered into multiple systems that do not always align. This inconsistency makes real-time, accurate information sharing with the public difficult and underscores the need for a single, streamlined data entry system that feeds multiple platforms. Additional challenges include limited availability of law enforcement support in work zones, difficulties getting information to major navigation providers such as Google and Apple, and staffing issues caused by turnover and the resulting training gaps. Respondents also noted that implementing new innovations takes time, and further development is needed for advanced tools such as real-time performance indicators, automated condition monitoring systems, and intelligent work zone data integration with traffic management centers.

2.1.3.10 Current Focus (November 2023)

MoDOT is advancing multiple safety-focused initiatives to reduce crashes and fatalities in work zones, with an emphasis on slowing traffic, minimizing driver distraction, and better protecting workers. Ongoing efforts include Public Information Outreach campaigns such as the Show-Me Zero Initiative, expanded work hours paired with increased communication to manage added impacts, and stronger internal policies to ensure work zones are set up as safely as possible. There is growing interest in improving coordination with major navigation providers like Google and Apple, expanding the use of intelligent work zones through more streamlined systems, and deploying traffic-calming features such as chicanes. Additional priorities include enhanced safety equipment and measures for maintenance operations, such as automated Truck Mounted Attenuators (TMAs) and improved flagger systems, to further reduce risk for both workers and motorists.

2.1.3.11 Work Zone Wish List

MoDOT's work zone wish list had a strong focus on improving work zone safety through more effective enforcement, communication, and operational strategies. Key priorities include exploring automated enforcement, such as efforts underway on the Improve I-70 project to significantly reduce worker injuries and fatalities, though these measures would require substantial coordination and support to implement. Respondents highlighted the need to eliminate serious crashes, reduce sudden braking and driver confusion, and minimize distracted driving, as well as to reduce impacts such as crashes involving TMAs. Improved consistency in work zone data entry and enhanced real-time information sharing with the public and navigation providers are seen as essential to safety. Some noted that more aggressive lane or work closures could further improve safety but acknowledged challenges in gaining public and community acceptance for such measures.

2.1.3.12 What Works Well in MoDOT Work Zones

The responses highlighted that effective work zone management relies on strong communication, clear signage, and the strategic use of technology to keep travelers informed and safe. Key practices include smart work zones that provide travel times, speed feedback, and real-time conditions through tools such as changeable message boards, speed detectors, and CCTV cameras. Advanced warning and coordination with potentially impacted areas/communities along with complete, detailed information shared with the public, internal MoDOT staff, law enforcement, and other stakeholders is critical. Successful projects often combine smart work zone technologies with traditional static signage, reliable communications networks (supporting cameras, detectors, Changeable Message Signs (CMS), and signals), police presence or enforcement, and regular coordination meetings on major projects to ensure timely updates and consistent messaging.

2.1.3.13 What Does Not Works Well in MoDOT Work Zones

Several key challenges affecting work zone safety and effectiveness were identified, including declining public compliance with work zone speeds and increasing issues with driver distraction. Unplanned emergency closures further complicate operations and communication. Respondents emphasized that smart work zone equipment must be properly maintained and monitored, noting past issues where poorly maintained queue detection systems and misaligned devices resulted in incorrect messages being displayed to drivers. Reliable and timely communication is critical, as delays or inaccuracies, such as long queues, insufficient sign spacing, conflicting or fallen signs, and non-relevant signage; can reduce driver trust and worsen safety risks. Overall, maintaining accurate, relevant, and well-functioning work zone messaging is seen as essential to improving compliance and reducing incidents.

2.1.3.14 Top Work Zone Challenges

1. Speeding

2. Distracted driving (*Note 1 and 2 were tied)
3. Communication – real time notification
4. Consistency and compliance (Work Zone Standards, Temporary Traffic Control (TTC) plans)

Based on the questionnaire findings and subsequent Technical Advisory Committee (TAC) meeting, the initial work zone challenges to be included in the project investigation are speeding, distracted driving, communication – real time notification, and consistency/compliance. SWZ applications identified for inclusion in the Literature Search:

- Speed feedback (both simple feedback and changeable/advisory)
- End of queue warning
- Temporary rumble strips
    - Including improvements for ease of use
- Vehicle entering system
- Travel time
    - Specifically temporary applications

2.2 Literature Search

This section presents a literature search of TSMO strategies, as identified during the current practice investigation, with the potential to reduce distracted driving, speeding, and work zone related crashes. The review also examines strategies that may lower construction costs by enhancing safety and reducing risk to highway personnel.

Key work zone challenges identified by the TAC including speeding, distracted driving, real-time notification, and consistency and compliance guided the literature search to support MoDOT in selecting appropriate TSMO strategies for implementation.

2.2.1 Speed Feedback

Speed feedback signs, also known as dynamic speed feedback signs (DSFSs), radar speed signs, or speed trailers, are traffic control devices designed to provide real-time feedback to drivers about their current speed. These signs typically incorporate radar or Light Detection and Ranging (LiDAR) technology to detect the speed of approaching vehicles. The detected speed is then displayed to the driver on a digital or Light Emitting Diode (LED display. The primary purpose of deploying speed feedback signs is to address and mitigate issues related to speeding on roadways (Brown, et al. 2022). Speeding is a significant contributing factor to road crashes and fatalities. By offering immediate feedback to drivers about their speeds, these signs aim to influence driver behavior and encourage compliance with posted speed limits. The visual display of a driver's current speed serves as a reminder and allows them to make real-time adjustments to adhere to the speed limit, promoting safer driving habits. Speed feedback signs are often strategically placed in areas where speeding is a concern, such as school zones, work zones, residential neighborhoods, curves, and areas with a history of traffic crashes (Hallmark, et al. 2019).

Additionally, these signs can be used as temporary or portable devices in response to specific events or projects. The deployment of speed feedback signs aligned with broader efforts to enhance road safety, reduce crashes, and create safer environments for both drivers and pedestrians. This literature search included the extent of effectiveness of speed feedback in the following metrics:

- Speeding
- Distracted driving
- Real-time notifications
- Compliance

2.2.1.1 Speeding

Numerous studies have underscored the effectiveness of speed feedback devices in mitigating speeding issues, particularly in work zones. These devices have proven instrumental in influencing driver behavior and reducing instances of speeding. Specific field studies in various states have provided valuable insights. For instance, in one study, different configurations of speed trailers led to substantial reductions in speeds during both daytime and nighttime conditions. Another study in Indiana observed a notable decrease in median speeds during specific nighttime hours when speed trailers were deployed. Additionally, a study in Kansas examined the impact of dynamic speed feedback signs in work zones, revealing significant reductions in vehicle speeds at designated locations. A broader Federal Highway Administration (FHWA) study quantified the effectiveness of dynamic speed feedback signs, reporting notable decreases in mean speeds and 85th percentile speeds across diverse vehicle types and contexts.

These findings are summarized in Table 2-1, providing a comprehensive overview of the observed speed reductions in various studies.

Table 2-1 Summary of findings on the impact of speed feedback signs on vehicle speeds

Study	State	Study Type/ Corridor(s)	Findings
(Brown, et al. 2022)	Missouri	Field study I-270	Speed Trailer Active reduces speed by 9.9% and 22.9% during daytime and nighttime, respectively. Speed Trailer Active with Flashing Speed Feedback reduces speed by 24.8%. Speed Trailer Active with Red/Blue Lights reduces 53.5% and 51.9% during daytime and nighttime, respectively.
(Sakhare, et al. 2021)	Indiana	Field study I-65	Outcomes indicate a decrease in median speeds ranging from 4 to 13 mph between 11 PM and 7 AM when speed trailers were deployed, in comparison to the baseline conditions.
(Cunningham, et al. 2021)	Kansas	Field study	Impact of dynamic speed feedback signs on vehicle speeds was examined in two work zones. The findings revealed notable reductions in speed at both of the designated locations.
(Fisher, et al. 2021)	FHWA	Field study	This study quantifies the effectiveness of DSFSs in reducing speeds. Findings reveal notable reductions: 4 mph decrease in mean speeds and 2-4 mph reduction in 85th percentile speeds across diverse vehicle types and contexts. Given

Study	State	Study Type/ Corridor(s)	Findings
			that over 26% of fatal crashes in 2019 were speed-related, these results highlight the significant impact of DSFSs in enhancing road safety by curbing excessive speeds.
(Gambatese, et al. 2015)	Oregon	Field study I-205, I-84, US-97	The reduction in vehicle speed from the Road Work Ahead (RWA) signs to the active work area is more pronounced when the speed feedback is activated. In the analyzed case study projects, the 85th percentile speeds experienced a decrease of about 2 to 5 mph (4% - 8%) when the speed feedback was off, and 3 to 13 mph (5% - 23%) when the speed feedback was turned on.

2.2.1.2 Distracted Driving

Research confirms that speed feedback signs effectively command attention and enhance road safety without causing significant distraction. A comprehensive study by the Center for Transportation Research and Education at Iowa State University focused on rural two-lane roadways with horizontal curves, conducting a before-and-after crash analysis. This study revealed crash modification factors (CMF) ranging from 0.93 to 0.95 for various crash types and directions, indicating that the signs are associated with a notable decrease in crashes (Hallmark, et al. 2015). This compelling evidence supports the argument that dynamic speed feedback signs positively impact road safety without introducing distractions. Careful design and strategic placement, considering factors such as frequency of activation, driver experience, and traffic conditions, are key to their effectiveness. Well-designed signs featuring clear messages are more likely to capture drivers' attention without being intrusive. Calibration to activate signs only when necessary, such as when a driver exceeds the speed limit, helps maintain their efficacy. Despite some variation in individual driver responses, the consensus is that dynamic speed feedback signs contribute positively to road safety when thoughtfully implemented, considering the specific context and characteristics of the road and traffic.

2.2.1.3 Real-time Notifications

Speed feedback signs are pivotal in improving real-time notifications for drivers by offering instantaneous feedback on their current speed. Equipped with advanced technologies, these signs provide visual cues and alerts to prompt motorists to adjust their speed immediately. Customizable thresholds allow agencies to set specific speed limits, triggering real-time notifications when exceeded (Zineddin, et al. 2016). Additionally, some signs feature dynamic messaging capabilities, displaying real-time information about changing road conditions or upcoming hazards. Overall, the incorporation of speed feedback signs into traffic management strategies enhances real-time notifications, fostering safer driving practices and improving overall road safety.

2.2.1.4 Compliance

Research consistently highlights a positive correlation between the implementation of speed feedback technology and increased compliance with work zone regulations. The visual cues provided by these systems contribute to a safer driving environment, ensuring that drivers adhere to designated speed limits and navigate work zones with heightened caution. In examining the effects of speed countermeasures on work zone safety, studies have shown that speed trailers increase compliance by 2% during daytime and an impressive 22.9% during nighttime (Brown, et al. 2022). Other research (Sakhare, et al. 2021) found that speed trailers were nearly 2 to 3.5 times as effective in commanding compliance with the posted speed limit compared to base conditions. In addition to compliance, speed feedback signs also enhance consistency/uniformity of speeds (reduces variability) (Wang, et al. 2011). These findings underscore the positive impact of speed feedback technology on enhancing compliance and safety in work zones, demonstrating their effectiveness.

2.2.2 End of Queue Warning

Queue warning systems, integral components of intelligent transportation systems (ITS), are strategically implemented to autonomously identify queuing conditions and provide timely warnings to drivers about slow-moving or stopped traffic ahead. These systems, whether permanent fixtures or temporary installations, are predominantly deployed in work zones or areas prone to frequent queuing, aiming to mitigate the occurrence of rear-end crashes at the tail end of queues. The deployment of queue warning systems encompasses diverse configurations, employing various detection methods and message signs. Specifically, an End-of-Queue (EOQ) warning system is composed of a portable setup featuring easily deployable radar speed sensors connected to one or more Portable Changeable Message Signs (PCMS) (Ullman, Iragavarapu and Brydia 2016). The EOQ warning system functions by assessing the speed of traffic in proximity to the sensors and automatically presenting pertinent queue warning messages based on the distance between the PCMS and the closest sensor, effectively identifying decelerated or stationary traffic (Alluri, et al. 2022). This literature review includes the following performance metrics:

- Speeding
- Distracted driving
- Real-time notifications
- Compliance

2.2.2.1 Speeding

EOQ systems serve as effective tools for encouraging speed reduction through a comprehensive set of features that prioritize safety and awareness. These systems leverage advanced sensors to detect queuing or slowed traffic conditions ahead, triggering early warning alerts to approaching drivers (Ullman, et al. 2018). This proactive notification equips drivers with timely information, prompting them to reduce their speeds in preparation for changing traffic dynamics. Integrated with EOQ systems, PCMS strategically communicate real-time information to drivers, influencing them to adjust speeds based on upcoming congestion, work zones, or other potential hazards.

The application of the EOQ system in Texas along I-35, as illustrated in Figure 2.2 depicting the conceptual operation of a portable EOQ warning system, exemplifies the success of this approach (Ullman, et al. 2016). Traffic sensors were strategically placed at multiple locations upstream of the work zone, spanning distances of 3.5, 4.5, 5.5, and 6.5 miles from the taper, while a PCMS was positioned 7.5 miles from the taper. The deployment of this system in Texas reduced traffic speeds and effectively reduced variations. An additional study conducted in Minnesota along I-

35W, even outside a work zone context, underscored the system's efficacy in significantly reducing speed variances (Hourdos, 2017). Another study in Colorado along I-25 found that the queue warning system significantly decreased the number of abrupt speed reductions resulting in smoother traffic conditions for travelers (Waldman, et al. 2020). This study highlighted the value of real-time electronic messages, signaling and preparing motorists for queuing conditions ahead. These findings collectively emphasize the consistent success of EOQ systems in fostering harmonized and reduced speeds, promoting a safer and more controlled driving environment.

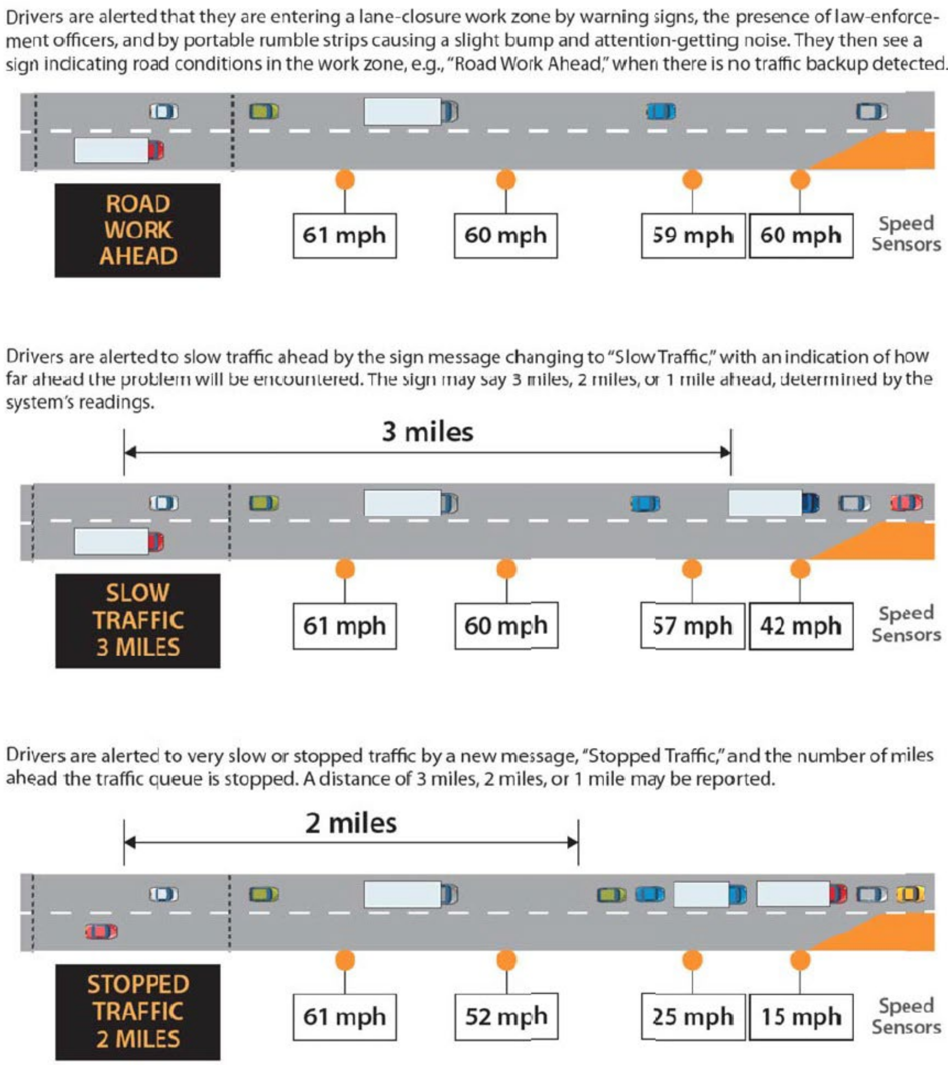


Figure 2.2 Conceptual Operation of Portable EOQ Warning System
(Ullman, Iragavarapu and Brydia 2016)

2.2.2.2 Distracted Driving

Research conducted in Texas along I-35 has compellingly demonstrated that the EOQ system, when coupled with rumble strips, significantly captures drivers' attention, thereby substantially enhancing safety. The study meticulously assessed the safety efficacy of the EOQ system by investigating crashes occurring at the tail end of queues within work zones associated with a road-widening project during nighttime lane closures. This comprehensive analysis, conducted in areas where queues were anticipated during nighttime operations, accounted for the dynamic changes in the position and frequency of lane closures due to project activities such as milling and paving. EOQ incidents, encompassing crashes within the lane closure segment and the queue section extending five miles upstream from the lane closure's starting point, were thoroughly documented. Through a meticulous comparative analysis, considering scenarios both with and without the EOQ system, the research unequivocally revealed a substantial 44% reduction in EOQ crashes during nighttime lane closures in work zones (Ullman, et al. 2016). Additionally, the study uncovered a noteworthy decrease in the proportion of severe crashes, dropping from 58% to 41%, directly attributed to the integration of the EOQ warning system with rumble strips. This concrete evidence underscores the system's efficacy in not only reducing overall crashes but specifically mitigating the severity of crashes, solidifying its role in enhancing roadway safety.

Although queue warning systems are commonly employed to enhance safety in work zones, they have found application as permanent fixtures on congested freeways. Illustratively, a permanent queue warning system was deployed on a segment of I-94 in downtown Minneapolis, Minnesota, aimed at detecting queues at multiple points along the freeway. Utilizing diverse detection methods and permanent changeable message signs, this system yielded significant results, leading to a 22% decrease in crashes and a noteworthy 54% reduction in near-crash events during a three-month evaluation period (Hourdos, et al. 2017).

2.2.2.3 Real-time Notifications

Practice has established that EOQ systems support real-time notifications through their sophisticated integration of sensor technology, data processing capabilities, and robust communication infrastructure (Ullman, et al. 2018). These systems employ advanced sensors, such as radar speed sensors or infrared sensors, to continuously monitor the speed and movement of vehicles in the monitored area. In real-time, the collected data undergoes thorough analysis by the system's algorithms, enabling the identification of patterns indicative of queuing or slowed traffic conditions. The EOQ system is seamlessly connected to communication networks, allowing instant transmission of pertinent information. Upon detecting a queuing condition, the system activates PCMS strategically placed along the roadway, providing drivers with immediate alerts about upcoming congestion or potential hazards. Moreover, real-time notifications can be directly sent to drivers through electronic message boards, mobile apps, or in-vehicle communication systems. This integration ensures that drivers receive timely information, empowering them to make informed decisions and contributing to overall road safety. Additionally, EOQ systems often interface with centralized Traffic Management Centers (TMC), allowing operators to monitor real-time data and implement adaptive control strategies, such as adjusting signal timings or dispatching emergency services, to manage traffic flow effectively. In essence, EOQ systems serve as proactive tools, leveraging real-time information to enhance situational awareness, mitigate congestion-related risks, and optimize the efficiency of the transportation network.

2.2.2.4 Compliance

EOQ systems significantly bolster compliance within work zones through a multifaceted approach that integrates advanced technology and proactive safety measures. These systems excel in providing early warning alerts to approaching drivers, effectively notifying them of potential queuing or slowed traffic conditions well in advance. This advanced warning not only encourages drivers to adjust their speed but also promotes compliance with designated speed limits, fostering a smoother and safer transition into the work zone (Hourdos, et al. 2017). The incorporation of PCMS within the EOQ framework is pivotal, as these signs strategically display real-time information related to work zone conditions, lane closures, and speed limits. Clear and visible signage enhances driver awareness, reinforcing adherence to prescribed rules and regulations within the work zone.

Furthermore, EOQ systems foster heightened situational awareness, encouraging drivers to adhere to prescribed traffic rules and regulations within work zones. By effectively managing traffic flow through the early detection of queuing conditions, EOQ systems contribute to a more orderly and predictable environment within work zones. This predictability not only enhances safety but also cultivates a culture of compliance as drivers can anticipate and respond to changing traffic patterns in a controlled manner. In essence, EOQ systems serve as integral components in creating a safer driving environment, a reason that has been cited to increase compliance rates as demonstrated by reduction in speed variance near the queue locations and the speed differential between upstream and downstream locations (Hourdos, et al. 2017).

2.2.3 Temporary Rumble Strips

Temporary Transverse Rumble Strips (TTRS) are deployed in work zones to enhance safety. Made of durable materials, these temporary installations produce a distinct rumbling sound and vibration as vehicles pass over them. The tactile and audible feedback serves as a warning to drivers about changes in road conditions, such as lane shifts or reduced speed limits. TTRS are effective in prompting drivers to reduce speed, pay attention to signage, and exercise caution in work zones (FHWA, n.d.). Their temporary nature allows for easy removal once the construction or maintenance activities are completed, minimizing disruption to regular traffic flow. This literature search includes the extent of effectiveness of transverse rumble strips in the following metrics:

- Speeding
- Distracted driving
- Real-time notifications
- Compliance
- Ease of use

2.2.3.1 Speeding

TTRS serve as effective traffic calming measures aimed at reducing speeding and enhancing overall road safety. In a sponsored research study by MoDOT, a comprehensive field evaluation of both short-term and long-term temporary rumble strips demonstrated significant reductions in speed violations, with short-term Transverse Rumble Strips (TRS) achieving a remarkable 21.2%

decrease and long-term TRS showing an 18.2% reduction (Brown, et al. 2022). Complementing these findings, additional research on the effectiveness of TRS at intersections, utilizing crash surrogates such as speed and stopping behavior, further supports the notion that TRS can contribute to a reduction in speed, ranging from 1 to 5 mph, as indicated in studies by (Harder, et al. 2006) and (Ray, et al. 2008). Additional findings from other studies are included below:

- 1 to 7.2 mph reduction in average speeds (WisDOT, 2018).
- 10.1%–13.8% reduction in mean speeds and 8.3%–14.5% reduction in the 85th percentile speeds (Yang, et al. 2013).
- 4.6 to 11.4 mph mean speed reduction for automobiles and 5 to 11.7 mph for trucks (Wang, et al. 2011).

2.2.3.2 Distracted Driving

Many drivers involved in work-zone crashes are reported to be completely unaware of the work zone. Distractions due to increased electronic device use in vehicles, daydreaming, or highway hypnosis are thought to be key contributing factors of many rear-end collisions (Theiss, et al. 2023). TTRS serve a crucial role in alerting drivers to the need to slow down, come to a stop, or anticipate upcoming changes, especially in situations that might catch an inattentive driver off guard. These strips, strategically placed perpendicular to the direction of travel in the travel lane, find typical applications on approaches to intersections, toll plazas, horizontal curves, and work zones (FHWA, n.d.). While not a direct measure of reduced distracted driving, research has consistently demonstrated that the utilization of TTRS correlates with a significant reduction in crashes. For instance, a study on the I-35 corridor in Texas analyzed crash data related to the deployment of temporary portable rumble strips for both queued (traffic queue of stopped vehicles exists) and non-queued (traffic queue of stopped vehicles does not exist) conditions in a work zone (Ullman, et al. 2018). In queued conditions, the reported Crash Modification Factor (CMF) was 0.40, signifying a remarkable 60% reduction in crashes. In non-queue conditions, the CMF was 0.89, indicating an appreciable 11% reduction. These findings underscore the significant safety benefits of transverse rumble strips, particularly in mitigating the risk of collisions and promoting attentive driving behavior (Ullman, et al. 2018).

In a more recent study, the Texas A and M Transportation Institute (TTI) researchers assessed the impact of Temporary Portable Rumble Strips (TPRS) on distracted driving within work zones. The study encompassed various sites, including flagging operations on two-lane highways and lane closures on multilane roadways. Instances of visual distraction, such as drivers looking at phones, passengers, reading, or adjusting the radio, were documented as they passed data collection observers. The study revealed that the rate of visually distracted drivers immediately before passing over the TPRSs ranged from 15% to 29%. These percentages appeared to be influenced by factors such as roadway type, land use, and the volume of traffic. Notably, researchers observed that several visually distracted drivers tended to refocus immediately after passing over the TPRSs. Additionally, data from a specific site, where information was collected at multiple points downstream of the TPRSs, suggested that their impact on driver distraction might be confined to approximately 1,500 feet downstream (Theiss, et al. 2023).

2.2.3.3 Real-Time Notifications

Rumble strips play a vital role in enhancing real-time notifications for drivers, serving as an effective means of alerting them to specific road conditions. These strips, often strategically placed on road surfaces, provide immediate tactile and audible feedback when crossed by a vehicle. The tactile sensation, often described as a vibration or rumbling, serves as a real-time notification to drivers, especially those approaching a critical area (Boodlal, et al. 2020). Rumble strips are versatile and can be customized to convey specific messages, such as upcoming stop signs, pedestrian crossings, or work zones. Their integration into larger traffic management systems allows for coordinated notifications based on changing road circumstances. Furthermore, these strips can be equipped with additional features such as reflectors for improved visibility during low-light conditions, contributing to heightened real-time awareness for drivers (Hallmark, et al. 2023). The instant and unmistakable feedback provided by rumble strips significantly contributes to overall road safety and situational awareness.

2.2.3.4 Compliance

Rumble strips have proven to be influential tools in enhancing speed compliance within work zones. Deployed strategically, these tactile and audible cues alert drivers to reduce speed, promoting heightened awareness and adherence to designated speed limits. Research studies, such as those conducted by transportation agencies, consistently demonstrate a positive correlation between the presence of rumble strips in work zones and increased speed compliance (Brewer, et al. 2005).

In a safety analysis conducted in Missouri, a comprehensive examination was undertaken, employing both descriptive and statistical analyses to assess the impact of temporary rumble strips on work zone speed compliance. The overall speed compliance rate within the work zone was initially observed at 23.4%. Notably, the findings revealed positive effects associated with the deployment of temporary rumble strips. The marginal effects, representing the impact of the rumble strips, indicated a substantial reduction in speed violations—21.2% for short-term rumble strips and 18.2% for long-term rumble strips, based on complete survey data. Further analysis, considering the segment before and after entering the rumble strips, indicated a remarkable 68.0% decrease in speed violation with long-term rumble strips. However, the study was inconclusive regarding the distinction in effects between short-term and long-term rumble strips on work zone speed violation and compliance (Brown, et al. 2022). The effectiveness of rumble strips in influencing speed compliance underscores their significance as a valuable countermeasure to mitigate speeding and enhance overall road safety in dynamic work zone settings.

2.2.3.5 Ease of Use

Many transportation agencies across the U.S. rely on the efficient deployment of temporary transverse rumble strips, also known as in-lane or travel-way rumble strips, with dual objectives: (a) alerting motorists to the imminent entry into a work zone with unusual road conditions, and (b) capturing the driver's attention to other warning devices (Boodlal, et al. 2020). Given the temporary nature of work zones, agencies prefer the use of portable rubber rumble strips, which are often made of a rubber compound, enhancing their user-friendly design. These strips are notable for their ease of use, allowing for quick and straightforward installation and removal. This user-friendliness contributes to their practicality and widespread implementation, particularly in various traffic management scenarios. Specifically designed for rapid deployment, portable rubber rumble strips facilitate swift responses to dynamic needs, such as work zones or temporary traffic control requirements. The removal process is equally efficient, minimizing disruption to regular traffic flow once the need for the strips has diminished. These strips prove to be ideal for work zones requiring frequent daily installation and removal, including pilot car, or flagging operations, lane closures, traffic safety checkpoints, routine maintenance projects, and paving operations. A single portable rubber rumble strip costs about $1,500. A minimum of three strips is required to form an array (or set) (Boodlal, et al. 2020). Some of their commendable attributes include (Plastic Safety Systems, 2013):

- Temporary - No nails or glue are needed for installation and use. Quick installation and removal, and no clean-up.
- Portable - No installation equipment needed. A crew of 2 can install an array in minutes.
- Durable - 3–5-year life under normal conditions. Suitable for use in rain and colder temperatures.

An alternative option for temporary use is the orange polymer rumble strips with pre-applied adhesive. Unlike their rubber counterparts, the use of adhesives may potentially extend the installation and removal process (Boodlal, et al. 2020). However, these types of rumble strips provide visual alertness in addition to vibration and sound (Ukkusuri, et al. 2016).

Regardless of the various types, certain concerns have been raised. A study conducted in Missouri revealed variations in the perceptions of the effectiveness of temporary rumble strips among installers. However, installers generally expressed the belief that temporary rumble strips can be effective in specific situations. Notable concerns voiced by installers encompassed the substantial weight of short-term temporary rumble strips, challenges associated with the removal of long-term temporary rumble strips on asphalt pavements, the time required for the installation of long-term temporary rumble strips, and potential worker exposure to traffic when installing short-term temporary rumble strips on a divided highway (Brown, et al. 2022).

2.2.4 Vehicle Entering System

The Vehicle Entering System, with the Trucks Entering System as a perfect example/component, is an innovative solution designed to heighten safety in highway work zones by providing real-time alerts to drivers about slow-moving construction vehicles entering or exiting the roadway. Also known as truck ingress/egress, this comprehensive system encompasses the detection of slow-moving construction vehicles, triggering immediate advanced warnings to motorists. The activation of these warnings can take the form of a portable changeable message sign or flashing lights on a static sign, ensuring that drivers receive prompt notifications to adjust their speed and navigate the work zone safely (Schroeder, et al. 2021).

The Trucks Entering System exemplifies a seamless approach to enhancing safety measures for both motorists and construction crews. This system, embedded within the standard traffic control devices, contributes significantly to proactively alerting drivers to the presence of construction vehicles entering or exiting the highway. This real-time communication plays a pivotal role in reducing the risk of crashes, enhancing overall situational awareness, and fostering a safer environment for everyone involved in construction or maintenance activities within the work zone and the motoring public (Schroeder, et al. 2021). Similarly, this literature review includes the impacts of Vehicle Entering System in the following performance metrics:

- Speeding
- Distracted driving
- Real-time notifications
- Compliance

2.2.4.1 Speeding

The Trucks Entering System plays a pivotal role in improving speed harmonization through its proactive measures designed to enhance driver awareness and influence driving behavior. Equipped with advanced sensors, this system detects the impending entry of trucks into specific areas, such as work zones or facilities. Upon detection, the system triggers early warning alerts, providing drivers with timely information about the approaching trucks. This preemptive notification serves as a catalyst for drivers to reduce their speeds or change lanes in anticipation of changing traffic conditions (Schroeder, et al. 2021). This reduces the number of sudden stops and resulting slowdowns in the traffic stream near the construction vehicle entrance/exit point (Schroeder, et al. 2021). Integrated with PCMS, the Trucks Entering System strategically communicates real-time information to drivers, displaying messages that prompt adjustments in speed. In essence, the Trucks Entering System orchestrates a comprehensive approach to speed reduction and harmonization, fostering an environment where drivers are proactively guided to moderate their speeds in response to the dynamic conditions associated with truck entry.

2.2.4.2 Distracted Driving

Similar to other technologies that use PCMS or flashing lights or sometimes coupled with rumble strips to provide audible and tactile alerts, Trucks Entering Systems play a crucial role in mitigating distracted driving by implementing proactive measures designed to enhance driver focus and situational awareness. Through the incorporation of early warning systems, these technologies alert drivers to the presence of trucks entering specific areas, providing timely information to anticipate changing traffic conditions. The utilization of PCMS further aids in minimizing distractions by presenting clear and concise visual messages related to truck entry without requiring prolonged attention shifts from the road (Schroeder, et al. 2021). While specific research findings may vary, the inherent design of Trucks Entering Systems aligns with principles aimed at reducing distracted driving and fostering a safer driving environment.

2.2.4.3 Real-time Notifications

Truck Entering Systems contribute significantly to improving real-time notifications. Early warning systems, a key component of these solutions, have consistently demonstrated effectiveness in providing timely information to drivers (Boodlal, et al. 2020). Studies emphasize that systems capable of detecting and communicating potential hazards, such as trucks entering specific areas, result in reduced reaction times and heightened driver awareness (Schroeder, et al. 2021). Research has also delved into the impact of incorporating PCMS into real-time notification strategies, highlighting their positive influence on traffic management. Furthermore, a broader exploration into human factors and attention management in transportation reveals that real-time notifications designed with consideration for simplicity, clarity, and timing are more effective in maintaining driver attention and reducing distractions (Schroeder, et al. 2021).

2.2.4.4 Compliance

While the literature on the impact of Truck Entering Systems in promoting compliance within work zones is limited, the proactive measures employed by these systems, which not only alert drivers but also guide their behavior in accordance with safety protocols, undoubtedly contributes to overall compliance. Research indicates that early warning systems, a key element of Truck Entering Systems, significantly enhance compliance by delivering timely information to drivers regarding potential hazards, such as the entry of trucks into specific areas (Hourdos, et al. 2017). Furthermore, the integration of PCMS has proven effective in influencing driver behavior and encouraging adherence to prescribed speed limits within work zones. While specific research findings may vary, collective evidence suggests that PCMS play a substantial role in fostering a culture of compliance within work zones, ultimately establishing safer environments for both drivers and construction crews.

2.2.5 Temporary Travel Times

Temporary Travel Time Information Systems are dynamic solutions deployed for short-term periods to offer real-time travel information to motorists facing specific events or conditions affecting traffic. Typically utilized along work zones, special events, or other incidents impacting normal traffic flow, these systems aim to enhance situational awareness and assist drivers in making informed decisions. Key components of these systems include PCMS that display real-time travel times. The temporary nature of these systems allows for flexible deployment along specific routes or in designated areas as needed. Benefits of Temporary Travel Time Information Systems include improved traffic flow, enhanced safety through informed driving decisions, and efficient route planning for travelers. Giving motorists the current travel time to a reference point beyond the work zone can alleviate some of the frustration that motorists experience (TxDOT, 2018). As technology and transportation management continue to advance, these systems evolve to meet the dynamic needs of temporary traffic disruptions. Similarly, this literature review includes the impacts of Temporary Travel Time Information Systems in the following performance metrics:

- Speeding
- Distracted driving
- Real-time notifications
- Compliance

2.2.5.1 Speeding

Practice has demonstrated that Temporary Travel Time Information Systems themselves do not directly influence traffic speed; rather, they provide real-time information to drivers about the current travel conditions, allowing them to make informed decisions. The impact on traffic speed depends on how drivers respond to the information provided. In some cases, the availability of real-time travel information can contribute to more efficient traffic flow and potentially reduce congestion and improve travel speed. When drivers receive timely updates about traffic conditions, they may make informed decisions to avoid congested areas, leading to smoother traffic flow and, in some instances, a reduction in overall travel time.

2.2.5.2 Distracted Driving

Temporary Travel Time Information Systems contribute to the reduction of distracted driving in work zones by providing drivers with critical information without necessitating prolonged attention shifts. The real-time travel time updates are presented in a clear and concise manner, minimizing distractions caused by the need for drivers to actively seek information. Research in the broader field of Human Factors and transportation safety suggests that systems designed with simplicity and minimal cognitive load contribute to sustained driver attention. Temporary Travel Time Information Systems align with these principles, presenting real-time data in an easily digestible format and supporting a focus on the primary task of driving, thereby reducing the risk of distracted driving incidents within work zones (TxDOT, 2018).

2.2.5.3 Real-time Notifications

Similar to other technologies that use PCMS, Temporary Travel Time Information Systems play a crucial role in enhancing real-time notifications for drivers navigating through work zones. These systems provide dynamic updates on travel times, enabling motorists to make informed decisions about their route and driving behavior (TxDOT, 2018). Research has highlighted that real-time information, such as travel times, significantly improves the effectiveness of notifications, especially in dynamically changing traffic scenarios. By integrating with PCMS or similar technologies, these systems enhance real-time communication, alerting drivers to potential hazards, lane closures, or changes in traffic patterns. The immediate and relevant notifications contribute to a safer and more efficient traffic flow within work zones, reducing uncertainty and enhancing overall situational awareness.

2.2.5.4 Compliance

Temporary Travel Time Information Systems contribute to improved compliance within work zones by fostering a proactive and informed approach among drivers. While the literature is constrained regarding the precise impact of these systems on compliance, research findings suggest that access to real-time travel time information positively influences compliance with posted regulations and guidelines. By offering dynamic updates based on current traffic conditions, these systems empower drivers to plan their routes effectively (TxDOT, 2018). Overall, Temporary Travel Time Information Systems serve as valuable tools in promoting a culture of compliance within work zones, enhancing safety for both drivers and construction crews.

2.2.6 Literature Search Summary

This chapter provides a summary of findings derived from a literature search on five key technologies aimed at improving safety and efficiency in highway work zones. Each technology, namely Speed Feedback Signs, End-of-Queue Warning System, Temporary Transverse Rumble

Strips, Trucks Entering System, and Temporary Travel Time Information Systems, was explored in detail, emphasizing their impact on performance metrics such as speeding, distracted driving, real-time notifications, and compliance. The following summaries offer key takeaways and insights from relevant studies, shedding light on the effectiveness of these technologies in creating safer and more controlled driving environments within work zones.

2.2.6.1 Speed Feedback

Speed feedback signs have demonstrated significant effectiveness in reducing vehicle speeds, as evidenced by studies in Missouri, Indiana, Kansas, and Oregon. Research supports their role in enhancing road safety, and the signs contribute to improved real-time notifications for drivers by promptly alerting them to adjust their speed. Moreover, the implementation of speed feedback technology showed a positive correlation with increased compliance in work zones, creating a safer driving environment and promoting consistency in speeds.

2.2.6.2 End of Queue Warning

Queue warning systems, like the EOQ setup with radar speed sensors and PCMS, effectively reduce speed variances, minimize abrupt speed reductions, and enhance traffic conditions in work zones. Studies in Texas, Minnesota, and Colorado underscore the EOQ system's success, showing a 44% reduction in nighttime end-of-queue crashes and improved roadway safety. These systems support real-time notifications, utilizing advanced sensors and communication infrastructure for instant alerts to drivers about queuing conditions. Additionally, EOQ systems significantly enhance compliance in work zones by providing early warnings, displaying real-time information through PCMS, and fostering heightened situational awareness. Overall, EOQ systems play a crucial role in creating a safer and more controlled driving environment by mitigating risks associated with queuing conditions and optimizing traffic flow.

2.2.6.3 Temporary Rumble Strips

Temporary Transverse Rumble Strips (TTRS) in work zones effectively enhance safety by significantly reducing speed violations, with studies demonstrating a 21.2% decrease with short-term TTRS and an 18.2% reduction with long-term TTRS. These strips also serve as effective traffic calming measures, showcasing varied reductions in average speeds, mean speeds, and 85th percentile speeds. TTRS play a crucial role in mitigating distracted driving, evidenced by a 60% decrease in crashes in queued conditions. They provide immediate tactile and audible feedback, enhancing real-time notifications and situational awareness. TTRS contribute to increased speed compliance in work zones, with research in Missouri showing substantial reductions in speed violations. The user-friendly design of portable plastic rumble strips allows for swift installation and removal, making them versatile tools for improving safety in dynamic work zone settings.

2.2.6.4 Vehicle Entering System

The Trucks Entering System enhances safety in highway work zones by issuing real-time alerts to drivers through PCMS or flashing lights, prompting timely speed adjustments. This system improves speed harmonization by detecting approaching trucks, reducing sudden stops and stream slowdowns. It mitigates distracted driving through proactive measures like PCMS enhancing driver focus. Additionally, it contributes to real-time notifications, reducing reaction times and improving driver awareness. While limited research focuses on compliance, the proactive measures are likely to enhance overall adherence to safety protocols, establishing a safer environment for both drivers and construction crews.

2.2.6.5 Temporary Travel Times

Temporary Travel Time Information Systems, utilizing PCMS, enhance traffic flow by providing real-time travel information to drivers in work zones. While not directly impacting speed, they contribute to efficiency by enabling informed route choices, reducing congestion. With clear presentations, these systems minimize distractions, aligning with human factors principles. Real-time updates improve communication and compliance, empowering drivers to adhere to regulations and guidelines, fostering a safer environment in work zones.

Chapter 3: Project Selection

Project selection for demonstration of TSMO work zone strategies on a Missouri work zone began with a TAC meeting to discuss potential projects for implementation, documentation on approximate costs, safety benefits, equipment requirements, and performance metrics was compiled as a reference resource for evaluating candidate construction projects. For the purposes of this project and potential deployment during the 2024 construction season, recommended systems included communications and software components to support data transfer, processing, and monitoring.

The 2024 Top Traffic Impacting Work Zones list was reviewed and a project roadshow presentation at the Statewide Resident Engineer (RE) Meeting was scheduled for February 14, 2024. The presentation covered the project overview and objectives and discussed possible 2024 or 2025 construction project locations and opportunities.

The potential project for demonstration included any project that was on an interstate or highway, avoiding arterials, has work that will be impacting traffic, has safety and mobility concerns, and would have a project duration of at least 3 months.
Discussion included:

- Is there a SWZ on any upcoming 2024 projects and do they fit these project needs?
    - Could this research project collect information on those SWZ systems and use the data for review?
- Is there a project that should have had SWZ and did not?
- Are there any projects coming up for 2025 that could be a fit for this project ahead of the bidding cycle?
    - This research project would create and provide the SWZ layout and the job special provisions.

Documentation was provided on different procurement methods to incorporate SWZ systems on MoDOT construction projects. There are two major procurement options for consideration:

1. Include the SWZ systems in the construction contract to be provided by the Contractor.
2. Award a separate contract to an SWZ vendor to install and operate the system.

The RE’s and TAC members identified two candidate projects for this TSMO research: I-44 Strafford to Ramp B interchange (7I3010 and SU0146) and I-64 Project (J6I3538). Following coordination with MoDOT project staff, the I-44 Strafford project was selected due to a planned SWZ and the ability to develop SWZ layouts and update the JSP prior to letting. As part of this effort, a traffic data review, SWZ layouts for Temporary Traffic Control Stages 1–8, job-specific JSPs, a daily data management plan, and a post-project analysis plan were developed and presented to the TAC in January 2025. In February 2025, the project was removed from the STIP letting.
The team quickly pivoted to a new I-44 project in Springfield planned for the 2025 construction season. The following section contains information on the I-44 Springfield project.

3.1 Project Overview I-44 Springfield

The Springfield Resident Engineer proposed a new project that was let in December 2024 to be completed during the 2025 construction season; I-44 Project J8I3044C/JSU0076: Eastbound (EB)/Westbound (WB) I-44 Glenstone to US 65 and EB/WB I-44 Route (Rte.) 13 to Glenstone Avenue located in Springfield, MO. The I-44 project in Greene County includes pavement reconstruction, lane widening, bridge replacements, construction of a sound wall and pedestrian underpass, and resurfacing to increase roadway capacity between Kansas Expressway and U.S. Route 65. This project is a component of the Forward 44 Planning Study and already included a SWZ as part of the contract documents.

Location: I-44 Springfield

- J8I3044C (EB/WB I-44 Glenstone Ave. to US 65); East portion of project
- JSU0076 (EB/WB I-44 Rte. 13 to Glenstone); West portion of the project

Work Type: Pavement Widening, Bridge, and Ramps
Staging Strategy: Splitting traffic into a contraflow pattern to maintain two EB and two WB lanes with crossovers. Ramp work will be completed using traffic detours.
Project Dates: Project start March 2025, SWZ activation April 2025
Duration: 2.5-year project; completion in May 2027
Safety and Mobility Concerns: Queuing was a concern at both ends of the project. The project team expected one-to-two-mile backups in the WB direction. This is a heavily traveled corridor with many using the area for recreational destination travel. Incidents and times with heavy weekend traffic could produce backups longer than 5 miles. The use of PCMS and in place CMS for route diversion will be used along I-44, Rte. 13, and US 65.
SWZ Layout and JSP: SWZ layout, messaging plan, JSP were consultant designed and included in the contract documents. Streetwise will be the SWZ provider for this project.

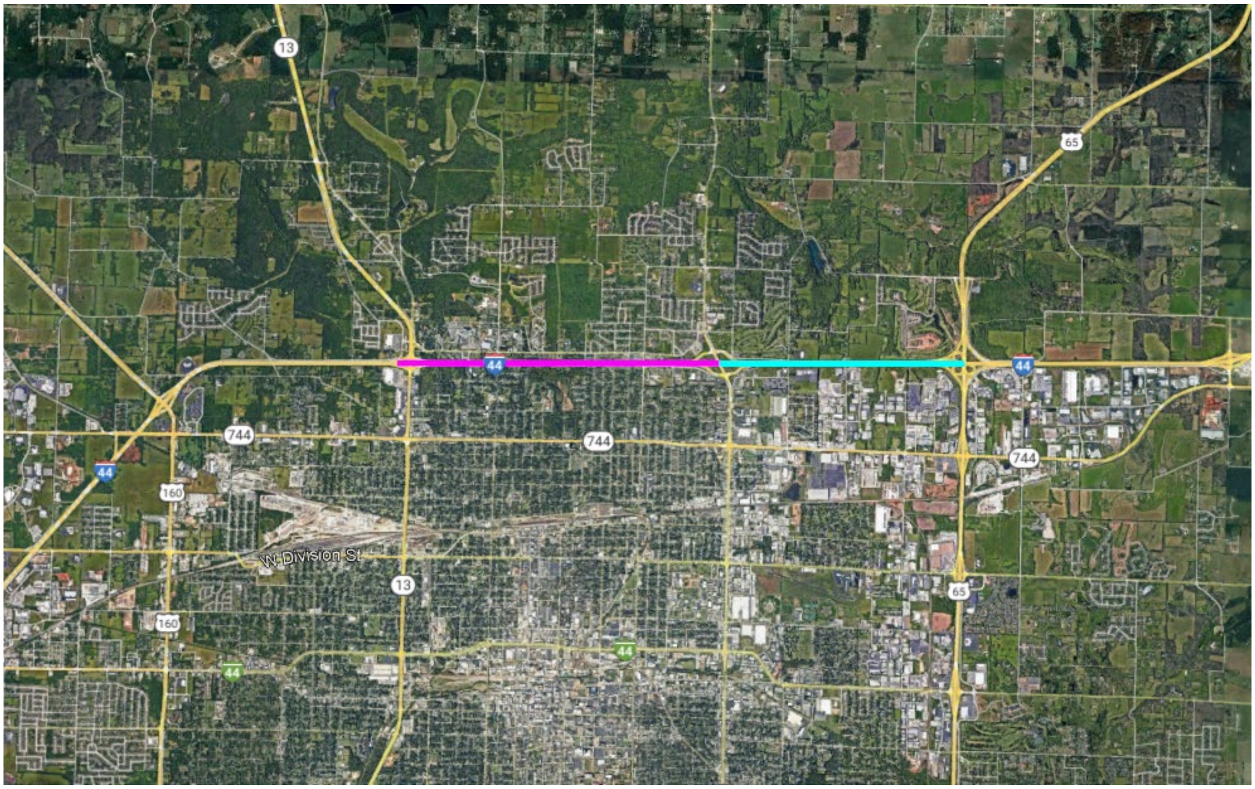


Figure 3.1 The project area is located on I-44 in Greene County from Kansas Expressway/MO 13 to US 65 in Springfield Missouri. The work will be performed in two sections: Job JSU0076 on EB/WB I-44 from Hwy 13 to Glenstone Avenue/Hwy H and Job J8I3044C on EB/WB

3.1.1 Existing Conditions I-44 Springfield

Review of the existing data for I-44 eastbound and westbound using the Work Zone Impact Analysis Spreadsheet showed no queuing in either direction. The Work Zone Impact Analysis Spreadsheet is primarily used to determine impacts due to lane reductions. Since this project will maintain two lanes in each direction throughout construction, the spreadsheet will not show queues forming. However, as queuing is expected due to the nature of the work zone, additional modeling using VISSIM was performed. Despite reducing the speed limits, narrowing lanes, and updating truck percentage and lane assignments, no queueing was observed in either direction. Based on these results, any queues outside of normal peak time slowdowns are expected to be driven by incidents or other abnormal traffic events.

3.2 SWZ Layout Per Plan

A SWZ layout for queue detection, temporary long term rumble strip locations, and the diversion route plan were provided as part of the traffic control plans for this project. The proposed SWZ layout begins at the start of the taper with a traffic sensor and consists of four traffic sensors and three PCMS with the device spacing provided in the plan. The planned SWZ configuration places the first PCMS at 3.5 miles from the taper with the last PCMS located 7.5 to 9.5 miles from the taper as shown in Figure 3.2 and 3.3 below.

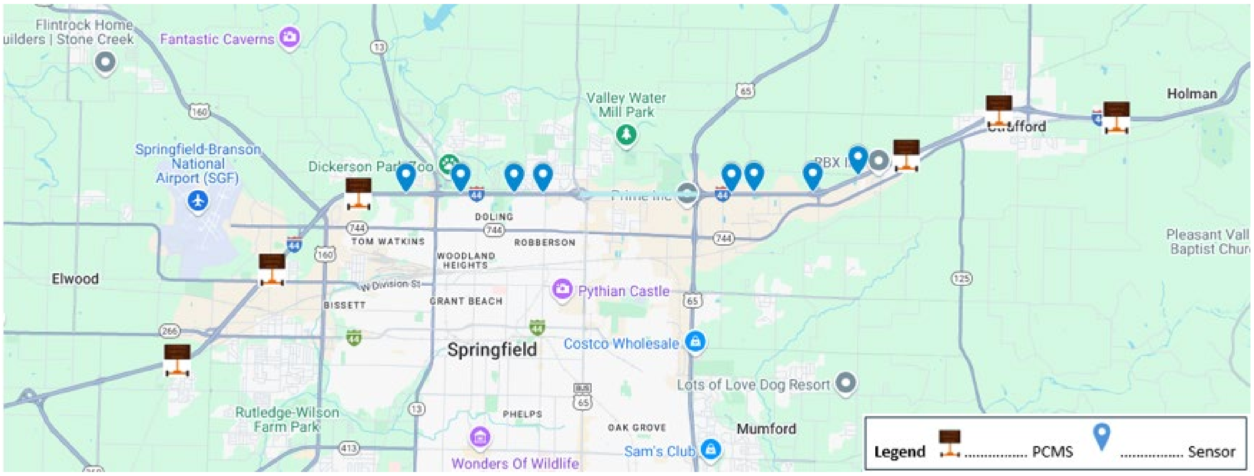


Figure 3.2 SWZ layout from Streetwise per plan

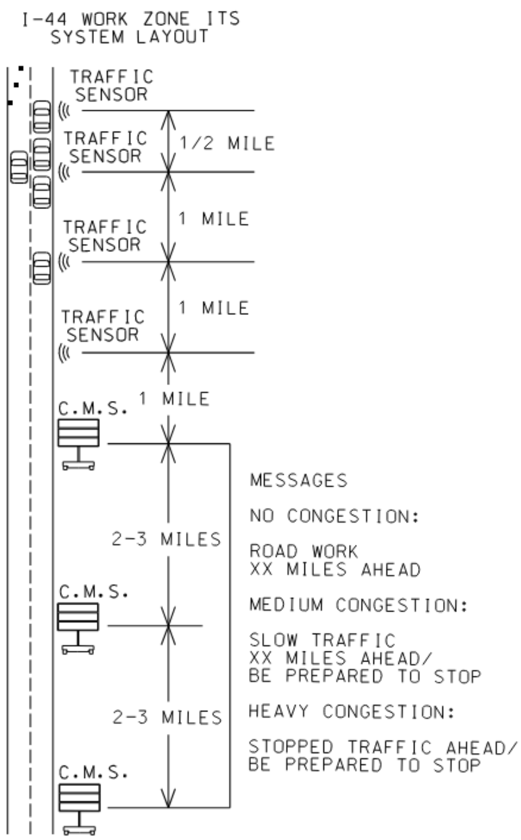


Figure 3.3 SWZ layout spacing as per the plan

3.3 I-44 Springfield SWZ Layout Review and Revision Options

Initial review of the project SWZ plan sheets, JSP and proposed SWZ layout raised some concerns about the device locations. Due to the expected queue length of one to two miles being the reoccurring slow and stopped traffic pattern the proposed SWZ layout in Figures 4.2 and 4.3 may not provide the most effective messaging to drivers. The proposed sensor and PCMS spacing could result in a less responsive system, slowdowns dissipating before drivers reach the end of queue, and public distrust of systems displaying messages that do not accurately reflect their current driving conditions.

The following options for alternative initial SWZ deployment locations were provided to MoDOT:

1. Deploy SWZ per plan and see how it reacts to queuing. Adjust locations as needed.
2. Relocate one PCMS in each direction so the messaging is capturing and messaging for the one-to-two-mile slowdowns. Adjust locations as needed after initial deployment.
3. Full SWZ location revision. Adjust locations as needed as needed after initial deployment. Diversion route suggestion: add another board for diversion after the furthest out queue warning board.

3.3.1.1 Option one: deploy SWZ per plan and see how it reacts to queuing; adjust locations as needed.

Option one is to deploy the SWZ as provided in the project contract documents, see how queueing occurs, and amend the SWZ device locations after a review of the system effectiveness. For research purposes, this option holds value as it would allow the team to evaluate the outcomes of a MoDOT approved SWZ without outside influence or modifications. However, since the first traffic pattern changes often lead to driver confusion and long queues, there is the incurred risk of reduced safety and ineffective messaging to drivers.

Figure 3.4 I-44 Springfield SWZ layout device location review per plan

Table 3-1 SWZ layout distances as per plan

Distant to Taper	Device
0.0 mile	Sensor 1
0.5 mile	Sensor 2
1.5 mile	Sensor 3
2.5 mile	Sensor 4
3.5 mile	PCMS 1
5.5 to 6.5 mile	PCMS 2
7.5 to 8.5 mile	PCMS 3

Pros:

- Allows for study of SWZ conditions per plan
- Keeps team on schedule with planned deployment and location expectations

Cons:

- Potential for safety impacts
- Miss the opportunity for the data and study of an updated system with the largest traffic impact

3.3.1.2 Option two: relocate one PCMS in each direction so the messaging is capturing the one to one and a half mile slowdowns. Adjust locations as needed.

Option two is to deploy the SWZ with adjustments to the PCMS layout to capture the one-to-1.5-mile expected queues with slow/stopped messaging. Once the project is underway, additional changes to the system could be made as needed.

For minimal disruption to the proposed SWZ layout, the research team suggests moving the furthest out PCMS 3 to be co-located with SWZ sensor 3. This updated layout would provide messaging as the driver enters the work area while still maintaining the spacing for PCMS 1 and 2. The staggered layout of sensors and PCMS will also allow the traffic management software to be more intentional in their sensor and PCMS pairing for activation. With this plan, sensors 1 and 2 would activate PCMS 3 providing notice for the slow/stopped traffic as they approach the active work zone area.

Figure 3.5 I-44 Springfield SWZ layout option two moving PCMS three

Table 3-2 SWZ layout distances: PCMS 3 move

Distant to Taper	Device
0.0 mile	Sensor 1
0.5 mile	Sensor 2
1.5 mile	Sensor 3 and PCMS 3
2.5 mile	Sensor 4
3.5 mile	PCMS 1
5.5 to 6.5 mile	PCMS 2

Pros:

- Minimal variation from original plan
- Will capture the one-mile queuing at the tapers
- Allows for a more reactive system
- There are signs out past the last queue warning sign that could be used for larger incidents if needed

Cons:

- Missed research opportunity of reviewing an unaltered layout

3.3.1.3 Option three: Full SWZ location revision. Adjust locations as needed. Diversion route suggestion: add another board for diversion after the furthest out queue warning board.

Option three is a full SWZ location adjustment prior to traffic impacts. This option would not change the number of SWZ devices but would change the distance from taper of both the sensors and PCMS deployed. Once the project is underway, additional changes to the system could be made as needed.

Co-locating PCMS and sensor pairs will allow for the queue software to activate signs based on length of queue. The WB moves would also allow for a diversion route sign to be seen after reaching the furthest out queue warning sign. While this layout does remove the furthest out seven-to-eight-miles PCMS, there is additional diversion route signing and permanent CMS that could be used in the event of an incident or an atypical back up.

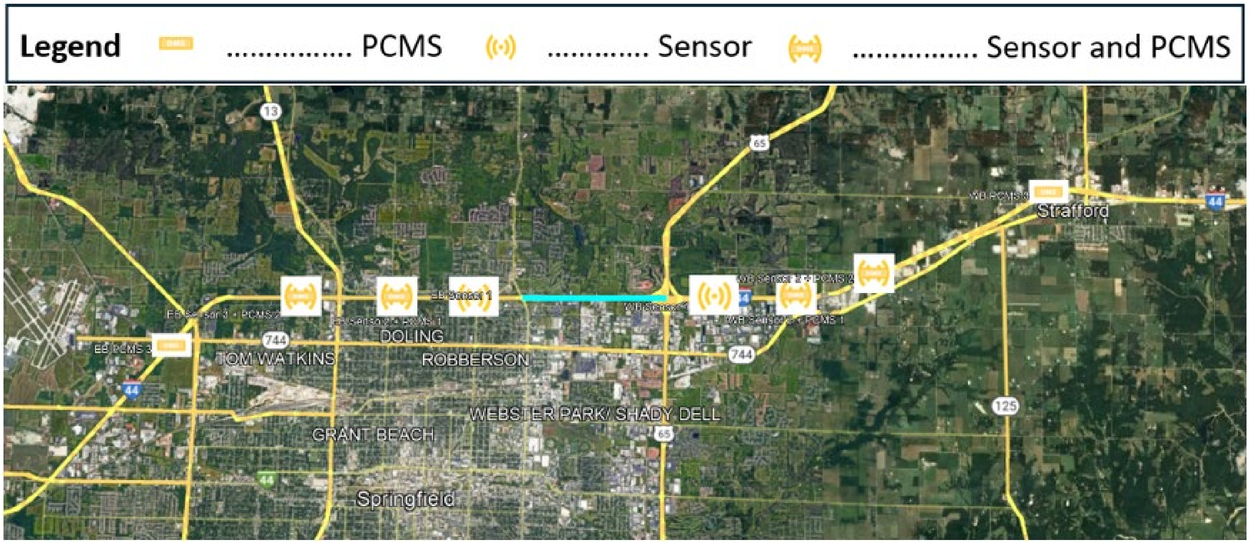


Figure 3.6 I-44 Springfield SWZ layout option three full update

Table 3-3 SWZ layout distances: full update

Distant to Taper	Device
0.0 mile	Sensor 1
1.0 mile	Sensor 2 and PCMS 1
2.5 mile	Sensor 3 and PCMS 2
4.5 miles (EB) and 5.2 miles (WB)	PCMS 3

Pros:

- Will capture the one-to-two-mile expected queues
- Allows more reactive system
- Diversion PCMS and permanent CMS could be used in the event of an incident in the area

Cons:

- Missed research opportunity of reviewing an unaltered layout
- Removed PCMS for the eight-and-a-half-mile queue
- Most disruptive to the SWZ providers mobilization plan

3.4 SWZ Recommendations I-44 Springfield

Based on discussion with MoDOT on March 21, 2025, it was decided that option two be implemented ahead of traffic changes. Moving in the furthest PCMS will allow for warning of the one-to-two-mile queue which is the anticipated slowdown length on this project. PCMS boards that are intended for diversion routing along I-44 could be used for further if the eight-mile queuing event occurs. Once traffic is in the new traffic pattern the system can be reevaluated using sensor data to see if other adjustments are necessary.

Additional discussion on the findings in the original SWZ design and JSP can be found in the evaluation recommendation section.

Chapter 4: Evaluation Plan

The SWZ evaluation occurred in two stages over the duration of the project with the first phase consisting of daily data collection for system monitoring and the second phase consisting of an evaluation of SWZ system performance and effectiveness. This section outlines both phases of the SWZ project evaluation plan.

4.1 Daily Data Management Plan

This section outlines the first phase, daily monitoring for the I-44 Springfield SWZ deployment in the summer of 2025.

4.1.1 Goals and Objectives

The following goals and objectives were identified to guide activities for daily device monitoring:

4.1.1.1 Goal 1: Verify System Design

Objective 1-1: Verify SWZ design meets all design requirements
Objective 1-2: Recommend revisions to design requirements as needed

4.1.1.2 Goal 2: Monitor System Reliability

Objective 2-1: Monitor device up time
Objective 2-2: Monitor troubleshooting response time of SWZ provider/contractor
Objective 2-3: Monitor frequency of failure

4.1.1.3 Goal 3: Evaluate System Effectiveness

Objective 3-1: Verify SWZ system displays timely and accurate messages or alerts
Objective 3-2: Determine logic quality
Objective 3-3: Determine data quality

4.1.2 Daily Data Monitoring

SWZ systems deployed are evaluated based on their ability to provide information and services on a 24/7 basis and on their ability to mitigate the traffic mobility and safety impacts of highway construction work zones. SWZ system daily performance is measured using active and passive monitoring methods. Active monitoring is manually performed using the SWZ Provider’s traffic management software. Active monitoring includes daily checks of all deployed devices for communications, correct time/date stamps, and correct views of deployed CCTVs. Where applicable automated alerts will be enabled to alert the project team of any device not functioning properly. Passive monitoring is the utilization of SWZ software to remotely download the evaluation sensor data. Reports are created daily for the previous day’s operations on all SWZ sensors. Datasets are analyzed for missing time intervals and low operational percentages.

4.1.3 Operational Performance Tracking

Device performance monitored by the project team.

4.1.3.1 PCMS Checks

The feeds of PCMS are reviewed daily for any issues impeding a message board's communication with the system in real time using the SWZ Provider software. The project team will document if a PCMS is having any issues in a tracking form (Figure 4.1). The SWZ Provider will be notified of any issues to begin the troubleshooting process. The SWZ Provider will either remotely reset the PCMS or manually fix or replace the PCMS. The project team will continue to monitor the PCMS returns to its normal operation state and record when the correction was made.

A	B	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU
499362		7/5/2024	7/6/2024	7/7/2024	7/8/2024	7/9/2024	7/10/2024	7/11/2024	7/12/2024	7/13/2024	7/14/2024	7/15/2024	7/16/2024	7/17/2024	7/18/2024	7/19/202
Project #	PDMS ID		Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F
1DD	1799	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DD	1058	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DD	994	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DH	2441 1922	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DH	1975 1805	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1663	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1292	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1286	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2506	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2525	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1206	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2507	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1EC	1843	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
2BN - Jam Logic	2627	ir			flir	flir	flir	flir	flir			flir	flir	flir	flir	flir
2BN - Jam Logic	1226	ir			flir	flir	flir	flir	flir			flir	flir	flir	flir	flir
2BP	1378	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
2BP	1811	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	1226	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2426	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2627	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2705	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	1996															
3AJ	1842	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
4.1	2436															

Figure 4.1 PCMS tracking sheet example

4.1.3.2 Sensor Data Reviews

Sensors are checked daily by the project team performing a review of the previous day's data. After a sensor runs for a day, the data will be automatically compiled as an exportable file. These files will then be processed to determine if the sensors successfully recorded all necessary data (Figure 4.2). Data from a more specific time period may be manually downloaded, if needed.

B	C	D	E	F	G	H	I	J	K	L	M
detector_name	Directi	zone	agg_vol	agg_occ	agg_spee	is_queue					
IWZ3339	EAST	2	1	0	64.6226	FALSE		1432	1440	8	
IWZ3339	EAST	2	0	0	0	FALSE		1 Minutes/packets of data			
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	64.6226	FALSE		423		423	
IWZ3339	EAST	2	1	0	68.35083	FALSE		1 Sensor count of cars is zero		1 Sensor count of no speeds reported	
IWZ3339	EAST	2	0	0	0	FALSE				0	
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	68.35083	FALSE			99%	100%	
IWZ3339	EAST	2	3	3	69.59357	FALSE		2 Sensor count of cars is zero		2 Sensor count of no speeds	
IWZ3339	EAST	2	0	0	0	FALSE		150		150	
IWZ3339	EAST	2	2	0.5	66.48672	FALSE					
IWZ3339	EAST	2	0	0	0	FALSE		0			
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	67.10809	FALSE					

Figure 4.2 Sensor data example

The uptime percentage showed how frequently a sensor transmitted data in 24-hour period using the following equation:

$$\% \text{ of uptime} = \frac{N}{P * 60 \frac{\text{minutes}}{\text{hour}} * 24 \frac{\text{hours}}{\text{day}}} * 100$$

Where:
N = number of data points
P = polling frequency

Equation 1. Example Percentage of Daily Sensor Uptime

This percentage is then recorded on a sensor tracking form (Figure 4.3). The spreadsheet is reviewed for any missing data. If a sensor is reporting below 90% uptime or the correct polling interval is not shown the SWZ Provider will be contacted by the project team. The SWZ Provider will then determine if the sensor needs to be reset, realigned, or replaced. If the sensor is operational in the field the traffic management software will be reviewed to ensure the sensor is set up correctly to collect and store data. The project team will continue to monitor until the sensor returns to its normal operation state and record when the correction was made.

	Corridor	City	Trailer ID #	Sensor Type	7/7/2024 Su	7/8/2024 M	7/9/2024 T	7/10/2024 W	7/11/2024 Th	7/12/2024 F	7/13/2024 Sa	7/14/2024 Su	7/15/2024 M	7/16/2024 T	7/17/2024 W	7/18/2024 Th
	1DH		IWZ1805	Wavetronix SS126	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3480	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1DW	1DW EB 1		DMDS112	Permanent	99%	100%	99%	99%	99%	99%	98%	99%	96%	99%	99%	99%
			DMDS113	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	99%	100%
			DMDS114	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW EB 2		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW WB 1		DMDS91	Permanent	100%	99%	100%	100%	100%	100%	100%	100%	100%	88%	66%	100%
			DMDS90	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	88%	66%	100%
			IWZ629	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW WB 2		DMDS91	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	88%	66%	100%
			DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
	1DW 86 NB/EB 3		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW 86 SB/EB 4		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW MH NB/WB 1		DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
	1DW MH SB/WB 2		DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
1EC	1EC NB Ramp		IWZ3555	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3088	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2BP	2BP SB 1		IWZ3359	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	2BP SB 2		IWZ1811	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3010	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 4.3 Sensor tracking sheet example

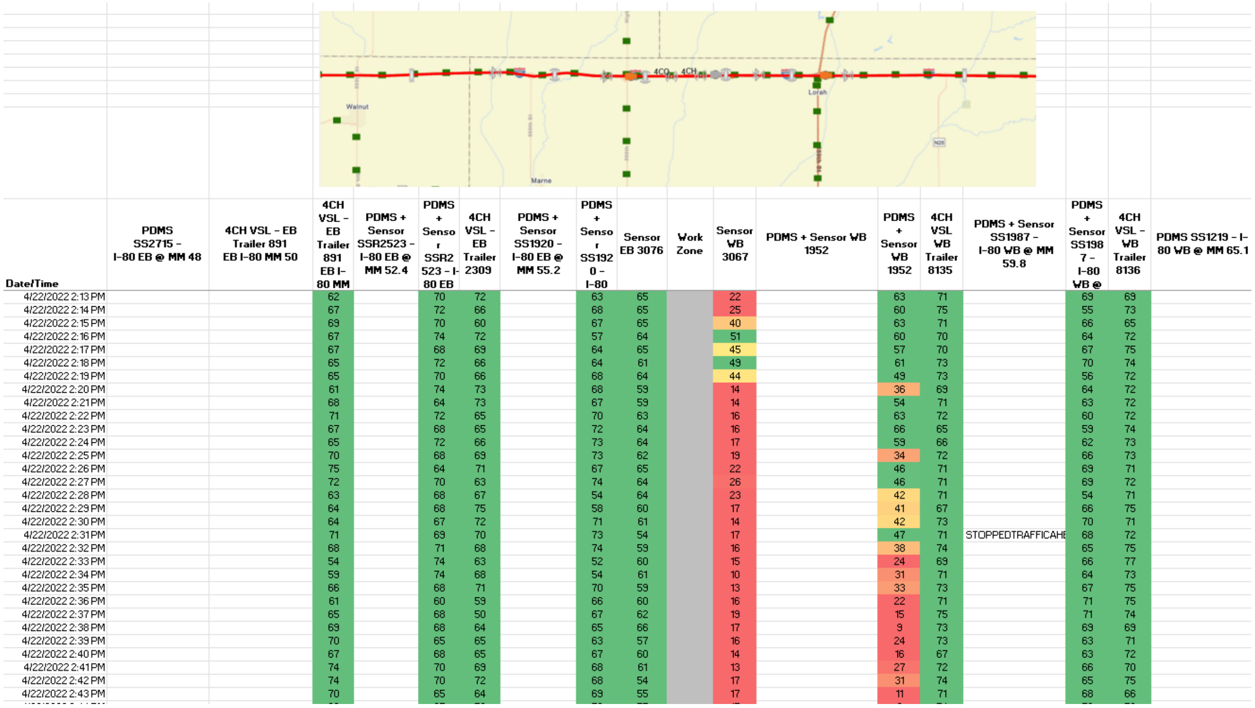
4.1.3.3 Queue Detection Validation

Queue detection systems use signs and sensors to warn vehicles of slow or stopped traffic ahead. The system is installed within or approaching a work zone corridor with detectors placed ahead of changeable message signs. Sensors detect the occupancy and speed of the roadway to determine whether traffic needs to be warned of a slow down or stop condition. When slow or stopped conditions are met, the PCMS displays a message of “Slow Traffic Ahead” or “Stopped Traffic Ahead.” The sign should then hold the correct message until the traffic returns to normal speeds.

There can be errors in queue detection systems which can be mitigated with data validation. The most common errors are false positives, missed activations, message start delays, and message stop delays. False positives are when PCMS display a slow or stopped message without meeting the preset thresholds. Missed activations occur when the preset thresholds are met, but there is no PCMS activation. Message start delay occurs when traffic has met the slow or stopped traffic conditions but takes more than the allowable latency to activate the PCMS. Message stop delay occurs when traffic conditions have returned to normal, but the PCMS stays activated longer than warranted. These errors are reported to the SWZ Provider to troubleshoot and fix any issue within the system software or threshold levels to correct system errors.

Queue detection corridors are validated upon deployment and spot checked throughout the duration of the project to ensure the system is running correctly. To perform validation the project team downloads sensor data and PCMS message logs to correlate the activations.

Queue length will be reviewed to ensure that the device locations selected reflect the construction traffic patterns. Data modeling provided an estimated queue length for each phase of the project that helped guide the SWZ device placement. However, it is best practice to review the queue length to ensure the SWZ device locations are appropriate for the actual queue length. Unforeseeable extraordinary queues will not result in device relocations, but if consistent longer than expected queue lengths are found new device locations or additional device deployments may be warranted. Heat maps of the project area are an effective way to visually represent the speeds through a work zone and will be used for this purpose. An example of a work zone speed heat map is shown below in Figure 4.4.



Date/Time	PDMS SS2715 – I-80 EB @ MM 48	4CH VSL – EB Trailer 891 EB I-80 MM 50	4CH VSL – EB Trailer 891 EB I-80 MM	PDMS + Sensor SSR2523 – I-80 EB @ MM 52.4	PDMS + Sensor SSR2523 – I-80 EB	4CH VSL – EB Trailer 2309	PDMS + Sensor SS1920 – I-80 EB @ MM 55.2	PDMS + Sensor SS1920 – I-80	Sensor EB 3076	Work Zone	Sensor WB 3067	PDMS + Sensor WB 1952	PDMS + Sensor WB 1952	4CH VSL WB Trailer 8135	PDMS + Sensor SS1987 – I-80 WB @ MM 59.8	PDMS + Sensor SS1987 – I-80 WB @	4CH VSL – WB Trailer 8136	PDMS SS1219 – I-80 WB @ MM 65.1
4/22/2022 2:13 PM			62		70	72		63	65		22		63	71		69	69	
4/22/2022 2:14 PM			67		72	66		68	65		25		60	75		55	73	
4/22/2022 2:15 PM			69		70	60		67	65		40		63	71		66	65	
4/22/2022 2:16 PM			67		74	72		57	64		51		60	70		64	72	
4/22/2022 2:17 PM			67		68	69		64	65		45		57	70		67	75	
4/22/2022 2:18 PM			65		72	66		64	61		49		61	73		70	74	
4/22/2022 2:19 PM			65		70	66		68	64		44		49	73		56	72	
4/22/2022 2:20 PM			61		74	73		68	59		14		36	69		64	72	
4/22/2022 2:21 PM			68		64	73		67	59		14		54	71		63	72	
4/22/2022 2:22 PM			71		72	65		70	63		16		63	72		60	72	
4/22/2022 2:23 PM			67		68	65		72	64		16		66	65		59	74	
4/22/2022 2:24 PM			65		72	66		73	64		17		59	66		62	73	
4/22/2022 2:25 PM			70		68	69		73	62		19		34	72		66	73	
4/22/2022 2:26 PM			75		64	71		67	65		22		46	71		69	71	
4/22/2022 2:27 PM			72		70	63		74	64		26		46	71		69	72	
4/22/2022 2:28 PM			63		68	67		54	64		23		42	71		54	71	
4/22/2022 2:29 PM			64		68	75		58	60		17		41	67		66	75	
4/22/2022 2:30 PM			64		67	72		71	61		14		42	73		70	71	
4/22/2022 2:31 PM			71		69	70		73	54		17		47	71	STOPPEDTRAFFICAHE	68	72	
4/22/2022 2:32 PM			68		71	68		74	59		16		38	74		65	75	
4/22/2022 2:33 PM			54		74	63		52	60		15		24	69		66	77	
4/22/2022 2:34 PM			59		74	68		54	61		10		31	71		64	73	
4/22/2022 2:35 PM			66		68	71		70	59		13		33	73		67	75	
4/22/2022 2:36 PM			61		60	59		66	60		16		22	71		71	75	
4/22/2022 2:37 PM			65		68	50		67	62		19		15	75		71	74	
4/22/2022 2:38 PM			69		68	64		65	66		17		9	73		69	69	
4/22/2022 2:39 PM			70		65	65		63	57		16		24	73		63	71	
4/22/2022 2:40 PM			67		68	65		67	60		14		16	67		63	72	
4/22/2022 2:41 PM			74		70	69		68	61		13		27	72		66	70	
4/22/2022 2:42 PM			74		70	72		68	54		17		31	74		65	75	
4/22/2022 2:43 PM			70		65	64		69	55		17		11	71		68	66	

Figure 4.4 Example work zone speed heat map

4.1.4 Project Meetings and Weekly Reports

Smart work zone deployments are only effective when all the components are working properly and have good communications. As part of a systems communication plan project team meetings and reports help maintain system functionality for the duration of the project.

4.1.4.1 Weekly Team Meetings

Weekly project check-in meetings that include the project manager, SWZ provider, and other stakeholders help facilitate a successful SWZ. Topics for the stand alone SWZ meetings include SWZ coordination, phase change coordination, and a SWZ system weekly report review. These check-in meetings can be combined with standard weekly or bi-weekly project meetings if they are held, otherwise a mutually agreed upon time will be chosen for the SWZ project team to meet. As this project has a standing weekly project call, a representative from the SWZ team will join that call for the duration of the SWZ deployment or length of project study.

4.1.4.2 Weekly System Report

A weekly overview report will be created and shared with the evaluation project team weekly to demonstrate of how traffic is flowing through the project area and interacting with the SWZ deployment. The weekly snapshot report will include a summary of any updates on the system such as system status, deployments or relocations, downed devices and remediation reports, and a current analysis of the system. These reports are expected to be generated in a similar way so that week-to-week findings are comparable. The reports can be used as a leading indicator if some part of the system should be changed to improve accuracy or device locations outside of any daily findings that need immediate remediation.

4.2 Post Project Evaluation Plan

This section outlines the second phase of project evaluation, post project evaluation for the I-44 Springfield SWZ deployment in the summer of 2025.

4.2.1 Goals and Objectives

The following goals and objectives were identified to guide activities for SWZ system performance and effectiveness:

4.2.1.1 Goal 1: Evaluate System Reliability

Objective 1-1: Evaluate system functionality
Objective 1-2: Evaluate troubleshooting response time of SWZ Provider/contractor
Objective 1-3: Evaluate frequency of failure

4.2.1.2 Goal 2: Evaluate System Effectiveness

Objective 2-1: Verify SWZ design meets all design requirements
Objective 2-2: Evaluate travel delay
Objective 2-3: Evaluate driver reaction
Objective 2-4: Evaluate incidents and response (if applicable)

4.2.1.3 Goal 3: Evaluate System Effectiveness

Objective 3-1: Verify SWZ system displays timely and accurate messages or alerts
Objective 3-2: Determine logic quality
Objective 3-3: Determine data quality

4.2.2 Data Types and Storage

4.2.2.1 Data Types

Following the deployment of the queue detection and temporary long-term rumble strip systems along I-44, data collection will commence for evaluation and monitoring purposes. This will include capturing timestamped system performance metrics, such as the number of warnings issued to travelers, average system downtime, and occurrences of false positives. The collected data will undergo quality checks to ensure its accuracy and to assess the Alert Processing System (APS) logic. Additionally, for evaluation purposes, the following data will be collected from portable traffic sensors located both upstream and downstream of the SWZ systems to analyze their performance and evaluate their impact:

- Vehicle speed data: To assess driver reaction to the SWZ alert.
- Vehicle count and classification data: To assess volume changes resulting from SWZ alert or operations.

4.2.2.2 Storage and Infrastructure

The data from the SWZ systems and evaluation traffic sensors will be stored in a structured manner to facilitate analysis and reporting. The data storage approach will include:

- SRF Servers: Data retrieved from SWZ and evaluation traffic sensors, such as vehicle speed, vehicle count, and classification data will be stored in SRF servers.

4.2.2.3 Data Preservation and Archiving

Data metrics are summarized below.

Type of data

- System performance data
- Vehicle speed data
- Vehicle count and classification data

Data collection method and formats

- Evaluation traffic sensors will collect vehicle speed, count, and classification data in near real-time.
- SWZ systems will collect systems performance data.
- Data will be stored in structured formats (e.g., Comma-Separated Values (CSV)) to facilitate analysis and integration with data management systems.

Documentation of data collection

- Data collection procedures will be documented in detail, including SWZ deployment locations, traffic sensor locations, sampling frequencies, and data transmission protocols.

Data reproducibility

- Data collection methods will be standardized to ensure reproducibility.
- Regular backups and version control mechanisms will safeguard against data loss or corruption

Use of pre-existing data

- Pre-existing data may be used for comparative analysis or historical trend assessment.
- Sources of pre-existing data may include traffic databases, previous studies, or DOT repositories.

Storage and backup strategy

- Data will be stored in Secure Digital (SD) cards. Some data may be stored in secure, scalable storage solutions, such as cloud-based storage or dedicated servers.
- Regular backups will be performed to ensure data redundancy and mitigate risks associated with data loss or corruption.

Retention period

- Raw data from all systems will be retained by SRF for the life of the project and provided to MoDOT at the end of the project. Aggregated data will be retained indefinitely for analytics.

4.2.3 Data Access and Sharing

Data collection and sharing within the scope of this project will strictly adhere to DOT privacy guidelines and regulations. Images if collected will be captured without displaying license plates to protect individual identities. Sharing of collected data will be restricted to authorized personnel only, ensuring that sensitive information remains confidential and is not accessible to unauthorized individuals. Incidents will not be broadcast or recorded to uphold privacy and prevent unnecessary exposure of sensitive events. Personally Identifiable Information (PII) will neither be reported nor published, safeguarding individuals' privacy and personal data. Furthermore, all data security protocols and procedures will be followed diligently to prevent unauthorized access, data breaches, or misuse of collected information, maintaining the highest standards of privacy and confidentiality throughout the data collection and sharing processes.

4.2.4 Post Project Evaluation Methodology

This section presents evaluation methodologies for the I-44 project in Springfield post project evaluation. Results will be presented in a clear and straightforward manner.

4.2.4.1 Performance Metrics

In evaluating the effectiveness of various transportation systems, several performance measures will be utilized to assess their impact and functionality. Specific metrics including the number of warnings issued, system downtime, false positives, queue length, travel delay, driver reaction to temporary long term rumble strips, and driver reaction to queue feedback will be examined. These metrics will provide insights into the performance of the Temporary Long Term Rumble Strips and Queue Detection systems. Further details on each metric and its application to the evaluation process will be discussed in subsequent sections.

4.2.4.2 Queue Detection

Queue detection will involve the collection and recording of queue lengths within the designated zone. Daily data downloads will be conducted to ensure timely access to queue metrics. To enhance queue detection accuracy, additional evaluation sensors will be strategically installed upstream of the detection zone to capture queue backups effectively. Similarly, data collected from the queue detection sensors will be stored on an SD card within the system, providing a secure and accessible repository for the queue length data. Leveraging remote communication capabilities, this data can be remotely accessed and transmitted for real-time monitoring and analysis, enabling efficient traffic management and response to queue conditions within the work zone.

The evaluation will be carried out using the following performance measures:

- System performance metrics: This will include documentation and analysis of the number of warnings provided to travelers, average downtime of the system, and false positives. False positives are instances where the queue detection system indicated queueing that did not correspond to actual vehicle backups. This system performance will be collected over several weeks, recording queue alerts triggered along with simultaneous manual queue checks using traffic cameras at specific locations.

- Driver reaction to the queue feedback: The driver response to the queue feedback, in terms of changes in speed, will be assessed using speed data collected from evaluation traffic sensors upstream of the system.

- Travel delay: To assess whether the system causes travel delays, the team will gather both baseline and operational travel time data. Baseline travel times along the route prior to system activation will establish a reference for measuring changes in travel duration once the system is in use. Travel time data will be obtained from evaluation traffic sensors to observe how travel behaviors vary under different traffic conditions. Statistical analysis of this data will enable quantification of the radar system's impact on travel delays, identifying factors like heightened congestion or shifts in driving patterns that contribute to reduced travel efficiency.

4.2.4.3 Temporary Long-Term Rumble Strips

Temporary Long-Term Rumble Strips can be instrumental in enhancing driver awareness and safety within the work zone. Traffic sensors positioned along the road will continue to play a vital role in data collection and evaluation efforts. By interpolating traffic sensor data with the rumble strip locations, a dataset can be compiled, providing valuable insights into vehicle speeds, driver reaction, and safety measures within the work zone.

The evaluation will be carried out using the following performance measures:

- Speed changes: The driver’s response to rumble strips and work zone, in terms of changes in speed, will be assessed using speed data collected from traffic sensors both upstream and downstream of the system. The assessment will also consider the inclusion of traffic sensors within the work zone, contingent upon their availability.

4.2.4.4 3rd Party Data Review

- Vehicle travel time data: To assess the change in travel time through the work zone area before, during and after the lane closures.
- Vehicle count/capacity analysis can be used to validate the spreadsheets used to calculate anticipated queues.

4.2.4.5 Cost Review

The system cost and procurement process will be documented for the contractor-provided systems. This cost will be provided for all SWZ systems reviewed. The amount of MoDOT infrastructure already deployed has a major effect on the contractor cost so this will be considered in the analysis. For example, if MoDOT's permanent detectors or CMS are planned to be used (saving significant deployment costs) this will be reported.

4.2.5 Conclusion

This Evaluation Plan establishes the project's goals and objectives and identifies how the evaluation will be conducted

Chapter 5: Evaluation Results

This section contains the results of the daily data collection for system monitoring and the post-project evaluation of SWZ system performance and effectiveness.

5.1 Daily Data Review Results

Smart work zone deployments are only effective when all the components are working properly and have good communications; only then can additional systems analysis be performed. The processes and system reviews below were employed for deployment through project end were critical to ensure successful outcomes.

5.1.1 I-44 Springfield SWZ System Review

Project Information:

Location: I-44 Springfield

- J8I3044C (EB/WB I-44 Glenstone to US 65); East portion of project
- JSU0076 (EB/WB I-44 RTE 13 to Glenstone); West portion of the project

Work Type: Pavement Widening, Bridge, and Ramps
Staging Strategy: Splitting traffic into a contraflow pattern to maintain two EB and two WB lanes with crossovers. Ramp work will be completed using traffic detours.
Project Dates: Project start March 2025, SWZ activation April 2025
Pre-Construction Meeting: February 14, 2025
Initial Construction Schedule: Starting with phase 0B of J8I3044C as soon as it is warm in March 2025; night work to build crossovers. Stage 1: 4/1/25 outside portion of the bridge. Stage 2: July 2025 (start asap). Stage 3: 2026 – ½ of trail middle to late 2026. Stage 4: switch trail and traffic end of 2026 into 2027.
SWZ Schedule: Deploying April 2025,
SWZ Research Evaluation: May 28, 2025 to November 23, 2025

StreetWise provided smart work zone devices and JamLogic software for this project. Per the construction plans eight radar sensors and six PCMS were to be deployed as part of the queue warning system and three additional PCMS were deployed for alternate route diversion.

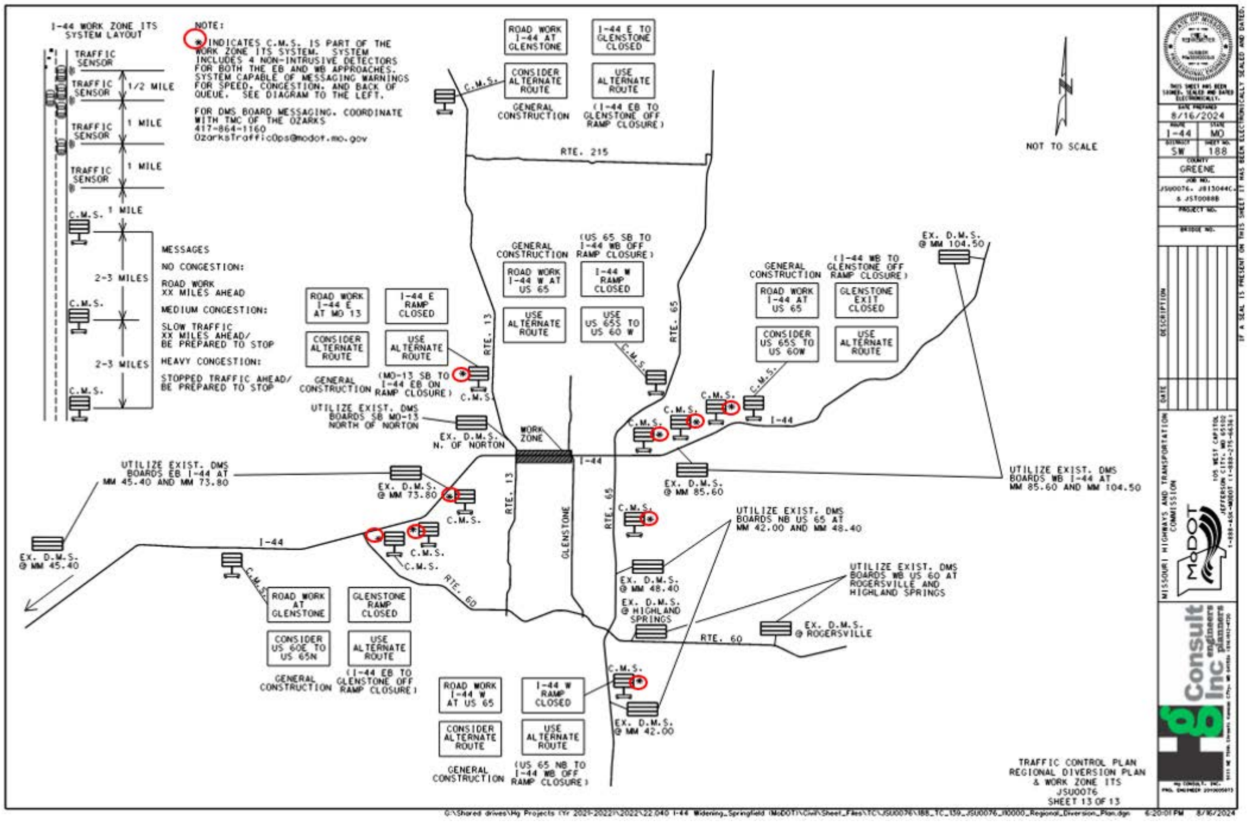


Figure 5.1 Work Zone ITS Plan Sheet for J8I3044C and JSU0076. Red circles indicate PCMS that are part of the WZITS system.

Prior to the initial SWZ deployment on I-44 changes to the SWZ layout as described in section 3.1.3. The updated layout relocated the furthest out PCMS in each direction to be co-located with SWZ sensor three and all other locations remaining as per plan. This change to the PCMS placement allows for messaging to driver to begin at the 1.5 mile mark vs starting 3.5 miles from the first sensor location.

5.1.1.1 JamLogic Integration

Vermac JamLogic software was utilized for the integration of the deployed sensors and PCMS as a standalone SWZ system not integrated into the area traffic management center's ATMS. StreetWise provided login access credentials to be used for system monitoring with read-only privileges and data download access to the project team. Upon deployment and integration all SWZ device locations and system information can be viewed via JamLogic.

Figure 5.2 JamLogic user interface

5.1.1.2 Review of I-44 Springfield System

Upon receiving access to the project within JamLogic the first step in reviewing the SWZ system is to review each device's location and what parameters have been set up in the system. To review the devices' location, navigate to the Global Positioning System (GPS) section of the settings to view the latitude and longitude of each device. Using another mapping program such as Google Earth the locations can be placed on the map to verify that devices were placed per plan and the tools within the mapping program can be used to verify parameters such as distance between devices. If TTC device locations have been added to the mapping the SWZ locations can be reviewed for any conflicts with other temporary signing. Review of the I-44 Springfield deployment of devices found that all devices were deployed as per plan and no adjustments were required.

The naming convention for the deployed devices provided by Streetwise is shown in Figure 5.3 below. Note that the device names did not always directly correlate with the actual milage of the devices from the work zone traffic shift which was at the first sensor location.

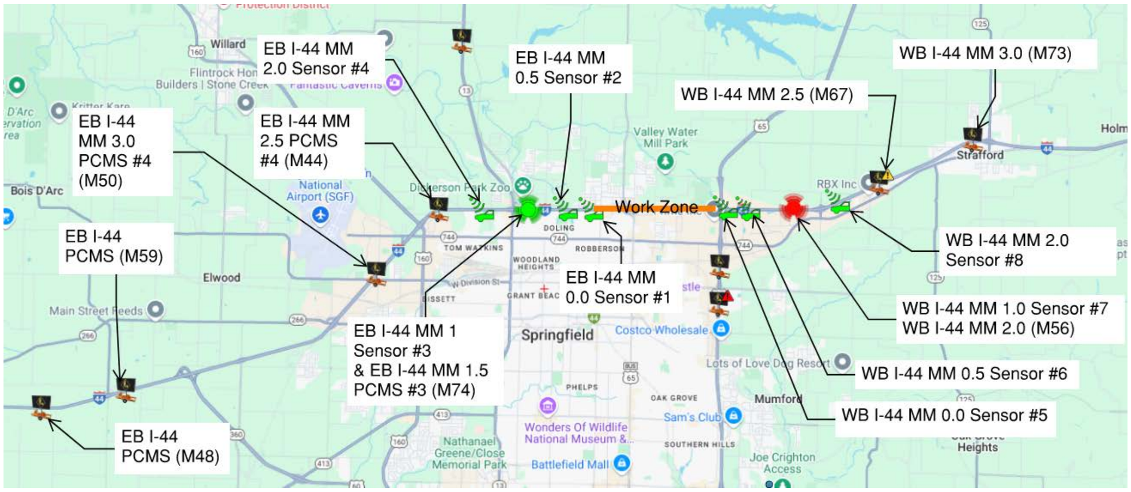


Figure 5.3 I-44 Springfield SWZ system layout

5.1.1.3 Eastbound I-44 System Layout

In the eastbound direction the smart work zone devices were deployed upstream of the work zone in the following formation:

- A sensor at the start of the taper (EB I-44 Mile Marker (MM) 0.0 Sensor #1).
  - 37.250118255615234, -93.2781524658203
- A sensor at approximately 0.5 mile (EB I-44 MM 0.5 Sensor #2).
  - 37.25014877319336, -93.288818359375
- A sensor and PCMS combination unit at 1.5 miles (EB I-44 MM 1 Sensor #3 and EB I-44 MM 1.5 PCMS #3 M74)
  - 37.250099182128906, -93.30422973632812
  - 37.25006103515625, -93.30419921875
- A sensor at 2.5 miles (EB I-44 MM 2.0 Sensor #4).
  - 37.25014114379883, -93.32333374023438
- A PCMS at 3.5 miles (EB I-44 MM 2.5 PCMS #4 M44).
  - 37.249908447265625, -93.34123229980469
- A PCMS at 5.5 miles (EB I-44 MM 3.0 PCMS #4 M50).
  - 37.228721618652344, -93.36702728271484
- A PCMS at 12 miles (EB I-44 PCMS M59). **Added 5/6/25 after an incident in April
- A PCMS at 14 miles (EB I-44 PCMS M48). ** Added 5/6/25 after an incident in April

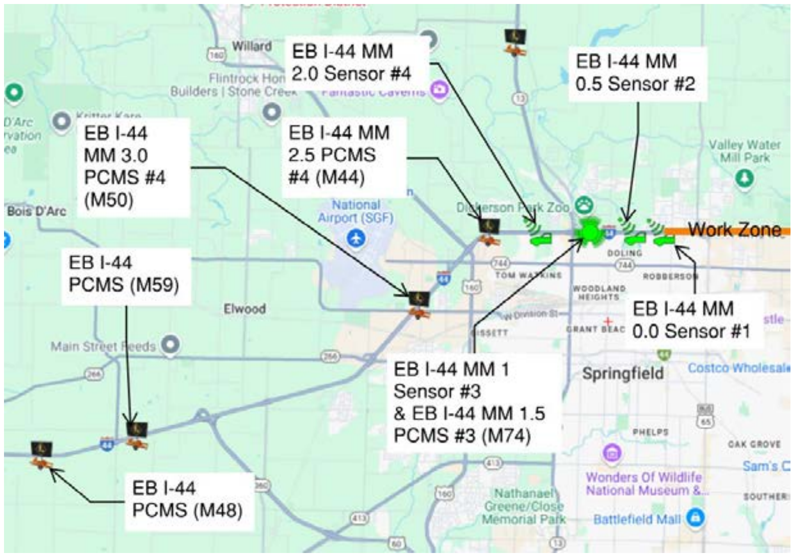


Figure 5.4 I-44 Springfield EB SWZ Layout

5.1.1.4 Westbound I-44 System Layout

In the westbound direction the smart work zone devices were deployed upstream of the work zone in the following formation:

- A sensor at the start of the taper (WB I-44 MM 0.0 Sensor #5).
    - 37.250450134277344, -93.22242736816406
- A sensor at approximately 0.5 mile (WB I-44 MM 0.5 Sensor #6).
    - 37.25040817260742, -93.21299743652344
- A sensor and PCMS combination unit at 1.5 miles (WB I-44 MM 1.0 Sensor #7 and WB I-44 MM 2.0 M56)
    - 37.25041961669922, -93.19441986083984
    - 37.250431060791016, -93.19539642333984
- A sensor at 2.5 miles (WB I-44 MM 2.0 Sensor #8).
    - 37.252811431884766, -93.17620086669922
- A PCMS at 3.6 miles (WB I-44 MM 2.5 M67).
    - 37.2587890625, -93.15892791748047
- A PCMS at 6 miles (WB I-44 MM 3.0 M73).
    - 37.27289962768555, -93.1199722290039

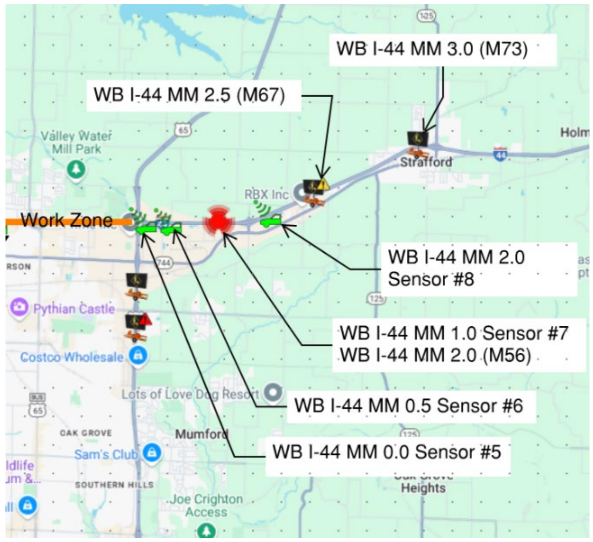


Figure 5.5 Springfield WB SWZ Layout

Once all SWZ device locations were reviewed and found to have been deployed per plan, the system parameters were reviewed. Inside of JamLogic the system owner (StreetWise) can setup the "congestion level parameters" which are used to active the PCMS when queues form by reacting to the pre-set speed thresholds. A review of those thresholds on April 15, 2025, and initial programmed setting are shown in table 5-1.

Table 5-1 I-44 Springfield SWZ Sensor Settings Review 4/15/25

Device Name	Free Flow Speed (mph)	Slow Speed (mph)	Slow Speed Count	Stopped Speed (mph)	Stopped Speed Count
EB I-44 MM 0.0 Sensor #1	≥ 60	< 40	>2	< 20	>2
EB I-44 MM 0.5 Sensor #2	≥ 45	< 40	>2	< 20	>2
EB I-44 MM 1.0 Sensor #3	≥ 45	< 40	>2	< 20	>2
EB I-44 MM 2.0 Sensor #4	≥ 45	< 40	>2	< 20	>2
WB I-44 MM 0.0 Sensor #5	≥ 40	< 40	>3	< 20	>3
WB I-44 MM 0.5 Sensor #6	≥ 40	< 40	>2	< 20	>2
WB I-44 MM 1.0 Sensor #7	≥ 40	< 40	>5	< 20	>5
WB I-44 MM 2.0 Sensor #8	≥ 40	< 40	>2	< 20	>2

The slow and stopped speed setting thresholds were programed as expected at less than 40 mph for slow traffic and less than 20 mph for stopped traffic. The variation in the free flow speed and the slow and stopped vehicle count thresholds was unexpected. This information was provided to the I-44 project manager to verify with StreetWise that these settings were intentional as this would affect how the daily tracking for performance was set up. It was confirmed that there were some original programming errors and that all sensors were now programmed to the same setting thresholds. A second review of the sensor programming confirmed that all parameters for all sensors were set to: Free flow speed ≥ 40 mph, Slow Speed < 40 mph, Slow Speed Count >3, Stopped Speed < 20, Stopped Speed Count >3, Delay in 1 minute, and Delay out 3 minutes. The updated congestion level parameters can be seen in the JamLogic Communication Setting window in figure 5.6.

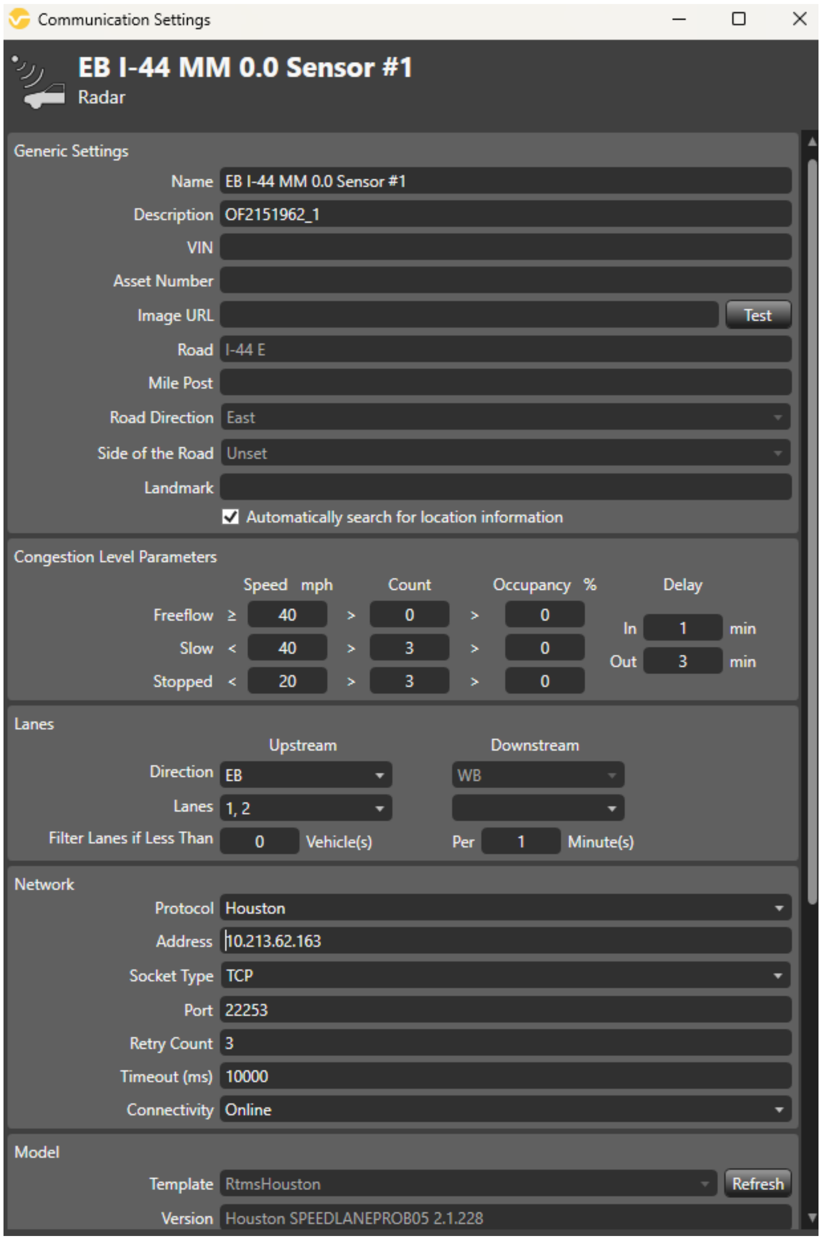


Figure 5.6 JamLogic congestion level parameters settings

Performing this location and setting reviews constitute the verifying of the system design goal and the objectives of:

- Objective 1-1: Verify SWZ design meets all design requirements

- Objective 1-2: Recommend revisions to design requirements as needed

5.1.2 Operational Performance

To facilitate the daily device tracking and monitoring Microsoft Excel was used to develop a Daily Device Tracker. This workbook provided an organized at-a-glance tool for managing daily data downloads from sensors and PCMS units.

The tracking workbook included a heat map spreadsheet designed to reflect the physical layout of the SWZ deployment. Date and time stamps from the data downloads were populated in the left most column followed by columns representing each device as deployed in the field on either side of the work zone. Conditional formatting was applied to the sensor data speeds to visually depict the slow and stopped speed thresholds configured within JamLogic for queue detection. The heat map spreadsheet displayed vehicle speeds, approximation of queue length, duration of slow or stopped conditions, PCMS activity, and any gaps in the speed data to provide a comprehensive visual summary of system performance and traffic conditions.

Additional sheets in the Daily Device Tracker workbook included a sensor uptime spreadsheet and the project item log. The sensor uptime sheet tracked the uptime percentage of each sensor for the previous day. Conditional formatting on the spreadsheet was set to highlight any percentage uptime less than 90%.

The project item log spreadsheet was populated to contain all issues with sensors, PCMS, and items observed during the SWZ project research phase, the date and time of the observation, who the reporting party was, when a response was received (if warranted), and the response time.

5.1.2.1 Pre-Evaluation Daily Device Tracking April 13, 2025, to May 27, 2025

The formal SWZ research evaluation took place from May 28, 2025, to November 23, 2025. However, the research team began downloading system data and populating the daily device tracker on April 13, 2025, in advance of the traffic phase change to the daytime head-to-head traffic configuration implemented overnight on May 28, 2025. These pre-traffic switch data reviews were performed to verify the SWZ system was fully operational and functioning as intended before major traffic impacts began. A summary of the identified SWZ issues and the corresponding resolution response are shown below:

Table 5-2 SWZ item and response before research start

SWZ Issue Examples	Resolution Response	Response Time
1. JamLogic threshold mismatch. 2. Missing PCMS activations may be due to the threshold mismatch or some intermittent sensor outages. 3. Down Sensor	There was an error in the initial threshold, this should be corrected now. Intermittent outages are most likely the cause; with more specific dates and times we could look further into this issue. Sensor back online.	10 days
Incident took several hours to clear. Large queues were detoured off I-44. Additional PCMS boards in the EB direction before the US 360 Interchange to be deployed for diversion routing for future incidents. DOT Reported.	New PCMS Deployed for incident diversion routes.	7 days
1. Down Sensor 2. PCMS messages are not displayed correctly, it is holding road work ahead message.	The storms on Tuesday impacted the work zone. Several PCMS boards were blown over, and sensors and PCMS need to be reset.	Same day
Down Sensor	No action needed returned to service ahead of reporting.	N/A
Requested updates to road work ahead milage.	DOT requested that the message be changed to Mile Marker vs distance to work zone.	Same day
1. Down Sensor 2. PCMS were not display slow/stopped messages during slow and stopped conditions.	Issues sent to SWZ Vendor. Sensors started reporting data and PCMS posting messages same day in the afternoon. Sensor returned to full uptime next day.	Same day

5.1.2.2 Daily Device Tracking May 28, 2025, to November 23, 2025

Prior to the official start of the research period, the research team began participating in the weekly I-44 Springfield construction coordination meetings and developed the standardized weekly report templates. Participation in these meetings ensured timely awareness of construction schedule updates, roadway incidents, changes to temporary traffic control, and field-observed issues related to the SWZ system. This approach eliminated the need for separate information transfer or distribution of meeting minutes from the construction team to the research team. Following confirmation of the traffic switch date by the project manager, formal daily device tracking activities and the preparation of weekly summary reports were initiated.

5.1.2.3 Weekly Reports

The research team used the Daily Device Tracker spreadsheet internally to monitor the system status daily, and issues were reported to the Project Manager as they arose with sensors, PCMS, and system functionality. The weekly reports were compiled and sent to the project manager as a snapshot of the previous week's performance with an email summary of any notable issues. Information included in the Weekly Reports:

- JamLogic Radar Speed Charts with slow and stopped speed threshold markers.

- Activation summary with number of activations, average event duration, and longest event duration.
- Sensor uptime report.

A summary of the SWZ issues identified during the evaluation period and the resolution response are discussed below.

5.1.2.4 Daily Device Tracking

Daily data reviews and PCMS one-touch checks were conducted to verify that the SWZ system remained operational and functioned as intended throughout the project evaluation duration. During the evaluation period, 32 items were documented in the Project Item Log as identified issues. Issues that were identified and resolved prior to formal notification were not immediately reported to the Project Manager; instead, they were summarized in the weekly report email. For example, if the SWZ system experienced multiple false activations for a few hours but the system returned to normal performance on its own, as confirmed by normal system activations; immediate notification to the DOT was not required.

Most notifications submitted to the DOT were related to sensor outages, with repeated issues observed at eastbound sensor two and westbound sensor seven. In the event of large slowdowns or system malfunctions the Project Manager was notified, some notable Project Item Logs are in Table 5-3.

Table 5-3 SWZ notable item and response during research evaluation

Project Log Item
Issue • Down Sensor • Extended Slowdown Response • Sent to SWZ Vendor for repair. • Extended slowdown due to incident.
Issue • Down Sensor • Spotty Data; due to extensive wind speeds and wind gusts around 30+ mph in the area overnight. Response • Sent to SWZ Vendor for repair. • Confirmed; the project was hit by thunderstorm last night with high winds. The contractor confirmed the wind but informed me that they did not have any issues after it went through.
Issue • Long duration queues overnight Response • The contractor was paved in the median overnight and had a lane closed in the area. Not sure if the slowdown was from the trucks coming into the WZ or just heavy congestion from the lane closure.
Issue • Down Sensor/Sensor stuck on one speed Response • Sent to SWZ Vendor for repair.

Troubleshooting response time of SWZ provider/contractor was very low for the duration of the project evaluation period; with all response times within 24 hours as StreetWise was very responsive to requests for device and system checks. While there were issues with some sensors as noted above, specifically eastbound sensor two and westbound sensor seven, that may have had low data reporting for a few days in a row, the overall sensors uptime for the duration of the evaluation period on a 24-hour cycle was within acceptable range as shown in Table 5-4.

Table 5-4 SWZ Daily Device Tracker sensor uptime report

Number Days Less than 90% from Sensor Uptime Tracker	Overall Uptime from Sensor Uptime Tracker; based on 180 day evaluation period	Average Uptime from Sensor Uptime Tracker
2	99%	99.36%
22	88%	91.87%
2	99%	99.21%
12	93%	97.24%
4	98%	98.65%
10	94%	94.89%
15	92%	95.53%
2	99%	99.05%

The “frequency of failure” as denoted by issues documented in the Project Item Log were primarily due to sensor-related failures, with periodic sensor outages representing the most common system issue. Due to the queue detection system configuration within JamLogic, the failure of an individual sensor did not prevent PCMS activation; however, it did result in reduced system responsiveness. Only one instance of PCMS activation without a corresponding sensor-reported speed slowdown was recorded as an issue in the Project Item Log.

It should be noted that system performance assessments based on visual inspections and Microsoft Excel macro processing, including the use of rounded speed values and minute-level data reviews, may introduce a degree of subjectivity. Post-project data analyses that strictly apply programmed system rules and thresholds may yield different interpretations of system performance.

As an example, Figure 5.7 below is a stop and go slowdown; as part of the daily tracking and system review the activations below would be within the appropriate level of system working as intended designation. However, a computer review of the sign responsiveness with time stamp review to the second and without rounded speeds, may find flaws in the activation patterns that are not seen in the visual representation below.

Date/Time	EB I-44 MM 3.0 PCMS #4 (M50)	EB I-44 MM 2.5 PCMS #4 (M44)	EB I-44 MM 2.0 Sensor #4	EB I-44 MM 1.5 PCMS #3 (M74)	EB I-44 MM 1.0 Sensor #3	EB I-44 MM 0.5 Sensor #2	EB I-44 MM 0.0 Sensor #1	Work Zone	WB I-44 MM 0.0 Sensor #5	WB I-44 MM 0.5 Sensor #6	WB I-44 MM 1.0 Sensor #7	WB I-44 MM 2.0 (M56)	WB I-44 MM 2.0 Sensor #8	WB I-44 MM 2.5 (M67)	WB I-44 MM 3.0 (M73)
7/6/2025 5:02 PM			60		56	58	54		43	70	61		74		
7/6/2025 5:03 PM			66		48	58	61		42	70	66		71		
7/6/2025 5:04 PM			68		52	53	62		50	64	57		71		
7/6/2025 5:05 PM			68		60	63	59		45	71	48		72		
7/6/2025 5:06 PM			65		59	62	60		41	70	37		67	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	SLOW 4 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:07 PM			57		60	66	66		39	65	46	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	67		
7/6/2025 5:08 PM			58		52	68	65		37	63	46		68		
7/6/2025 5:09 PM			47		60	63	65		43	35	39	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	68	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	
7/6/2025 5:10 PM			50		53	62	58		43	26	48		71		
7/6/2025 5:11 PM			55		43	61	60		50	29	45		58		
7/6/2025 5:12 PM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	60	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	39	54	58		43	52	42		68	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	SLOW 4 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:13 PM			59		50	45	48		45	43	43		65		SLOW 5 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:14 PM			62		55	48	44		46	37	39		66	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	SLOW 4 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:15 PM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	62	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	54	45	42		43	38	52		65		
7/6/2025 5:16 PM			64		59	45	41		49	45	53		69		
7/6/2025 5:17 PM	SLOW 5 MILES AHEAD/BE PREPARED TO STOP	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	65	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	54	49	37		47	59	52		59		SLOW 5 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:18 PM			64		55	55	35		43	47	40	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	62	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM
7/6/2025 5:19 PM			64		43	55	43		42	58	60		58		
7/6/2025 5:20 PM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	65		39	55	44		48	59	60		56		
7/6/2025 5:21 PM			63		53	49	48		49	53	60		63		
7/6/2025 5:22 PM			63		47	45	43		56	57	58		59		
7/6/2025 5:23 PM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	55	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	41	47	45		51	62	57		58		
7/6/2025 5:24 PM	SLOW 5 MILES AHEAD/BE PREPARED TO STOP	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	60	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	43	28	39		47	55	57		63		
7/6/2025 5:25 PM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	67		36	32	38		49	59	60		62		
7/6/2025 5:26 PM			65		33	42	34		30	55	55	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	65	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 6 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:27 PM			66		48	40	27		37	63	48		68		
7/6/2025 5:28 PM			70		50	45	34		42	62	42		60		
7/6/2025 5:29 PM	SLOW 5 MILES AHEAD/BE PREPARED TO STOP	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	68		53	48	34		45	66	52		63		
7/6/2025 5:30 PM			69		53	38	38		40	63	47	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	60		WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM
7/6/2025 5:31 PM			66		47	37	42		41	57	55		62	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	
7/6/2025 5:32 PM			64		48	40	39		41	52	46		64	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	
7/6/2025 5:33 PM			61		44	41	37		39	55	42	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	62		
7/6/2025 5:34 PM			65		40	51	33		39	47	40		62	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 6 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:35 PM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	66		37	48	42		43	40	40		57		
7/6/2025 5:36 PM			65		47	44	47		30	38	41		54		
7/6/2025 5:37 PM			48		46	45	46		35	38	47		62	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	SLOW 5 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:38 PM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	49		47	55	48		41	45	43		58		
7/6/2025 5:39 PM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP		51	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	39	56	55		32	50	45		60		
7/6/2025 5:40 PM		SLOW 2 MILES AHEAD/BE PREPARED TO STOP	54	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	34	45	55		29	49	37		60		
7/6/2025 5:41 PM			43		37	40	49		27	49	38		57	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	SLOW 4 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:42 PM			48		43	40	45		25	48	39		55		
7/6/2025 5:43 PM			47		35	47	48		32	40	29		56		
7/6/2025 5:44 PM			45		39	36	40		35	47	32		58		
7/6/2025 5:45 PM			51		32	31	39		35	44	33		51		
7/6/2025 5:46 PM			56		39	40	34		43	47	34		48		
7/6/2025 5:47 PM			61		35	44	40		44	52	39		45		
7/6/2025 5:48 PM			63		33	39	42		40	50	37		51		
7/6/2025 5:49 PM	STOPPED TRAFFIC AHEAD/BE PREPARED TO STOP	STOPPED TRAFFIC AHEAD/BE PREPARED TO STOP	62	STOPPED TRAFFIC AHEAD/BE PREPARED TO STOP	50	19	37		46	47	41	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	48		
7/6/2025 5:50 PM			58		55	19	30		50	50	42		50		
7/6/2025 5:51 PM			63		52	29	30		43	55	42		53		WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM
7/6/2025 5:52 PM			61		52	45	28		43	46	39		46	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	SLOW 4 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:53 PM			60		48	52	18		39	49	46	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	47	SLOW 2 MILES AHEAD/BE PREPARED TO STOP	
7/6/2025 5:54 PM			63		57	55	29		43	51	54		53		
7/6/2025 5:55 PM			62		52	60	35		45	56	50		48	SLOW 4 MILES AHEAD/BE PREPARED TO STOP	SLOW 6 MILES AHEAD/BE PREPARED TO STOP
7/6/2025 5:56 PM	SLOW 5 MILES AHEAD/BE PREPARED TO STOP		62	SLOW 1 MILE AHEAD/BE PREPARED TO STOP	53	59	52		43	57	48	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	55	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM	WB I-44 CLOSING AT MM 77/7/11 9PM TO 7/14 6AM
7/6/2025 5:57 PM		STOPPED TRAFFIC AHEAD/BE PREPARED TO STOP	62		58	63	61		45	51	55		48		
7/6/2025 5:58 PM	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	62	EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	53	62	60		48	55	45		51		
7/6/2025 5:59 PM		EB I-44 CLOSING AT MM 75/7/11 9PM TO 7/14 6AM	65		55	64	65		46	45	53		56		
7/6/2025 6:00 PM			61		53	61	63		47	49	55		53		
7/6/2025 6:01 PM			66		48	59	55		48	53	51		55		
7/6/2025 6:02 PM			62		60	63	63		49	55	50		58		

Figure 5.7 I-44 Springfield Daily Device Tracker Heat Map slowdown example

Performing the daily device review, submitting weekly reports, and tracking issues and errors via the project item log constitute the monitor system reliability and evaluate system effectiveness goals and the objectives of:

- Objective 2-1: Monitor device up time
- Objective 2-2: Monitor troubleshooting response time of SWZ provider/contractor
- Objective 2-3: Monitor frequency of failure
- Objective 3-1: Verify SWZ system displays timely and accurate messages or alerts
- Objective 3-2: Determine logic quality
- Objective 3-3: Determine data quality

5.2 Post Project Data Evaluation Results

Successful completion of daily device monitoring ensures that the SWZ data would be avaible for post project data analysis.

5.2.1 Data Sets

Queue detection systems use portable changeable message signs (PCMS) and radar sensors to warn vehicles of slow or stopped traffic ahead. Sensors detect the vehicle count and speed to determine whether traffic needs to be warned of a slow down or stop condition. When slow or stopped conditions are met, the PCMS displays a message of “SLOW TRAFFIC AHEAD” or “STOPPED TRAFFIC AHEAD.” The sign should hold the correct message until traffic returns to normal speeds. Data was collected from PCMS and radar sensors deployed along the project corridor using JamLogic software. This section discusses the data sets that were used for the final evaluation.

5.2.1.1 Radar Sensor Data

Data was collected at the radar sensors located upstream of the work zone continuously from May 28, 2025, to November 23, 2025. After a sensor ran for a 24-hour period, the data became available in JamLogic for exporting. The sensors were set to collect data in one-minute bins for the duration of the day. Data collected includes gap, headway, speed, 85th-percentile speed, vehicle count, and classification by lane. Figure 5.8 shows an example of the exported data set.

A	AC	AD	AE	AF	AG	AH	AI	AJ
Date/Time (UTC-06:00) Central Time	LaneGap - 1-Gap	LaneGap - 2-Gap	LaneGap - 3-Gap	LaneGap - 4-Gap	LaneHeadway - 1-Headway	LaneHeadway - 2-Headway	LaneHeadway - 3-Headway	LaneHeadway - 4-Headway
11/23/2025 12:00 AM	11.1400003	0	0	9.48999977	11.3500004	0	0	10.2799997
11/23/2025 12:01 AM	10.6000004	0	0	15.9499998	10.8100004	0	0	16.1399994
11/23/2025 12:02 AM	0.300000012	0	0	13.5500002	0.589999974	0	0	13.9700003
11/23/2025 12:03 AM	13.4799995	11.8800001	0	7.09000015	13.8299999	12.3199997	0	7.67999983
11/23/2025 12:04 AM	5.80000019	14.9899998	0	4.25	6.23999977	15.54	0	4.63999987
11/23/2025 12:05 AM	8.97999954	0	11.8199997	5	9.23999977	0	12.0100002	5.61999989
11/23/2025 12:06 AM	21.7299995	0	5.30000019	17.3400002	21.8500004	0	5.48000002	17.4899998
11/23/2025 12:07 AM	7.71000004	8.75	0	7.42999983	8	9.32999992	0	7.9000001
11/23/2025 12:08 AM	7.9000001	0	0	10.3800001	8.07999992	0	0	10.8900003
11/23/2025 12:09 AM	4.28000021	29.7999992	0	22.6299992	4.69999981	30.2900009	0	23.1200008
11/23/2025 12:10 AM	9.31000042	14.5600004	0	7.34000015	9.59000015	15.4799995	0	8.07999992
11/23/2025 12:11 AM	7.19999981	0	5.88999987	4.98000002	7.44000006	0	6.05999994	5.32000017
11/23/2025 12:12 AM	6.48999977	17.0300007	14.9099998	11.8800001	6.76999998	17.3299999	15.1000004	12.4399996
11/23/2025 12:13 AM	18.9899998	53.5900002	0	25.4799995	19.4300003	54.3199997	0	25.6499996
11/23/2025 12:14 AM	6.32000017	15.3199997	36.4399986	7.63000011	6.57000017	15.5799999	37.2299995	7.90999985
11/23/2025 12:15 AM	11.0500002	13.6800003	10.29	6.19999981	11.5900002	14.1099997	11.0600004	6.98999977

Figure 5.8 Sensor data example

5.2.1.2 PCMS Data

Data was collected at PCMS located upstream of the work zone. At the end of each day, the data was available in JamLogic for exporting. The data included date/time stamps for each time the message sign changed, along with the status of the device. Figure 5.9 shows an example of the exported data set.

A	D	G	J	N	O	P	Q
Date/Time (UTC-06:00) Central Time (US & Canada)	ActivationType	Direction-TrafficHeading	Message	Illumination-Mode	Io - IO	Landmark	MessageName
	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 12:31:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 12:41:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 1:11:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 1:31:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 1:41:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 1:48:49 AM	Automation	NE 041°	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	Photocell	0000		WorkflowGenerat
11/23/2025 1:51:21 AM	Automation	NE 041°	SLOW 3 MILES AHEAD/BE PREPARED TO STOP	Photocell	0000		WorkflowGenerat
11/23/2025 1:52:50 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 2:31:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 2:41:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 3:11:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 3:21:22 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat
11/23/2025 3:51:21 AM	Automation	NE 041°	ROAD WORK AHEAD/STAY ALERT	Photocell	0000		WorkflowGenerat

Figure 5.9 PCMS data example

The queue warning system was set up to review radar speeds from all sensors in a given direction every minute. When a sensor detected slow or stopped conditions for one to two minutes and the vehicle count was three or greater, the message sign activated to post a “SLOW TRAFFIC” or “STOPPED TRAFFIC” ahead message based on the speed. When traffic returned to free flow speed, the PCMS maintained the slow or stopped traffic message for approximately three minutes. If traffic remained at free flow speed for three minutes, the special messaging deactivated and reverted to the standard message, “ROAD WORK/XX MILES AHEAD.” The system was able to identify which radar sensor experienced slow speeds and the message was only updated at the PCMS that were upstream of that sensor. The system updated the number of miles ahead shown on the PCMS based on the distance between the PCMS and the sensor that identified the slowdown or stop. The speed thresholds that were used to determine the PCMS message are shown in Table 5-5.

Table 5-5 Speed thresholds for PCMS messages

PCMS Message	Speed Threshold
ROAD WORK/X MILES AHEAD (EB) TRAFFIC SPLIT MM 82 (WB)	40+ mph
SLOW X MILES AHEAD/BE PREPARED TO STOP	21 – 39 mph
STOPPED TRAFFIC AHEAD/BE PREPARED TO STOP	20 mph or less

5.2.2 Compiling Data

Both PCMS and radar sensor data were available via JamLogic for various time intervals (i.e., one hour, one day, or one week). Data logs for sensors and PCMS were exported daily for the data collection period of April 13, 2025, to November 23, 2025; the daily reporting and analysis was performed May 12, 2025, to November 23, 2025. The raw data was compiled using Python and placed into a PostgreSQL database for evaluation.

5.2.3 Data Evaluation and Results

This section presents data evaluation methodologies for the post-project analysis of the I-44 project in Springfield and the results obtained from these analyses.

5.2.3.1 Slow/Stopped Events posted to the PCMS

The first performance metric of interest is the number of event warnings issued to travelers by the PCMS. There are two different aspects that are of interest: the number of slow/stopped events and the duration of the slow/stopped events. The first deals with the number of times that the PCMS reports slow or stopped traffic. The second considers the complete time duration of slow/stopped events. Both are defined as an event that begins with either a “SLOW TRAFFIC” or “STOPPED TRAFFIC” message and continues until the “ROAD WORK AHEAD” message returns. The methodology for PCMS analysis along with results of the analysis are detailed below.

5.2.3.2 Part A: Number of Slowdown/Stopped Events

Using the PCMS data, the column containing messages was reviewed for the number of times that there was a break in “ROAD WORK AHEAD” messages when the PCMS changed to either “SLOW TRAFFIC” or “STOPPED TRAFFIC” messages. It should be noted that the PCMS does not have to change to a “SLOW TRAFFIC” message before changing to a “STOPPED TRAFFIC” message. Also, there were instances in the data when the same message appears multiple times in a row, usually due to a system error. This was considered a single warning, and all duplicate messages appearing sequentially were only counted as a single warning. The following method was used to create a new column called Slowdowns in the PCMS data that tracked the change in messages:

- The first line in the Message data for all PCMS showed “ROAD WORK AHEAD.” The number zero was manually entered in the first cell of the new Slowdowns column.
- For each subsequent line, the current message was compared to the previous message, and numbers were added to the Slowdown column according to the following algorithm:
    - If the current message = “SLOW TRAFFIC” or “STOPPED TRAFFIC” and the previous message = “ROAD WORK AHEAD” → 1
    - If the current message = “ROAD WORK AHEAD” and the previous message = “SLOW TRAFFIC” or “STOPPED TRAFFIC” → 2
    - Else → 0

The number of slowdowns for the duration of the project based on PCMS data was determined by counting the number of cells in the Slowdown column that contained the number 1 for each PCMS (see Table 5-6).

5.2.3.3 Part B: Duration of Slowdown/Stopped Events

After the number of slowdowns were identified, the duration of each slowdown was determined by creating a table with one column listing the timestamps corresponding with rows containing “1” s in the Slowdown column and a second column that contains the timestamps corresponding with rows containing “2” s. These columns represented the start and stop times of each slowdown. The duration of the slowdowns was then calculated by finding the difference between the timestamps. The average slowdown duration and the longest slowdown duration for the overall project are shown in Table 5-6 and a device location map for reference in Figure 5.10. On average, westbound traffic experienced more slowdowns with longer durations than eastbound traffic. It should be noted that the longer slowdown durations for westbound occurred mostly at night, which could indicate the occurrence of nighttime construction. Possible causes of the slowdowns could be lane closures or slow-moving construction vehicles being detected by the sensor.

Table 5-6 Overall number of slowdowns and average duration of slowdowns by PCMS

PCMS Name	Direction	Number of Slowdowns	Average Duration of Slowdowns (min.)	Longest Slowdown Duration (hr.)
1 – M74	Eastbound	237	9.52	3.43
2 – M44	Eastbound	303	8.72	3.53
3 – M50	Eastbound	302	8.86	3.53
4 – M48	Eastbound	302	8.73	3.53
5 – M59	Eastbound	297	9.03	3.53
6 – M56	Westbound	618	11.22	9.00
7 – M67	Westbound	700	11.06	9.00[1]
8 – M73	Westbound	702	11.01	8.93

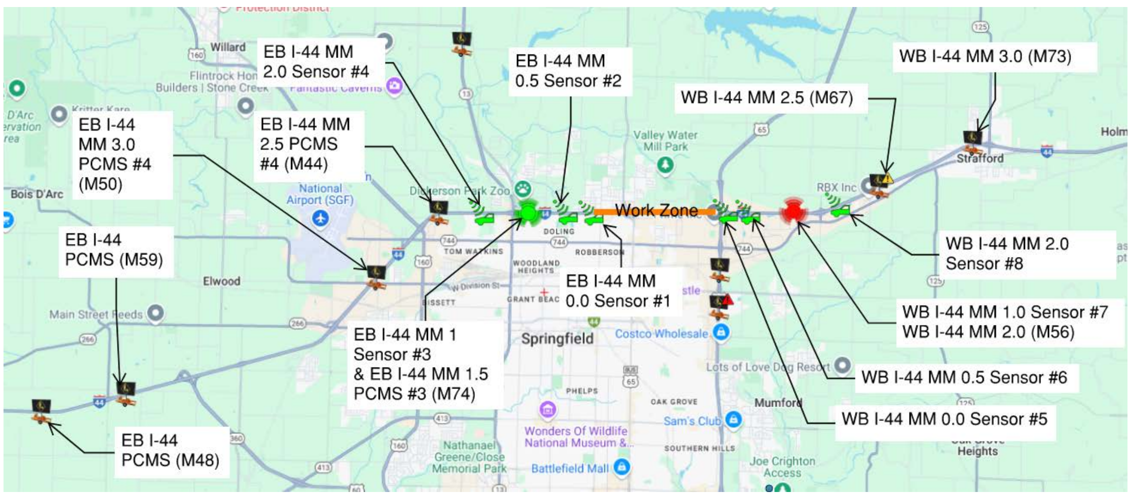


Figure 5.10 I-44 Springfield SWZ system layout with PCMS locations

[1] The nine mile "slowdown" occurred due to extended overnight queues, with sustained low speeds and intermittent slowdowns. These conditions coincided with median paving operations involving a WB lane closure with congestion potentially influenced by construction traffic and reduced roadway capacity.

5.2.4 System Uptime

System uptime refers to the average time the system is reporting data via JamLogic software. A sensor must report data at or above 90% of every 24 hours to be considered functional. Percentage of uptime was calculated using the following equation:

$$\% \; of \; uptime = \left(\frac{\mathrm{N}}{\frac{1}{P} * 60 \frac{minutes}{hour} * 24 \frac{hours}{day}} \right) * 100$$

Where:
N = number of data points
P = polling frequency (minutes)

Equation 2 Percentage of Daily Sensor Uptime

The polling frequency refers to how often the data is segmented. In this case, the polling frequency was one minute. The methodology used for determining sensor uptime is described below.

The Radar Speed in the sensor data was analyzed for blank cells. A blank cell in the data indicated that the system was not properly functioning at that time. Even if no vehicles were present at the time data was collected, a smoothed speed was calculated based on the speed from the previous minute. To determine sensor uptime, the number of blank cells was counted for the given time period, which equals N in Equation 1. Since each cell represents one minute, the number of blank cells was the number of minutes that the system was inoperable. In other words, N is the number of minutes of downtime. The percentage of uptime was calculated on a daily level, weekly level, monthly level, and over the duration of the project for each sensor. Table 5-7 shows the uptime for each sensor over the duration of the project. All sensors had uptime percentages greater than 90%, meaning they were functioning at an acceptable level.

Table 5-7 Overall system uptime by sensor

Sensor No.	Direction	Downtime (min)	% Uptime
1	Eastbound	1,829	99.29%
2	Eastbound	21,263	91.80%
3	Eastbound	2,235	99.14%
4	Eastbound	7,345	97.17%
5	Westbound	3,683	98.58%
6	Westbound	13,443	94.81%
7	Westbound	11,782	95.45%
8	Westbound	2,647	98.98%

5.2.5 System Accuracy

As with any system, there can be errors with the queue detection system. System accuracy refers to how frequently the system experiences errors in messaging relative to speed. The most common errors are false positives, false negatives, message delay, and duplicate messages. False positives occur when the PCMS displays a “ROAD WORK AHEAD,” “SLOW TRAFFIC” or “STOPPED TRAFFIC” message without meeting the preset speed thresholds, or in other words, the PCMS updated, but no corresponding change in speed was found. Missed activations, or false negatives occur when the preset speed thresholds are met, but there is no PCMS activation. Message delay or latency is the amount of time it takes to activate or deactivate the PCMS after the radar sensor indicated a change in speed above or below the specified threshold. The methodology used for the System Accuracy analysis is described below.

The sensor data for all radar sensors in a given direction was reviewed to determine when the Radar Speed indicated a change from one speed threshold to another. Under certain conditions, the PCMS is also supposed to update to reflect this new speed category. A PCMS for a given direction of traffic should display a “SLOW TRAFFIC” or “STOPPED TRAFFIC” message when all the following are true:

1. Speeds reported by a sensor downstream of the PCMS goes below the threshold speed.
2. Speeds stay below this threshold speed for a one to two-minute interval.
3. Vehicle count at the sensor that is below the threshold speed is greater than or equal to three.

When one or all these conditions is no longer met, the system is programmed to continue displaying the “SLOW TRAFFIC” or “STOPPED TRAFFIC” message for three minutes to account for possible situations where the slow or stopped conditions are once again met within this short three-minute period. After the three-minute period, the PCMS is designed to return to its default “ROAD WORK AHEAD” message.

Based on the conditions described above, a desired message was determined for each PCMS using the speed data from the radar sensors. The desired PCMS message for most PCMS was determined using all four radar sensors for that direction, as most PCMS were located upstream of all four sensors in each direction. However, the PCMS closest to the work zone in either direction (M74 – eastbound and M56 – westbound) only referenced the sensor data for the sensors located at MM 0.0, MM 0.5, and MM 1.0, as these were the sensors downstream of these PCMS.

Each change to the desired PCMS message was compared to the change in the actual PCMS message (obtained from PCMS data) by taking the timestamp of the change to the desired message and finding the next change in the actual PCMS message. This information was used to determine true positives, false positives, and false negatives. The following algorithm explains how these were identified:

- Use radar data for a given direction to detect whether there is a change to the desired PCMS message:

- Yes
  - Check the Message column for all PCMS in that direction to determine whether the actual PCMS message (“SLOW TRAFFIC,” “STOPPED TRAFFIC” or “ROAD WORK AHEAD”) changed correctly after the appropriate conditions were met.
    - PCMS message changed correctly
      - True Positive
    - PCMS message changed incorrectly
      - False Negative
- No
  - Proceed to the next part

- Use the timestamp from the PCMS data when a change in the actual message occurred to determine whether the desired PCMS message changed, which would indicate a change in speed threshold because the desired message was based on radar sensor data.
  - A desired message, and therefore speed threshold change occurred
    - True Positive
  - A desired message, and therefore speed threshold change did not occur
    - False Positive

5.2.5.1 System Accuracy

The overall system accuracy was determined using the following equation:

$$\%\,accuracy = \left(\frac{\text{true positives}}{\text{false positives} + \text{true positives} + \text{false negatives}}\right) * 100$$

Equation 3 Percent System Accuracy

5.2.5.2 False Positives

False positives are when PCMS display a “SLOW TRAFFIC” or “STOPPED TRAFFIC” message without meeting the preset speed thresholds or other conditions. The percentage of false positives was calculated using the following equation:

$$\%\,false\ positives = \left(\frac{\text{false positives}}{\text{false positives} + \text{true positives} + \text{false negatives}}\right) * 100$$

Equation 4 Percentage of False Positives

5.2.5.3 False Negatives

False negatives, also called missed activations, occur when the preset thresholds are met, but there is no PCMS activation. The percentage of false negatives was calculated using the following equation:

$$\% \, false \; negatives = \left(\frac{\text{false negatives}}{\text{false negatives} + \text{true positives} + \text{false positives}}\right) * 100$$

Equation 5 Percentage of False Negatives

Table 5-8 shows the overall system accuracy by direction. The accuracies for eastbound and westbound are approximately 85% and 80%, respectively. It should be noted that system accuracy was difficult to calculate due to the delay in changing messaging. Since there was not a specific interval of time for the message to change, it was difficult to pair the actual message timestamps to the correct desired message (speed threshold change) timestamps and vice versa. It is also important to note that when calculating system accuracy, the focus is on how accurately the system is making message change decisions, not how reliable the equipment is. As a result, data from time periods when the sensors were not functioning properly were not included in determining system accuracy.

Table 5-8 Overall system accuracy by direction

Direction	% False Positives	% False Negatives	System Accuracy
Eastbound	4.3%	10.9%	84.9%
Westbound	4.3%	14.9%	80.8%

5.2.6 Message Delay

Message delay, or latency is the amount of time it takes to activate or deactivate the PCMS after the radar sensors indicate a change in speed threshold. The allowable latency programmed in the smart work zone system is one to two minutes. It should be noted that the speeds often oscillated between two speed groups in quick succession, causing the PCMS to change multiple times within a short timeframe. If there were multiple message changes within a five-minute period, only the first sign activation was kept, and the remaining instances of sign updates were treated as no change. Additionally, only true positives were used when determining message delay.

The message delay was determined by calculating the difference between the timestamps for the first PCMS alert message activation and the PCMS alert message deactivation. The frequency of various lengths of message delay over the duration of the project is shown in Figure 5.11.

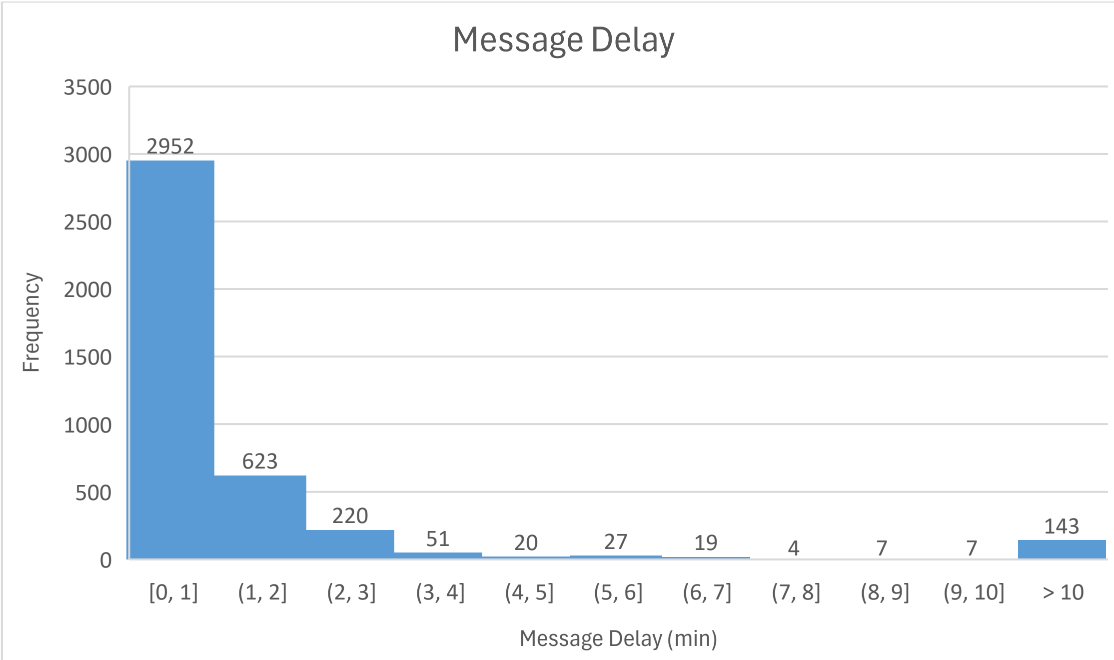


Figure 5.11 Spread of message delay for project duration

This graph shows that most message delays were less than four minutes. However, there were a significant number of delays greater than ten minutes. For this reason, the median message delay was determined instead of the average message delay because the median provides a better representation of the data when there are large outliers present in the dataset. The message frequency and median message delay for each PCMS is shown in Table 5-9. The overall median message delay was 55 seconds for eastbound devices and 59 seconds for westbound devices.

Table 5-9 Frequency and median message delay by PCMS

PCMS Name	Direction	Frequency of Message Change	Median Message Delay (sec.)
1 – M74	Eastbound	302	53
2 – M44	Eastbound	388	52
3 – M50	Eastbound	381	54
4 – M48	Eastbound	389	56
5 – M59	Eastbound	383	57
6 – M56	Westbound	674	60
7 – M67	Westbound	777	58
8 – M73	Westbound	779	59

5.2.7 Duplicate Activations

A duplicate activation occurs when there is an error within the system. Typically, the correct message is displayed on the PCMS, but in the data, the same message is shown multiple times in a row. The overall accuracy of the PCMS is not affected because the message being displayed to drivers is correct.

Using the PCMS data, the number of total activations and total unique activations over the duration of the project were determined. Total activations were determined by counting the total number of messages logged over the duration of the project for each PCMS. A unique activation means that if the same message were shown multiple times in a row, only the first occurrence would be counted. These were determined by comparing the previous message to the current message in the PCMS data to see if they matched. If the messages did not match, then the current message was a unique activation. The percent of duplicate activations were calculated using the following equation:

$$\%\ duplicate\ activations = \left(\frac{\text{total activations} - \text{total unique acitvations}}{\text{total activations}}\right) * 100$$

Equation 6 Percentage of Duplicate Activations

The percentage of duplicate activations was calculated for the duration of the project for each PCMS, and the results are shown in Table 5-10. Based on the results, all PCMS had a percentage of duplicate activations over 50%, meaning over half of all activations were not unique.

Table 5-10 Percentage of duplicate activations by PCMS

PCMS Name	Direction	Total Activations	Total Unique Activations	% Duplicate Activations
1 – M74	Eastbound	3,049	627	79.4%
2 – M44	Eastbound	6,945	768	88.9%
3 – M50	Eastbound	3,535	766	78.3%
4 – M48	Eastbound	2,008	793	60.5%
5 – M59	Eastbound	1,833	796	56.6%
6 – M56	Westbound	4,645	1,411	69.6%
7 – M67	Westbound	6,056	1,602	73.5%
8 – M73	Westbound	3,595	1,621	54.9%

5.2.8 Queue Length

Queue length refers to the length of the queue of vehicles caused by a bottleneck, in this case the work zone. Due to the setup of the queue detection system, the exact queue length cannot be determined from the data provided, it can only be approximated based on the location of the available sensors. The longest queue that the system can determine is 2.5 miles, which corresponds with the MM 2.0 sensor in each direction. For this analysis, only these 2.5 mile or longer queues were investigated.

To determine whether the queue passed the MM 2.0 sensor in each direction, the Radar Speed from the sensor data was analyzed to determine when all four sensors in a given direction was less than 40 mph. If the speed is less than 40 mph at all four sensors, this indicated that the queue started at the beginning of the work zone and extended past the MM 2.0 eastbound or westbound sensor. Over the duration of the project, the queue extended past the MM 2.0 sensors a total of 17 times, with three eastbound events and 14 westbound events. Most events lasted less than 20 minutes. The longest queue duration, lasting almost three hours, occurred in the eastbound direction in July of 2025, during rush hour. In August of 2025, there was likely overnight construction in the westbound direction, causing five brief queue events to occur.

5.2.9 Vehicle Count

Vehicle count and capacity addresses the number of vehicles passing through the work zone. The average daily traffic helps determine capacity of the work zone which was used to validate the spreadsheet that calculated anticipated queues in the work zone. The vehicle count was obtained from the sensor data in the form of one-minute increments for the entire day by lane and by vehicle classification. The Vehicle Counts columns were summed at a daily level for each direction to determine average daily traffic counts. The overall project Average Annual Daily Traffic (AADT) along with the highest volume day and highest volume week are shown in Table 5-11. The highest volume day for both directions of travel was August 29, 2025, which was the Friday before Labor Day.

Table 5-11 AADT by travel direction

Direction	Average Project AADT	Highest Volume Day	Highest Volume Week
Eastbound	29,966	8/29/2025 (40,379)	7/20/2025 – 7/26/2025 (240,831)
Westbound	26,202	8/29/2025 (35,794)	7/20/2025 – 7/26/2025 (198,837)

5.2.10 Driver Reaction to Queue Feedback

Driver’s reaction to queue feedback refers to how a driver adjusts their vehicle’s speed in response to encountering a PCMS advising a queue ahead on the road. Unfortunately, based on the setup of the sensors on this project, the granularity of the data collected, and the variance in message delay, it is difficult to accurately determine driver’s reaction. In an ideal configuration, sensors would be located at each of the PCMS and one mile after each of the PCMS to determine speed changes more accurately. With that configuration, the sensor located at the PCMS provides the initial speed of the vehicle and the sensor one-mile downstream provides the speed one-mile later, allowing a speed differential to be calculated. For this project, this ideal setup is currently only available at the closest PCMS to the work zone in each direction, located approximately 1.5 miles from the work zone. At this point, the vehicle has already passed several other PCMS, making it hard to determine if there was an initial driver response to the PCMS.

Additionally, when using the closest PCMS to the work zone for evaluation, the slow-moving vehicles that triggered PCMS change may have already reached the first sensor downstream of the PCMS, making it difficult to determine if the vehicle is reacting to the PCMS or the back of the queue, which is likely visible at this point.

Due to the transition from the I-44 Strafford to Highway B interchange project (J7I3010), which included a SWZ specifically designed to evaluate driver responses to queue warning, speed feedback, and temporary long-term rumble strips, to the I-44 Glenstone Avenue to U.S. Route 65 project (J8I3044C), which utilized a pre-designed smart work zone layout, driver reactions to the queue warning system or the temporary long term rumble strips could not be evaluated. The location of the available sensors within the work zone did not support assessment of driver behavior using the collected data.

5.2.11 Comparison Of Predicted Queue Lengths and Observed Queue Lengths

A direct comparison between predicted queue lengths generated by modeling software and observed queue lengths within the work zone could not be performed. Review of the I-44 eastbound and westbound data using the Work Zone Impact Analysis Spreadsheet indicated that no queuing was expected in either direction. The spreadsheet is primarily intended to evaluate traffic impacts resulting from lane reductions; because this project maintained two travel lanes in each direction throughout construction, the model did not predict queue formation.

Given that some level of queuing was anticipated based on the operational characteristics of the work zone, additional traffic modeling was conducted using VISSIM. Despite incorporating reduced speed limits, narrowed lane widths, updated truck percentages, and revised lane assignments, the VISSIM analysis similarly did not indicate queuing conditions in either direction. Based on these modeling results, queues occurring outside of typical peak-period slowdowns are therefore most likely attributable to incidents or other non-recurring traffic events rather than routine work zone capacity constraints.

The project team anticipated westbound backups of approximately one to two miles under certain conditions, with the potential for queues exceeding five miles during incidents or periods of heavy weekend traffic. Queue analysis during the evaluation period identified a limited number of extended congestion events, with queues exceeding 2.5 miles occurring a total of 17 times. While eastbound PCMS recorded between 237 and 303 slowdown events, westbound locations experienced substantially more slowdowns, ranging from 618 to 702, with longer average durations.

Although pre-construction modeling did not substantiate the occurrence of queuing, the queues observed during the evaluation period were generally consistent with project team expectations based on operational experience and observed traffic conditions.

5.3 Third Party Data Analysis

In addition to data collected from the devices within the queue detection system, third party data was used to analyze high level changes in traffic patterns throughout the full transportation network during the construction period from May 28, 2025, through November 23, 2025, when eastbound and westbound traffic was head-to-head. As part of this analysis, data was obtained from third party data providers StreetLight Data and HERE.

5.3.1 Streetlight Data

The StreetLight Data platform was used to obtain volume data to perform an origin-destination (O-D) analysis with the goal of determining if drivers traveling through Springfield on I-44 diverted to alternate routes during the construction period when eastbound and westbound traffic was head-to-head, and if so, the magnitude of traffic diverting. To do this, volumes with similar origins and destinations were compared across various routes. In addition to I-44, the routes analyzed were the primary signed detour of US Route 60 to US Route 65 and other likely alternate routes - Kearney Street, Chestnut Expressway (Business 44), and Sunshine Street. For eastbound analysis, the study was configured that an origin segment was selected on I-44 west of the work zone and before reaching any of the diversion points for alternate routes. The destination segment was selected to be east of the work zone and after all the alternate routes would rejoin traffic on I-44. The volumes provided for each route are only those of vehicles that pass both the origin and destination, so no local trips using the alternate routes were counted, only through trips diverting from I-44 on one end and getting back onto I-44 on the other end. The origin and destination segments for eastbound analysis can be seen in Figure 5.12. For westbound analysis, the origins and destinations were reversed.

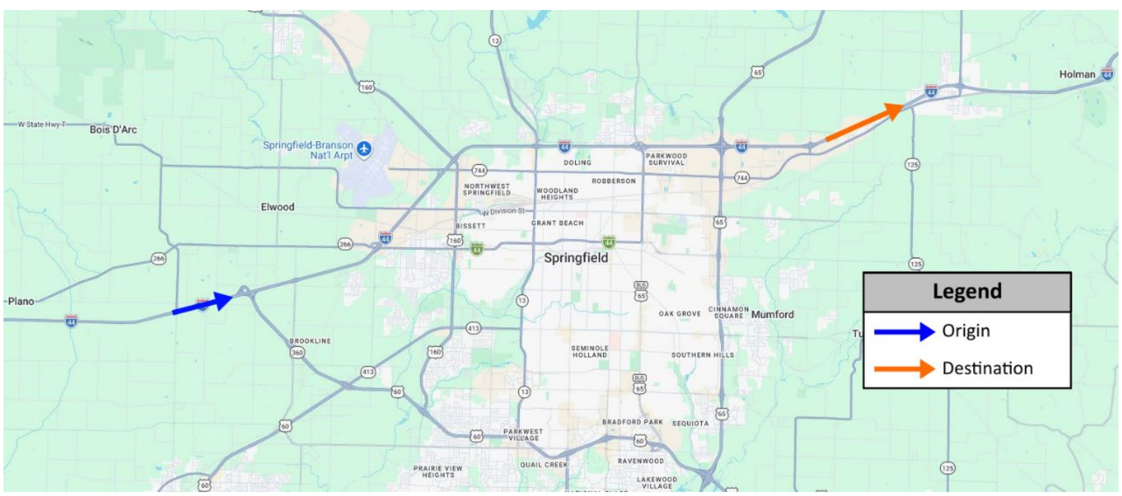


Figure 5.12 Origin and Destination Points for Eastbound O-D Analysis

Volumes for both eastbound and westbound were obtained for two periods: the “Before” period prior to traffic shifting head-to-head and the “During” period, which was during the traffic shift that resulted in eastbound and westbound traffic travelling head-to-head. The “Before” data was obtained from the period of January 2025 through March 2025 and the “During” data was obtained for the period of June 2025 through October 2025. For each route, the average hourly volume of vehicles passing the origin and destination points that used that route over the respective time period was obtained. The results are shown in Table 5-12. As can be seen, “During” volumes were higher across the board, likely due to seasonal fluctuations in traffic. To create a fairer comparison of the “Before” and “During” data, the hourly volumes were used to determine the percentage of the total trips through the origin and destination that used each route. These results are shown in Table 5-13.

Table 5-12 Average hourly volumes before and during construction

Route	Eastbound	Eastbound	Westbound	Westbound
	Before	During	Before	During
I-44	2510	2906	2304	2942
US 60/US 65	6	12	7	19
Kearney St	2	1	3	8
Chestnut Expwy	1	1	3	3
Sunshine St	1	2	0	2

Table 5-13 Percent Of O-D trips using various routes before and during construction

Route	Eastbound	Eastbound	Westbound	Westbound
	Before	During	Before	During
I-44	99.60%	99.45%	99.44%	98.92%
US 60/US 65	0.24%	0.41%	0.30%	0.64%
Kearney St	0.08%	0.03%	0.13%	0.27%
Chestnut Expwy	0.04%	0.03%	0.13%	0.10%
Sunshine St	0.04%	0.07%	0.00%	0.07%

Based on the results of the O-D analysis, it was determined that there was no significant impact to traffic patterns throughout the transportation network because of the traffic shift. Traffic travelling on I-44 through the work zone only dropped by 0.15% in the eastbound direction and 0.52% in the westbound direction during the shift. This likely indicated that the impacts of construction on traffic were not significant enough to entice drivers to select an alternate route. However, when traffic did divert from I-44 to an alternate route, most diverting traffic appeared to select the signed alternate route of US Route 60 and US Route 65.

5.3.2 HERE Data

To further analyze the impacts of construction on the transportation network, HERE data was used to analyze speed and travel time on I-44 and alternate routes. The routes selected for analysis were I-44, US Route 60, US Route 65, Kearney Street, Chestnut Expressway (Business 44), and Sunshine Street. For I-44, the segment limits were selected to be just west and just east of the work zone limits so as only to capture traffic remaining on I-44 through the work zone and not picking up any traffic that may end up on an alternate route before they divert from the interstate prior to encountering the work zone. For the alternate routes, the limits of each route were selected so that they would capture any traffic diverting from I-44 before reaching the work zone on either end of the corridor. The selected limits for each route can be seen in Figure 5.13 below.

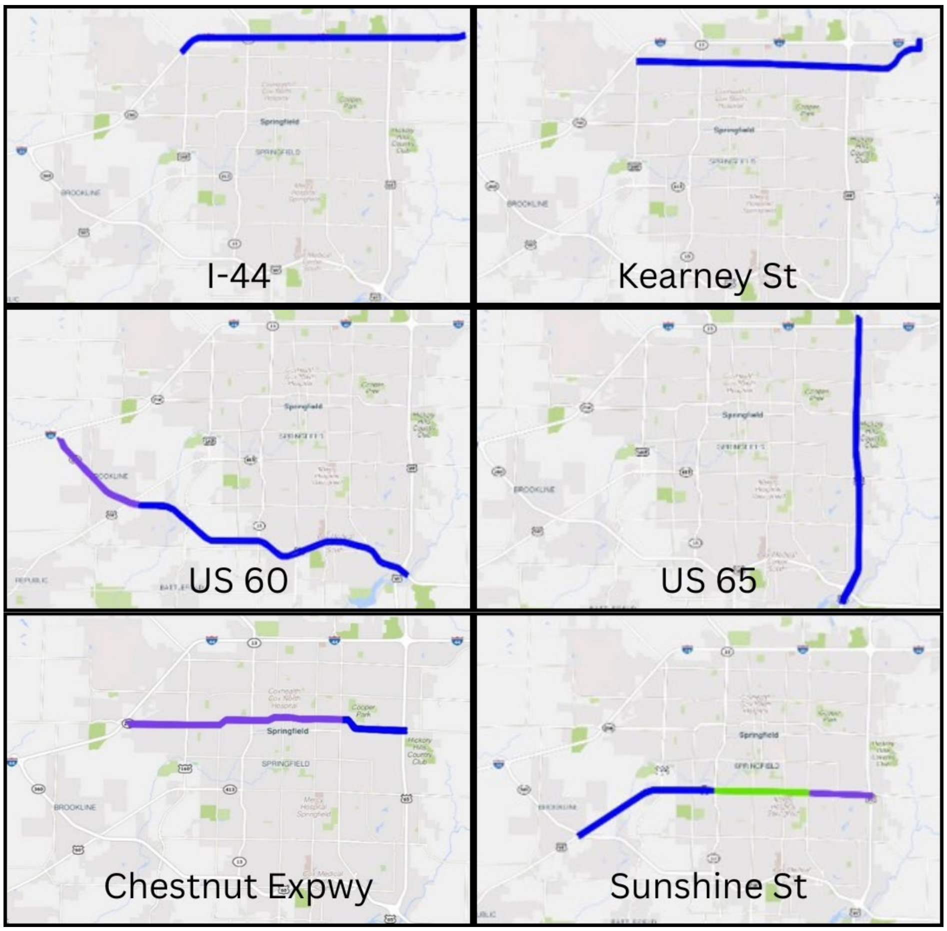


Figure 5.13 Route limits for HERE data

For each route, average speeds throughout the corridor and route travel times were obtained for a period before traffic was shifted head-to-head (January 2025 through March 2025), and for a period during the traffic shift (June 2025 through October 2025). Both speeds and travel times were averaged for both directions over the entire corridor throughout each period of analysis. The average speeds on each route before and during the traffic shift can be seen in Table 5-14 and the average route travel times for each route before and during the traffic shift can be seen in Table 5-15.

Table 5-14 Speed (mph) comparisons before and during construction for various routes

Route	Before	During	Difference
I-44	66.2	63.1	-3.1
US 60	66.1	67.3	1.2
Kearney St	33.9	33.9	0.0
Chestnut Expwy	33.4	33.2	-0.2
Sunshine St	34.0	34.0	0.0
US 65	64.8	65.5	0.7

Table 5-15 Travel time (minutes) comparisons before and during construction for various routes

Route	Before	During	Difference
I-44	17.52	18.36	0.84
US 60	25.05	24.61	-0.44
Kearney St	34.10	34.08	-0.02
Chestnut Expwy	31.93	32.14	0.21
Sunshine St	35.84	35.88	0.04
US 65	17.1	16.89	-0.21

The HERE data indicated that there was no significant change in either speed or travel time on either I-44 or any of the alternate routes because of the traffic shift, which corroborates the results of the O-D analysis using StreetLight Data. While traffic on I-44 through the work zone did experience a slight decrease in speed (3.1 mph) and a slight increase in travel time (0.84 minutes), changes on the alternate routes were minimal, and in some cases, speeds actually increased and travel times decreased during the evaluation period, which indicated that the traffic shift did not have a significant impact on travel patterns throughout the network. Additionally, since delay can be defined as additional travel time experienced by drivers compared to free-flow conditions and there was not a significant increase in travel time, these results also indicate that there was no significant increase in delay on I-44 or any other routes in the surrounding network as a result of the construction project during the evaluation period.

5.4 Economic Evaluation

An economic evaluation was performed to review costs associated with the advanced traffic management strategies deployed on I-44 Springfield project. The cost of the SWZ system was reviewed as a comparison to the low, mid, and high range cost estimates assembled during the project selection phase (document in Appendix B) and to the approximated costs derived from the MoDOT Work Zone Impact Analysis Spreadsheet.

Contract cost information for the I-44 Springfield projects (J8I3044C and JSU0076) was provided by the project manager, with the temporary traffic control and WZITS components identified for evaluation (see Appendix D). At the time of this report, the only TTC addendum pertained to the installation of a radar-based speed advisory system. As shown in the tables below, SWZ costs represented a relatively small portion of overall TTC expense, accounting for 3.65 percent of TTC costs in the eastbound portion of the project and 3.02 percent in the westbound portion.

Table 5-16 Percent of TTC spent on SWZ for both phases of I-44 Springfield

Total TTC J8I3044C	$4,111,246.10
Total SWZ J8I3044C	$150,000.00
Percent SWZ J8I3044C	3.65%
Total TTC JSU0076	$4,962,894.50
Total SWZ JSU0076	$150,000.00
Percent SWZ JSU0076	3.02%

As a percentage of the total project cost, the SWZ system cost was less than 0.5%.

Table 5-17 Percent of project dollars allocated to SWZ

Total Project Cost	$70,750,000		
Total SWZ Cost	$300,000	0.42%	percent of total project cost w/o radar system
Radar Speed Advisory System	$27,000	0.46%	percent of total project cost w/ radar system

**Only other TC additions to the project was a Radar Speed Advisor System: $27,000.

Approximate SWZ system costs on a per-day and per-week basis are presented below, based on the start and end dates discussed during the pre-construction meeting held on February 14, 2025. These cost estimates are subject to change if there are adjustments to the project end date. At the time of the meeting, temporary traffic control deployment was scheduled to begin on February 17, 2025, with Stage 1 construction activities starting on April 1, 2025.

Table 5-18 SWZ system costs per day and week

I-44 Springfield: Duration: 2.5-year project; completion in May 2027				
Project Dates	3/1/25	5/21/27	811	Days
SWZ System Days	4/1/25	5/21/27	780	Days
			111	weeks (approx.)
			56	weeks per job package (approx.)
SWZ System Cost Per Day	Cost per day (approx.)		$384.62	
SW System with added speed feedback signs	Cost per day (approx.)		$419.23	
SWZ System Cost Per Week	Cost per week (approx.)		$2,692.31	
SW System with added speed feedback signs	Cost per week (approx.)		$2,934.62	

The actual cost of the I-44 Springfield SWZ package was evaluated against low, medium, and high SWZ cost ranges identified in Fall 2023. To ensure consistency with cost data from other states, all values were normalized to reflect a one-year deployment period for comparative purposes.

This analysis determined that the I-44 Springfield SWZ costs were generally consistent with industry benchmarks. Specifically, the speed feedback system aligned with the low- to mid-range cost estimates, the queue warning system was categorized within the low-cost range, and the temporary rumble strips were just slightly below the high-cost estimate (Figure 5.14).

Comparison to approximate low, mid and high range costs developed while identifying potential TSMO strategies in Fall of 2023				
	Low	Mid	High	Actual Cost
Speed Feedback Systems	Minnesota (High level cost estimate; duration and needs unknown)	Iowa (VSL)	Texas (VSL)	MoDOT I-44 Springfield
** Costs normalized to a 12 month schedule for comparison with MoDOT	$ 13,000.00	$ 22,000.00	$ 124,200.00	$ 27,000.00
	$ 26,000.00	$ 22,000.00	$ 124,200.00	
	$ (1,000.00)	$ (5,000.00)	$ 97,200.00	
	Low	Mid	High	Actual Cost
End of Queue Warning	Iowa (6-month deployment, 4 sensors and 4 PCMS; 2 per direction)	Minnesota (High level cost estimate; duration and needs are unknown)** assumed $25,000 for 3 months	Nebraska (6-month deployment, 1 CCTV, 3 Sensors, 4 PCMS)	MoDOT I-44 Springfield; assume duration of job package (JSU0076)
** Costs normalized to a 12 month schedule for comparison with MoDOT	$ 39,800.00	$ 75,000.00	$ 166,225.00	$ 150,000.00
	$ 79,600.00	$ 300,000.00	$ 332,450.00	
	$ (70,400.00)	$ 150,000.00	$ 182,450.00	
	Low	Mid	High	Actual Cost
Temporary Rumble Strips	Kansas (cost per approach, not including install cost)	Missouri (set of 3 per direction, not including install cost)	Maryland (set of 3 per direction)	MoDOT I-44 Springfield, (4 each, 2 each direction for full project duration; includes traffic switch)
** Costs normalized to a 2 each direction; with one removal and reinstall for traffic switch for comparison with MoDOT	$ 1,537.00	$ 5,115.00	$ 6,200.00	$ 11,200.00
	$ 6,148.00	$ 10,230.00	$ 12,400.00	
	$ 5,052.00	$ 970.00	$ (1,200.00)	

Figure 5.14 Low, mid, and high range SWZ cost comparison

A review was conducted comparing the I-44 SWZ costs to estimates generated using the MoDOT Work Zone Impact Analysis Spreadsheet. An approximate cost comparison was developed by utilizing the spreadsheet's hidden Advanced Work Zone Calculations section and reviewing the underlying formulas applied when project-specific inputs are entered.

Where feasible, the Analysis Spreadsheet was populated with I-44 project data to allow the tool to self-generate cost estimates. However, as previously noted, because traffic modeling did not predict queuing for this project, certain cost components could not be automatically calculated and were instead estimated separately using the spreadsheet's documented calculation methodologies. Figure 5.15 below shows the Step 4a - Advanced Work Zone Synopsis output generated using only Step 3a - Advanced Work Zone Analysis input parameters.

Advanced Work Zone Strategy Analysis

Advanced Work Zone Strategy	Applicable	Base Points (From SWZ Calc Sheet)	Manual Adjustment (From SWZ Calc Sheet)	Cost (From SWZ Calc Sheet)	Score*	Rank	Recommendation	Budgetary Estimate
1. Construction Vehicle Warning System	FALSE	55	0	$0	0	-	Not Applicable	$0
2. Dynamic Late Merge (Zipper Merge) System	FALSE	61	0	$50,000	0	-	Not Applicable	$0
3. Queue Warning System	FALSE	69	0	$8,000	0	-	Not Applicable	$0
4. Road Closure	FALSE	26	0	$177,000	0	-	Not Applicable	$0
5. Speed Warning System	TRUE	100	0	$190,000	100	1	Strongly Recommended	$190,000 **
6. Temporary Rumble Strips	FALSE	67	10	$2,000	0	-	Not Applicable	$0
7. Temporary Traffic Incident Management and ITS System	FALSE	16	0	$948,000	0	-	Not Applicable	$0
8. Travel Time Advisory System	FALSE	33	0	$94,000	0	-	Not Applicable	$0
9. Travel Time Advisory System with Alternative Route	FALSE	31	0	$94,000	0	-	Not Applicable	$0

Scoring Criteria

From	<= To	Recommendation
0	1	Not Applicable
1	30	Not Recommended
30	70	Should be Considered
70	100	Strongly Recommended

* Scores in blue include a manual score adjustment to reflect current initiatives or to de-emphaisize specific initiatives.

** Speed trailer cost assumes contractor-provided trailers

Figure 5.15 Step 4a - Advanced Work Zone Synopsis output page

Application of the spreadsheet's calculation formulas produced varying levels of alignment with observed costs. The end-of-queue warning cost calculation slightly under approximated the expected project costs, while the estimated cost for the speed warning system was substantially higher than the actual implementation cost. Conversely, the projected cost for temporary rumble strips was lower than the realized project costs.

Table 5-19 SWZ cost comparison to MoDOT Work Zone Impact Analysis Spreadsheet approximated costs

Comparison to MoDOT WZ Impact Analysis Advance Work Zone Calculations				
End of Queue Warning	Base Cost	Weekly Maint. Cost	WZ Impact Cost Estimate	MoDOT I-44 Springfield; assume full project duration
From WZ Impact Spreadsheet: $20,000/mile * max of (queue length and taper length) + $200/mile/week	$20,000	$200	$198,870	$300,000
Taper TTC - phase 1 (EB) J8I3044C page 157: 707ft EB lane shift	0.13			
Taper TTC - phase 1 (WB) J8I3044C page 161: 554ft WB lane shift	0.10			
Assumed queue length 2 miles	2			
2.5 year project; assume 56 weeks per work package, 111 weeks for both, or 780 days	780			
Length of project 4.703 (from plans)	4.703			

Speed Warning System	Base Cost	WZ Impact Cost Estimate	MoDOT I-44 Springfield Actual Cost
From WZ Impact Spreadsheet: Number of trailers (assuming 1 per every 5 miles) * WZ length. Contractor provided Cost: $10/hour.	$10	$187,200	$27,000
2.5 year project; assume 56 weeks per work package, 111 weeks for both, or 780 days	780		
Length of project 4.703 miles (from plans)	4.703		

Temporary Rumble Strips	Base Cost	WZ Impact Cost Estimate	MoDOT I-44 Springfield, (4 each) Actual Cost
From WZ Impact Spreadsheet: Assumes 1 set and 1 approach	$2,000	$8,000	$11,200
Assume 2 approaches: 4 each	4		

5.5 Results Summary

Westbound traffic experienced significantly more slowdowns and longer durations than eastbound traffic. Westbound slowdowns were nearly double in frequency and averaged about two minutes longer, with some lasting up to nine hours, compared to a maximum of approximately 3.5 hours eastbound. Most extended westbound slowdowns occurred at night, suggesting impacts from nighttime construction activities such as lane closures or slow-moving construction vehicles.

All sensors demonstrated strong reliability, with system uptimes exceeding 90 percent throughout the study period. Most sensors achieved uptime levels above 95 percent, indicating consistent and acceptable performance across both eastbound and westbound directions.

Overall system accuracy was approximately 85 percent eastbound and 81 percent westbound. Accuracy assessment focused on the system's decision-making for message changes rather than equipment reliability, with periods of sensor malfunction being excluded from analysis. While false positive rates were low in both directions (about 4 percent), higher false negative rates, particularly westbound, reflect challenges associated with message change delays and the lack of precise timestamp alignment between desired and actual messages.

The smart work zone system generally met the programmed allowable message latency of one to two minutes, with most PCMS message changes occurring within four minutes of a speed threshold change. Because occasional large delays exceeded ten minutes, median message delay was used to better represent typical system performance. The overall median message delay was 55 seconds for eastbound devices and 59 seconds for westbound devices, indicating timely response across all PCMS locations despite occasional outliers caused by rapid speed fluctuations and repeated message changes.

All PCMS locations experienced a high rate of duplicate activations, with more than 50 percent of message activations repeating the same message consecutively. Duplicate activation rates ranged from approximately 55 to 89 percent across devices. While these duplicates indicate system-level redundancies in message logging or activation processes, they did not affect overall system accuracy, as the correct message was consistently displayed to drivers.

Queue analysis identified a limited number of extended congestion events during the project. Queues exceeding 2.5 miles occurred 17 times in total, with substantially more events in the westbound direction (14) than eastbound (3). Most queue events were short in duration, typically lasting less than 20 minutes. The longest event occurred eastbound in July, during the afternoon peak, and lasted nearly three hours. Several brief westbound queue events in August were likely attributed to overnight construction activity. Overall, extended queues were infrequent and predominantly westbound.

Vehicle count analysis indicated that the work zone operated under substantial traffic demand throughout the project. Average annual daily traffic was approximately 30,000 vehicles eastbound and 26,000 vehicles westbound, supporting the capacity assumptions used in queue modeling. The highest traffic volumes in both directions occurred on August 29, 2025, the Friday preceding Labor Day, with peak weekly volumes observed during late July. These results confirm that the work zone accommodated high traffic volumes during peak travel periods.

Driver response to queue warning messages could not be reliably evaluated for this project due to limitations in sensor placement, data resolution, and message latency. The available sensor configuration did not support accurate measurement of speed changes immediately before and after drivers encountered PCMS messages, and vehicles may have already been reacting to visible queues rather than the messages themselves. Additionally, the transition from a project specifically designed to study driver behavior to a pre-designed smart work zone layout prevented meaningful assessment of driver reactions to queue warnings or rumble strips using the collected data.

A direct comparison between modeled and observed queue lengths was not feasible, as pre-construction modeling tools did not predict queuing due to the project maintaining two travel lanes in each direction throughout construction. Additional VISSIM modeling, which accounted for reduced speeds, narrowed lanes, and updated traffic characteristics, likewise did not indicate routine queuing, suggesting that congestion outside normal peak periods was primarily driven by incidents or other non-recurring events rather than work zone capacity constraints. During the evaluation period, extended queues exceeding 2.5 miles were infrequent, occurring 17 times, and were predominantly westbound. Although not supported by pre-project modeling, the observed queuing patterns were generally consistent with project team expectations based on operational experience and prevailing traffic conditions.

Origin–destination and travel time analyses indicate that the head-to-head traffic configuration on I-44 did not result in significant diversion to alternate routes or broader network impacts. StreetLight Data analysis showed that more than 99 percent of through traffic in both directions continued to use I-44 during construction, with only marginal decreases in I-44 usage (0.15 percent eastbound and 0.52 percent westbound). When diversion occurred, most traffic shifted to the signed detour route (US 60/US 65).

Speed and travel time analysis using HERE data corroborated these findings. I-44 experienced a modest reduction in average speed (approximately 3 mph) and a slight increase in travel time (less than one minute), while alternate routes showed minimal changes, and in some cases improved speeds and travel times during the construction period. Overall, the results indicate that the traffic shift did not significantly alter travel patterns, cause notable diversion, or create measurable increases in delay across the surrounding transportation network.

The economic evaluation of the SWZ system implemented on the I-44 Springfield project found that system costs represented a small share of overall project expenses while aligning well with industry benchmarks. SWZ systems accounted for approximately 3–4% of total TTC costs in both project phases and less than 0.5% of the total construction cost, even when including the radar-based speed advisory system. When compared to low, medium, and high-cost ranges from other states or previous SWZ research the SWZ costs were generally consistent with expectations: queue warning systems fell within the low cost range, speed feedback systems aligned with low-to-mid range estimates, and temporary rumble strips were slightly below the high range benchmark. Comparison with cost estimates generated by the MoDOT Work Zone Impact Analysis Spreadsheet showed mixed alignment. The spreadsheet underestimated queue warning and the cost of temporary rumble strips compared to actual implementation, while overestimating the cost of the speed warning system. Overall, the results demonstrate that SWZ systems can be implemented at relatively modest cost while remaining generally consistent with both national benchmarks and MoDOT planning tools.

Chapter 6: Recommendations

This section provides recommendations for effective design, deployment, and institutionalizing SWZ systems into MoDOT standard practices.

6.1 Recommended Best Practices for Matching Construction Projects with SWZ Solutions

Roadway construction projects are each unique, and not all are suitable for the application of SWZ solutions. Numerous factors, including AADT, length of work zone, duration of the project, and geometric factors such as lane shifts and lane width come into play. Other variables include the percentage of heavy commercial vehicles, traffic control schemes, and type of work zone activity. MoDOT has a robust Work Zone Impact Analysis Spreadsheet to predict potential queueing within a work zone that also provides additional information on potential systems to use and approximate costs.

As observed on the I-44 Springfield project, the spreadsheet has certain limitations. It performs best when there is a change in the number of available lanes and requires recent traffic data located within an acceptable distance of the planned work zone to function effectively. These limitations may hinder the application of SWZs on projects that are expecting safety and mobility impacts that could benefit from a SWZ solution. In the case of the I-44 Springfield project, use of contraflow maintained two lanes of travel in each direction so the models indicated no queues would form. Unfortunately, the human factor element predicts that there will be slowdowns that are not shown in the data due to the “complicated” work zone.

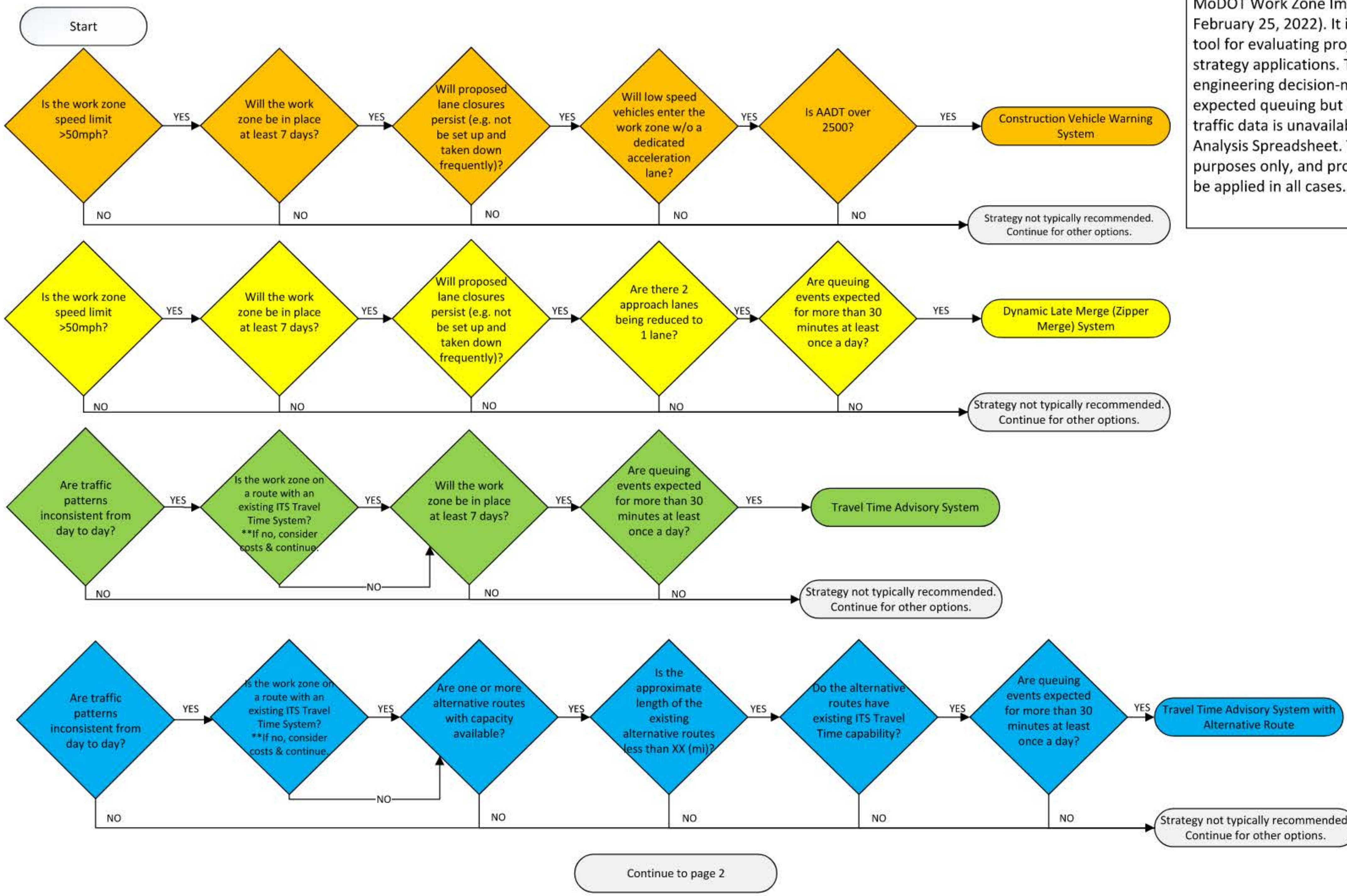
MoDOT’s Work Zone Impact Analysis Spreadsheet has a wealth of information and key indicators for determining when advanced work zone strategies are warranted and identifying appropriate systems. For projects that meet the required criteria, the spreadsheet should be applied as the primary evaluation tool. For projects that are outliers a simplified reference guide may offer a practical alternative for work zone practitioners to assess project needs. Creation of a visual representation of the spreadsheets analysis process removes the ‘black box’ functions of the MoDOT tool. While the spreadsheet includes supporting background information, expecting users to conduct extensive independent analysis is not time-efficient.
Recommendations include the following:

- **Recommendation:** Develop a quick reference guide based on the Work Zone Impact Analysis Spreadsheet for times when a full data analysis cannot be performed. See Figure 6.1, 6.2, and 6.3 below for an example flow chart, and Appendix E to view full page flow charts.

Use this decision tree quick reference guide to identify potential Advanced Work Zone Strategies for projects on freeways or interstates that will have negative impacts to safety, mobility, or delay.

Advanced Work Zone Strategies Quick Reference Flow Chart

This decision tree was developed using information from the MoDOT Work Zone Impact Analysis Spreadsheet (Revised February 25, 2022). It is intended to serve as a quick-reference tool for evaluating projects for potential advanced work zone strategy applications. The decision tree may be used to support engineering decision-making when modeling results indicate no expected queuing but queuing is anticipated, or when sufficient traffic data is unavailable to apply the Work Zone Impact Analysis Spreadsheet. This guide is provided for informational purposes only, and professional engineering judgment should be applied in all cases.

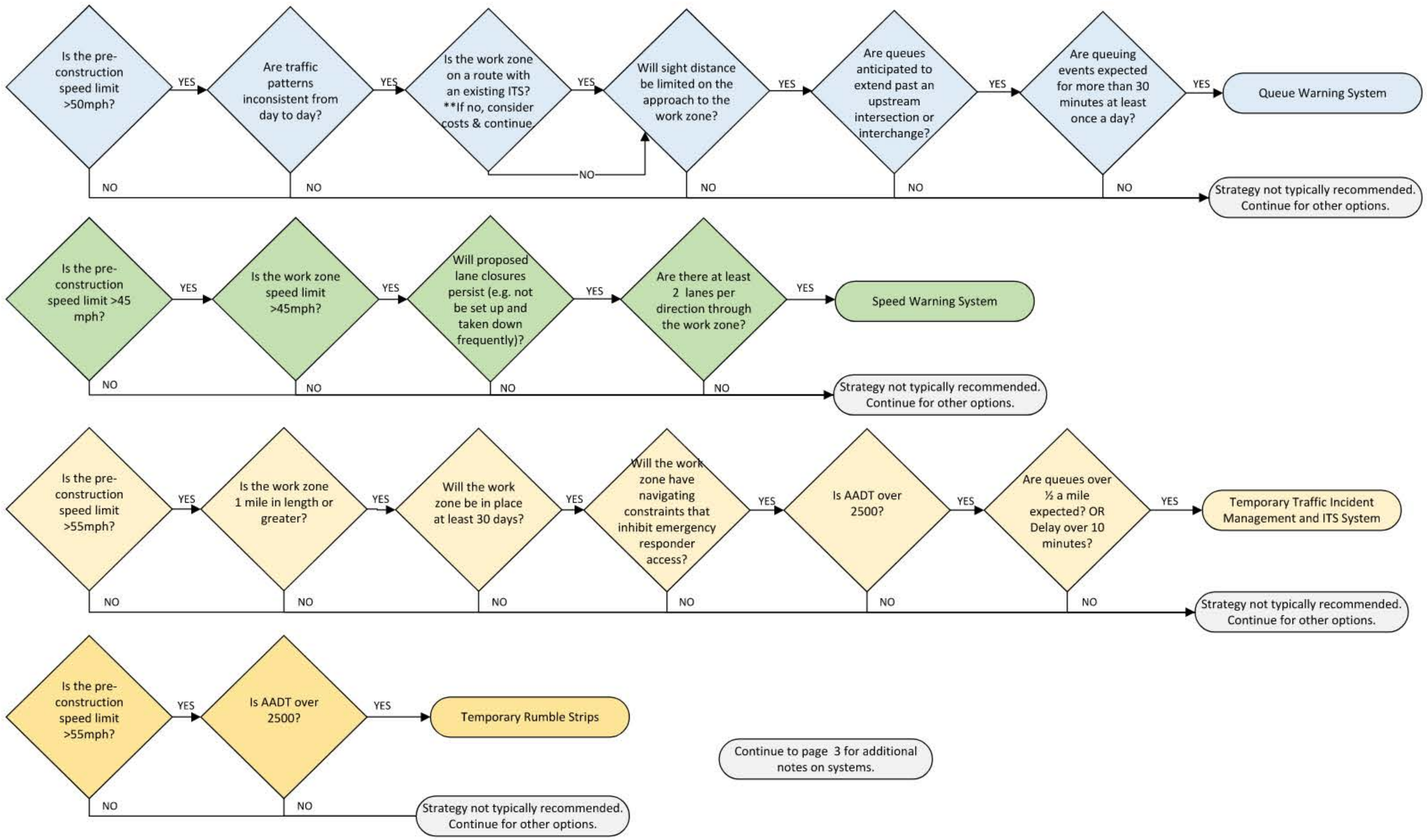


Continue to page 2

Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

Figure 6.1: Advanced Work Zone Strategies Flow Chart page 1

Use this decision tree quick reference guide to identify potential Advanced Work Zone Strategies for project on freeways or interstates that will have negative impacts to safety, mobility, or delay.



Continue to page 3 for additional notes on systems.

Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

Figure 6.2 Advanced Work Zone Strategies Flow Chart page 2

Advanced Work Zone Strategies Quick Reference Flow Chart

This decision tree was developed using information from the MoDOT Work Zone Impact Analysis Spreadsheet (Revised February 25, 2022). It is intended to serve as a quick-reference tool for evaluating projects for potential advanced work zone strategy applications. The decision tree may be used to support engineering decision-making when modeling results indicate no expected queuing but queuing is anticipated, or when sufficient traffic data is unavailable to apply the Work Zone Impact Analysis Spreadsheet. This guide is provided for informational purposes only, and professional engineering judgment should be applied in all cases.

Considerations for Construction Vehicle Entering Systems:

- Higher work zone speeds will lead to a higher potential for crashes with entering construction vehicles.
- Lower volumes will permit construction vehicles to enter the roadway with few potential conflicts.

Considerations for Dynamic Late Merge (Zipper Merge System)

- Approach speed must be at least 50 mph. Higher approach speeds increase the probability of conflicts and crashes at the back of a queue.
- Work zone must be in place at least 7 days.
- Because of the work required to set up and calibrate the system, it should not be installed on short term closure.
- System should cost approximately 1.9% of total project cost or a max of $50k per setup.
- Must have 2 approach lanes that reduce to 1 open lane.
- A greater number of hours a queue is present has a greater potential for conflicts and crashes.

Considerations for Travel Time Advisory System

- TT Advisory systems are more useful when traffic is inconsistent.
- If this falls within an existing ITS system, then the setup cost is estimated at 75% lower.
- Assume base cost of $20k/mile of work zone and assume $200/week/mile of WZ+Queue system.
- Queue anticipated a minimum of 30 minutes per day. Longer durations increase the need for a TT Advisory system.
- Min delay of 5 minutes, and longer delays increase the need for a TT system.
- Sensors must be set up to monitor in the queueing area, and portable DMS signs to advise of the travel times.

Considerations for Travel Time Advisory System with Alternative Route

- Variability in traffic patterns increases the value of a TT/Alt Route system.
- An existing ITS system in the project area increases the feasibility for and reduces cost for this system.
- If no alternate routes are available, do not consider this option.
- Cost to outfit alternate routes with ITS devices. **note that this system may increase the mileage needed along the primary route also, but this is not accounted for here because of the added complexity and time needed for a user.
- Assume base cost of $20k/mile of work zone and assume $200/week/mile of WZ+Queue system.
- Assume 75% discount if ITS devices and TT Capability already exist on the routes.
- Queue anticipated a minimum of 30 minutes per day. Longer durations increase the need for a TT Advisory system.
- Min delay of 5 minutes, and longer delays increase the need for a TT system.
- Sensors must be set up to monitor in the queueing area, and portable DMS signs to advise of the travel times.

Considerations for Queue Warning System

- Higher pre-construction roadway speeds increase risk for vehicles approaching the back of a queue.
- Unpredictable traffic patterns increases the value of a queue warning system.
- Existing ITS devices may reduce the cost of detecting real-time queues.
- A Queue warning system has greater value if sight distance issues exist.
- A Queue warning system has greater value if upstream conflicts exist.
- Assume $20,000/mile * max of (queue length and taper length) + $200/mile/week.

Considerations for Speed Warning System

- Applicable in work zones with higher speeds.
- Number of trailers (assuming 1 per every 5 miles) * WZ length. Contractor provided Cost:$10/hour. No additional cost if MoDOT owned trailers are used.
- For use on multi lane routes.

Considerations for Temporary Traffic Incident Management and ITS System

- Assume $150/device/day/mile. Assumes 2 devices (camera/sensor) per mile. Assumes portable DMS are covered elsewhere. Reduce cost for existing sensors/cameras. Add if emergency response units on standby.

Considerations for Temporary Rumble Strips

- Assume 1 set and 1 approach base cost of $2000.

End

Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

Figure 6.3 Advanced Work Zone Strategies Flow Chart page 3

- **Recommendation:** Add additional information to the Engineering Policy Guide for what to do when data does not warrant advanced work zone strategy applications, but engineering judgement and past experience warrants work zone mitigation measures.
- **Recommendation:** Review and update the content and cost information included in the Work Zone Impact Analysis Spreadsheet on an annual or bi-annual schedule. If no updates are needed a review certification date should be added.

6.2 Recommended Standard Layout Updates and Guidelines for Design

The MoDOT Work Zone Management Guidebook from March of 2021 should be updated or amended to match the current content on the 616.19 Work Zone Capacity, Queue and Travel Delay page of the MoDOT Engineering Policy Guide.

Specifically, changes should be made to replace the Dynamic Merge (Zipper Merge) System Diagram in the Guidebook with the Dynamic Late Merge/Zipper Merge Figure linked on the EPG, and the Queue Warning System Diagram from the Guidebook should be updated to more closely resemble the Dynamic Merge System Diagram from the Guidebook and can be modified to include the use of rumble strips if warranted. Conflicting information provided by a DOT can hinder effective design implementation; documents and manuals that are no longer recommended for use should be removed or archived.

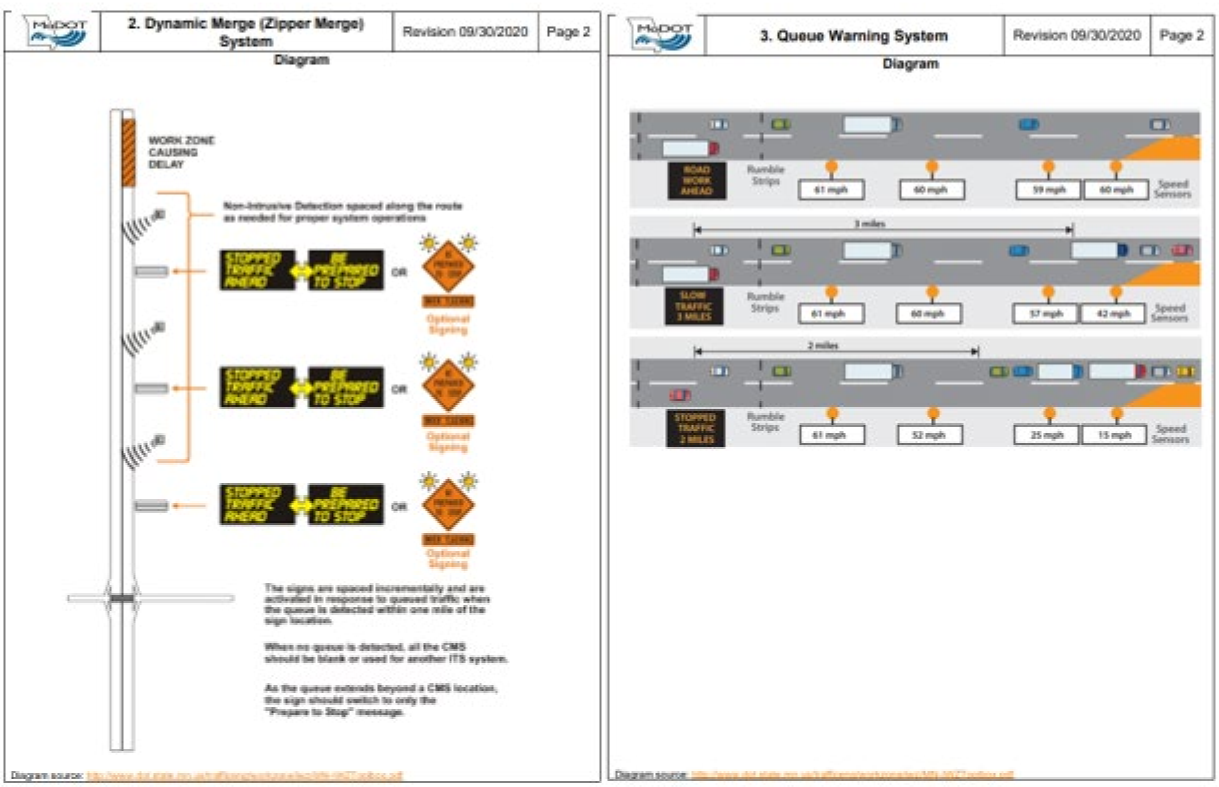


Figure 6.4 MoDOT Work Zone Management Guidebook Diagrams for Dynamic Merge and Queue Warning Systems

While standard plans for SWZ systems are difficult to implement due to every work zone having its own specific needs, the following are device layout guidelines that can be used to supplement diagrams to help with device placement:

6.2.1 Queue Warning Device Layout Guidelines

1. Primary Sensor located 0 to 600' in advance of the flashing arrow board, beginning of lane drop, or beginning of taper for traffic shifts.
2. Place additional sensors at ½ to 1 mile Intervals (1.25 miles maximum) in advance of the primary sensor. Preferred placement is at locations that cannot be seen easily by approaching traffic. Continue sensor placement to a point where a "worst-case" queue is not expected to exceed.
3. Place PCMS at points where sight distance to the road ahead is limited by alignment or obstructions (hills, bridges, curves, etc.). PCMS must be spaced as far as possible from other static signs, including temporary work zone signs, ideally 800 feet. PCMS in advance of the work zone for queue detection should be spaced at 1-2 mile intervals. Preference should also be given for locations ½ to 1.5 miles in advance of exits, so they can also be used to divert traffic.
4. Consider co-locating sensors and PCMS to reduce the number of portable trailers along the roadway.
5. Layouts should be created using standard spacing guidelines and then modified to accommodate each work zone's unique needs, taking into consideration horizontal and vertical curves, perception and reaction time for driver messages, and other roadway elements in the area including both permanent and temporary road signs.

6.2.2 Traffic Monitoring for Speed Warning or Travel Time Systems Device Layout Guidelines

1. Sensors approaching and within a work zone should be spaced at ½ to 1 mile intervals and should collect data from both directions of travel when possible.
2. Queue detection sensors also act as monitoring sensors.
3. PCMS should be placed ½ to 1.5 miles in advance of the work zone and in advance of each exit within a work zone. These PCMS should also be programmed for queue detection when possible; with the default messaging being used for variable speed display or travel time display.
4. Layouts should be created using standard spacing guidelines and then modified to accommodate each work zone's unique needs, taking into consideration horizontal and vertical curves, perception and reaction time for driver messages, and other roadway elements in the area including both permanent and temporary road signs.

6.2.3 Portable Camera Location Layout Guidelines

1. Cameras should provide visible coverage of the entire work zone, plus any potential queuing areas.

2. If a single camera is used it must be able to be able to pan-tilt-zoom to see all critical areas (e.g., merge points, crossovers, likely queuing areas, etc.), if more than one camera is deployed default camera views should be set to cover (and record) all critical areas.
3. Maximum camera spacing is 1.2 miles between cameras, even when sight lines are clear.
4. Optional camera coverage may be provided along diversion routes.

6.2.4 Diversion Route Device Location Layout Guidelines

1. PCMS should be placed to divert traffic when a diversion route is in effect.
2. A single PCMS can be used for both queue detection and diversion direction.
3. PCMS for diversion routes should be placed 0.5 to 1.5 miles in advance of the exit.
4. Known diversion routes should be trail blazed using static signs like detour signing. If there are variable diversion routes, a PCMS should be used
5. Optional camera coverage may be considered along diversion routes.

Recommendations include the following:

- **Recommendation:** Update the Work Zone Management Guidebook to match the current content on the 616.19 Work Zone Capacity, Queue and Travel Delay page of the MoDOT Engineering Policy Guide and reflect the most up to date information for MoDOT's Advanced Work Zone Strategy information. An annual or bi-annual schedule should be set for review and updates. If no updates are needed a review certification date should be added.
- **Recommendation:** Remove or archive documents and manuals that are no longer recommended for use during advanced transportation system planning for TSMO and SWZ.
- **Recommendation:** Develop additional design guidelines for MoDOT advanced transportation systems in lieu of SWZ standard plans to supplement the standard layout guidelines MoDOT provides.

6.3 Recommendation for Standard Job Special Provisions for SWZ

Current practice investigation and information provided by the TAC indicated that there are currently no standard JSPs for SWZ in Missouri. As seen in the contract documents from the I-44 Springfield project, the lack of standard special provisions for advanced traffic control applications results in a mismatch of the design shown on the plan sheets and the specifications required by the DOT. The onus is then put on the smart work zone provider to interpret what is required to assemble their work zone ITS plan (Appendix D). While StreetWise did a good job inferring what was needed for the queue warning on this project, unclear direction provided in let plan sets may be a leading reason MoDOT is not seeing the improved safety and mobility benefits typically seen when these applications are deployed.

A recommended boiler plate job special provisions have been created for the following systems:

- Construction Vehicle Warning System
- Dynamic Late (Zipper) Merge (DLM) System

- Queue Warning System
- Temporary Long Term Rumble Strips
- Speed Warning System
- Temporary Traffic Incident Management System
- Travel Time Advisory System
- Travel Time Advisory System with Alternate Routes

The developed boiler plate JSP also includes information on device and system requirements, work plan, and test plan requirements, operation testing plans, and payment. The recommended structure of measurement and payment was modified to hold back larger portions of the lump sum until the project requiring use of SWZ is complete. While possibly an unpopular addition to the SWZ JSP this change will allow MoDOT to enforce deductions for failed systems; language was added to define a failed system as not just one component being down unless the failure of one component makes the entire system inoperable for a predetermined period of time.
The full boiler plate JSP recommendation can be found in Appendix F.

- **Recommendation:** Publish the developed boiler plate JSP for SWZ Systems.

6.4 Recommended Best Practice for Effective SWZ Deployment

Proper prior planning and standardized deployment efforts are needed to implement the most effective outcomes for SWZ systems.

6.4.1 SWZ Deployment Process Standardization

A standard operational procedure for deployment defines a process for successful implementation of SWZ systems onto the roadway. Due to the dynamic nature of construction projects modifications to device locations, deployment timeframe, and other unforeseen impacts may arise. A standard plan for deployments provides the team with a clear path even in the face of last-minute changes.

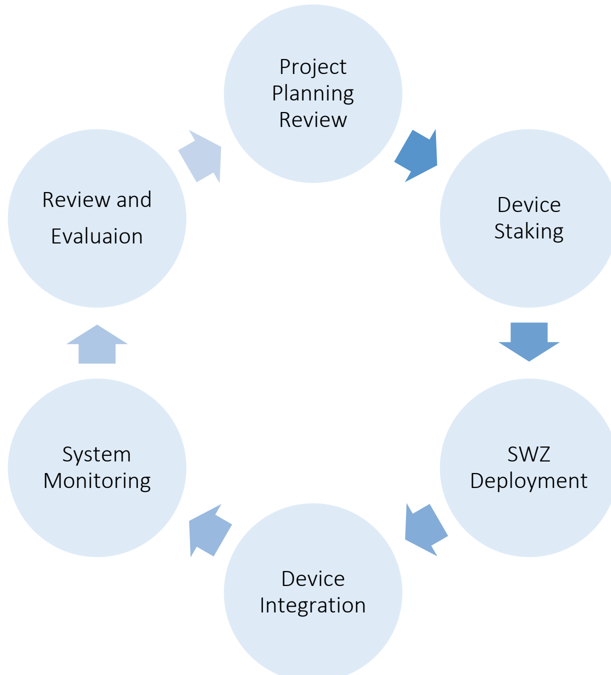


Figure 6.5 Smart work zone deployment cycle diagram

The figure 6.5 diagram above demonstrates the basic path that can be used for any SWZ deployment. Below is a brief description of each step in the deployment cycle.

- Project Planning Review involves reviewing the proposed SWZ concept design using the project's smart work zone plans and a mapping tool such as google earth or Geographic Information System (GIS). Placing device markers onto an online mapping tool allows for a visual review of device locations before they are placed in the field and allows for capture of the proposed coordinates of all devices.
- Device Staking involves field verifying planned SWZ device locations and marking where equipment should be placed for optimal visibility or data collection. This task may be completed by DOT, a DOT representative, a contractor, a traffic control sub, or a representative of the DOT. Field reviews ensure that SWZ devices can be placed in the field in an appropriate location avoiding areas without the proper space to safely deploy portable trailers.
- SWZ Deployment involves the SWZ Provider, Contractor, or Sub-Contractor bringing SWZ equipment on site for placement at marked locations in the project corridor.
- Software Integration involves adding the SWZ equipment into the traffic management software and developing any alert processing logic required for the SWZ systems to operate. Integration parameters should always be double checked for input accuracy.
- System Monitoring involves monitoring all devices deployed in an SWZ system to ensure all equipment is functioning and communicating properly with the traffic management software and is displaying the proper messages to motorists.

- System Evaluation/Review involves using performance data and lessons learned during the SWZ deployment to develop efficiencies for future deployments or future program goals.

Establishing a standard operating procedure with clearly defined steps for deployment allows for a better understanding of the level of effort needed to implement successful SWZ systems. This framework for deployment can be modified based on the project team's familiarity and comfortability with the systems being deployed or can be expanded for more complex projects.

- **Recommendation:** Establish and publish a standard operating procedure for the deployment of SWZ Systems.

6.4.2 SWZ Device Naming Convention Standardization

Portable SWZ devices deployed in the field are named upon integration into the SWZ management software. These are the device names seen when you interact with the devices in a software's user interface and are typically a combination of route name, roadway direction, mile marker, and the SWZ providers device fleet number.

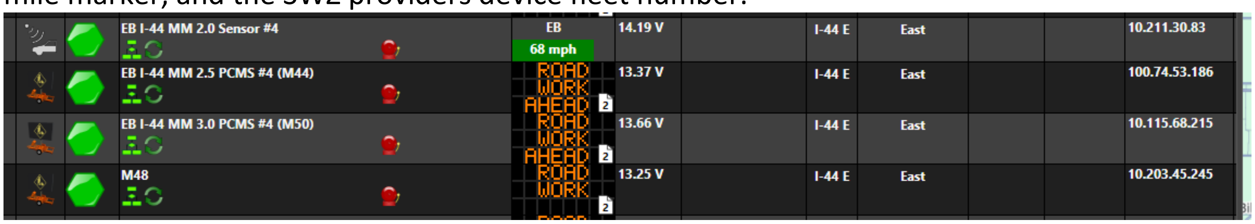


Figure 6.6 SWZ device name example

While somewhat arbitrary, standardization of SWZ device names allows for a more streamlined application of devices out on the roadway that follow current MoDOT device naming standards. Figure 6.5 below is an example of standard CMS naming for permanent ITS devices.

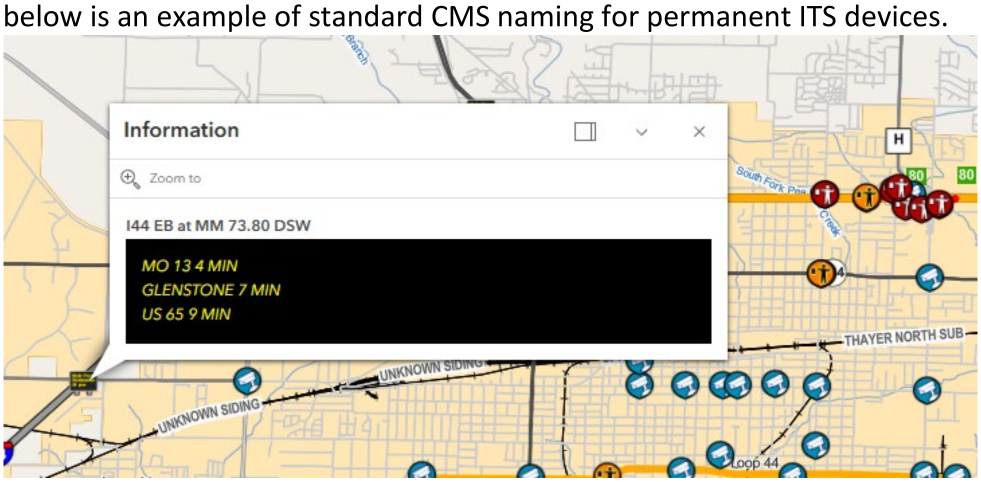


Figure 6.7 MoDOT CMS naming example

Adopting a consistent format for temporary devices enables practitioners familiar with permanent ITS naming conventions to quickly identify deployed equipment and understand device locations. Establishing standard naming conventions for SWZ deployments also supports future integration of portable devices into MoDOT TMC ATMS platforms, improving operational consistency and alignment with the existing ITS framework.

The recommended convention would include a SWZ indicator, route, direction, mile marker, device type, provider id, and fleet number.

For example (*note provider id "StW" in this example stands for StreetWise):
Deployed Sensor Name: EB I-44 MM 0.0 Sensor #1

- Standardized Name: SWZ I44 EB MM 79 Sensor StW

Deployed Sensor Name: EB I-44 MM 2.0 Sensor #4

- Standardized Name: SWZ I44 EB MM 77 Sensor StW

Deployed PCMS Name: EB I-44 MM 2.5 PCMS #4 (M44)

- Standardized Name: SWZ I44 EB MM 76.5 PCMS StWM44

- **Recommendation:** Establish a standard convention for portable devices in line with MoDOT naming conventions for permanent ITS.

6.4.3 SWZ Device Daily Monitoring

Smart work zone deployments are only effective when all the components are working properly and have good communications. The daily data management plan provided in this report can be used as a guide for implementing daily tracking standards. This effort does take some initial set up at the beginning of a project, but automation of some tasks such as the daily data downloads and uptime percentage calculations can be done if warranted. After the initial tracking setup for a project the daily device checks take, on average, less than a half hour a day. Compilation of weekly report summaries is an optional task to monitor performance but typically takes approximately one hour a week. Depending on the size and complexity of a project this task can be outsourced to an outside services team. Ongoing system monitoring during deployment ensures device operability and supports the viability of post-construction data analysis.

- **Recommendation:** Consider implementing daily monitoring of SWZ systems as outlined in daily data management plan.

6.4.4 SWZ Device ATMS Integration

Currently all three Missouri TMC's Advanced Traffic Management Systems are using TransCore's TranSuite software. The TMCs do support queue warning and variable speed warning messages as part of normal operations using permanent ITS devices that are not specifically linked to roadwork or construction.

The ATMS platforms MoDOT currently uses are capable of integrating portable ITS devices. While such integration would require a review of existing software contracts and potentially contract modifications, it is strongly recommended that MoDOT initiate an evaluation of the requirements for integrating portable devices. Enabling TMC integration would allow centralized monitoring, improved situational awareness, and more consistent operational management of SWZ deployments. Integrating all devices into the TMC ATMS would enable operators to support daily device monitoring, assume control of PCMS during incident response, and reduce operational complexity by eliminating the need to manage multiple standalone platforms (e.g., separate logins for systems such as JamLogic). In addition, centralized integration would support more consistent data sharing with third-party mapping providers and ensure that work zone device information is accurately reflected across MoDOT's official traveler information systems, including the Traveler Information Map.

- **Recommendation:** Initiate an evaluation of the requirements for integrating portable devices into Missouri ATMS systems.

6.5 Recommended Best Practices for Institutionalizing SWZ Systems into MoDOT Standard Practices

Institutionalizing SWZ systems within MoDOT's standard practices requires broad stakeholder engagement across districts and disciplines, including district management, traffic and construction engineers, resident engineers, planners, and technical staff. The recommendations presented in this report highlight the need to streamline processes and procedures to support consistent, effective SWZ deployment statewide.

Continued development and expansion of MoDOT's TSMO program can further support these objectives, along with coordinated outreach as new guidance, best practices, and JSPs for SWZs are developed and released. To facilitate communication between groups current standing meetings and groups such as the Statewide Resident Engineer should be utilized to provide a platform for information sharing, reinforce awareness of available tools and guidance, and soliciting feedback. Incorporating a recurring SWZ agenda item and distributing links to the most current resources can help ensure consistent statewide communication and alignment on SWZs.

In addition, a review and update of current pre-design protocols is recommended to ensure advanced work zone strategies are considered early in project development. Initial project scoping should include guiding questions such as:

1. Will the project impact mobility or safety?
2. Is the project located in an area with existing peak-hour delay or recurring queues, and will construction increase these impacts?
3. Have advanced work zone strategies been evaluated for this project?
    - **Yes:** Document the strategies evaluated.
    - **No, but evaluation is planned:** Identify the responsible group and anticipated date.
    - **No:** Document the rationale for determining advanced strategies are not needed.

4. If advanced work zone strategies are being considered, have the appropriate high level cost estimates been included in the project scoping documents?

Incorporating these considerations into early project development promotes proactive planning and supports more consistent integration of SWZ strategies across MoDOT projects.

- **Recommendation:** Incorporate a recurring SWZ agenda item on annual statewide meetings and/or trainings to distribute information and links to the most current SWZ resources, promote available SWZ tools and guidance, and solicit feedback.
- **Recommendation:** Review and update of current pre-design protocols to ensure advanced work zone strategies are considered early in project development.

Chapter 7: Next Steps

This project was conducted to quantify the effectiveness of SWZ deployments and document best practice recommendations for their successful application. The study focused on identifying proven practices for effective SWZ deployment, developing recommendations for institutionalizing SWZ systems within MoDOT's standard procedures, and establishing guidance to align specific construction project characteristics more easily with appropriate SWZ solutions. Collectively, these efforts are intended to support consistent, effective, and scalable implementation of SWZ strategies across future Missouri projects. The findings of this report support MoDOT's ongoing mission to advance work zone safety and operations while addressing workforce constraints and position the Department to apply successful strategies to future projects statewide.

The full list of recommendations from Chapter 6 incudes:

1. **Recommendation:** Develop a quick reference guide based on the Work Zone Impact Analysis Spreadsheet for times when a full data analysis cannot be performed.
2. **Recommendation:** Add additional information to the Engineering Policy Guide for what to do when data does not warrant advanced work zone strategy applications, but engineering judgement and past experience warrants work zone mitigation measures.
3. **Recommendation:** Review and update the content and cost information included in the Work Zone Impact Analysis Spreadsheet on an annual or bi-annual schedule. If no updates are needed a review certification date should be added.
4. **Recommendation:** Update the Work Zone Management Guidebook to match the current content on the 616.19 Work Zone Capacity, Queue and Travel Delay page of the MoDOT Engineering Policy Guide and reflect the most up to date information for MoDOT's Advanced Work Zone Strategy information. An annual or bi-annual schedule should be set for review and updates. If no updates are needed a review certification date should be added.
5. **Recommendation:** Remove or archive documents and manuals that are no longer recommended for use during advanced transportation system planning for TSMO and SWZ.
6. **Recommendation:** Develop additional design guidelines for MoDOT advanced transportation systems in lieu of SWZ standard plans to supplement the standard layout guidelines MoDOT provides.
7. **Recommendation:** Publish boiler plate JSP for SWZ Systems.
8. **Recommendation:** Establish and publish a standard operating procedure for the deployment of SWZ Systems.
9. **Recommendation:** Establish a standard naming convention for portable devices in line with MoDOT naming conventions for permanent ITS.
10. **Recommendation:** Consider implementing daily monitoring of SWZ systems as outlined in daily data management plan.
11. **Recommendation:** Initiate an evaluation of the requirements for integrating portable devices into Missouri ATMS systems.

12. **Recommendation:** Incorporate a recurring SWZ agenda item on annual statewide meetings and/or trainings to distribute information and links to the most current SWZ resources, promote available SWZ tools and guidance, and solicit feedback.
13. **Recommendation:** Review and update of current pre-design protocols to ensure advanced work zone strategies are considered early in project development.

Next steps for accomplishing these recommendations can be realized by categorizing the recommendations into a tiered approach. Tier One would be a review of the list for “low hanging fruit” or items that can be easily implemented with small changes and assigning relatively low effort action items. Tier Two would indicate larger tasks that would include more time, effort, and planning to accomplish. Tier Three items would be larger initiatives that may require outside services, additional funding, and/or coordination with multiple offices/regions/levels of management.

An example of some Tier One action items from the recommendation list above may include:

- Recommendation 1,7, 8 Action Item: Pull the provided tables, tools, and text from this report for review and testing on an upcoming SWZ deployment. After use by a small group make any adjustments needed to better fit MoDOT’s business practice and distribute for wider use.
- Recommendation 2 Action Item: Add a short paragraph in the Engineering Policy Guide 616.19 section with additional direction on who to contact via email when data does not warrant advanced work zone strategy applications, but engineering judgement and past experience warrants work zone mitigation measures.
- Recommendation 4 Action Item: Review and update portions of the Work Zone Management Guidebook; a full re-write is not likely required.

Examples of Tier Two items from the recommendation list above may include:

- Recommendation 3,5,6,10,12

Examples of Tier Three items from the recommendation list above may include:

- Recommendation 9,11,13

Additional item to consider for future research: it is recommended that the information that was assembled for the I-44 Strafford I-44 Project (7I3010 and SU0146): I-44 Strafford to Ramp B interchange be reviewed and utilized as MoDOT sees fit. The documentation in Appendix C was assembled to provide a research opportunity for driver reaction to speed feedback systems and driver reaction to queue warning. As this project has now been combined with larger corridor efforts edits and additions to the plan may be needed ahead of implementation.

The recommendations provided as part of this research aim to expand and improve on the already robust tools and guidance the Missouri Department of Transportation provides for work zones. Streamlining and updating current practices and procedures will aid the DOT in improving work zone safety, present already developed MoDOT tools for when to use work zone automation in a more user friendly and accessible manner, standardize advanced work zone practices to achieve consistent repeatable safety outcomes for travelers and workers when deployed, and reduce the frequency and severity of work zone crashes.

Chapter 8: References

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A1. Appendix A: Discovery Questionnaire

Discovery Questionnaire – TR202415 MoDOT TSMO Strategies and Automation
October 27, 2023

Name:
Position:
Department/Office:
Email address:
Phone:

Thinking of Missouri DOT's current use of Intelligent Work Zones (IWZ) and/or Work Zone TSMO please answer the following questions:

1. Design
   a. How are IWZ projects initiated? Are they part of the TMP (transportation management plan)?
   b. How is the IWZ project/work design developed? (in house plans, standard details, other?)
   c. If applicable, does post-construction feedback from previous projects influence the design of new IWZ projects?

2. Project coordination
   a. What methods are used to avoid conflicting/adjoining work areas/projects?
   b. Are closures coordinated with other departments when work is to be performed in overlapping or adjoining areas to optimize the closure?
   c. How does this coordination take place? If no coordination takes place - why not?

3. Outreach to the public
   a. How do you communicate project activities to the public? Trucking/Commercial Motor Vehicles?
   b. What determines the level of public communication for a project?

4. Current Work Zone Traffic Control and Operations Focus
   a. What "needs work" in your department? (what are the issues/challenges?)
   b. What is your department "currently working on"? (i.e., safety, etc.)
   c. What does your department want to work on? (ignoring money/time/staffing constraints)

5. Other items:
   a. What has worked well in the past in work zones?
   b. What has not worked well in work zones?
   c. What are the problems you want solved with this project?
   d. Top 5 challenges on Missouri Work Zones?
   e. What would be considered a successful outcome for this project?
   f. Any Additional Input?

B1. Appendix B: TSMO Strategy Memo 1.0

To:	Jenni Hosey, Senior Research Analyst Missouri Department of Transportation
From:	SRF Consulting Group
Date:	December 2023
Subject:	TR202415 – Preliminary Technical Memorandum of Potential TSMO Strategies

Technical Memorandum of Potential TSMO Strategies for the MoDOT

This preliminary memorandum summarizes a discovery investigation into the current practices within the Missouri Department of Transportation (MoDOT) for Smart Work Zone (SWZ) deployments. SRF gained insight into the Department's practices through outreach questionnaires, review of MoDOT documentation of current standard operating procedures (SOPs) for SWZ deployments, investigation into the in-place systems and technology used by MoDOT, and the current MoDOT business practices. Based upon the needs identified by the Technical Advisory Committee (TAC) and additional outreach within MoDOT, SRF assembled a list of potential SWZ strategies. This document summarizes findings of the Department's current SWZ processes and procedures, current work zone challenges, and provides information on identified potential TSMO strategies such as approximate cost, safety benefits, equipment needs, and common performance metrics for each strategy.

Existing Conditions

Determination of current practices in Missouri work zones was investigated through a literature search of published MoDOT guidance, a questionnaire completed by the TAC and/or MoDOT personnel that members of the TAC included in their responses, and a follow up meeting of the TAC. Additional information was provided on the advanced transportation management systems (ATMS) and device connectivity capabilities from the Missouri Traffic Management Centers (TMCs).

Existing Policy and Procedures

Policy and procedure inquiry was made with a focus on SWZ design, coordination, and public outreach. MoDOT's policy and best practices for work zones was found in the Engineering Policy Guide (EPG) section 616.13 (now 616.19) and 616.14 (now 616.20). Information on capacity restrictions and cautionary zones, estimation of demand vs capacity and queue length are all provided here as well as links to the Work Zone Impact Analysis Spreadsheet. Section 616.13.6.3 on SWZ Strategy Selection provides an overview of eight smart work zone strategies that can be used on Missouri work zones to provide improved warning and real-time work zone traffic information to the traveling public. Unfortunately, many links in section 616.13, such as the instructional videos for the Work Zone Impact Analysis Spreadsheet and the nonstandard Work Zone Intelligent Transportation System special provision, are not functional at this time.

Standalone documents from MoDOT were also consulted for this investigation including the Work Zone Management Guidebook from March of 2021 and the Transportation Systems

Management and Operations (TSMO) Program and Action Plan from January of 2017. The Work Zone Management Guidebook seems to act as a supplement to section 616.13.6.3 of the EPG by providing additional discussion on applications, benefits, and diagrams on SWZ deployments. The Guidebook also provides TSMO Priority Index Maps for Major Routes and a walkthrough of how to assess work zone impacts using the Work Zone Impact Analysis Spreadsheet. The 2017 TSMO Program and Action Plan Work Zone Management (WZM) Section provided information on the action items identified previously by MoDOT, but as there are no updates to this publication it is unclear how many of the action items are completed or how many remain in progress.

Existing Procedure – Questionnaire Responses

Information provided directly by DOT personnel that work in or with work zones is typically more valuable than what can be found in published policies or manuals. These insights give a better understanding of how SWZs are managed, what resources are being used, how widely information is shared, and how many people have knowledge of the available DOT resources. Like the policy review, the questionnaire focused on design, coordination, and public outreach, but also had additional sections on the Department's current focus and current successes and challenges.

Based on the questionnaire findings and subsequent TAC meeting, the initial work zone challenges to be included in the project investigation are speeding, distracted driving, communication – real time notification, and consistency/compliance. A full summary of the questionnaire responses will be included in the final report.

SWZ applications identified for inclusion in the Literature Search:

- Speed feedback (both simple feedback and changeable/advisory)
- End of queue warning
- Temporary rumble strips
    - Including improvements for ease of use
- Vehicle entering system
- Travel time
    - Specifically temporary applications

Traffic Management Center (TMC)

The Missouri DOT utilizes three TMCs to manage their roadways. The St. Louis Gateway Guide covers the five-county region that makes up the greater St. Louis area, including the City of St. Louis, St. Louis County, Jefferson County, Franklin County, and St. Charles County. Kansas City Scout provides traffic incident management services to the Kansas City metropolitan region and beyond, including portions of Kansas and Missouri statewide. TMC of the Ozarks in Springfield cover the 21 counties in the Southwest District, as well as the I-44 corridor in the Central District. A map of the TMC management areas is shown in Figure 1.

All three TMCs use Transcore's TranSuite and/or Parsons iNET ATMS software. The St. Louis region uses both iNET; for freeway operations and TranSuite; for arterial operations.

Currently, temporary smart work zone applications, such as portable changeable message signs (PCMS), sensors, and cameras, are not integrated into the Gateway or KC Scout TMCs. The TMCs do support queue warning and variable speed warning messages as part of normal operations using permanent Intelligent Transportation System (ITS) devices that are not specifically linked to roadwork or construction. TMC of the Ozarks has 34 PCMS boards, 2 portable radar trailers, and 5 portable CCTV cameras. However, SWZ deployments are the responsibility of the contractor and are not integrated into the ATMS.

Figure B.1: Map of TMS Management Areas

Potential TSMO Strategies

A full investigation of the identified potential TSMO strategies is included in the Literature Search. Information such as approximate cost, safety benefits, equipment needs, and common performance metrics for each strategy are included in this section. For the purposes of this project and deployment during the 2024 construction season, it is recommended that any system deployed includes communications and software components. Communication methods will depend on the system but may include radio connections between devices and modem communications for remote data downloads. Software type is also dependent on the system deployed but may consist of onboard programmed computer processing units (CPUs) and software provided by the vendor that can be accessed online to view and download data and show device health information.

Speed Feedback Systems

The work zone management guidebook defines a speed feedback system as "a sensor-based speed warning system used in a work zone is the Speed Advisory display, which informs the approaching motorists of the posted advisory speed and their current speed to warn them if they are driving above the speed limit defined. This speed displays are portable and can be used in the work zone wherever excessive speeding is a problem." Variations of this system include using advisory speeds based on worker presence and variable speed limit (VSL) based on real-time traffic speeds to assist with speed harmonization.

Approximate Cost

System costs vary based on project duration, number of units deployed, and vendor. High level cost estimates should be used if the duration and number of devices is unknown. Communications and software costs also need to be considered. As these are all unknown at this time, cost information from other US states was reviewed for approximation.

Table B-1: Cost range of speed feedback system

Minnesota (High level cost estimate for use if duration and needs are unknown)	Iowa (VSL)	Texas (VSL)
$13,000	$22,000	$124,200

Safety Benefits

Safety metrics identified during the literature search show speed feedback trailers reduce speeds anywhere from 2mph-13mph, show a notable decrease in crashes, and show a positive correlation between the implementation of speed feedback technology and increased compliance with work zone regulations.

Equipment Needs

Equipment needs vary depending on the complexity of the system:

- Speed feedback standard: speed feedback trailer.
- Speed feedback integrated: speed feedback trailer, traffic sensors, modem (communications), and software integration
- Speed feedback integrated variable: speed feedback trailer, traffic sensors, modem (communications), and software integration

Common Performance Metrics

Two performance metrics are commonly used:

- Speed compliance
- Consistency of speeds throughout the work zone

End of Queue Warning

EPG definition of a queue warning systems (Section 616.13.6.3): "A Queue Warning system is used to inform travelers about upcoming congested or stopped traffic conditions. The queue warning system informs drivers of an impending traffic situation and avoid emergency braking and queue-related collisions. This system typically consists of roadside sensors and Portable Changeable Message Signs (PCMS) placed upstream of the work zone. The basic principle of this system is when sensors detect slowing or stopped vehicles, it sends signals to the PCMS where warning signs are displayed advising travelers about an impending traffic queue. The sensors and PCMS should be placed in such a way that if the queue reaches within 1-2 miles (based on the speed and length of work zone) of PCMS, it should start displaying the warning signs alerting the approaching motorists of queue conditions."

Approximate Cost

System costs will vary based on project duration, number of units deployed, and vendor. High level cost estimates should be used if the duration and number of devices is unknown. Communications and software costs also need to be considered. As these are all unknown at this time, cost information from other US states was reviewed for approximation.

Table B-2: Cost range of end of queue warning system

Minnesota (High level cost estimate for use if duration and needs are unknown)	Iowa (6-month deployment, 4 sensors and 4 PCMS; 2 per direction)	Nebraska (6-month deployment, 1 CCTV, 3 Sensors, 4 PCMS)
$75,000	$39,800	$166,225

Safety Benefits

Safety metrics identified during the literature search show that proactive notification from end of queue warning systems equips drivers with timely information, prompting them to reduce their speeds in preparation for changing traffic dynamics. These systems also help with significantly decreasing the number of abrupt speed reductions resulting in smoother traffic conditions. Studies in both Texas and Minnesota demonstrated a reduction in rear end crashes of 44% and 22% respectively, with Minnesota reporting a 54% reduction in near-crash events when end of queue warning systems are utilized.

Equipment Needs

Required equipment includes traffic sensors, PCMS, modem (communications), and software integration. Optional equipment includes portable camera with modem (communications), and software integration.

Common Performance Metrics

Common performance metrics include:

- Traffic volumes
- Travel speeds
- Crash data
- System compliance
- Queue length

Temporary Rumble Strips

EPG definition of temporary rumble strips (Section 616.13.6.3): "temporary rumble strips are a strategy for reducing distracted driving and achieving MoDOT's work zone safety goals. Temporary rumble strips are comprised of a series of raised elongated bumps placed upon the surface of the roadway to provide an audible and vibratory alert to drivers of the upcoming work zone."

Approximate Cost

System costs will vary based on project duration, number of units deployed, and vendor. High level cost estimates should be used if the duration and number of devices is unknown. Communications and software costs also need to be considered for evaluation of performance. As these are all unknown at this time, cost information from other US states was reviewed for approximation.

Table B-3: Cost range of temporary rumble strips

Kansas (cost per approach, not including install cost)	Missouri (set of three, one direction, not including install cost)	Maryland (set of three, one direction)
$1,537	$5,115	$6,200

Safety Benefits

Safety metrics identified during the literature search show decreases in speed violations between 18.2 % and 21.2% with speed reductions between 1mph to 11.4mph.

Equipment Needs

Preformed rumble strips are the only equipment needed. Monitoring equipment for this deployment includes traffic sensors for data collection and evaluation.

Common Performance Metrics

Common performance metrics include:

- Traffic volumes
- Travel speeds
- Speed compliance

Vehicle Entering System

Work Zone Management Guidebook definition of a Vehicle Entering Systems: "The usage of detectors and CMS helps in notifying the motorists when a construction vehicle is planning to enter or exit from work zones. This display of messages can prepare travelers for a slowdown or potential merging conflicts due to construction vehicles. These warnings also reduce the frequency of incidents where motorists follow work vehicles."

Approximate Cost

System costs will vary based on project duration, number of units deployed, and vendor. High level cost estimates should be used if the duration and number of devices is unknown. Communications and software costs need to be included for system evaluation. As these are all unknown at this time, cost information from other US states was reviewed for approximation.

Table B-4: Cost range of vehicle entry system

Minnesota (High level cost estimate for use if duration and needs are unknown)	Iowa (one sensor and PCMS pair deployed for three months)	FHWA (3 PCMS, 2 sensors)
$13,000	$5,790	$53,450

Safety Benefits

Safety benefits identified during the literature search show vehicle entering systems prompt speed reduction and harmonization. They also provide real time notification to drivers of changing traffic conditions and effectively assist with maintaining driver attention and reducing distractions when looking at human factors and attention management in transportation.

Equipment Needs

Required equipment includes a sensor for vehicle detection, PCMS, modem (communications), and software integration. Optional equipment includes portable camera with modem (communications), and software integration.

Common Performance Metrics

Common performance metrics include:

- Traffic volumes
- Travel speeds
- System compliance

Travel Times (Temporary)

EPG definition of temporary travel time systems (Section 616.13.6.3): "a travel time advisory system consists of travel times through a work zone. Travelers seek accurate, timely, and reliable information regarding their travel routes in a convenient form. Apart from benefitting the individual motorist, travel time information can lead to system-wide benefits when many users respond in a predictable way to the information they received.

The benefits of travel time information for work zones include less stressful conditions for the motorists and more predictable and safe travel conditions.

Work zones are infamous for travel delays and lead to traffic conditions that violate travelers' expectations. Hence, the usage of travel times becomes important rather than a good-to-have for work zones. Travel time systems gather real-time traffic information in work zones with the help of sensors, video cameras, and communicate the scenario to upstream motorists with the help of portable Changeable Message Signs (PCMS).

The messages of travel time are displayed on CMS activated by the sensors. This information helps drivers understand the magnitude of delay they will encounter and to make an informed decision in how to conduct their travels.

Probe data may be used for travel time measurement where available, and volumes provide sufficient sample size."

Approximate Cost

System costs will vary based on project duration, number of units deployed, and vendor. High level cost estimates should be used if the duration and number of devices is unknown. Communications and software costs also need to be considered. As these are all unknown at this time, cost information from other US states was reviewed for approximation.

Table B-5: Cost range of temporary travel time system

Wisconsin (5 months, 14 PCMS, 16 sensors, 2 CCTV)	Iowa (6 months, 12 sensors, 8 PCMS	Texas (24 months, 4 PCMS, 4CCTV, 8 Sensors)
$113,000	$94,720	$410,000

Safety Benefits

Safety benefits identified during the literature search include allowing drivers to make informed decisions by providing critical real-time information.

Equipment Needs

Required equipment includes sensors and PCMS, modem (communications), and software integration. Optional equipment includes portable camera with modem (communications), and software integration.

Common Performance Metrics

Common performance metrics include:

- Traffic volumes
- Travel speeds
- System compliance
- System Accuracy

Next Steps

This preliminary memorandum summarizes a discovery investigation into the current practices within MoDOT for SWZ deployments. A secondary memorandum will be completed upon project selection to better estimate the system costs based on the project details and device needs.

C1. Appendix C: I-44 Strafford I-44 Project (7I3010 and SU0146): I-44 Strafford to Ramp B interchange; Work Zone Data Analysis and I-44 Strafford SWZ Materials

I-44 Strafford WZ Data and Analysis; available upon request.
I-44 Strafford SWZ Materials:

- 01_TR202415 _ Project Selection Information for I-44 Strafford_J7I3010
- 02_TR202415_TSMO Strategy Memo Update_J7I3010
- 03_SWZ Layout_J7I3010
- 04_SWZ JSP_J7I3010_DRAFT
- 05_TR202415 _ Daily Monitoring Plan_J7I3010_DRAFT
- 06_TR202415 _ Project Evaluation Plan_J7I3010_ DRAFT

8.1.1 01_TR202415 _ Project Selection Information for I-44 Strafford_J7I3010

TR202415 TSMO Strategies in Work Zones I-44 Strafford

By

SRF Consulting Group

Prepared for

Missouri Department of Transportation

Winter 2024

Project Overview I-44 Strafford

Location: I-44 Strafford to Hwy B interchange and Hwy B interchange to Conway Rest Area
Work Type: Pavement replacement and deceleration lanes.

Staging Strategy: Splitting traffic into a contraflow pattern to maintain two EB and two WB lanes with crossovers. Ramp deceleration lane work will be to the east of the main project area. This project will not have traffic in contraflow lanes during the winter months.

Project Dates: October 2024 letting, project start Spring 2025.
Duration: 2.5-year project completion in 2027

Safety and Mobility Concerns: Queuing is a concern at both ends of the main project section. Reducing to one lane in each direction showed that 10-to-15-mile backups are expected in the WB direction. Utilization of a contraflow lane designation should reduce backups to 1-2 miles. There are a lot of vertical curves in this area that may cause backups due to slower moving trucks. PCMS to direct trucks into the outside lane and additional cameras in the work zone were discussed.

Traffic Data for the area and grade information was obtained from the MoDOT Transportation Planning Office from the Automatic Traffic Recorder (ATR) located on I-44 one half mile south of the Highway B interchange. MoDOT's Work Zone Impact Analysis Spreadsheet was used to review the 2023 traffic data under four separate scenarios: summer peak time traffic volumes, a three present grade test, all trucks in right lane, and trucks using either lane (ATR lane utilization). The Work Zone Impact Analysis Spreadsheet results can be found in Appendix C; a summary of the results is below.

Existing Conditions I-44 Strafford

Table C-1 I-44 Strafford existing traffic conditions

	Average Daily Traffic
AADT (2023)	39,983
Construction Year (2026)	40,488
Design Year (2036)	44,366
Directional Distribution (E/W)	49.4% / 50.6%
Peak Hour	7.06%
Percent Trucks	34.72%

Review of the data for I-44 eastbound and westbound using the Work Zone Impact Analysis Spreadsheet showed queue lengths of one to two miles with longer queues expected in the westbound direction. *Data source: Automatic Traffic Recorder (ATR) located at I-44 0.5 mile SW/O RT B provided by MoDOT Transportation Planning.*

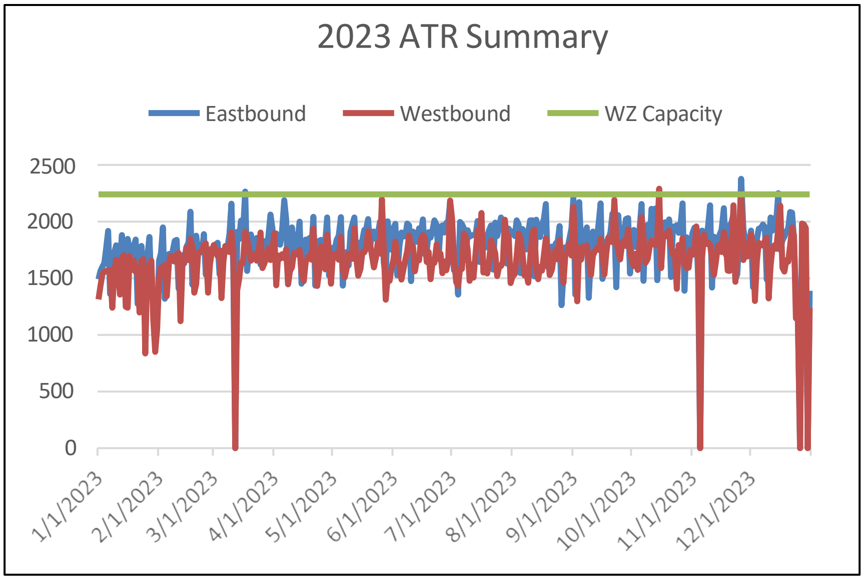


Figure C.1 I-44 Strafford traffic capacity review

A review of grade changes through the project area, lane utilization, and trucks directed into one lane was completed to investigate the impacts on queue length.

Review of grade impact on length of queue:

- Changing the grade percentage from <2% to >3% has minimal impact when the length of grade is set to 1-mile, when the grade is changed, and the length is set to 1.5-miles or longer this has an impact on queue lengths:
- 1.5-mile grade length at >3%
    - ~2-mile queue in the EB direction
    - ~1-mile queue in the WB direction

Review of queue length impacts when trucks are kept into one lane vs. letting them use both lanes:

- 50/50 total lane volume split
- 1.5-mile grade length at >3%
    - ~3-4-mile queue in both the EB and WB directions

Review of the lane utilization from the data summary for sensitivity analysis:

- Lane utilization varied by time of day and volume; however, the hourly lane utilization profile was applied to the average summer peak day.
- Assumed all trucks in one lane:
    - 1-mile grade length at >3%
        - 0.5 to 1 mile queue in both the EB and WB directions
        - 1.5-mile grade length at >3%
        - 3.5 mile to 7-mile queue in both the EB and WB directions

Based on the above summary, the length of the grade is the contributing factor when looking at the impacts of grade on the capacity of the work zone and potential queue lengths. The ATR Lane utilization was very imbalanced in the overnight hours as anticipated and was closer to 60/40 during peak periods. This does have an impact on the anticipated queues, especially when combined with a 1.5 mile long grade. This review demonstrated that anticipated queues, assuming two lanes still remain open, we would not anticipate seeing queues longer than 7 miles under a typical summer peak day (Friday or Sunday). Of course, if a day is not typical or there is an incident, these queues may be longer. Based on this review, if trucks are directed into designated lanes, it may be necessary to extend the queue warning system.

The following recommendations are based on two lane operations in each direction as stated in the traffic control plans.

SWZ Recommendations I-44 Strafford

Based on data review and meetings with the DOT the following systems are recommended:

- Queue detection with CCTV
- Speed Feedback System with monitoring

As part of the SWZ project planning for I-44 Project (7I3010 and SU0146): I-44 Strafford to Ramp B interchange SWZ layout for temporary traffic control stages 1-8 were created and a job specific JSP was created for submittal to MoDOT in 2024 with a scheduled project start in Spring of 2025. A daily data management plan and a post project analysis plan were written and presented to the TAC in January 2025. In February 2025, the project team was notified that I-44 Project (7I3010 and SU0146) had been removed from the STIP Letting. All SWZ materials developed for Project (7I3010 and SU0146): I-44 Strafford to Ramp B interchange is located in this Appendix C.

Items prepared for I-44 Project (7I3010 and SU0146): I-44 Strafford to Ramp B interchange:

1. WZ Data and Data Review
    a. JSU0146 and J7I3010 - I-44 Traffic Data
    b. SU0146_and_7I3010_Length_and_Grade
    c. 2023_Summer Peak
    d. 2023_Summer Peak_3 percent grade test
    e. 2023_Summer Peak All Trucks in RT Lane
    f. 2023_Summer Peak ATR Lane Utilization
2. TR202415_TSMO Strategy Memo Update_J7I3010
3. SWZ Layout_J7I3010
4. SWZ JSP_J7I3010_DRAFT
5. TR202415 _ Daily Monitoring Plan_J7I3010_DRAFT_MoDOT Template
6. TR202415 _ Project Evaluation Plan_J7I3010_ DRAFT _MoDOT Template

8.1.2 02_TR202415_TSMO Strategy Memo Update_J7I3010

SRF No. 16729

To:	Jenni Hosey, Senior Research Analyst Missouri Department of Transportation
From:	SRF Consulting Group
Date:	May 2024
Subject:	TR202415 – TSMO Strategies for I-44 Project J7I3010
Attachments:	SWZ Layout.pdf and SWZ JSP_J7I3010_DRAFT.docx

Potential TSMO Strategies for I-44 Project J7I3010

This preliminary memorandum summarizes the proposed smart work zone recommendations for I- 44 Project J7I3010. We are seeking feedback on the proposed SWZ layouts and accompanying JSP.

Project Overview:

Location: I-44 Strafford to Hwy B interchange and Hwy B interchange to Conway Rest Area

Work Type: Pavement replacement and deceleration lanes.

Staging Strategy: Splitting traffic into a contraflow pattern to maintain two EB and two WB lanes with crossovers. Ramp deceleration lane work will be to the east of the main project area. This project will not have traffic in contraflow lanes during the winter months.

Project Dates: October 2024 letting, project start Spring

2025. Duration: 2.5-year project completion in 2027

Safety and Mobility Concerns: Queuing is a concern at both ends of the main project section. Reducing to one lane in each direction showed that 10-to-15-mile backups are expected in the WB direction. Utilization of a contraflow lane designation should reduce backups to 1-2 miles. There are a lot of vertical curves in this area that may cause backups due to slower moving trucks. PDMS to direct trucks into the outside lane and additional cameras in the work zone were discussed.

Existing Conditions

Table C-2 I-44 Strafford existing traffic conditions

	Average Daily Traffic
AADT (2023)	39,983
Construction Year (2026)	40,488
Design Year (2036)	44,366
Directional Distribution (E/W)	49.4% / 50.6%
Peak Hour	7.06%
Percent Trucks	34.72%

Review of the data for I-44 eastbound and westbound using the Work Zone Impact Analysis Spreadsheet showed queue lengths of one to two miles with longer queues expected in the westbound direction. *Data source: Automatic Traffic Recorder (ATR) located at I-44 0.5 mile SW/O RT B provided by MoDOT Transportation Planning.*

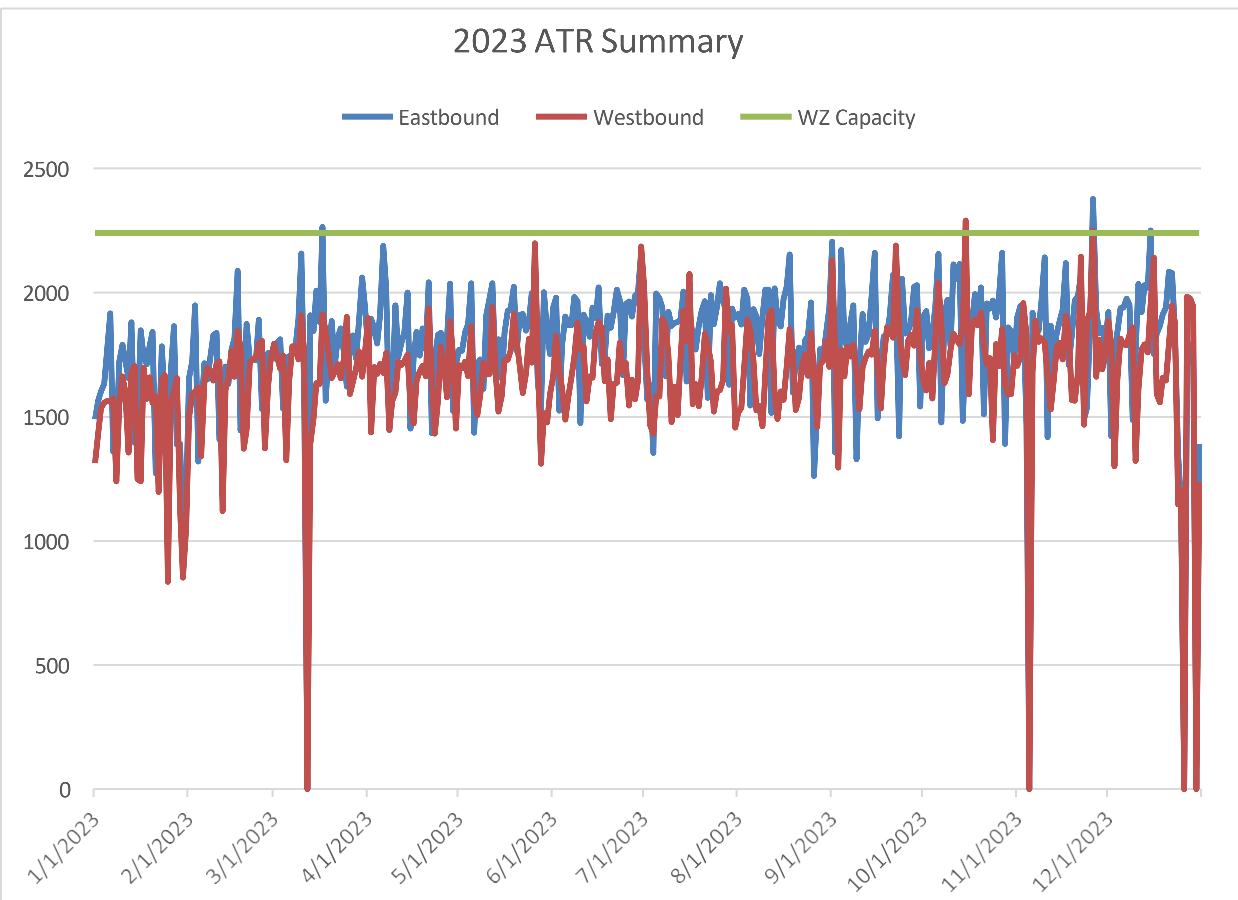


Figure C.2 I-44 Strafford traffic capacity review

A review of grade changes through the project area, lane utilization, and trucks directed into one lane was completed to investigate the impacts on queue length.

Review of grade impact on length of queue:

- Changing the grade percentage from <2% to >3% has minimal impact when the length of grade is set to 1-mile, when the grade is changed, and the length is set to 1.5-miles or longer this has an impact on queue lengths:
- 1.5-mile grade length at >3%
    - ~2-mile queue in the EB direction
    - ~1-mile queue in the WB direction

Review of queue length impacts when trucks are kept into one lane vs. letting them use both lanes:

- 50/50 total lane volume split
- 1.5-mile grade length at >3%
    - ~3-4-mile queue in both the EB and WB directions

Review of the lane utilization from the data summary for sensitivity analysis:

- Lane utilization varied by time of day and volume; however, the hourly lane utilization profile was applied to the average summer peak day.
- Assumed all trucks in one lane:
    - 1-mile grade length at >3%
        - 0.5 to 1 mile queue in both the EB and WB directions
    - 1.5-mile grade length at >3%
        - 3.5 mile to 7-mile queue in both the EB and WB directions

Based on the above summary, the length of the grade is the contributing factor when looking at the impacts of grade on the capacity of the work zone and potential queue lengths. The ATR lane utilization was very imbalanced in the overnight hours as anticipated and was closer to 60/40 during peak periods. This does have an impact on the anticipated queues especially when combined with a

1.5 mile long grade. This review demonstrated that anticipated queues, assuming two lanes still remain open, we would not anticipate to see queues longer than 7 miles under a typical summer peak day (Friday or Sunday). Of course if a day is not typical or there is an incident, these queues may be longer.

Based on this review, if trucks are directed into designated lanes it may be necessary to extend the queue warning system.

The following recommendations are based on two lane operation in each direction as stated in the traffic control plans.

Recommendations

Based on data review and meetings with the DOT the following systems are recommended:

- Queue detection with CCTV.
- Speed Feedback System with monitoring.

End of Queue Warning

EPG definition of a queue warning systems (section 616.13.6.3): "A Queue Warning system is used to inform travelers about upcoming congested or stopped traffic conditions. The queue warning system informs drivers of an impending traffic situation and avoid emergency braking and queue- related collisions. This system typically consists of roadside sensors and Portable Changeable Message Signs (PCMS) placed upstream of the work zone. The basic principle of this system is when sensors detect slowing or stopped vehicles, it sends signals to the PCMS where warning signs are displayed advising travelers about an impending traffic queue. The sensors and PCMS should be placed in such a way that if the queue reaches within 1-2 miles (based on the speed and length of work zone) of PCMS, it should start displaying the warning signs alerting the approaching motorists of queue conditions."

Safety Benefits

Safety metrics identified during the literature search show that proactive notification from end of queue warning systems equips drivers with timely information, prompting them to reduce their speeds in preparation for changing traffic dynamics. These systems also help with significantly decreasing the number of abrupt speed reductions resulting in smoother traffic conditions. Studies in both Texas and Minnesota demonstrated a reduction in rear end crashes of 44% and 22% respectively, with Minnesota reporting a 54% reduction in near-crash events when end of queue warning systems are utilized.

Equipment Needs

The required equipment includes traffic sensors, PCMS, modem (communications), and software integration. Suggested equipment includes portable camera with modem (communications), and software integration.

Common Performance Metrics

Common performance metrics include:

- Traffic volumes
- Travel speeds
- Crash data
- System compliance
- Queue length

Speed Feedback Systems

The work zone management guidebook defines a speed feedback system as “a sensor-based speed warning system used in a work zone is the Speed Advisory display, which informs the approaching motorists of the posted advisory speed and their current speed to warn them if they are driving above the speed limit defined. This speed displays are portable and can be used in the work zone wherever excessive speeding is a problem.”

Safety Benefits

Safety metrics identified during the literature search show speed feedback trailers reduce speeds anywhere from 2 mph-13 mph, show a notable decrease in crashes, and show a positive correlation between the implementation of speed feedback technology and increased compliance with work zone regulations.

Equipment Needs

Equipment needs:

- Speed feedback integrated: speed feedback trailer, traffic sensors, modem (communications), and software integration.

Common Performance Metrics

Two performance metrics are commonly used:

- Speed compliance
- Consistency of speeds throughout the work zone

Queue Warning System Staging Summary – see attachment for layout images.

Stage 1 Traffic: I-44 EB outside lane night work lane closures for shoulder strengthening.

Stage 1 SWZ: Queue Warning for night work outside shoulder strengthening.

I-44 EB: Sensor 500 ft from merge point. In place CCTV 44 at Strafford should be able to see the merge point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS just over 1 mile upstream, placed in between the work zone entrance signing plan.

Stage 2 Traffic: I-44 EB lanes pushed to outside lane and newly paved outside shoulder for inside shoulder work.

Stage 2 SWZ: Queue warning for daytime inside shoulder strengthening and guardrail install.

I-44 EB: Sensor 600 ft from lane shift point. In place CCTV 44 at Strafford should be able to see the merge point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan.

Stage 3 Traffic: I-44 WB inside lane closed, I-44 EB in contra flow (2 EB outside, 1 WB inside)

Stage 3 SWZ: I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS.

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

Stage 4 Traffic: I-44 WB outside lane closed, I-44 EB in contra flow (2 EB outside, 1 WB inside)

Stage 4 SWZ: I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS.

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

Stage 5 Traffic: I-44 WB inside lane closed, I-44 EB in contra flow (2 EB outside, 1 WB inside)

Stage 5 SWZ: I-44 EB: Sensor 500 ft from lane shift point. Combo CMS + Sensor 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford, MM 88 should be able to see merge area.

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

Stage 6 Traffic: I-44 WB outside lane closed, I-44 EB in contra flow (2 EB outside, 1 WB inside)

Stage 6 SWZ: I-44 EB: Sensor 500 ft from lane shift point. Combo CMS + Sensor 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford, MM 88 should be able to see merge area.

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

Stage 7 Traffic: Curve realignment. EB I-44 inside lane closed, one lane EB in WB lanes. WB shoulder closure.

Stage 7 SWZ: I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS.

Planned CMS at work zone EB entrance can be used for TIM if needed.

I-44 WB: Sensor+ CCTV 600 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS+ Sensor 1.2 miles upstream. CMS 1.5 miles upstream.

Stage 8 Traffic: Curve realignment. EB I-44 outside lane closed, one lane EB in WB lanes. WB shoulder closure.

Stage 8 SWZ: I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS.

Planned CMS at work zone EB entrance can be used for TIM if needed.

I-44 WB: Sensor+ CCTV 600 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS+ Sensor 1.2 miles upstream. CMS 1.5 miles upstream.

Speed Feedback System Staging Summary – see attachment for layout images.

This deployment will be done in two phases. Phase one will be data collection during stage 3 to review traffic speeds and driver behavior with no feedback on their speeds while they are in the construction area. Phase two will be during the deployment of the speed feedback system during stage 4 and beyond to review traffic speed and driver compliance when they are notified of their speeds while they are in the construction area.

Stage 3: Data collection; use queue detection sensors at EB and WB work area approaches and 2 sensors within the work zone at 1.6 mile spacing.

Stage 4: Add Speed Feedback trailers within the work zone at approximately 1.5 mile spacing; 9 trailers. For WB traffic place three single trailers alongside the open lane, for EB contraflow traffic place one trailer per direction of travel in three locations.

Stage 5 and 6: Add Speed Feedback trailers within the work zone at approximately 1.2 mile spacing; 6 trailers. For WB traffic place two single trailers alongside the open lane, for EB contraflow traffic place one trailer per direction of travel in two locations.

Stage 7 and 8: Add Speed Feedback trailers within the work zone at approximately 1.2 mile spacing; 3 trailers. For WB contraflow traffic place one trailer per direction of travel at one location, for EB traffic place one trailer alongside the open lane.

Other System Consideration

Temporary Long-Term Rumble Strips are listed in the plan quantities but were not planned for an active review as part of this investigation due to the moving work zone extents between stages. If the contractor has chosen locations to install this system SRF would be willing to monitor the effectiveness.

Alternate route travel times were reviewed and determined not to be a good fit as there was no good alternate route of less than 15 minutes.

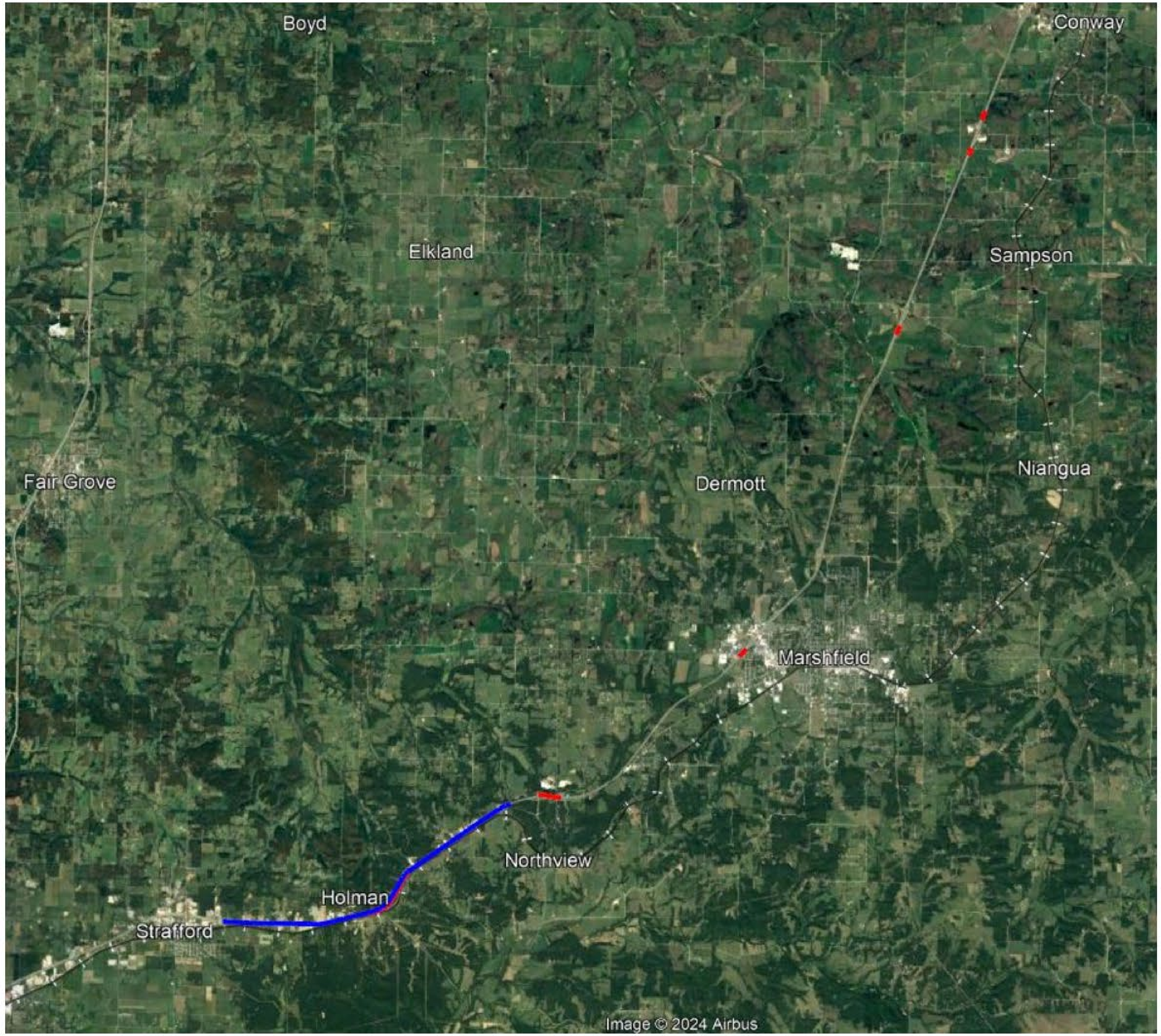
Approximate Cost

An engineer's estimate can be provided after review and approval of smart work zone layouts and JSP.

Next Steps

This memorandum summarizes the proposed smart work zone layouts for I-44 project J7I3010. Please review and provide comments by **Wednesday June 5th, 2024**. SRF is available to provide a walkthrough of the layouts and answer any questions.

8.1.3 03_SWZ Layout_J7I3010



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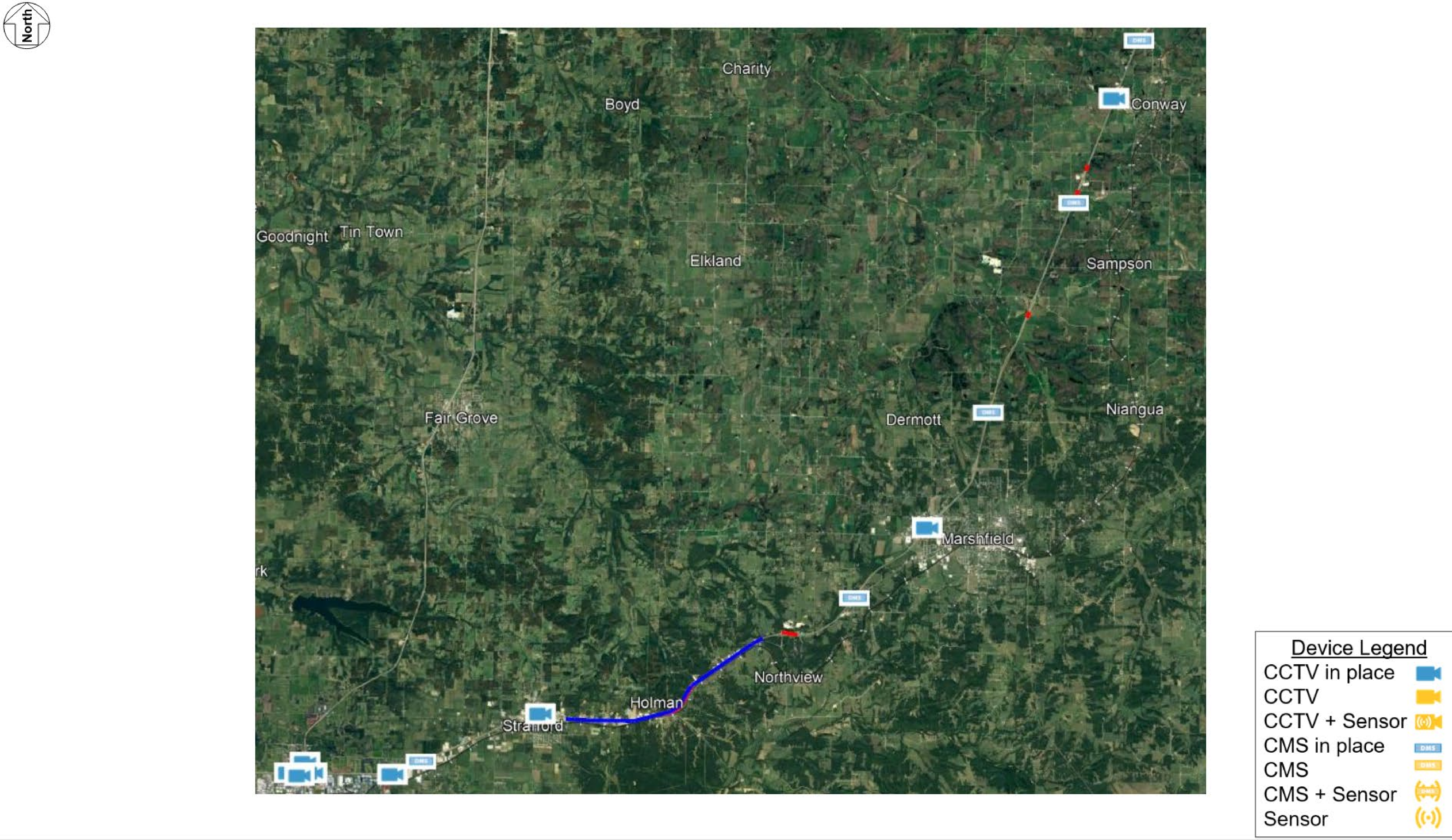
SRF no. 16729
May 2024

J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

Project Overview

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 1



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SRF no. 16729
May 2024

J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

In Place ITS

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 2

North

Stage 1: Queue Warning for night work outside shoulder strengthening.

I-44 EB : Sensor 500 ft from merge point. In place CCTV 44 at Strafford should be able to see the merge point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS just over 1 mile upstream, placed in between the work zone entrance signing plan.

Device Legend

- CCTV in place
- CCTV
- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
- Sensor

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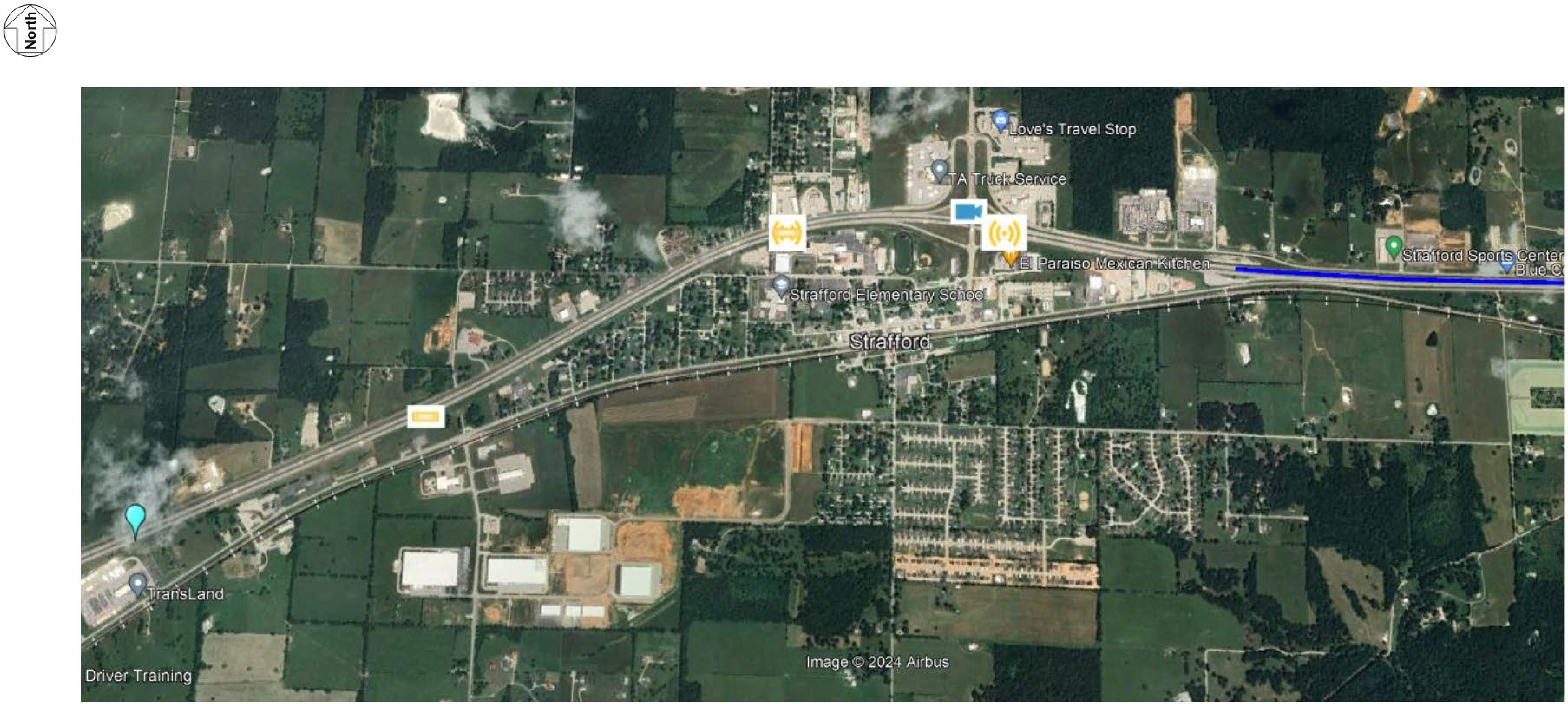
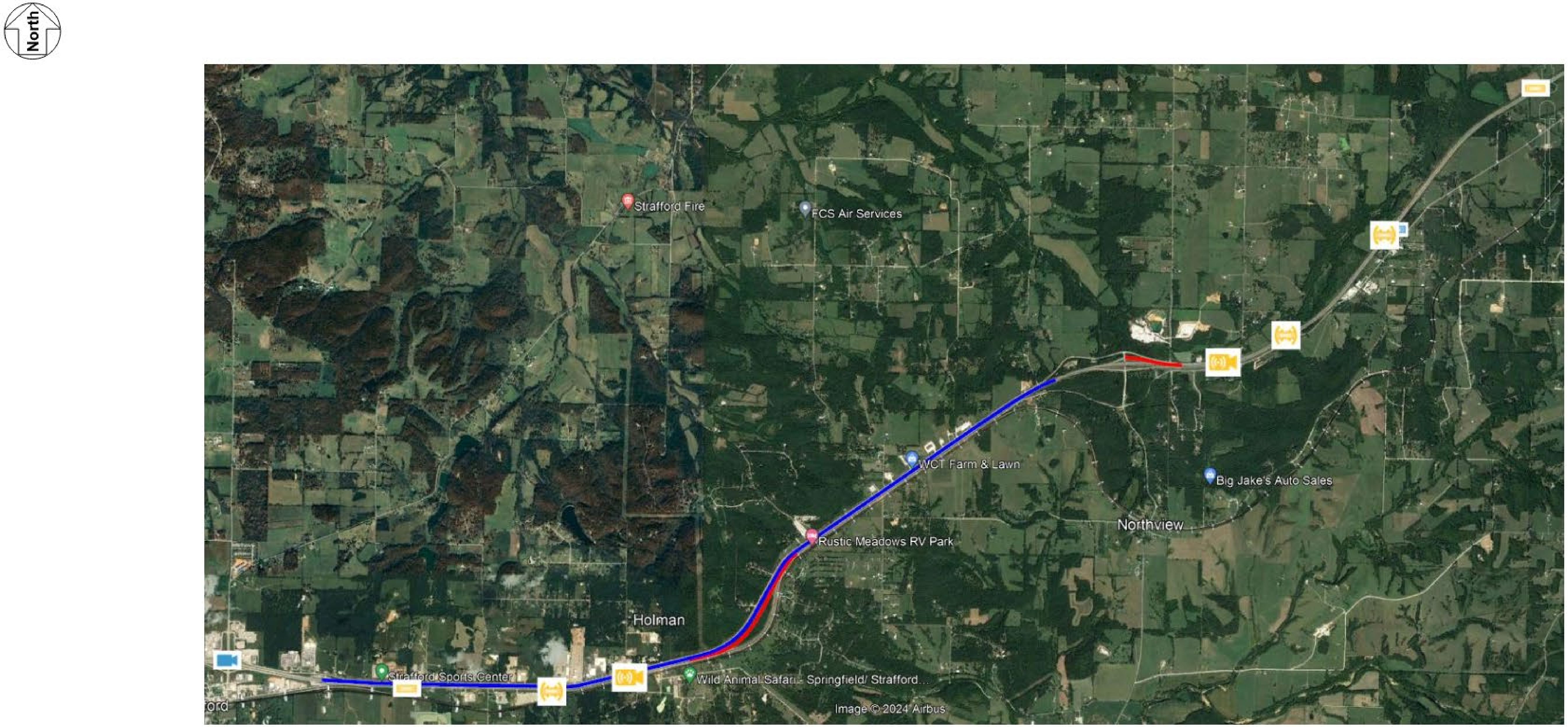


Stage 2: Queue warning for daytime inside shoulder strengthening and guardrail install.
I-44 EB : Sensor 600 ft from lane shift point. In place CCTV 44 at Strafford should be able to see the merge point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan.

Device Legend
- CCTV in place
- CCTV
- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
- Sensor



Stage 3 & 4:

I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS.

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

Device Legend

- CCTV in place
- CCTV
- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
- Sensor

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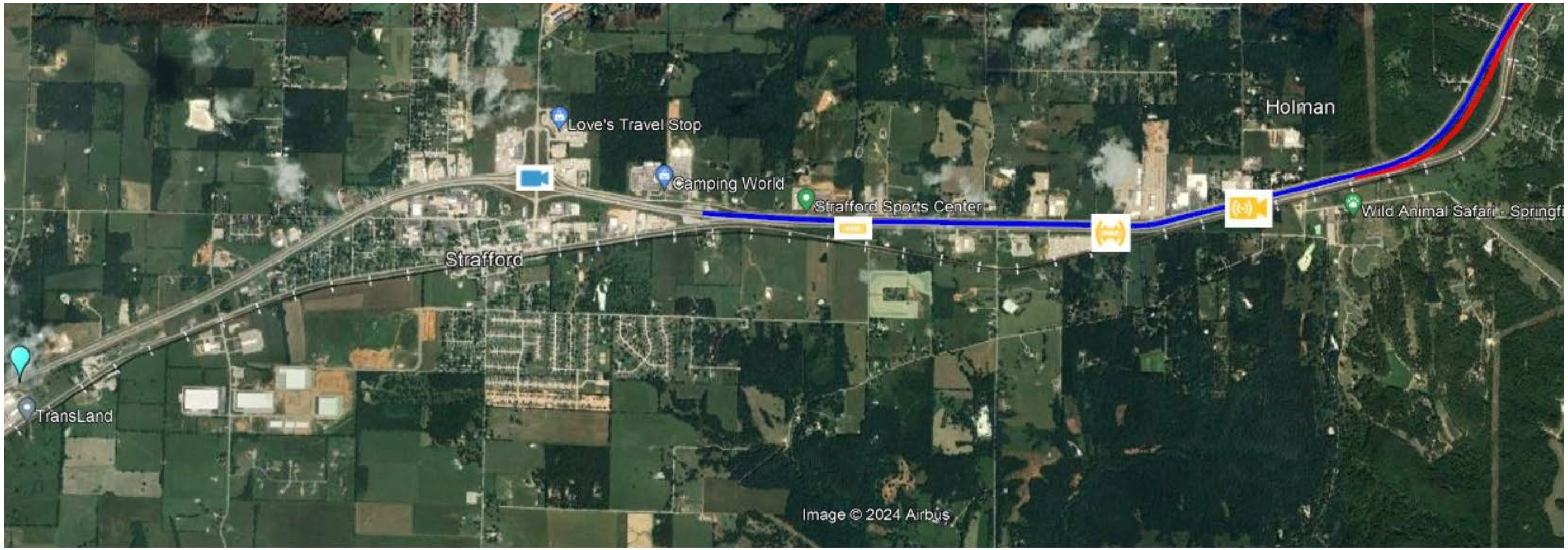
J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

Stage 3 & 4 Overview Queue Detection

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 5

North



Stage 3 & 4:

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Device Legend
CCTV in place
CCTV
CCTV + Sensor
CMS in place
CMS
CMS + Sensor
Sensor

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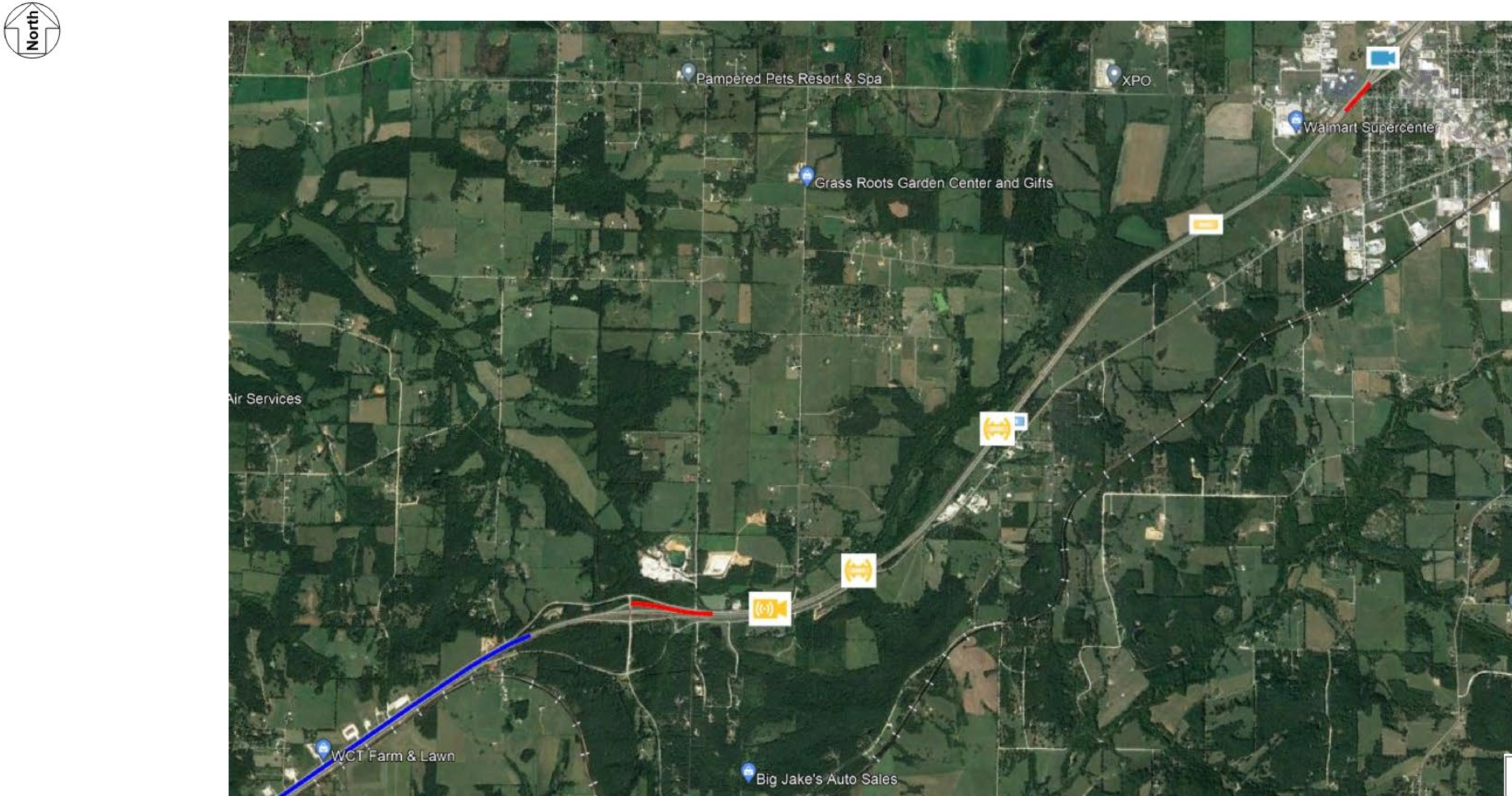

Device Legend
CCTV in place
CCTV
CCTV + Sensor
CMS in place
CMS
CMS + Sensor
Sensor

Stage 3 & 4:

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

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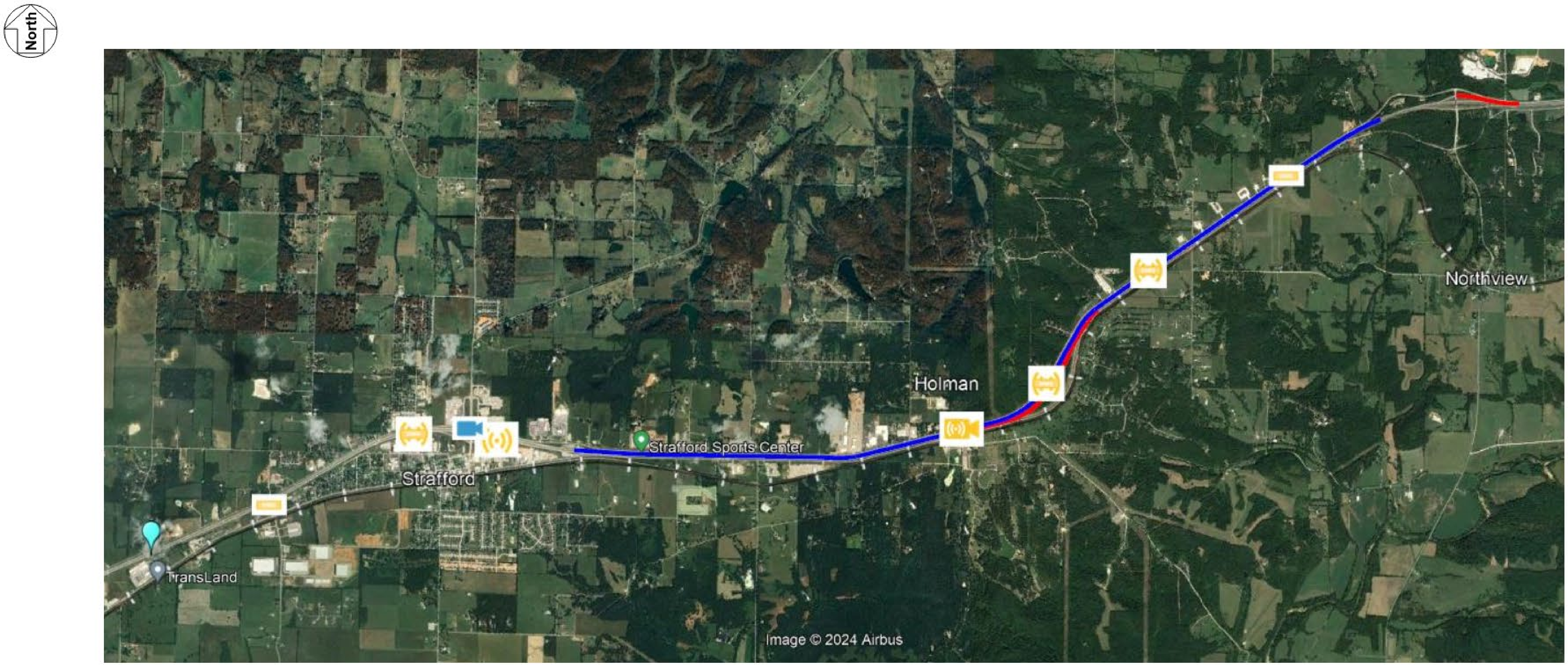
J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

Stage 3 & 4 WB Queue Detection

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 7



Stage 5 & 6:

I-44 EB: Sensor 500 ft from lane shift point. Combo CMS + Sensor 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford, MM 88 should be able to see merge area.

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Device Legend
- CCTV in place
- CCTV
- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
- Sensor

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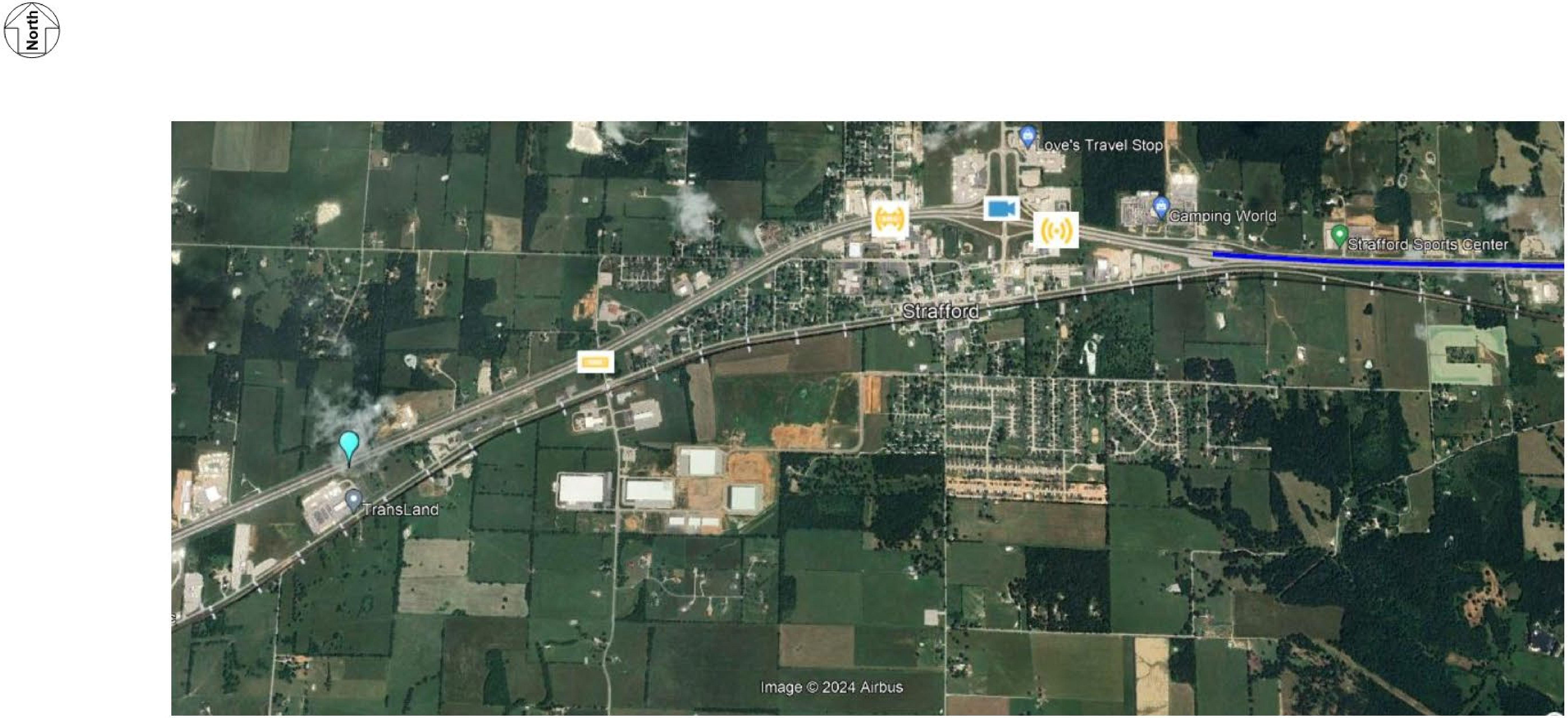

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<u>Device Legend</u>

- CCTV in place
- CCTV
- CCTV + Sensor
- CMS in place
- CMS
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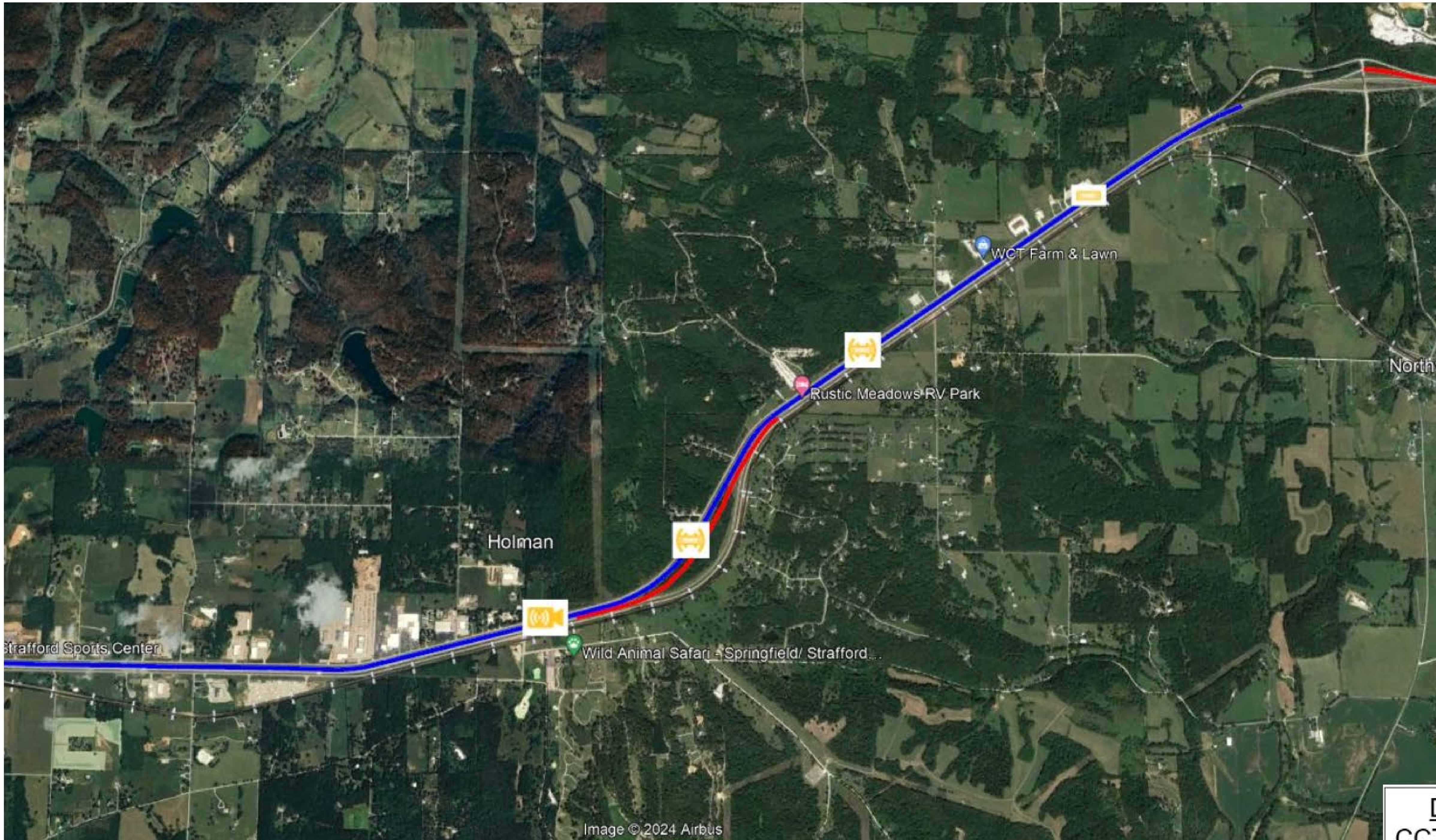
- Sensor



Stage 5 & 6:

I-44 WB: Sensor+ CCTV 500 ft from lane shift/crossover point. Combo CMS + Sensor just over 1/2 mile from first sensor. Combo CMS + Sensor 1 mile upstream. CMS 1.5 miles upstream.

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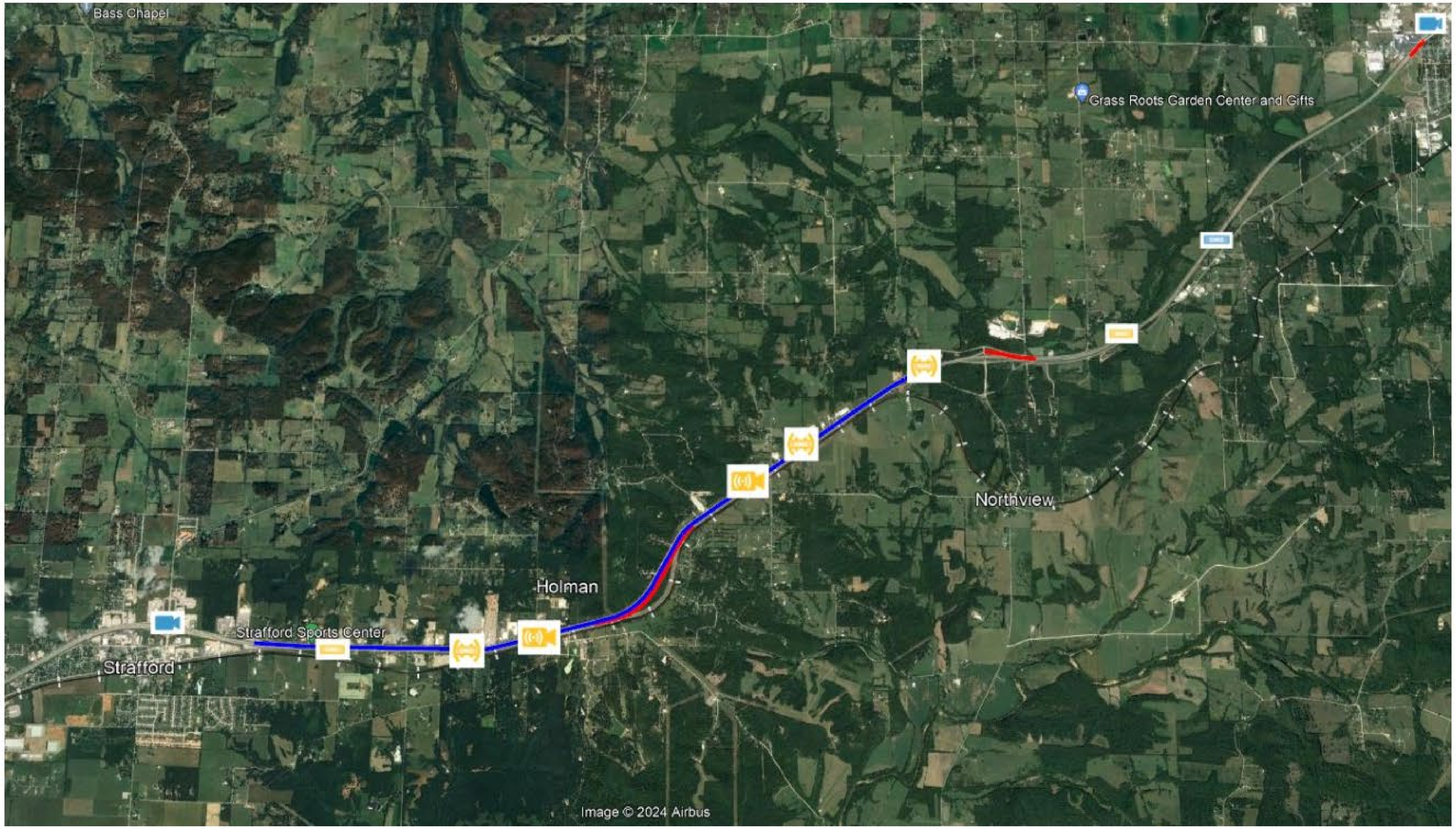

North

Stage 7 & 8:

I-44 EB: Sensor+ CCTV 500 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS 1 mile upstream, placed in between the work zone entrance signing plan. In place CCTV 44 at Strafford should be able to see area near the last CMS. Planned CMS at work zone EB entrance can be used for TIM if needed.

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Device Legend
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- CCTV
- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
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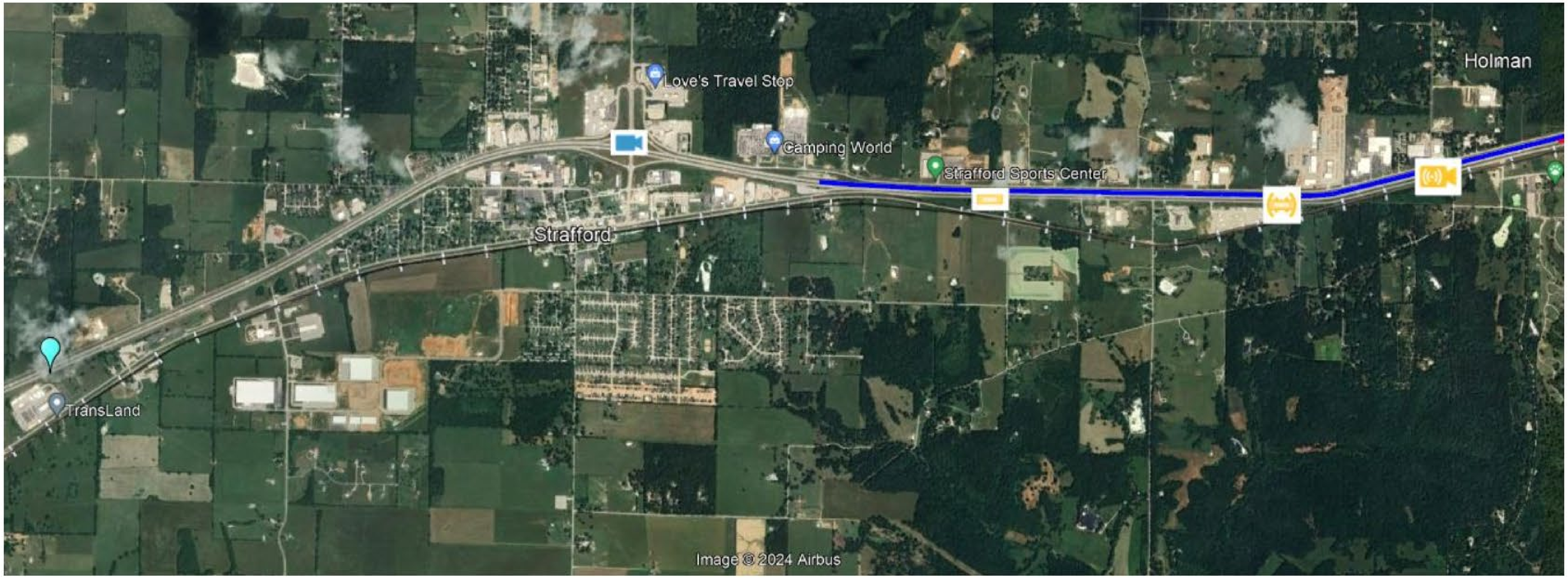
North



Stage 7 & 8:

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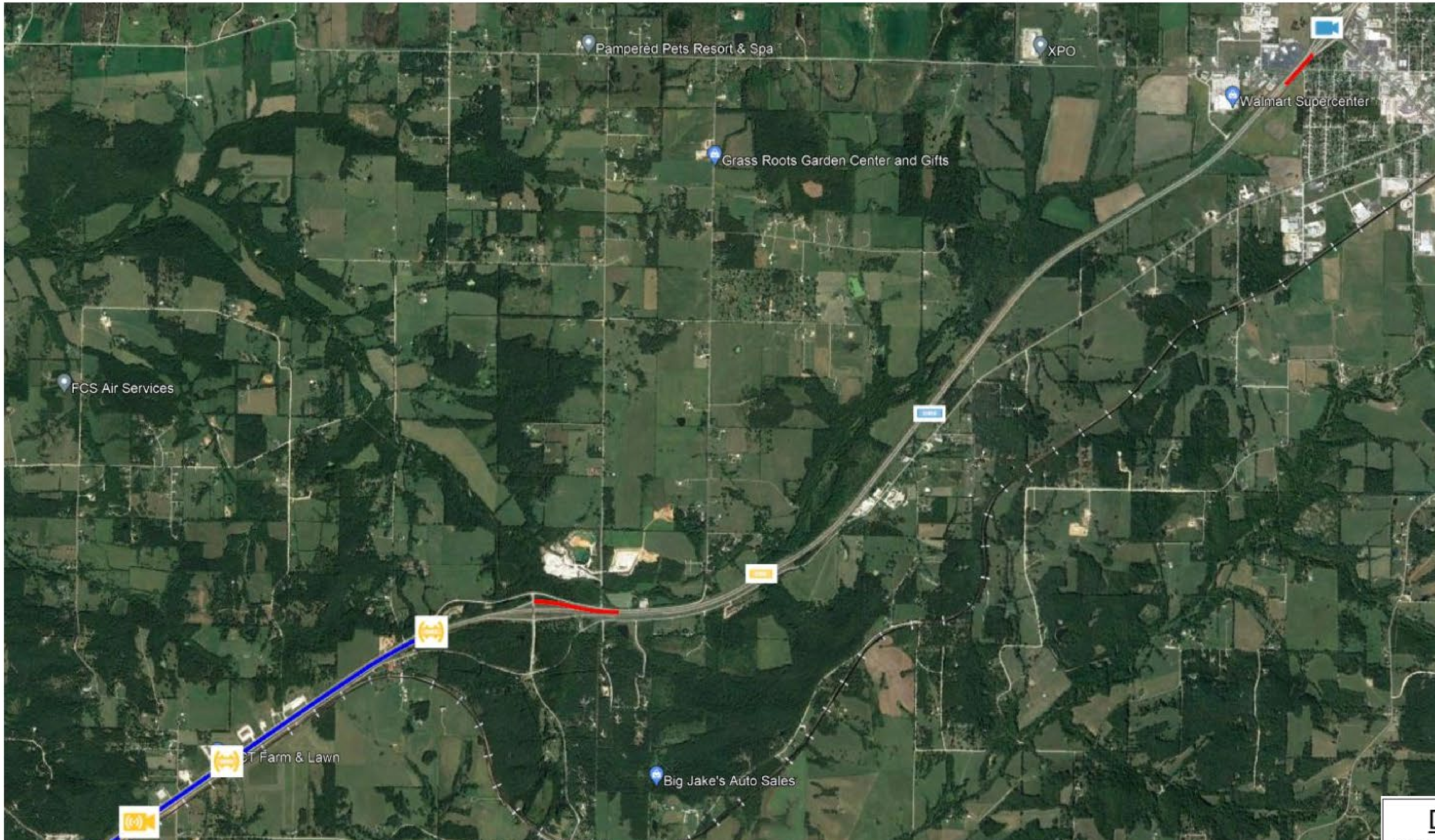
North



Device Legend

- CCTV in place
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- CCTV + Sensor
- CMS in place
- CMS
- CMS + Sensor
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Stage 7 & 8:

I-44 WB: Sensor+ CCTV 600 ft from lane shift point. Combo CMS + Sensor just over 1/2 mile from first sensor. CMS+ Sensor 1.2 miles upstream. CMS 1.5 miles upstream.

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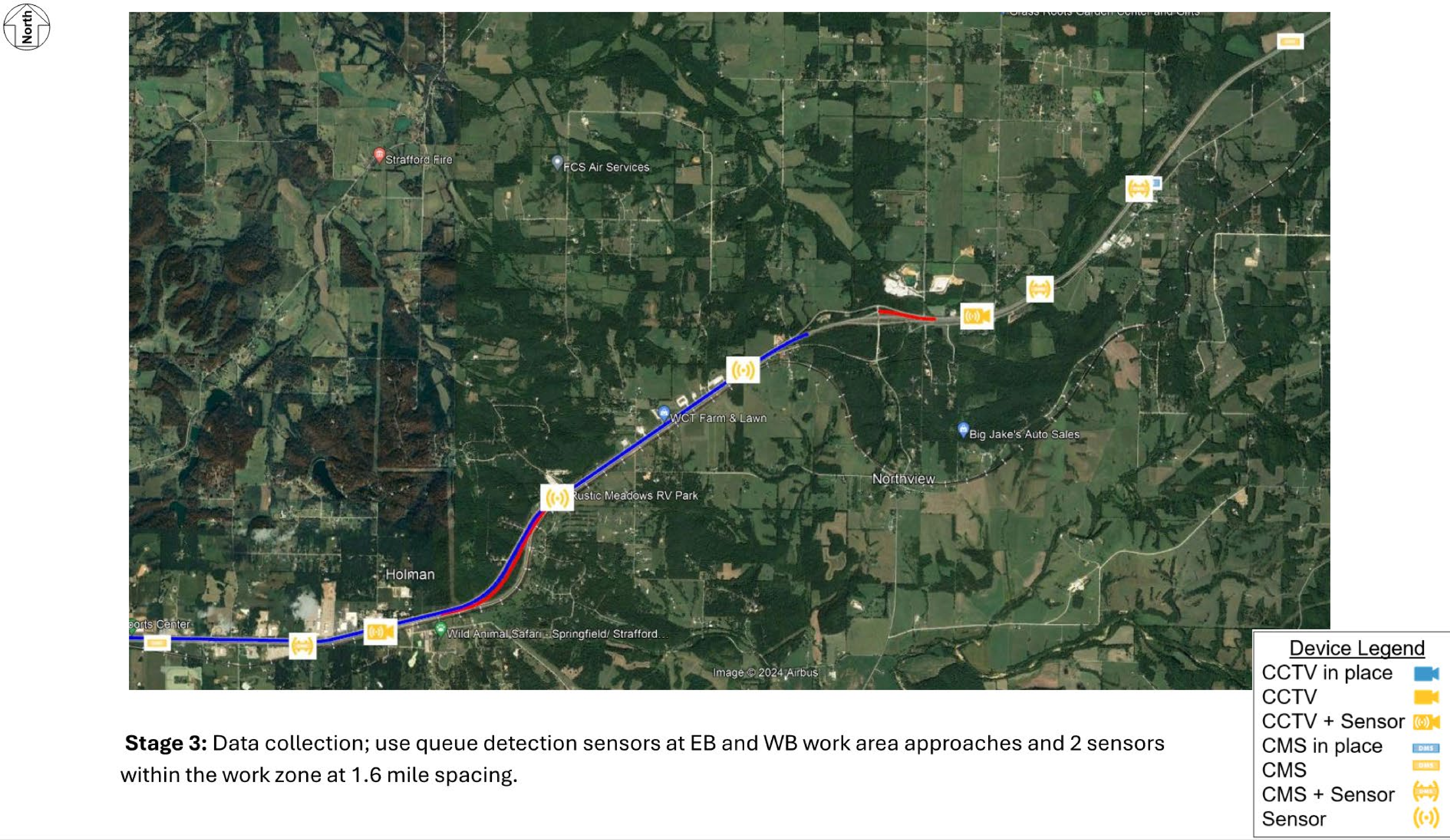
SRF no. 16729
May 2024

J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

Stage 7 & 8 WB Queue Detection

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 13



Stage 3: Data collection; use queue detection sensors at EB and WB work area approaches and 2 sensors within the work zone at 1.6 mile spacing.

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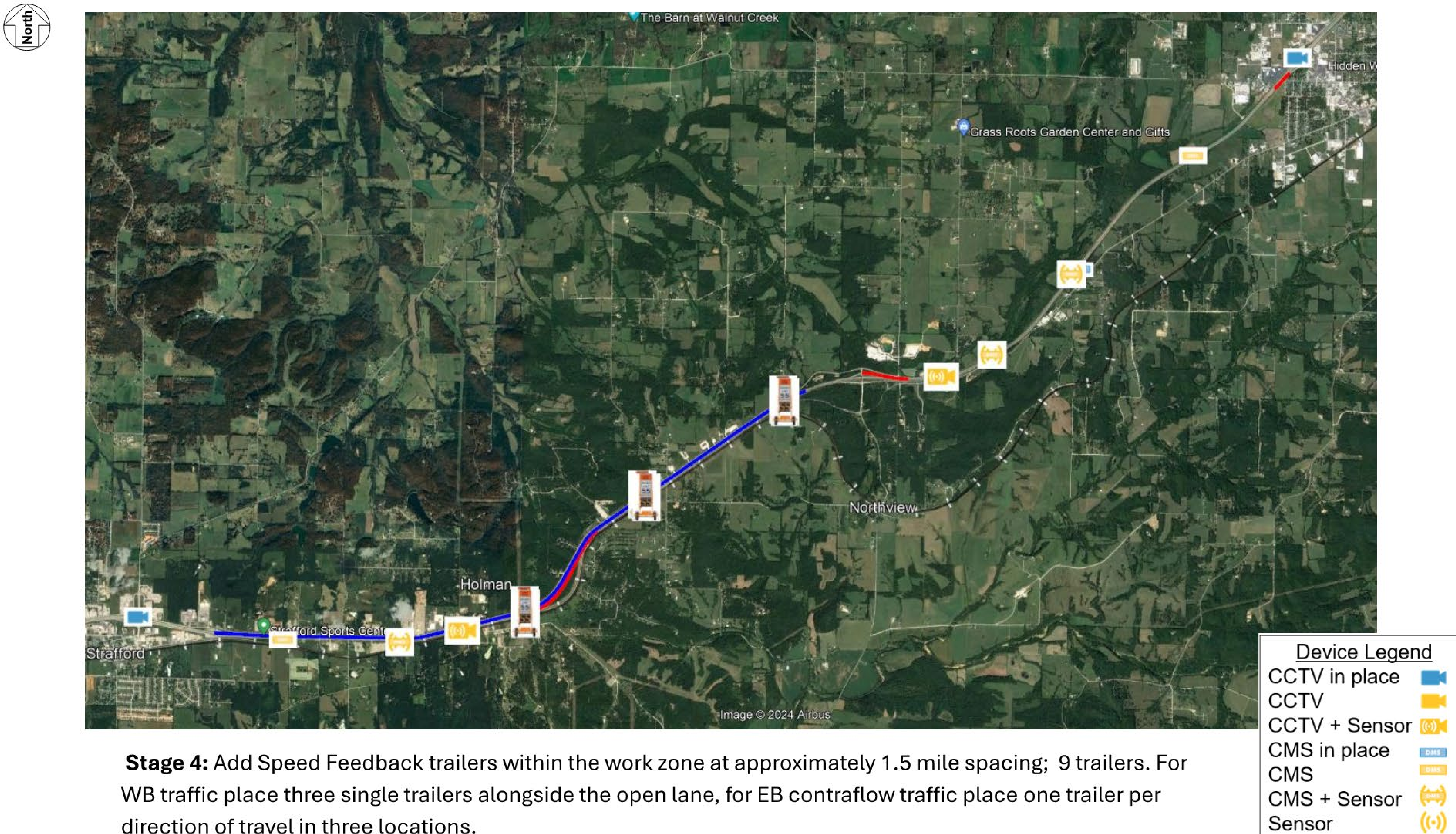
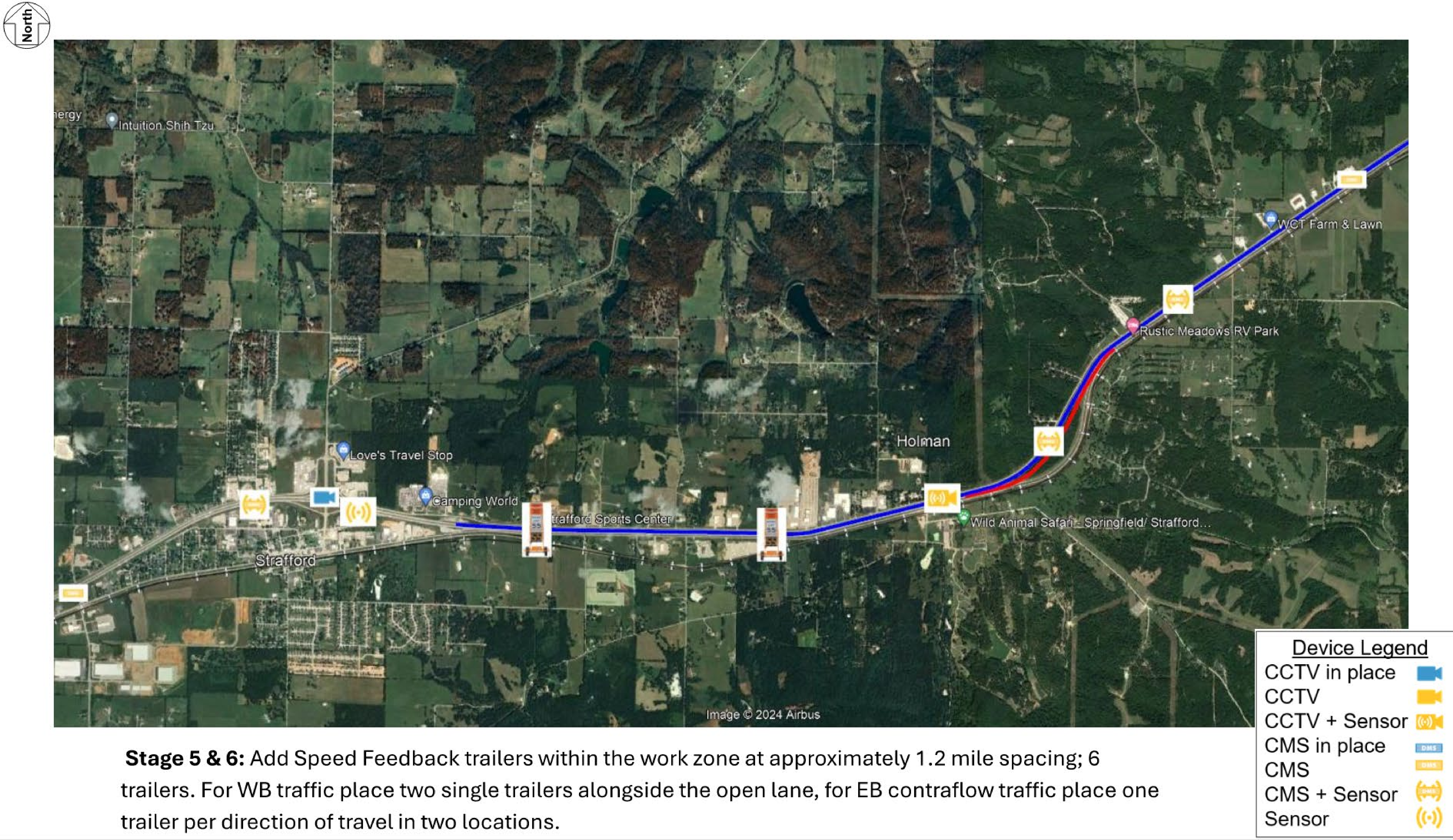


Stage 4: Add Speed Feedback trailers within the work zone at approximately 1.5 mile spacing; 9 trailers. For WB traffic place three single trailers alongside the open lane, for EB contraflow traffic place one trailer per direction of travel in three locations.



Stage 5 & 6: Add Speed Feedback trailers within the work zone at approximately 1.2 mile spacing; 6 trailers. For WB traffic place two single trailers alongside the open lane, for EB contraflow traffic place one trailer per direction of travel in two locations.

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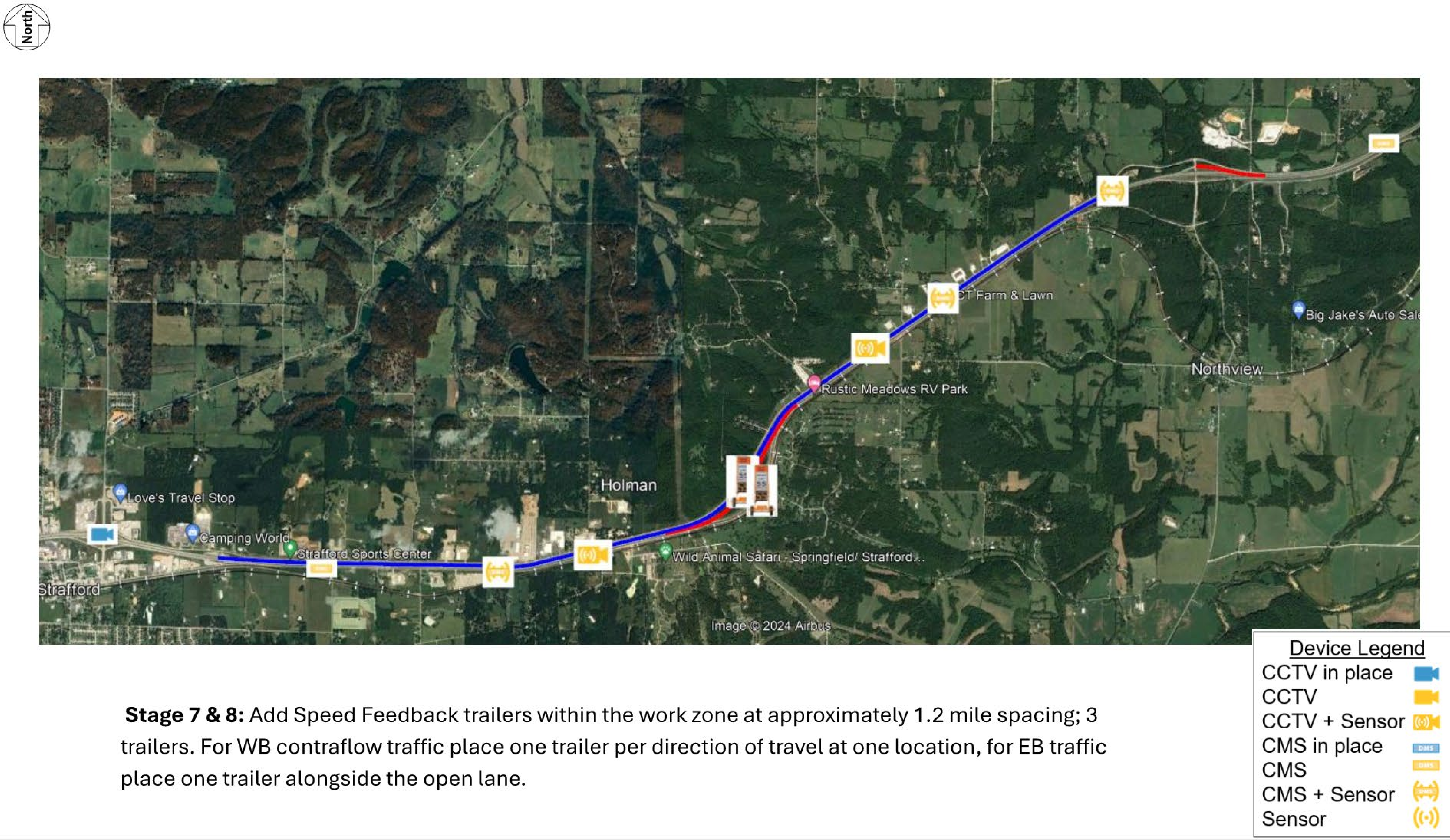

Stage 7 & 8: Add Speed Feedback trailers within the work zone at approximately 1.2 mile spacing; 3 trailers. For WB contraflow traffic place one trailer per direction of travel at one location, for EB traffic place one trailer alongside the open lane.

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SRF no. 16729
May 2024

J7I3010 I-44 Pavement Replacement & Curve Realignment – Smart Work Zone

Stage 7 & 8 Speed Warning System

EB & WB I-44 MM 125 to MM 113 Webster County, Missouri

Figure 17

8.1.4 Smart Work Zone (SWZ) Systems JSP-J7I3010

1.0 General

Smart Work Zone (SWZ) Systems shall be portable, real-time, automated, solar powered systems that calculate and display warnings and real-time work zone traffic information to the traveling public. The goal of these systems is to provide advance traffic condition information to motorists at key decision points due to construction activity. Systems shall be in operation 24 hours per day, seven days per week, during the construction period unless otherwise instructed by the Project Engineer or DOT Project Manager.

(**Insert the following paragraph/information as needed)

The Commission seeks a qualified Responder that has the capability, experience, and resources required to provide, operate, and maintain SWZ Systems to support road work projects located on Interstates, U.S., and State highways in Missouri.

1.0 Pre-Bid Conference This contract requires Responders, their Sub-contractors, and key personnel to have specific qualifications and experience with deploying SWZ solutions within work zones. The SWZ system and supplier shall be a proven system provider verifiable by at least one completed deployment of at least ten months. All Contractors/Subcontractors are required to attend a Pre-Bid Conference at the Missouri Department of Transportation office, (address), on (date). This meeting, which is held to clarify the scope of the work for this project, will begin promptly at (time). All contractors will be required to bring proof of prior deployments as well as contact information from prior deployments (names and phone numbers) to this Pre-Bid Conference. The references will be contacted by the Department and a determination will be made as to whether the Contractor's systems and services meets the requirements and conditions of this specification. The Department reserves the right to reject any bids received from Contractors who do not meet the qualifications and certifications as described here. The decision to reject a bid may be based on information about past performance. Non-attendance by Contractors/Subcontractors at the Pre-Bid Conference may result in rejection of the bid.

1.0.2 Responder and Sub-contractors. This contract requires Responders and their Sub-contractors and key personnel to have specific qualifications and experience with deploying SWZ solutions within work zones. Responders, including Sub-contractors, must document their companies' qualifications and experience on previous similar projects. Information specific to this project is required. Submittals of standard marketing packages alone may cause reduced technical scores.

1.0.3 Description. This item shall consist of submittal and approval of a Smart Work Zone System plan, furnishing, installing, relocating, and operating a portable, automated, solar powered real-time work zone system ("Smart Work Zone System") meeting the requirements noted herein, and providing a system manager to maintain the system throughout the duration of the project. The Contractor shall assume responsibility for any damaged equipment due to crashes, vandalism, adverse weather, etc. that may occur during the system's deployment.

1.0.4 The Contractor shall furnish, install, relocate, operate, maintain, and remove this system for measuring and delivering real-time messages for the work zone.
1.0.5 The Contractor is responsible for coordinating any work in adjacent roadway construction projects. *Provide brief description of how the Contractor can acquire contact information for staff responsible for adjacent project, since adjacent project may be sponsored by a different agency.*

1.0.6 The Contractor will be responsible for relocating the devices as directed by the Project Engineer or DOT Project Manager. When the equipment is no longer required for this project, the Contractor shall remove it and retain ownership.

1.1 Availability of Equipment. The successful Responder shall be required to provide the SWZ equipment defined in this JSP. The successful Responder must be able to provide and maintain sufficient equipment to meet the demands of the Commission. The Schedule of Prices form provides an estimate of quantities for *20XX (specify year)* based on recent years, but those are only estimated quantities. Actual quantities may vary. The Responder must have the capability, experience, and resources required to provide, operate, and maintain SWZ systems and components for this project.

1.2 System Manager. The Contractor shall employ one (1) qualified System Manager assigned to manage the SWZ systems. The System Manager shall be an employee of the Responder or of a Sub-contractor. The System Manager shall be locally available to maintain system components, maintain the website, move portable devices as necessary, and respond to emergency situations, within four (4) hours of notification. The System Manager shall be responsible for coordinating the placement of devices in the project areas. It is the responsibility of the System Manager to move system components that interfere with construction operations and relocate the components to another area. The System Manager shall supply a local phone number and/or a toll-free number to the Project Engineer or DOT Project Manager to contact the System Manager or other System Representative at any time. The System Manager shall not perform any other duties on the jobsite. Any replacement of the System Manager must have prior written approval from the Commission. If a substitute System Manager is proposed during the contract, they should be equally qualified or more qualified than the original System Manager.
The DOT Project Manager also reserves the right to require replacement of a System Manager, that is non-responsive or whose performance does not meet contract requirements.

1.3 Required Meetings The System Manager shall participate in the project kickoff/pre-con meeting and then any additionally held weekly/bi-weekly/monthly meetings or conference calls with the DOT Project Manager and others as directed to assess the effectiveness of deployed systems and to address any operational issues or concerns. Project meetings are considered incidental to the daily operation and maintenance of SWZ devices.

2.0 SWZ Device and System Requirements

These requirements apply to all systems, sub-systems, and individual components, including but not limited to changeable message signs (CMS), Sensor Trailers, and Camera Trailers. These requirements apply to all SWZ system components furnished, placed, and maintained to provide for SWZ Systems that are part of this contract.

Unless otherwise required by the DOT Project Manager, the Responder will use their own software to operate the SWZ Systems described.

If TMC integration is required, a SWZ Communication Plan that describes how system devices and central computer will communicate with MoDOT's (*Kanas City, St. Louis, Springfield)* Traffic Management Center's must be provided as noted in section 3.2.2.

2.0.1 Cellular Modem Communications

Responder shall provide cellular modems and network service on all of their SWZ equipment or systems as detailed in this RFP. At a minimum, Responder must be able to use cellular communications to locate, track and monitor device or system status and condition.

Cellular modems on devices shall have the following requirements. Cellular modems on all CMS, all Sensor Trailers, and Camera Trailers defined in Section 2.2 shall be capable of providing a minimum bandwidth comparable to a 4G/LTE network for remote communications. The cellular service provider shall have data coverage within the project limits. The software, and any username/password for web interface shall be supplied to the DOT Project Manager via a DOT operated web-accessible, password protected spreadsheet. Electronic access shall be protected by a unique username and password that is not the manufacturer's default username and password.

Each cellular modem shall be capable of obtaining its location by global positioning system (GPS) of satellites. Current location from GPS coordinates shall be stored in the cellular modem's memory for retrieval. The modem shall have firewall security protections that limit who and what can communicate to it. The Response shall include details of the security protections the Responder will use to meet this requirement. A static set of coordinates shall be provided in the IP address spreadsheet for each modem.

The Contracting Authority expects monthly data usage to be:

- 5 to 50 MB per PDMS
- 50 to 100 MB per Sensor Trailer
- 30 GB per Camera Trailer

2.0.2 Changeable Message Signs (CMS)

SWZ systems shall utilize MoDOT approved portable changeable message signs (CMS) in accordance with Missouri Standard Specifications for Highway Construction section 616 Temporary Traffic Control and 1063 Temporary Traffic Control Devices and Standard Plans for Highway Construction 616.10. For CMS, typical monthly data usage by the Contracting Authority is expected to range from 5 to 50 MB. Additional data usage is possible if remote troubleshooting or maintenance is required.

All system components including the onboard computer, communication devices, solar panels, batteries, and charge controller shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a unique username and password that is not the manufacturer's default username and password. The username and password shall not be recorded on any part of the trailer. The power supply shall be capable of providing continuous service for 10 days without recharging. The trailer shall be capable of supporting the system on any typical roadway shoulder including concrete, asphalt, granular or turf. When deployed, the trailer and sign shall present a level appearance. The message panel shall be mounted at a height of at least 7 feet, measured from the bottom of the sign to the ground directly below.

The sign shall be capable of displaying three lines of up to eight characters at one time. Character height shall be 18 inches and configured using a 7 pixel tall by 5 pixel wide font. The message panel may be configured as character matrix, line matrix, or full matrix.

The message panel shall be visible from 1/2 mile under both day and night conditions. Letters shall be legible from 750 feet. Message sign shall include automatic dimming for nighttime operation and a power supply capable of providing continuous service for ten (10) days without recharging.

The message panel shall be controlled by an onboard computer which shall:

- Store a minimum of 99 programmed messages for instant recall.
- Accept messages created by the operator via a locally connected alpha- numeric keyboard, and
- Be programmed remotely via a networked wide area connection by the National Transportation Communication for Intelligent Transportation Systems Protocols (NTCIP) DMS software.
- Be compatible with NTCIP 1203 v1.

2.0.3 Sensor Trailer Portable Non-Intrusive Traffic Sensors

A Sensor Trailer includes the portable non-intrusive traffic sensor, trailer and all components required to operate the sensor including the serial converters, communication devices, solar panels, batteries, and charge controller. All equipment shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a username and password that is not the manufacturer's default username and password. The power supply shall be capable of providing continuous service for 10 days without recharging. These sensors shall be capable of acquiring traffic data from up to six (6) lanes of traffic on a lane-by-lane basis. The trailer shall be capable of supporting the system on any typical roadway shoulder including concrete, asphalt, granular or turf. When deployed, the trailer shall present a level appearance. The trailer shall be capable of supporting the sensor at a variable height of 12 to 30 feet above the ground elevation.

Sensor Trailers shall be equipped with cellular modems as specified in Section 2.0.1 and be configured to transmit data as defined by the Commission. Typical data transmittal is per lane data every minute and includes lane-specific speeds, volumes, occupancy and three vehicle classifications.

Sensors are required to provide accurate data with no less than 90% communications uptime as viewed by daily data reporting.

2.0.4 Camera Trailer

Camera Trailer includes the camera, portable trailer, and all components required to power and operate the Camera Trailer. Camera must encode video with h.264 codec and be capable of providing two, simultaneously configurable video streams consumable via RTSP.

All cameras shall be capable of full Pan-Tilt-Zoom (PTZ) operation. The camera shall be capable of panning 360 degrees, at least 20x optical zoom, at least 4CIF (704 × 576) color video with a user-selectable frame rate (5, 10, 15, 20, 25, 30 frames per second). Responder shall set up on- screen displays including compass direction and a descriptive camera name.

All Camera Trailers shall be capable of recording at least one (1) week of video locally, with the ability to review and download recorded video remotely and in a non-proprietary format.

All system components including the camera, onboard computer, communication devices, solar panels, batteries, and charge controller shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a unique username and password that is not the manufacturer's default username and password. The username and password shall not be recorded on any part of the trailer. The power supply shall be capable of providing continuous service for 10 days without recharging. The trailer shall be capable of supporting the system on any typical roadway shoulder including concrete, asphalt, granular or turf. When deployed, the trailer shall present a level appearance. The trailer shall be capable of supporting the camera at a variable height of 18 to 30 feet above the ground elevation.

Cellular communications to be provided by the Responder as described in Section 2.0.1.

For Camera Trailers, typical monthly data usage is expected to be up to 30 GB. Data usage shall be monitored and documented by the successful Responder and reported to the DOT Project Manager on weekly basis.

2.1 Central Computer and System Software. The central computer and system software shall provide the functionality described below:

<u>General</u>

- Provide a Graphical User Interface that is compliant with Windows standards.
- Communication between the central computer and any device shall be independent and *non-reliant* upon communications with any other CMS or sensor.

- Alerts to MoDOT TMC or District staff and the Project Engineer or DOT Project Manager shall be provided via text and/or e-mail. Alerts shall be sent in the event of device failure or traffic delays over 15 minutes.

Data Processing Software

- The capability to collect, display, and store sensor data.
- The capability to compare traffic data collected from sensors to user-defined thresholds and automatically update one or more CMS's based on the SWZ systems intended purpose.

Data Management

- Storage of speed, volume, occupancy, CMS message history, and travel times as well as appropriate sensor status for each day.
- Ability to view and download (export) data including sensor data, sign logs, and CCTV images in real time or near real time.

Website and Online Access

- The Contractor will be responsible for hosting the SWZ System software and must provide MoDOT TMC or District staff and the Project Engineer or DOT Project Manager login access. System permissions such as create, read-only, update, and delete (CRUD) will be specified by the DOT Project Manager.
- The Contractor will be responsible for hosting a website and obtaining domain names. Possible domain names and overall website design must be submitted to the Project Engineer or DOT Project Manager for approval prior to it being made available.
- The website shall contain an accurate map of the area affected by the work zone, including state highways or routes that may be used as alternates.
- Icons or hyperlinked text should accurately depict the current location of the system components and give real-time information provided by each component. In the event components are moved to a new location, the website or software must reflect these changes to the system layout.
- Data should be password protected and stored on the website for each day the system is in use, with date and time stamps included.
- Data shall be available to MoDOT staff at all times for the duration of work zone activity.
- An electronic copy of all data, including date and duration of system malfunction, shall be provided to MoDOT staff each day for the previous day.
- An electronic copy of all data, including date and duration of system malfunction, shall be provided to MoDOT staff after all work zone activity is completed and the SWZ system(s) has been removed.
- Device information shall be provided to MoDOT TMC or District staff and the Project Engineer or DOT Project Manager through icons or hyperlinked text representing each device. Detectors should provide real-time speeds at the respective locations and CMS's should provide the current message of each sign, and cameras snapshots of the current project view.
- The website shall be designed and operated to allow 20 users to access the site at one

time.

2.2 SWZ Systems. The following SWZ systems are approved for use by MoDOT as described in the MoDOT Engineering Policy Guide Section 616.13. Note that the Engineering Policy Guide may contain updated information or systems. *Number (X) dependent on SWZ Plan provided by the contractor, unless DOT designed.*

2.2.1 Queue Warning System. Informs travelers about upcoming congested or stopped traffic condition. Components of a queue warning system include, but are not limited to:

- *Seven (7)* Sensor Trailer Non-Intrusive Detection System
- *Five (5)* CMS
- *Two (2)* Camera
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.2 Temporary Long Term Rumble Strips. A strategy for reducing distracted driving and achieving MoDOT's work zone safety goals. Design per JSP-13-04C

- *Number (X)* Preformed rumble strips

Optional monitoring equipment:

- *Number (X)* Sensor Trailer Non-Intrusive Detection System
- *Number (X)* Camera
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.3 Speed Warning System. Speed displays using intelligent transportation system (ITS) or SWZ technologies that give the driver information about their speed as well as the posted advisory speed. The speed displays are portable and can be used in the work zone wherever excessive speeding is a problem.

- *Nine (9)* CMS with Radar or standard speed feedback trailer with comms.
- Communication link between radar and the CMS.
- Communication link between system and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

Note about dual use trailers:

To reduce impacts to the smart work zone footprint dual use trailers; defined as trailers that house one or more SWZ device may be used. If dual use trailers are used the updated quantities for this project are as follows:

Two (2) Camera + Sensor
Two (2) CMS
Three (3) CMS + Sensor

Two (2) Sensor
Nine (9) Speed Feedback Signs

3.0 Smart Work Zone Plan, Work Plan, and Test Plan

3.1 General. The Contractor shall submit to the Engineer or DOT Project Manager for approval a detailed written and illustrated SWZ Plan that addresses and meets all requirements of this specification three (3) weeks prior to mobilization of any component of the SWZ System. Commission may propose changes or modifications to specific procedures and requirements of the Plans prior to approval.

Approval of the SWZ Plan by the Engineer or DOT Project Manager is required prior to the placement of any SWZ devices. Approval is conditional and will be predicated on satisfactory performance during construction. The Project Engineer or DOT Project Manager reserves the right to require the Contractor to make changes in the SWZ Plan and operations, at no additional cost to the DOT, including removal of personnel, as necessary, to obtain the quality specified. The Contractor shall notify the Engineer or DOT Project Manager in writing a minimum of seven (7) calendar days prior to any proposed changes in the SWZ Plan. Proposed changes are subject to approval by the Engineer or DOT Project Manager. The Plans shall be executed upon approval from the DOT Project Manager.

The Contractor will not be allowed to start any construction activities that will affect traffic on the project until the SWZ Plan is approved by the Engineer or DOT Project Manager.

3.2Content of the SWZ Plan. The SWZ Plan shall include, as a minimum, the following items:

- A detailed plan showing the proposed locations of all SWZ devices and equipment description including make and model.
- A description of all proposed thresholds and proposed CMS messages to be implemented.

3.2.1 Management Plan

- The name and contact information of the SWZ System Manager, Field Technicians, and any Sub-contractors or suppliers.
- The responsibility and authority of each individual on the Responder's team. The relationships between and authority over all individuals on the Responder's team.

3.2.2 Work Plan

Responses shall include a Work Plan that includes, but is not be limited to, these major areas:

- SWZ Equipment Availability:
  - Quantities of equipment owned by responder that is available for this contract.

    - Plans for obtaining additional equipment (if needed).
- A detailed description of the proposed methods of communication between SWZ devices, SWZ Central Computer, and SWZ Software.
- How the Responder plans to meet all requirements in Section 1.0.
- How the Responder proposes to accomplish the initial deployment of each system and related components for each individual project in the contract. This shall include minimum advance notice for component delivery and deployment and how this ensures meeting all requirements of the contract, so all systems are operational.
- How the Responder proposes to maintain the system, including availability of spare parts and equipment, response methods, and times, and how the Responder will ensure all requirements are met to respond to system failures, including damage and equipment failures.
- A detailed description of the Responder company's process to verify that each piece of equipment is in proper working condition including, but not limited to, preventative maintenance schedules, equipment depreciation and replacement schedules, pre- deployment testing procedures, equipment component replacement schedules, and procedures, etc.
- Proposed corrective method procedures including response times and notification process.
- A detailed description of the System Managers plan for daily devices checks, data validation review plan and frequency, and system validation review plan and frequency.

3.2.3 Test Plan

Responses shall include a complete Test Plan that includes, but not be limited to, these major areas:

- A list of items to be tested
- Test methods and expected minimum results for each item to be tested.
- Test procedures and all forms used to document testing results, including the proposed method for submittal of completed documents.

3.2.4 Additional Devices, Systems or Technologies

Responders are encouraged to propose additional systems, devices, or technologies that the Commission may want to consider for improving safety and operations in work zones. Additional systems may include both devices that can be integrated into ATMS software, or stand-alone devices or systems.

Additional items included in a Response may improve evaluation scores. Unit costs for additional items shall be provided in the Cost Proposal, but prices for additional items will not factor into the cost portion of the evaluation.

Details about additional devices, systems or technologies may be provided in cut sheets or standard marketing brochures. All of the equipment, processes, software, and operating system information shall be included in these details and the unit costs.

4.0 Operational Test

Once the SWZ is installed, it shall undergo a five-day operational test. The operational test shall include a test of the system in operation during to ensure that all SWZ equipment (including the changeable message signs, traffic sensors, central computer, communication devices, and website/interface) is operating in a fully functional manner and in accordance with the Smart Work Zone Plan for a duration of at least five (5) consecutive calendar days. The Contractor shall provide for complete operations support from the vendor during the operational test, and the Contractor shall provide verification that the reported data in the work zone accurately reflects actual field conditions. If any equipment malfunctions occur for a combined period of four (4) hours or more during this operational test on any day, no credit will be given for that day for the operational test period, and the five-day operational test will reset.

The Contractor shall maintain records of equipment stoppages and resumptions during the five-day operational test for submission to the Engineer or DOT Project Manager for his approval. In the event that ten percent or more of the time similar malfunctions occur that affect the proper operation of the SWZ system, the Project Engineer or DOT Project Manager may declare a system component defective and require replacement of the equipment at no additional cost. When a system component defect is declared, the five-day operational test shall begin again after all defective equipment is replaced and the system is fully operational.

4.2 Operational Test Report. The Contractor shall submit a report to the Project Engineer or DOT Project Manager detailing the daily activity of the system during the operational test. The report shall indicate the date and time of any activity necessary to maintain operation of the SWZ during the operational test period. Each entry shall include the following information:

- Identity of the equipment on which work was performed
- Cause of equipment malfunction (if known)
- A description of the type of work performed
- Time required to repair equipment malfunction

Once the operational test report is received and approved by the Project Engineer or DOT Project Manager, the SWZ will be considered operational and the system will be accepted for use.

5.0 Measurement And Payment

All SWZ devices furnished, installed, and maintained by the Responder shall be measured by one lump sum and shall be divided into the following payment schedule:

- 35 percent will be paid when all of the SWZ equipment is delivered to the jobsite.
- 10 percent will be paid when the Project Engineer or DOT Project Manager approves the Operational Test Report.
- 10 percent will be paid after 30 calendar days of full system operation.
- 45 percent will be paid after work that requires the use of SWZ system has been completed, the Contractor's SWZ equipment has been removed from the project, and historical data has been provided to the Project Engineer or DOT Project Manager.

5.1 Deduction for Failed System

A percentage of the lump sum will be deducted should the system malfunction for three (3) or more consecutive calendar days or any total of five (5) calendar days in any one calendar month after the approval of the operational test. This deduction will be based on a ratio of calendar days of unsuccessful operation to total calendar days of operation following the approval of the operational test. This deduction will not reduce the total system payment to less than 60 percent of the lump sum. System malfunction will be defined as any provided device or component failure that causes the SWZ system it is supporting to provide inadequate information or warning to the motorist. For example: If a Sensor fails causing the Queue Warning System it supports to be inoperable, none of the other Sensors or PDMS for that Queue Warning System shall be considered operable for that time period.

6.0 Basis of Payment. Payment for submittal and approval of a Smart Work Zone System plan, furnishing, installing, relocating, operating, maintaining, testing, monitoring, providing a website, providing daily data and historical data, and removal of the Smart Work Zone System (SWZ), including all items required for proper operation of this installation, will be completely covered by the contract unit price for Item Number 6169901, "Intelligent Work Zone", per lump sum.

8.1.5 05_TR202415 _ Daily Monitoring Plan_J7I3010_DRAFT

TR202415 TSMO Strategies in Work Zones Daily Monitoring Plan

By
SRF Consulting Group

Prepared for
Missouri Department of Transportation

Winter 2025

Draft Report

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List of Abbreviations and Acronyms

DOT ……………………….Department of Transportation

FHWA ……………………. Federal Highway Administration

PCMS ……………………..Portable Changeable Message Signs

SWZ………………………. Smart Work Zone

TSMO…………………….. Transportation Systems Management and Operations

VSL ………………………. Variable Speed Limit

Introduction

Managing traffic during construction is necessary to minimize traffic delays, maintain motorist and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents. As the Missouri Department of Transportation continues to advance its Work Zone Management Priorities, the Department seeks to identify implementable strategies that benefit both areas of workforce shortage and safety.

Goals and Objectives

One of the primary goals of the project is to monitor and evaluate automated Smart Work Zone (SWZ) system performance and effectiveness, and to create a best practice summary that can be used for future SWZ applications. The evaluation will occur in two stages over the duration of the project with the first phase consisting of daily data collection for system monitoring and the second phase consisting of an evaluation of SWZ system performance and effectiveness. This plan outlines the first phase, daily monitoring. A separate document covers the second phase of the project evaluation, the Project Evaluation Plan. The following goals and objectives were identified to guide activities for daily device monitoring:

Goal 1: Monitor System Reliability

Objective 1-1: Monitor device up time
Objective 1-2: Monitor troubleshooting response time of SWZ provider/contractor Objective 1-3: Monitor frequency of failure

Goal 2: Test System Performance

Objective 2-1: Verify SWZ design meets all design requirements
Objective 2-2: Recommend revisions to design requirements as needed

Goal 3: Evaluate System Effectiveness

Objective 3-1: Verify SWZ system displays timely and accurate messages or alerts
Objective 3-2: Determine logic quality
Objective 3-3: Determine data quality

System Overview and Project Location

This project aims to implement and evaluate the following work zone systems that will be deployed on I-44 in Webster County during Summer 2025.

- Radar speed advisory system: A sensor-based speed warning system (Speed Advisory display) used in a work zone which informs the approaching motorists of the posted advisory speed and their current speed to warn them if they are driving above the defined speed limit. These speed displays are portable and can be used in the work zone wherever excessive speeding is a problem. Variations of this system include using advisory speeds based on worker presence and variable speed limit (VSL) based on real-time traffic speeds to assist with speed harmonization.

- Queue detection: A queue detection and warning system is used to inform travelers about upcoming congested or stopped traffic conditions. This system informs drivers of an impending traffic situation and avoids emergency braking and queue-related collisions. The system typically consists of roadside sensors and Portable Changeable Message Signs (PCMS) placed upstream of the work zone. The basic principle of this system is when sensors detect slowing or stopped vehicles, it sends signals to the PCMS where messages are displayed advising travelers about an impending traffic queue.

The project is located on I-44 in Webster County from north of Strafford, MO to Conway, MO. Most of the work and the SWZ applications will be located between Strafford, MO and Northview, MO shown in Figure C5.1.

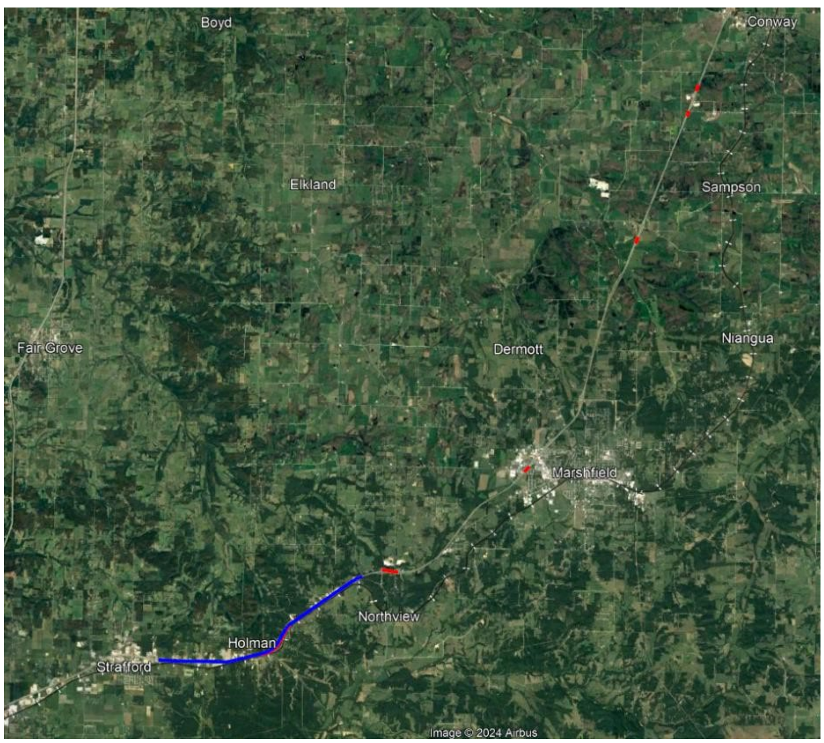


Figure C5.1 Project Location EB and WB I-44 MM 125 to MM 113 Webster County, Missouri
(image source: MoDOT kml file)

SWZ Deployment Process

A standard operational procedure for deployment defines a process for successful implementation of SWZ systems onto the roadway. Due to the dynamic nature of construction projects modifications to device locations, deployment timeframe, and other unforeseen impacts may arise. A standard plan for deployments provides the team with a clear path even in the face of last minute changes.

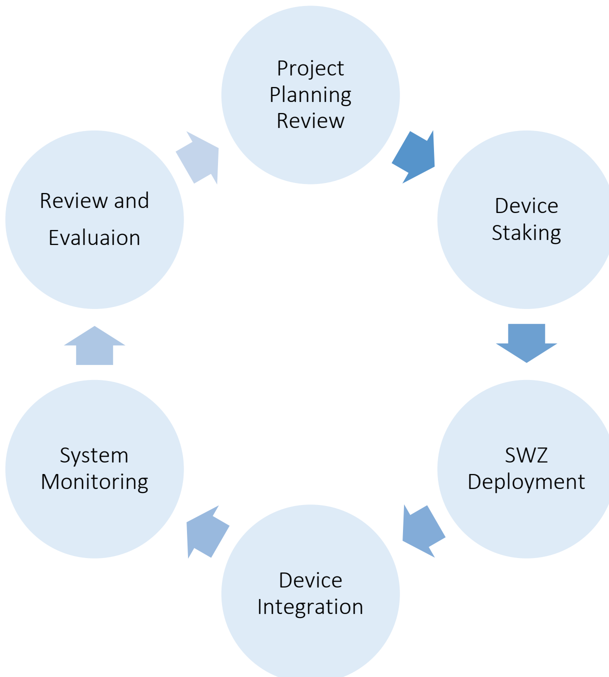


Figure 5C.2 Smart Work Zone Deployment Cycle Diagram

The figure 5C.2 diagram above demonstrates the basic path used for SWZ deployment. Below is a brief description of each step in the deployment cycle.

- Project Planning involves developing preliminary SWZ concepts using the project's temporary
  traffic control plans and a mapping tool such as google earth or GIS.

- Device Staking involves field verifying planned SWZ device locations and marking where equipment should be placed for optimal visibility or data collection. This task may be completed by DOT, a DOT representative, a contractor, a traffic control sub, or a representative of the DOT.

- SWZ Deployment involves the SWZ Provider, Contractor, or Sub-Contractor bringing SWZ equipment on site for placement at marked locations in the project corridor.

- Software Integration involves adding the SWZ equipment into the traffic management software and developing any alert processing logic required for the SWZ systems to operate.

- System Monitoring involves monitoring all devices deployed in an SWZ system to ensure all equipment is functional, communicating properly with the traffic management software, and is displaying the proper messages to motorists.

- System Evaluation/Review involves using performance data and lessons learned during the SWZ deployment to develop efficiencies for future deployments or future program goals.

Methodology Daily Data Monitoring

This section presents evaluation methodologies for the I-44 project in Webster County daily data monitoring. Results will be presented in a clear and straightforward manner.

SWZ Daily Monitoring

SWZ systems deployed are evaluated based on their ability to provide information and services on a 24/7 basis and on their ability to mitigate the traffic mobility and safety impacts of highway construction work zones.

SWZ system performance is measured using active and passive monitoring methods. Active monitoring is manually performed using the SWZ Provider's traffic management software. Active monitoring includes daily checks of all deployed devices for communications, correct time/date stamps, and correct views of deployed CCTVs. Where applicable automated alerts will be enabled to alert the project team of any device not functioning properly. Passive monitoring is the utilization of SWZ software to remotely download the evaluation sensor data. Reports are created daily for the previous day's operations on all SWZ sensors. Datasets are analyzed for missing time intervals and low operational percentages.

Operational Performance Tracking

Device performance is monitored by the SRF project team.

CCTV Checks

Camera feeds are reviewed daily to identify any performance issues, such as correct time and date banner, connection quality, camera damage, or objects obscuring the camera view using the SWZ Provider's software. The project team will remotely correct any improperly positioned cameras. If for any reason a camera is not operational, the malfunction will be documented in a tracking sheet. Otherwise, the camera will be recorded as functional (Figure 3). In the event of a malfunction, the SWZ Provider/Contractor will be notified by the SRF project team to begin the troubleshooting process. The SWZ Provider can either remotely reset the CCTV or manually go in the field to fix or replace the CCTV. The SRF project team will continue to monitor until the CCTV returns to its normal operational state and then record when the correction was made.

	Project	City	Trailer ID #	Camera ID #	7/17/2024	7/18/2024	7/19/2024	7/20/2024	7/21/2024	7/22/2024	7/23/2024	7/24/2024	7/25/2024	7/26/2024	7/27/2024
					W	Th	F	Sa	Su	M	T	W	Th	F	Sa
	1DD		3113		Good	Good	Good			Good	Good	Good	Good	Good	
	1DD		3173		Good	Good	Good			Good	Good	Good	Good	Good	
	1DH		~~3703~~ 3167	11093	Good	Good	Good			Good	Good	Good	Good	Good	
	1DH		3131	11128	Good	Good	Good			Good	Good	Good	Good	Good	
	1DM		204		Good	Good	Good			Good	Good	Good	Good	Good	
	1DM		3103		Good	Good	Good			Good	Good	Good	Good	Good	
	1DM		3176		Good	Good	Good			Good	Good	Good	Good	Good	
	1DW		3172		Good	Good	Good			Good	Good	Good	Good	Good	
	1DX		3116 N		Good	Good	Good			Good	Good	Good	Good	Good	
	1DX		3116 S		Good	Good	Good			Good	Good	Good	Good	Good	
	1EC		3151 E		Good	Good	Good			Good	Good	Good	Good	Good	
	1EC		3151 W		Good	Good	Good			Good	Good	Good	Good	Good	
	1EC		8502		Good	Good	Good			Good	Good	Good	Good	Good	
	1EJ		3578		Good	Good	Good			Good	Good	removed			
	2BP		3359		Good	Good	Good			Good	Good	Good	Good	Good	
	2BP		3169		Good	Good	Good			Good	Good	Good	Good	Good	
	2BK		3184S	4578S											
	3AC		3123	5256	Good	Good	Good			Good	Good	Good	Good	Good	
	3AC		3168	4590	Good	Good	Good			Good	Good	Good	Good	Good	
	3AC		3138	4638	Good	Good	Good			Good	Good	Good	Good	Good	
	3AC		3114	4607	Good	Good	Good			Good	Good	Good	Good	Good	
	3AJ		3718		Good	Good	Good			Good	Good	Good	Good	Good	
	3AJ		3185	5235	Good	Good	Good			Good	Good	Good	Good	Good	

Figure 5C.3 Camera Tracking Sheet Example

PCMS Checks

The feeds of PCMS are reviewed daily for any issues impeding a message board's communication with the system in real time using the SWZ Provider software. The project team will document if a PCMS has any issues in the PCMS tracking forms (Figure 4). The SWZ Provider will be notified of any issues to begin the troubleshooting process. The SWZ Provider will either remotely reset the PCMS or manually fix or replace the PCMS. The project team will continue to monitor the PCMS returns to its normal operation state and record when the correction was made.

A	B	GG	GH	GI	GJ	GK	GL	GM	GN	GO	GP	GQ	GR	GS	GT	GU
499362		7/5/2024	7/6/2024	7/7/2024	7/8/2024	7/9/2024	7/10/2024	7/11/2024	7/12/2024	7/13/2024	7/14/2024	7/15/2024	7/16/2024	7/17/2024	7/18/2024	7/19/202
Project #	PDMS ID		Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F
1DD	1799	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DD	1058	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DD	994	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DH	2441 1922	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DH	1975 1805	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1663	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1292	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1286	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2506	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2525	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	1206	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1DW	2507	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
1EC	1843	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
2BN - Jam Logic	2627	ir			flir	flir	flir	flir	flir			flir	flir	flir	flir	flir
2BN - Jam Logic	1226	ir			flir	flir	flir	flir	flir			flir	flir	flir	flir	flir
2BP	1378	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
2BP	1811	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	1226	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2426	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2627	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	2705	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
3AJ	1996															
3AJ	1842	iood			Good	Good	Good	Good	Good			Good	Good	Good	Good	Good
4.1	2436															

Figure 5C.4 Sensor Tracking Sheet Example Sensor Data Reviews

Sensors are checked daily by the project team performing a review of the previous day's data. After a sensor runs for a day, the data will be automatically compiled as an exportable file. These files will then be processed to determine if the sensors successfully recorded all necessary data (Figure 5C.5). Data from a more specific timeframe may be manually downloaded, if needed.

B	C	D	E	F	G	H	I	J	K	L	M
detector name	Directi	zone	agg vol	agg occ	agg spee	is queue					
IWZ3339	EAST	2	1	0	64.6226	FALSE		1432	1440	8	
IWZ3339	EAST	2	0	0	0	FALSE		1 Minutes/packets of data			
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	64.6226	FALSE		423		423	
IWZ3339	EAST	2	1	0	68.35083	FALSE		1 Sensor count of cars is zero		1 Sensor count of no speeds reported	
IWZ3339	EAST	2	0	0	0	FALSE				0	
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	68.35083	FALSE			99%	100%	
IWZ3339	EAST	2	3	3	69.59357	FALSE		2 Sensor count of cars is zero		2 Sensor count of no speeds	
IWZ3339	EAST	2	0	0	0	FALSE		150		150	
IWZ3339	EAST	2	2	0.5	66.48672	FALSE					
IWZ3339	EAST	2	0	0	0	FALSE		0			
IWZ3339	EAST	2	0	0	0	FALSE					
IWZ3339	EAST	2	1	0	67.10809	FALSE					

Figure 5C.5 Sensor Data Example

The uptime percentage shows how frequently a sensor is transmitting data in 24-hour period.

$$\%\text{ of uptime}=\frac{N}{P*60\frac{\text{minutes}}{\text{hour}}*24\frac{\text{hours}}{\text{day}}}*100$$

Where:

N = number of data points P = polling frequency

Equation 5C.1: Example Percentage of Daily Sensor Uptime

This percentage is then recorded on a sensor tracking form (Figure 6). The spreadsheet is reviewed for any missing data. If a sensor is reporting below 95% uptime or the correct polling interval is not shown the SWZ Provider will be contacted by the project team. The SWZ Provider will then determine if the sensor needs to be reset, realigned, or replaced. If the sensor is operational in the field the traffic management software will be reviewed to ensure the sensor is set up correctly to collect and store data. The project team will continue to monitor until the sensor returns to its normal operation state and record when the correction was made.

A	Corridor	City	Trailer ID #	Sensor Type	7/7/2024 Su	7/8/2024 M	7/9/2024 T	7/10/2024 W	7/11/2024 Th	7/12/2024 F	7/13/2024 Sa	7/14/2024 Su	7/15/2024 M	7/16/2024 T	7/17/2024 W	7/18/2024 Th
	1DH		IWZ1805	Wavetronix SS126	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3480	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
1DW	1DW EB 1		DMDS112	Permanent	99%	100%	99%	99%	99%	99%	98%	99%	96%	99%	99%	99%
			DMDS113	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	99%	100%
			DMDS114	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW EB 2		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW WB 1		DMDS91	Permanent	100%	99%	100%	100%	100%	100%	100%	100%	100%	88%	66%	100%
			DMDS90	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	88%	66%	100%
			IWZ629	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW WB 2		DMDS91	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	88%	66%	100%
			DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
	1DW 86 NB/EB 3		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW 86 SB/EB 4		DMDS110	Permanent	100%	100%	100%	100%	100%	100%	100%	99%	100%	100%	100%	100%
			DMDS93	Permanent	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	1DW MH NB/WB 1		DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
	1DW MH SB/WB 2		DMDS33	Permanent	100%	100%	99%	100%	100%	100%	100%	99%	100%	96%	57%	100%
1EC	1EC NB Ramp		IWZ3555	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3088	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
2BP	2BP SB 1		IWZ3359	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	2BP SB 2		IWZ1811	Wavetronix SS125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
			IWZ3010	Wavetronix 125	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Figure 5C.6 Sensor Tracking Sheet Example

Radar Speed Advisory Validation

A radar speed advisory system informs approaching motorists of the posted advisory speed and their current speed to warn them if they are driving above the defined speed limit. These speed displays are portable and can be used in the work zone wherever excessive speeding is a problem. Variations of this system include using advisory speeds based on worker presence and variable speed limit (VSL) based on real-time traffic speeds to assist with speed harmonization.

Errors in speed advisory systems can be mitigated with data validation. The most common speed advisory error is displaying incorrect speed. To validate the system upon deployment, the project team monitors the system in real time to visually check the system performance and reviews sensor data and speed sign activations. Additional review is done with downloaded data and sign log information to review and correlated sign postings. Speed advisory signs will be validated upon deployment and then spot checked throughout the duration of the project to ensure the system is functioning correctly.

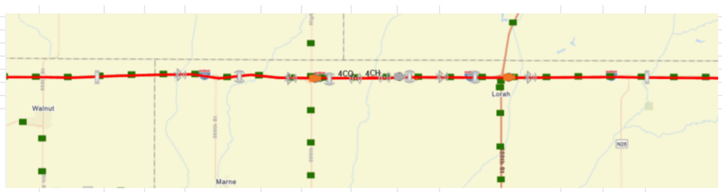
Queue Detection Validation

Queue detection systems use signs and sensors to warn vehicles of slow or stopped traffic ahead. The system is installed within or approaching a work zone corridor with detectors placed ahead of changeable message signs. Sensors detect the occupancy and speed of the roadway to determine whether traffic needs to be warned of a slow down or stop condition. When slow or stopped conditions are met, the PCMS displays a message of “Slow Traffic Ahead” or “Stopped Traffic Ahead.” The sign should then hold the correct message until the traffic returns to normal speeds.

There can be errors in queue detection systems which can be mitigated with data validation. The most common errors are false positives, missed activations, message start delays, and message stop delays. False positives are when PCMS display a slow or stopped message without meeting the preset thresholds. Missed activations occur when the preset thresholds are met, but there is no PCMS activation. Message start delay occurs when traffic has met the slow or stopped traffic conditions but takes more than the allowable latency to activate the PCMS. Message stop delay occurs when traffic conditions have returned to normal, but the PCMS stays activated longer than warranted. These errors are reported to the SWZ Provider to troubleshoot and fix any issue within the system software or threshold levels to correct system errors.

Queue detection corridors are validated upon deployment and spot checked throughout the duration of the project to ensure the system is running correctly. To perform validation the project team downloads sensor data and PCMS message logs to correlate the activations.

Queue length will be reviewed to ensure that the device locations selected reflect the construction traffic patterns. Data modeling provided an estimated queue length for each phase of the project that helped guide the SWZ device placement. However, it is best practice to review the queue length to ensure the SWZ device locations are appropriate for the actual queue length. Unforeseeable extraordinary queues will not result in device relocations, but if consistent longer than expected queue lengths are found new device locations or additional device deployments may be warranted. Heat maps of the project area are an effective way to visually represent the speeds through a work zone and will be used for this purpose. An example of a work zone speed map is shown below in Figure 5C.7.



Date/Time	PDMS SS2715 – I-80 EB @ MM 48	4CH VSL – EB Trailer 891 EB I-80 MM 50	4CH VSL – EB Trailer 891 EB I-80 MM	PDMS + Sensor SSR2523 – I-80 EB @ MM 52.4	PDMS + Sensor SSR2523 – I-80 EB	4CH VSL – EB Trailer 2309	PDMS + Sensor SS1920 – I-80 EB @ MM 55.2	PDMS + Sensor SS1920 – I-80	Sensor EB 3076	Work Zone	Sensor WB 3067	PDMS + Sensor WB 1952	PDMS + Sensor WB 1952	4CH VSL WB Trailer 8135	PDMS + Sensor SS1987 – I-80 WB @ MM 59.8	PDMS + Sensor SS1987 – I-80 WB @	4CH VSL – WB Trailer 8136	PDMS SS1219 – I-80 WB @ MM 65.1
4/22/2022 2:13 PM			62		70	72		63	65		22		63	71		69	69	
4/22/2022 2:14 PM			67		72	66		68	65		25		60	75		55	73	
4/22/2022 2:15 PM			69		70	60		67	65		40		63	71		66	65	
4/22/2022 2:16 PM			67		74	72		57	64		51		60	70		64	72	
4/22/2022 2:17 PM			67		68	69		64	65		45		57	70		67	75	
4/22/2022 2:18 PM			65		72	66		64	61		49		61	73		70	74	
4/22/2022 2:19 PM			65		70	66		68	64		44		49	73		56	72	
4/22/2022 2:20 PM			61		74	73		68	59		14		36	69		64	72	
4/22/2022 2:21 PM			68		64	73		67	59		14		54	71		63	72	
4/22/2022 2:22 PM			71		72	65		70	63		16		63	72		60	72	
4/22/2022 2:23 PM			67		68	65		72	64		16		66	65		59	74	
4/22/2022 2:24 PM			65		72	66		73	64		17		59	66		62	73	
4/22/2022 2:25 PM			70		68	69		73	62		19		34	72		66	73	
4/22/2022 2:26 PM			75		64	71		67	65		22		46	71		69	71	
4/22/2022 2:27 PM			72		70	63		74	64		26		46	71		69	72	
4/22/2022 2:28 PM			63		68	67		54	64		23		42	71		54	71	
4/22/2022 2:29 PM			64		68	75		58	60		17		41	67		66	75	
4/22/2022 2:30 PM			64		67	72		71	61		14		42	73		70	71	
4/22/2022 2:31 PM			71		69	70		73	54		17		47	71	STOPPEDTRAFFICAHE	68	72	
4/22/2022 2:32 PM			68		71	68		74	59		16		38	74		65	75	
4/22/2022 2:33 PM			54		74	63		52	60		15		24	69		66	77	
4/22/2022 2:34 PM			59		74	68		54	61		10		31	71		64	73	
4/22/2022 2:35 PM			66		68	71		70	59		13		33	73		67	75	
4/22/2022 2:36 PM			61		60	59		66	60		16		22	71		71	75	
4/22/2022 2:37 PM			65		68	50		67	62		19		15	75		71	74	
4/22/2022 2:38 PM			69		68	64		65	66		17		9	73		69	69	
4/22/2022 2:39 PM			70		65	65		63	57		16		24	73		63	71	
4/22/2022 2:40 PM			67		68	65		67	60		14		16	67		63	72	
4/22/2022 2:41 PM			74		70	69		68	61		13		27	72		66	70	
4/22/2022 2:42 PM			74		70	72		68	54		17		31	74		65	75	
4/22/2022 2:43 PM			70		65	64		69	55		17		11	71		68	66	

Figure 5C.7 Example Work Zone Speed Map

Project Meetings and Weekly Reports

Smart work zone deployments are only effective when all the components are working properly and have good communications. As part of a systems communication plan project team meetings and reports help maintain system functionality for the duration of the project.

Weekly Team Meetings

Weekly project check-in meetings that include the project manager, SWZ provider, and other stakeholders help facilitate a successful SWZ. Topics for the meetings include SWZ coordination, phase change coordination, and a SWZ system weekly report review. These check-in meetings can be combined with standard weekly or bi-weekly project meetings if they are held, otherwise a mutually agreed upon time will be chosen for the SWZ project team to meet.

Weekly System Report

A weekly overview report will be created and shared with the evaluation project team during the weekly call to develop an understanding of how traffic is flowing through the project area and interacting with the SWZ deployment. The weekly snapshot report will include a summary of any updates on the system such as system status, deployments or relocations, downed devices and remediation reports, and a current analysis of the system. These reports are expected to be generated in a similar way so that week- to-week findings are comparable. The reports can be used as a leading indicator if some part of the system should be changed to improve accuracy or device locations outside of any daily findings that need immediate remediation.

8.1.6 06_TR202415 _ Project Evaluation Plan_J7I3010_ DRAFT

TR202415 TSMO Strategies in Work Zones Project Evaluation Plan

By
SRF Consulting Group

Prepared for
Missouri Department of Transportation

Winter 2025

Draft Report

Table of Contents

List of Figures

List of Abbreviations and Acronyms

AADT........Average Annual Daily Traffic
DOT........Department of Transportation
FHWA........Federal Highway Administration
PCMS........Portable Changeable Message Signs
SD........Secure Digital
SWZ........Smart Work Zone
PPI........Personally Identifiable Information
TSMO........Transportation Systems Management and Operations

Introduction

Managing traffic during construction is necessary to minimize traffic delays, maintain motorist and worker safety, complete roadwork in a timely manner, and maintain access for businesses and residents. As the Missouri Department of Transportation continues to advance its Work Zone Management Priorities, the Department seeks to identify implementable strategies that benefit both areas of workforce shortage and safety.

Goals and Objectives

One of the primary goals of the project is to monitor and evaluate automated Smart Work Zone (SWZ) system performance and effectiveness and to create a best practice summary that can be used for future SWZ applications. The evaluation will occur in two stages over the duration of the project with the first phase consisting of daily data collection for system monitoring and the second phase consisting of an evaluation of SWZ system performance and effectiveness. This plan outlines the second phase of project evaluation. The first phase of the project evaluation is covered by a separate document, the Daily Monitoring Plan. The following goals and objectives were identified to guide activities for SWZ system performance and effectiveness:

Goal 1: Evaluate System Reliability

Objective 1-1: Evaluate system functionality

Objective 1-2: Evaluate troubleshooting response time of SWZ Provider/contractor Objective 1-3: Evaluate frequency of failure

Goal 2: Evaluate System Effectiveness

Objective 2-1: Verify SWZ design meets all design requirements
Objective 2-2: Evaluate travel delay

Objective 2-3: Evaluate driver reaction

Objective 2-4: Evaluate incidents and response (if applicable)

Goal 3: Cost Analysis

Objective 3-1: Evaluate economic impact

Goal 4: SWZ Best Practice Review

Objective 4-1: Determine SWZ best practices for effective deployment
Objective 4-2: Recommend best practices for institutionalizing SWZ systems into standard practices Objective 4-3: Recommend best practices for matching construction projects with SWZ solutions

System Overview and Project Location

This project aims to implement and evaluate the following work zone systems that will be deployed on I-44 in Webster County during Summer 2025.

- Radar speed advisory system: A sensor-based speed warning system (Speed Advisory display) used in a work zone which informs the approaching motorists of the posted advisory speed and their current speed to warn them if they are driving above the defined speed limit. These speed displays are portable and can be used in the work zone wherever excessive speeding is a problem. Variations of this system include using advisory speeds based on worker presence and variable speed limit (VSL) based on real-time traffic speeds to assist with speed harmonization.

- Queue detection: A queue detection and warning system is used to inform travelers about upcoming congested or stopped traffic conditions. This system informs drivers of an impending traffic situation and avoids emergency braking and queue-related collisions. The system typically consists of roadside sensors and Portable Changeable Message Signs (PCMS) placed upstream of the work zone. The basic principle of this system is when sensors detect slowing or stopped vehicles, it sends signals to the PCMS where messages are displayed advising travelers about an impending traffic queue.

- Temporary long-term rumble strips (if utilized by contractor): A strategy for reducing distracted driving and achieving work zone safety goals. Temporary rumble strips are comprised of a series of raised elongated bumps placed upon the surface of the roadway to provide an audible and vibratory alert to drivers of the upcoming work zone.

The project is located on I-44 in Webster County from north of Strafford, MO to Conway, MO. Most of the work and the SWZ applications will be located between Strafford, MO and Northview, MO shown in Figure C6.1.

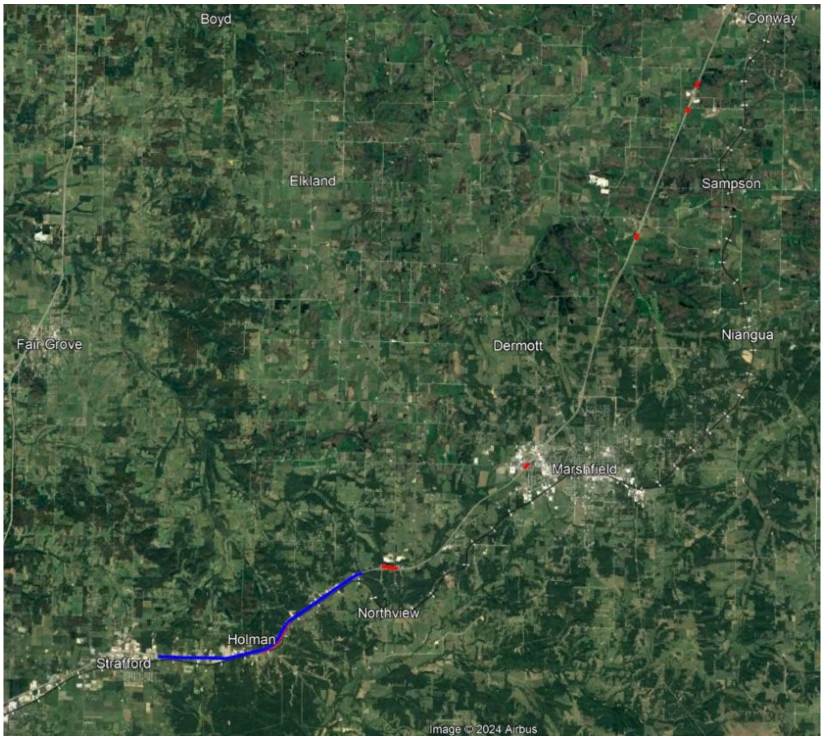


Figure C6.1 Project Location EB and WB I-44 MM 125 to MM 113 Webster County, Missouri
(image source: MoDOT)

Data Types and Storage

Data Types

Following the deployment of the Radar Speed Advisory System, Temporary Long-term Rumble Strips, and Queue Detection systems along I-44, data collection will commence for evaluation and monitoring purposes. This will include capturing timestamped system performance metrics, such as the number of warnings issued to travelers, average system downtime, and occurrences of false positives. The collected data will undergo quality checks to ensure its accuracy and to assess the Alert Processing System (APS) logic. Additionally, for evaluation purposes, the following data will be collected from portable traffic sensors located both upstream and downstream of the Intelligent Work Zone (SWZ) systems to analyze their performance and evaluate their impact:

- Vehicle speed data: To assess driver reaction to the SWZ alert.
- Vehicle count and classification data: To assess volume changes resulting from SWZ alert or operations.
- Video data: For video analytics, monitoring, and checks at selected locations (video will not be recorded over the entire work zone).

Storage and Infrastructure

The data from the SWZ systems and evaluation traffic sensors will be stored in a structured manner to facilitate analysis and reporting. The data storage approach will include:

- Secure Digital (SD) Card: Utilize SD cards to store timestamped system data, such as the number of warnings issued to motorists.
- SRF Servers: Data retrieved from SWZ and evaluation traffic sensors, such as vehicle speed, vehicle count, and classification data will be stored in SRF servers.
- File Storage for Video: Storing video clips in a secure file storage system with metadata linking each video segment to the respective timestamp and system event.

Data Preservation and Archiving

Retention Period: Raw data from all systems will be retained by SRF for the life of the project and provided to MoDOT at the end of the project. Aggregated data will be retained indefinitely for analytics.

Data metrics are summarized below.

Metric	Description
Type of data	• System performance data • Vehicle speed data • Vehicle count and classification data • Video data
Data collection method and formats	• Evaluation traffic sensors will collect vehicle speed, count, and classification data in near real-time. • SWZ systems will collect systems performance data.
	• Data will be stored in structured formats (e.g., CSV) to facilitate analysis and integration with data management systems. • Video data will be recorded in standard video formats (e.g., MP4) for playback and analysis.
Documentation of data collection	• Data collection procedures will be documented in detail, including SWZ deployment locations, traffic sensor locations, sampling frequencies, and data transmission protocols.
Data reproducibility	• Data collection methods will be standardized to ensure reproducibility. • Regular backups and version control mechanisms will safeguard against data loss or corruption.
Use of pre-existing data	• Pre-existing data may be used for comparative analysis or historical trend assessment. • Sources of pre-existing data may include traffic databases, previous studies, or DOT repositories.

Storage and backup strategy	• Data will be stored in SD cards. Some data may be stored in secure, scalable storage solutions, such as cloud-based storage or dedicated servers. • Regular backups will be performed to ensure data redundancy and mitigate risks associated with data loss or corruption.

Data Access and Sharing

Data collection and sharing within the scope of this project will strictly adhere to DOT privacy guidelines and regulations. Video footage will be captured without displaying license plates to protect individual identities. Sharing of collected data will be restricted to authorized personnel only, ensuring that sensitive information remains confidential and is not accessible to unauthorized individuals. Incidents will not be broadcast or recorded to uphold privacy and prevent unnecessary exposure of sensitive events. Personally Identifiable Information (PII) will neither be reported nor published, safeguarding individuals' privacy and personal data. Furthermore, all data security protocols and procedures will be followed diligently to prevent unauthorized access, data breaches, or misuse of collected information, maintaining the highest standards of privacy and confidentiality throughout the data collection and sharing processes.

Evaluation

This section presents evaluation methodologies for the I-44 project in Webster County post project evaluation. Results will be presented in a clear and straightforward manner.

Performance Metrics

In evaluating the effectiveness of various transportation systems, several performance measures will be utilized to assess their impact and functionality. Specific metrics including the number of warnings issued, system downtime, false positives, queue length, advisory speed, travel delay, driver reaction to advisory speed, and driver reaction to queue feedback will be examined. These metrics will provide insights into the performance of the Radar Speed Advisory System, and Queue Detection systems. Further details on each metric and its application to the evaluation process will be discussed in subsequent sections.

Performance Metric	Description	Radar Speed Advisory System	Queue Detection
Number of warnings	Number of warnings issued to travelers per time period (e.g., daily, weekly).	X	X
System downtime	Average time to repair for system failures or component breakdowns.	X	X
False positives	Percentage of false warnings triggered by the system.	X	X
Queue length	Length of queue of vehicles from the bottleneck.		X
Advisory Speed	Real-time speed that informs and alerts the driver about their current speed relative to the advisory speed threshold.	X	
Travel delay	Delay effect following the operation of the system.	X	
Driver reaction on advisory speed	How a driver adjusts their vehicle's speed in response to encountering an advised speed on the road and how long a driver maintains the adjusted speed.	X	
Driver reaction on queue feedback	How a driver adjusts their vehicle's speed in response to encountering an advised queue ahead on the road.		X
Vehicle count/capacity	Number of vehicles passing through the work zone in order to determine capacity of the work zone.	X	

Radar Speed Advisory System

The radar speed advisory system will capture, and record vehicle speeds displayed by the system. This speed data will be stored on an SD card within the system. Additionally, the system will feature remote communication capabilities, enabling remote control and access to the stored data. To facilitate evaluation, traffic sensors will be positioned along the road to independently collect speed data both upstream and downstream of the system. This approach will enable an analysis of vehicle speeds and driver behavior in relation to the advisory system's operations.

The evaluation will be carried out using the following performance measures:

- System performance metrics: This will include documentation and analysis of the timestamped number of warnings provided to travelers, average down time of the system, and false positives. False positives are instances where the radar system indicated speeding that did not correspond to actual vehicle speeds.
- Driver reaction to the advisory speed: The driver response to the speed feedback, in terms of changes in speed, will be assessed using speed data collected from evaluation traffic sensors installed both upstream and downstream of the system. This reaction review will also aim to determine how long the driver maintains the speed adjustment after notification.
- Travel delay: To assess whether the system causes travel delays, the team will gather both baseline and operational speed data. Baseline speeds along the route prior to system activation will establish a reference for measuring changes in travel duration once the system is in use. Speed data will be obtained from traffic sensors to observe how travel behaviors vary under different traffic conditions, including responses to speed advisories triggered by the system. Statistical analysis of this data will enable quantification of the system's impact on travel delays, identifying factors like heightened congestion or shifts in driving patterns that contribute to reduced travel efficiency.
- Number of crashes (if applicable): To evaluate the impact of the system on safety, the team will collect crash data on both baseline and operational scenarios. Establishing crash rates before implementing the system will provide a benchmark for assessing changes once the system is deployed. Crash data will be obtained from MoDOT crash database to analyze how the system affects crash occurrences under various conditions, including responses to speed advisories and other safety alerts triggered by the system. Statistical analysis of this data will allow us to quantify the system's effectiveness in reducing crashes, identifying factors contributing to improved safety outcomes, such as changes in driver behavior or traffic patterns influenced by the system's interventions. The number of crashes will only be considered a valid metric if a statistically significant number of crashes occur during the evaluation period.
- Breakdown capacity: To determine the capacity of the work zone, traffic counts will be collected using the radar system and from evaluation sensors located upstream and downstream of the system. Using the data, the point right before the breakdown in traffic can be determined. Additionally, the vehicle counts can be used to back check the volume estimates used to predict queues caused by the work zone.

Queue Detection

Queue detection will involve the collection and recording of queue lengths within the designated zone. Daily data downloads will be conducted to ensure timely access to queue metrics. To enhance queue detection accuracy, additional evaluation sensors will be strategically installed upstream of the detection zone to capture queue backups effectively. Similarly, data collected from the queue detection sensors will be stored on an SD card within the system, providing a secure and accessible repository for the queue length data. Leveraging remote communication capabilities, this data can be remotely accessed and transmitted for real-time monitoring and analysis, enabling efficient traffic management and response to queue conditions within the work zone.

The evaluation will be carried out using the following performance measures:

- System performance metrics: This will include documentation and analysis of the number of warnings provided to travelers, average downtime of the system, and false positives. False positives are instances where the queue detection system indicated queueing that did not correspond to actual vehicle backups. This system performance will be collected over several weeks, recording queue alerts triggered along with simultaneous manual queue checks using traffic cameras at specific locations.
- Driver reaction to the queue feedback: The driver response to the queue feedback, in terms of changes in speed, will be assessed using speed data collected from evaluation traffic sensors upstream of the system.
- Travel delay: To assess whether the system causes travel delays, the team will gather both baseline and operational travel time data. Baseline travel times along the route prior to system activation will establish a reference for measuring changes in travel duration once the system is in use. Travel time data will be obtained from evaluation traffic sensors to observe how travel behaviors vary under different traffic conditions. Statistical analysis of this data will enable quantification of the radar system's impact on travel delays, identifying factors like heightened congestion or shifts in driving patterns that contribute to reduced travel efficiency.
- Number of crashes (if applicable): To evaluate the impact of the system on safety, the team will collect crash data on both baseline and operational scenarios. Establishing crash rates before implementing the system will provide a benchmark for assessing changes once the system is deployed. Crash data will be obtained from MoDOT crash database to analyze how the system affects crash occurrences under various conditions. Statistical analysis of this data will allow us to quantify the system's effectiveness in reducing crashes, identifying factors contributing to improved safety outcomes, such as changes in driver behavior or traffic patterns influenced by the system. The number of crashes will only be considered a valid metric if a statistically significant number of crashes occur during the evaluation period.

Cost Review

The system cost and procurement process will be documented for the contractor-provided systems. This cost will be provided for all SWZ systems reviewed. The amount of MoDOT infrastructure already deployed has a major effect on the contractor cost so this will be considered in the analysis. For example, if MoDOT's permanent detectors or DMS are planned to be used (saving significant deployment costs) this will be reported.

Evaluation Report

The Evaluation Report produced for this project will quantify the effectiveness of SWZ deployments and document a variety of best practices. Key elements of the report are summarized below.

Determine SWZ best practices for effective deployment

This objective will document the best practices for implementing SWZ solutions to obtain the most effective outcomes. The details of what, where and how SWZ solutions are best implemented will be documented. For example, best practices for testing may include pre-testing, startup testing, and ongoing testing. Best practices for laying out field equipment may include detector spacing and sign placement relative to roadway geometry. These various key considerations will be documented to provide a valuable reference tool for ongoing use by practitioners.

Recommend best practices for institutionalizing SWZ systems into MoDOT standard practices

MoDOT project development and delivery procedures will be reviewed to understand how best to incorporate SWZ solutions. Equally important is the engagement of district/project stakeholders including Managers, District Traffic Engineers, District Construction Engineers, planners, and technicians to obtain informed consensus that SWZ initiatives can bring value to providing mobility and safety during construction operations. The evaluation will document this process and present best practices, key considerations, and next steps for institutionalizing SWZ. Key considerations will be developed for work zones, SWZ systems and the SWZ Provider.

Recommend best practices for matching construction projects with SWZ solutions

Roadway construction projects are each unique, and not all are suitable for the application of SWZ solutions. Numerous factors, including AADT, length of work zone (distance), duration of work zone (time) and geometric factors such as lane shifts and lane width come into play. Other variables include the percentage of heavy commercial vehicles, traffic control schemes, and type of work zone activity. These variables will all be reviewed, and best practices, key considerations, and next steps for matching construction projects to the most suitable SWZ solution will be presented. Key considerations will be developed for work zones, SWZ systems and the SWZ Provider. As MoDOT already has some tools developed to assist with SWZ application selection this section may cover recommendations on outreach and will cover easy to follow recommendations for matching construction projects with SWZ systems, how often to update current program resources, a SWZ scoping decision tree and cost estimates, and boiler plate SWZ job special provisions.

Provide a summary of the comparison of predicted queue lengths and observed queue lengths within the work zone

The DOT has a robust spreadsheet based model to predict potential queueing within a work zone. The SWZ and the traffic counting devices will provide insight into how the observed queues compared to the predicted queues. This will help support the need for SWZs in the future.

Conclusion

This Evaluation Plan establishes the project's goals and objectives and identifies how the evaluation will be conducted. Next steps for the project are to begin discussion with the I-44 project team and SWZ provider and set up the methods for receiving or downloading data from the SWZ contractor and MoDOT.

The results of the evaluation will be used to develop effective easy to use processes that will facilitate institutionalization of effective SWZ TSMO applications and recommended next steps that will result in consistent consideration and application of SWZ technologies in construction work zones.

D1. Appendix D: J8I3044C_JSU0076_WZITS JSP and StreetWise WZITS Submittal

8.1.7 J8I3044C_JSU0076_WZITS JSP

Job No. J8I3044C, JSU0076, JST0088B, J8I3225, and JSU0114
Route: I-44
County: Greene

QQ. Temporary Long-Term Rumble Strips JSP-13-04C

long-term rumble strips, as shown in the plans, or as designated by the engineer.

2.0 Material.

2.1 The long-term rumble strips shall be 10 feet to 12 feet in length, fabricated from a polymer material, and be orange in color.

2.2 The long-term rumble strips shall have a minimum width of 4 inches, but no greater than 6 inches. The long-term rumble strips shall have a minimum thickness of 0.25 inch, but no greater than 0.50 inch.

2.3 The long-term rumble strips shall have a pre-applied adhesive backing for securing to the asphalt or concrete roadway surface.

3.0 Construction. Long-term rumble strips layout and spacing shall be in accordance with the plans or as approved by the engineer. The long-term rumble strips shall be installed and removed in accordance with manufacturer's recommendation. The contractor shall monitor and repair and maintain if necessary the long-term rumble strips until removed.

3.1 Each set shall consist of five individual strips spaced ten to twelve feet on center.

3.2 The long-term rumble strips removal process shall not damage the roadway surface. If any damage occurs to the pavement during the removal of long-term rumble strips, the contractor shall replace or repair the damaged pavement at no cost to the Commission.

4.0 Method of Measurement. Measurement of long-term rumble strips will be per each complete set of five strips.

5.0 Basis of Payment. The accepted quantity of Temporary Long-Term Rumble Strips sets will be paid for at the contract unit price for 616-20.02, Temporary Long-Term Rumble Strips, per each set. The long-term rumble strips unit bid price shall include the cost of all labor, equipment and materials to install, maintain, and remove the rumble strips.

RR. Work Zone Intelligent Transportation System NJSP-15-32A

1.0 General. The Work Zone Intelligent Transportation System (WZITS) shall be a portable, real- time, automated, solar powered system that calculates and displays travel time through work zones. The goal of this system is to provide advance traffic condition information to motorists at key decision points due to construction activity. The information reported to the public will include an accurate drive time through the work zone. This system shall be in operation 24 hours per day, seven days per week, during the construction period.

2.0 Description. This item shall consist of submittal and approval of a Work Zone Intelligent Transportation System plan, furnishing, installing, relocating, and operating a portable, automated, solar powered real-time work zone system ("Work Zone Intelligent Transportation System") meeting the requirements noted herein, and providing a system manager to maintain the system during the duration of the project. The contractor shall assume responsibility for any damaged equipment due to crashes, vandalism, adverse weather, etc. that may occur during the system's deployment.

2.1 The Contractor shall furnish and maintain this system for measuring and delivering real-time messages for the work zone.

2.2 The contractor is responsible for coordinating any work in adjacent roadway construction projects.

2.3 The contractor will be responsible to relocate the devices as directed by the engineer. When the equipment is no longer required for this project, the contractor shall remove it and retain ownership.

3.0 System Requirements

3.1 The Work Zone Intelligent Transportation System shall be installed on *I-44*. It shall consist of the following as a minimum:

- 9 portable changeable message signs (three per I-44 eastbound and westbound approaches, one per Route 13 southbound approach, and one per US-65 northbound approach)
- portable non-intrusive traffic sensors (4 per approach)
- 1 central computer

4.0 Smart Work Zone Plan

4.1 General. The contractor shall submit to the Engineer for approval a written and illustrated WZITS Plan three (3) weeks prior to mobilization of any component of the WZITS System. The WZITS Plan shall include the items required in this specification. The Contractor will not be allowed to start any construction activities that will affect traffic on the project until the WZITS Plan is approved by the Engineer.

4.2 Content of the WZITS Plan. The WZITS Plan shall include, as a minimum, the following items:

(a) A detailed plan showing the proposed locations of all WZITS devices and equipment description including make and model.

(b) A description of all proposed thresholds and proposed CMS messages to be implemented.
(c) The name and contact information of the WZITS System Manager.
(d) A detailed description of the proposed methods of communication between WZITS devices and WZITS Central Computer and between WZITS Central Computer and the MoDOT Transportation Management Center (TMC) located at 1107 W Chestnut Expressway, Springfield, MO.
(e) Proposed corrective method procedures including response times and notification process.

Review MnDOT or ATSSA ITS solutions for possible WZITS plans.

4.3 Approval of Plan. Approval of the WZITS Plan by the Engineer is required prior to the placement of any WZITS devices. Approval is conditional and will be predicated on satisfactory performance during construction. The Engineer reserves the right to require the Contractor to make changes in the WZITS Plan and operations, at no additional cost to the Commission, including removal of personnel, as necessary, to obtain the quality specified. The Contractor shall notify the Engineer in writing a minimum of seven (7) calendar days prior to any proposed changes in the WZITS Plan. Proposed changes are subject to approval by the Engineer.

5.0 Materials.

5.1 Changeable Message Signs. The Work Zone Intelligent Transportation System shall utilize MoDOT approved portable changeable message signs (CMS) in accordance with Missouri Standard Specifications for Highway Construction section 616 Temporary Traffic Control and 1063 Temporary Traffic Control Devices and Standard Plans for Highway Construction 616.10. Each CMS shall be capable of displaying eight characters on each of three rows. Each CMS power supply shall be properly sized to allow continuous operation for up to ten days during periods of darkness and inclement weather.

5.2 Each CMS shall be integrated with a radio/modem, and/or a traffic sensor or other equipment (e.g., controller) mounted on it and shall act as a single “device” for the purpose of communicating with similarly integrated “devices” and displaying real-time traffic condition information. Each device shall be capable of communicating through radios/modems with other device(s) at upstream or downstream locations. MoDOT District TMC staff must have the ability to override messages displayed on any CMS in the system. This feature must be password protected and on a website separate from MoDOT's public website.

5.3 Portable Non-Intrusive Traffic Sensors. The Smart Work Zone System traffic sensors shall be side-fired microwave radar type whose accuracy is not degraded by inclement weather and visibility conditions including precipitation, fog, darkness, excessive dust, and road debris. These sensors shall be capable of acquiring traffic data from up to six 6 lanes of traffic on a lane-by- lane basis.

5.4 Central Computer. The central computer shall provide the functionality described below:

General

- Provide a Graphical User Interface that is compliant with Windows standards.
- Communication between the central computer and any device shall be independent and *non-reliant* upon communications with any other CMS or sensor.
- Alerts to MoDOT TMC staff and the Engineer shall be provided via pagers and/or e-mail. Alerts shall be sent in the event of device failure or traffic delays over 15 minutes.

Data Processing Software

- The capability to collect and store sensor data.
- The capability to compare traffic data collected from sensors to user-defined thresholds and automatically update one or more CMS's.
- The capability to estimate travel times and automatically update one or more portable CMS's consistent with user-defined thresholds.
- The capability to display alternate route messages consistent with user-defined thresholds.

Data Management

- Storage of speed, volume, occupancy, CMS message history, and travel times as well as appropriate sensor status for each day.

Website

- The Contractor will be responsible for hosting the website and obtaining domain names. Possible domain names and overall website design must be submitted to the Engineer for approval prior to it being made available.
- The website shall contain an accurate map of the area affected by the work zone, including state highways or routes that may be used as alternates.
- Icons or hyperlinked text should accurately depict the current location of the system components and give real-time information provided by each component. In the event components are moved to a new location, the website must reflect these changes to the system layout.
- Historical data should be password protected and stored on the website for each day the system is in use, with date and time stamps included. The above data shall be available to MoDOT staff at all times for the duration of work zone activity. An electronic copy of all data, including date and duration of system malfunction, shall be provided to MoDOT staff after all work zone activity is completed and the WZITS has been removed.
- The MoDOT TMC staff and the Engineer shall have the capability to override messages, via password protection, from the website.
- Device information shall be provided to MoDOT TMC staff through icons or hyperlinked text representing each device. Detectors should provide real-time speeds at the respective locations and CMSs should provide the current message of each sign.
- The website shall be designed and operated to allow 20 users to access the site at one time

6.0 System Manager. The contractor shall employ a system manager for the WZITS. The system manager shall be locally available to maintain system components, maintain the website, move portable devices as necessary, and respond to emergency situations. The system manager shall be responsible for coordinating the placement of devices in the project areas. It is the responsibility of the system manager to move system components that interfere with construction operations and relocate the components to another area. The system manager shall supply a local phone number and/or a toll free number to the engineer to contact the system manager or other system representative at any time. The system manager shall not perform any other duties on the job site.

7.0 Operational Test. Once the WZITS is installed, it shall undergo a five-day operational test. The operational test shall include a test of the system in operation during a lane closure to ensure that all WZITS equipment (including the changeable message signs, traffic sensors, central computer, communication devices, and website) is operating in a fully functional manner and in accordance with the Smart Work Zone Plan for a duration of at least five (5) calendar days. The contractor shall provide for complete operations support from the vendor during the operational test, and the contractor shall provide verification that the reported drive time through the work zone accurately reflects actual field conditions. If any equipment malfunctions occur for a combined period of four (4) hours or more during this operational test on any day, no credit will be given for that day for the operational test period, and the five-day operational test will reset.

7.1 The contractor shall maintain records of equipment stoppages and resumptions during the five-day operational test for submission to the engineer for his approval. In the event that ten percent or more of the time similar malfunctions occur that affect the proper operation of the WZITS, the engineer may declare a system component defective and require replacement of the equipment at no additional cost. When a system component defect is declared, the five-day operational test shall begin again after all defective equipment is replaced and the system is fully operational.

7.2 Report. The contractor shall submit a report to the engineer detailing the daily activity of the system during the operational test. The report shall indicate the date and time of any activity necessary to maintain operation of the WZITS during the operational test period. Each entry shall include the following information:

- Identity of the equipment on which work was performed
- Cause of equipment malfunction (if known)
- A description of the type of work performed
- Time required to repair equipment malfunction

Once the operational test report is received and approved by the engineer, the WZITS will be considered operational and the system will be accepted for use.

8.0 Method of Measurement. Work Zone Intelligent Transportation System (WZITS) shall be measured by one lump sum and shall be divided into the following payment schedule:

- 35 percent will be paid when all of the WZITS equipment is delivered to the jobsite.
- 25 percent will be paid when the engineer approves the Operational Test Report.
- 20 percent will be paid after calendar days of full system operation.
- 20 percent will be paid after traffic is in its final position, the contractor's equipment has been

removed from the project, and historical data has been provided to the engineer.

8.1 Deduction for Failed System. A percentage of the lump sum will be deducted should the system malfunction for three (3) or more consecutive calendar days or any total of five (5) calendar days in any one calendar month after the approval of the operational test. This deduction will be based on a ratio of calendar days of unsuccessful operation to total calendar days of operation following the approval of the operational test. This deduction will not reduce the total system payment to less than 60 percent of the lump sum.

9.0 Basis of Payment. Payment for submittal and approval of a Work Zone Intelligent Transportation plan, furnishing, installing, relocating, operating, maintaining, testing, monitoring, providing a website, providing historical data, and removal of the Work Zone Intelligent Transportation System (WZITS), including all items required for proper operation of this installation, will be completely covered by the contract unit price for Item Number 616 99.01, "Work Zone Intelligent Transportation System," per lump sum.

8.1.8 StreetWise WZITS Submittal

WZITS Submittal

State Project # J8I3044C, JSU0076,

JST0088B, J8I3225, and JSU0114

SUBMITTAL PACKAGE FOR
Work Zone Intelligent Transportation System (WZITS) NJSP-15-32A

FEB 3, 2025

BY:

and

WZITS EQUIPMENT

All proposed WZITS equipment information for signs and sensors is in the Literature Appendix of this submittal.

WZITS SYSTEM MANAGER - CONTACT INFORMATION:

Deployment, Maintenance and Operation:
Mega Rentals, Inc. – Ryan Lee
rlee@streetwise-inc.com or (816) 331-2355 (cell)

System Hardware and Software Provider:
Ver-Mac, Inc. – Support
support@ver-mac.com or 877-545-1953 (ask for Smart Work Zone Support)

WZITS COMMUNICATIONS

Communications with each sign and sensor platform is via independent LTE cellular communications every 60 seconds.

Communications from the WZITS system to the MoDOT TMC is via our JamLogic software utilizing individual pre-approved usernames (work emails) and passwords via our web-based mobile friendly access or our full featured client-based programs on a user's PC or laptop.

WZITS MALFUNCTION ALERTS and CORRECTIVE MEASURES

All WZITS devices are programmed to provide instant text and/or email alerts to a designated list of recipients for LOW POWER and COMMUNICATION LOSS. The WZITS System Manager is the primary person responsible for getting any malfunctioning devices back online ASAP. The WZITS System Manager is trained on repairs and stocks many commonly needed parts. For any parts not in stock, Ver-Mac can provide overnight shipping of most component parts. The goal is to not have any device out of service for more than 48 hours from the time of notification and often in less time.

LAYOUT and LOGIC:

Google Map of Equipment Layout:

[Link to the Streetwise Google Map of Equipment Layout.]

Note that there are two layers on this map (1 for each phase of construction – East vs West) and the Queue Warning Devices shift accordingly based on the relative taper points during each phase, based on the typical layout.

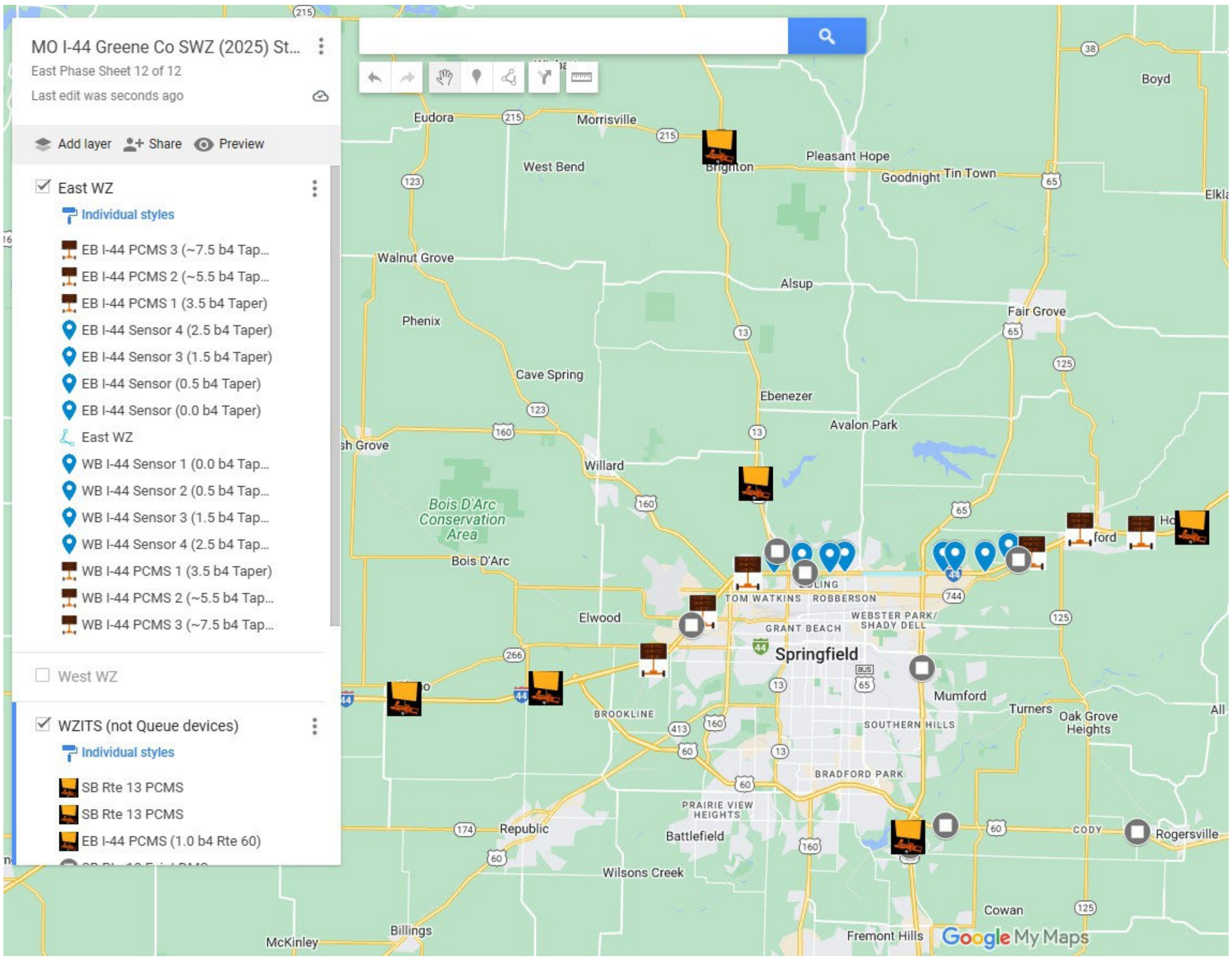


Figure D2.1: EAST WORK ZONE PHASE

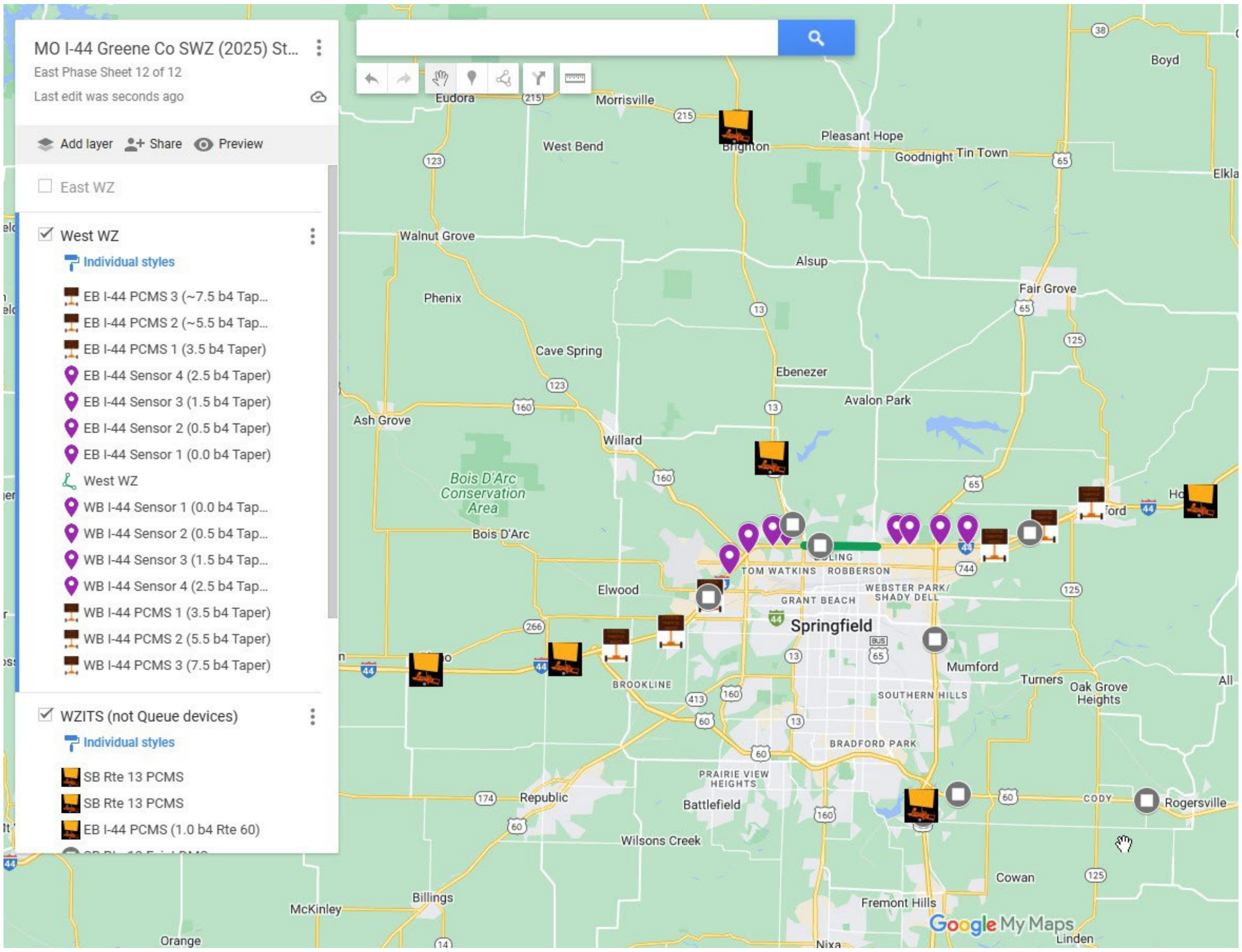


Figure D2.2: WEST WORK ZONE PHASE

TYPICAL LAYOUT

The WZITS typical system layout will be at the following locations:

Distance to Taper	**Device**
0.0 mile	Traffic Sensor 1
0.5 miles	Traffic Sensor 2
1.5 miles	Traffic Sensor 3
2.5 miles	Traffic Sensor 4
3.5 miles	Portable CMS 1
5.5 to 6.5 miles	Portable CMS 2
7.5 to 8.5 miles	Portable CMS 3

I-44 WZITS
TYPICAL LAYOUT

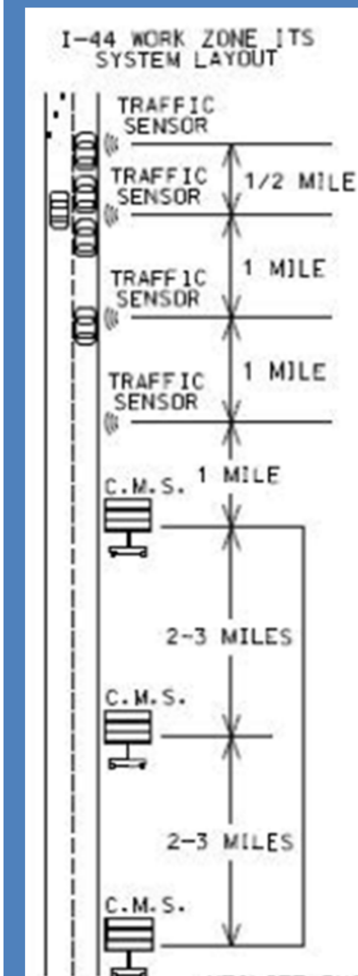


Figure D2.3: I-44 WZITS Typical Layout

QUEUE SYSTEM LOGIC

FREE FLOW TRAFFIC (>40 mph):

If the speed on all downstream sections is at or above 40 mph, the upstream PCMS(s) shall display "ROAD WORK" – "XX MILES AHEAD" where XX is the shortest rounded down distance to accommodate growing queues.

FRAME 1	FRAME 2
ROAD WORK	XX MILES AHEAD

SLOW TRAFFIC (</= 39 mph and > 20 mph):

If the speed on any downstream section of the roadway is between 39 mph and 20 mph (for example, 35 mph), the following two-phase messages will be displayed on the upstream PCMS as shown below:

FRAME 1	FRAME 2
SLOW XX MILES AHEAD	BE PREPARED TO STOP

STOPPED TRAFFIC (</= 20 mph):

If the current speed on any downstream section of the roadway is equal to or below 20 mph, the following two-phase messages will be displayed on the upstream PCMS as shown below:

FRAME 1	FRAME 2
STOPPED TRAFFIC AHEAD	BE PREPARED TO STOP

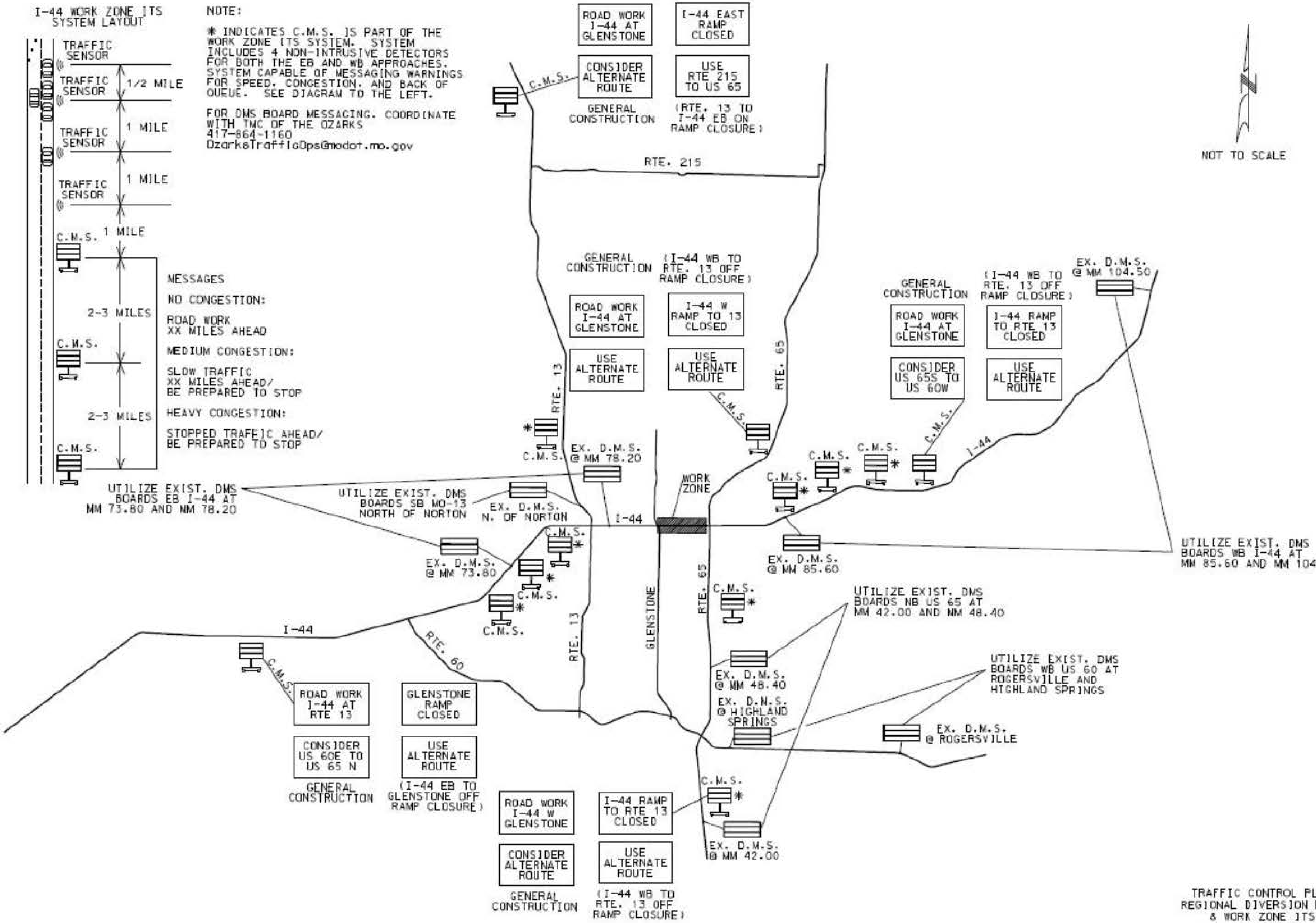
ALTERNATE ROUTE LOGIC

All advanced PCMS will display the designated messages in accordance with the WZITS plan sheets (see following 2 pages)

NOTE:

* INDICATES C.M.S. IS PART OF THE WORK ZONE ITS SYSTEM. SYSTEM INCLUDES 4 NON-INTRUSIVE DETECTORS FOR BOTH THE EB AND WB APPROACHES. SYSTEM CAPABLE OF MESSAGING WARNINGS FOR SPEED, CONGESTION, AND BACK OF QUEUE. SEE DIAGRAM TO THE LEFT.

FOR DMS BOARD MESSAGING, COORDINATE WITH TMC OF THE OZARKS
417-864-1160
OzarksTrafficOps@modot.mo.gov



TRAFFIC CONTROL PLAN
REGIONAL DIVERSION PLAN
& WORK ZONE ITS
JBI3044C
SHEET 12 OF 12

THIS SHEET HAS BEEN SIGNED, SEALED AND DATED ELECTRONICALLY.

DATE PREPARED	
8/19/2024	
ROUTE I-44	STATE MO
DISTRICT SW	SHEET NO. 119
COUNTY GREENE	
JOB NO. JSU0076, JBI3044C, & JST0088B	
PROJECT NO.	
BRIDGE NO.	

DESCRIPTION | DATE

IF A SEAL IS PRESENT ON THIS SHEET IT HAS BEEN ELECTRONICALLY SEALED AND DATED.

MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION
105 WEST CAPITOL
JEFFERSON CITY, MO 65102
1-888-ASK-MODOT (1-888-275-6636)

HG Consult Inc engineers planners

G:\Shared drives\Hg Projects (Yr 2021-2022)\2022\22.040 I-44 Widening_Springfield (MoDOT)\Civil\Sheet_Files\TC\JBI3044\119_TC_70_JBI3044C_10000_Regional_Diversion_Plan.dgn 12:38:50 PM 8/19/2024

NOTE:

* INDICATES C.M.S. IS PART OF THE WORK ZONE ITS SYSTEM. SYSTEM INCLUDES 4 NON-INTRUSIVE DETECTORS FOR BOTH THE EB AND WB APPROACHES. SYSTEM CAPABLE OF MESSAGING WARNINGS FOR SPEED, CONGESTION, AND BACK OF QUEUE. SEE DIAGRAM TO THE LEFT.

FOR DMS BOARD MESSAGING, COORDINATE WITH TMC OF THE OZARKS
417-864-1160
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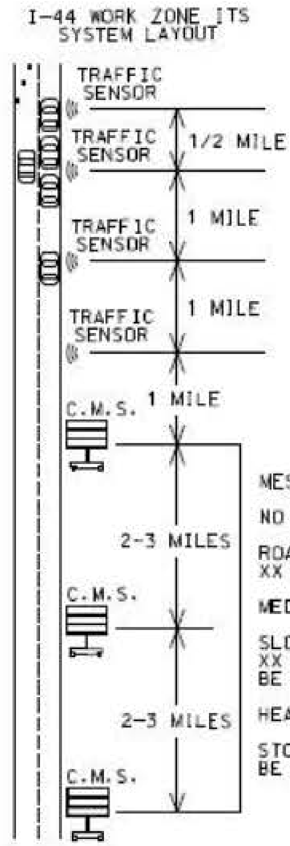
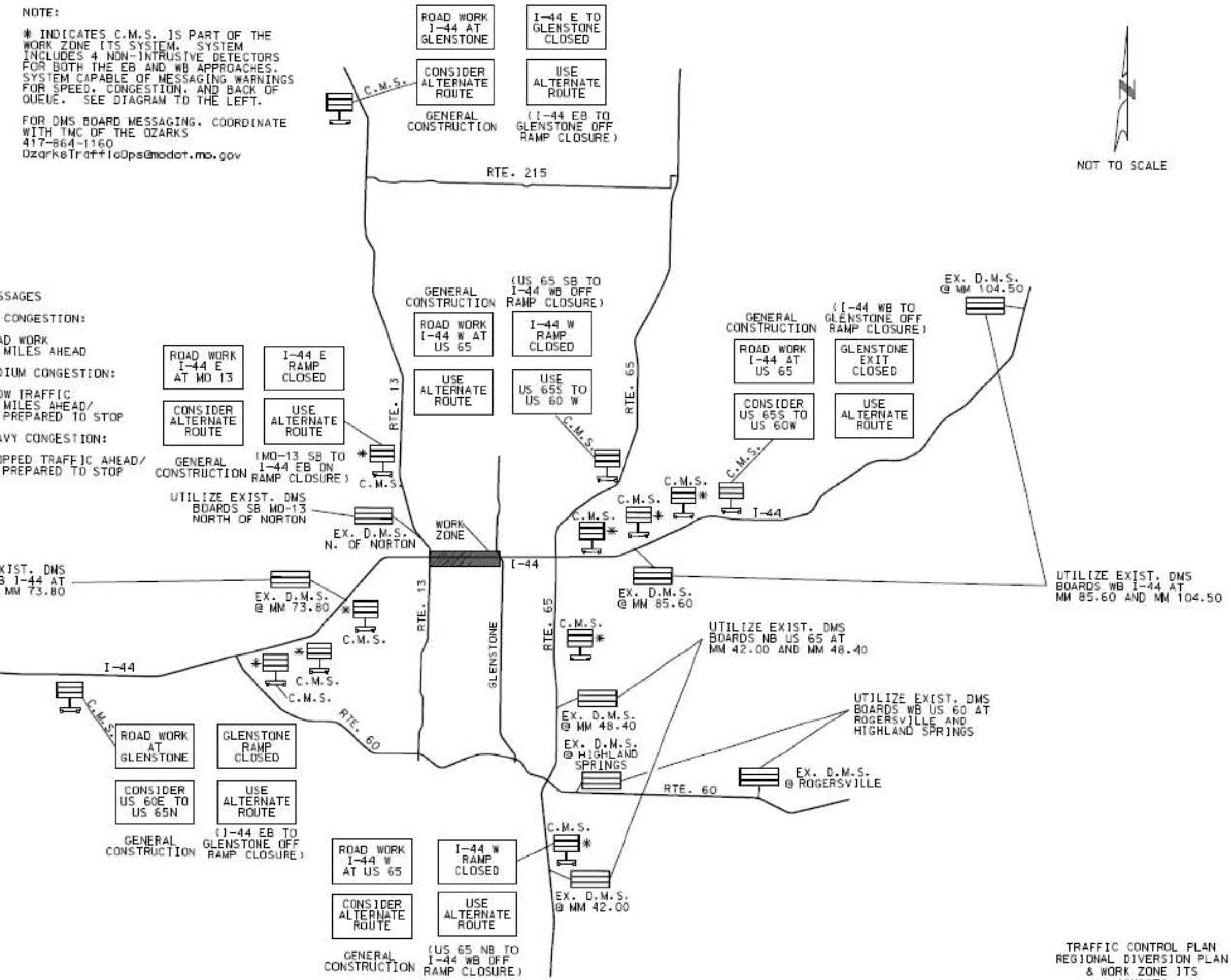




TRAFFIC CONTROL PLAN
REGIONAL DIVERSION PLAN
& WORK ZONE ITS
JSU0076
SHEET 13 OF 13

THIS SHEET HAS BEEN SIGNED, SEALED AND DATED ELECTRONICALLY.

DATE PREPARED	8/16/2024
ROUTE	I-44
STATE	MO
DISTRICT	SW
SHEET NO.	188
COUNTY	GREENE
JOB NO.	JSU0076, J8I3044C, & JST0088B
PROJECT NO.	
BRIDGE NO.	

DESCRIPTION | DATE

IF A SEAL IS PRESENT ON THIS SHEET IT HAS BEEN ELECTRONICALLY SEALED AND DATED.

MISSOURI HIGHWAYS AND TRANSPORTATION COMMISSION
105 WEST CAPITOL
JEFFERSON CITY, MO 65102
1-888-ASK-MODOT (1-888-275-6636)

Hg Consult Inc engineers planners
Hg CONSULT, INC.
PRO. ENGINEER 2010005673

LITERATURE APPENDIX

Ver-Mac Smart Work Zones Brochure

Ver-Mac Message Sign Trailer

PCMS-1210

Ver-Mac Sensor Trailer

Ver-Mac CT-2020-MW

Houston Radar SpeedLane Pro Digi IX30

Digital Cellular Modem

VER-MAC

JAMLOGIC

SMART WORK ZONE SOLUTIONS

JAMLOGIC

·····› WHY USE JAMLOGIC IN SMART WORK ZONES?

IN US WORKZONES, THERE WERE:

669	47,758	41%
FATALITIES IN 2014	INJURIES IN 2013	OF FATAL CRASHES WERE REAR-END COLLISIONS IN 2014

Smart Work Zones (SWZ) improve safety and mobility and save lives by providing useful driver information, improving traffic flow and reducing incidents. Data demonstrates that during the past 5 years, Smart Work Zones, along with other safety initiatives, have reduced fatalities in US work zones nearly 30%. An example of effectiveness that the implementatation of smart work zone systems brought to the TxDOT during I-35 construction in central Texas:

18 to 45%	\$6,000 - \$10,000	\$1,400,000 - \$1,800,000
REDUCTION IN CRASHES	SAVINGS / NIGHT DEPLOYMENT	SAVINGS IN SOCIETAL CRASH COSTS SO FAR

SWZ EQUIPMENT

Ver-Mac is a leading manufacturer of NTCIP-compliant SWZ equipment:

- Portable changeable message sign (PCMS)
- Permanent dynamic message sign (DMS)
- Portable sensors and cameras
- Speed-Mac portable sensors
- Work zone and variable speed limit signs (VSL)
- Speed information feedback signs
- Additional SWZ devices

JAMLOGIC SOFTWARE

Ver-Mac's JamLogic software provides transparent web-based access to all devices and data. The software analyzes traffic data and provides real-time information to the motoring public, project managers, agency traffic management centers (TMC) and public websites. Ver-Mac can provide the right technology and application to make your work zone smart.

- Queue detection and warning
- Work zone travel time / alternate route
- Work zone and variable speed limits
- Zipper merge (Late merge)

EXPERTISE

- Over 15 years and 250 successful SWZ deployments
- A team of engineers that designs detailed SWZ plans
- Trained technicians to implement the logic and deploy the equipment
- Software and staff to manage the project

* http://www.ops.fhwa.dot.gov/wz/resources/facts_stats/safety.htm
U.S. Department of Transportation/Federal Highway Administration (FHWA)

*https://www.workzonesafety.org/publication/innovative-end-of-queue-warning-system-reduces-crashes-up-to-45/
workzonesafety.org

JAMLOGIC SYSTEM OVERVIEW

STEP 1

JamLogic software wirelessly **collects** data via high-speed modems from a variety of field sensing devices and/or third-party traffic flow data.

STEP 2

JamLogic server **analyzes** the data based on algorithms. The logic and messages are predetermined by the project engineer and/or agency.

STEP 3

JamLogic **automates** the messages and provides real-time information to the motoring public, project managers, agency TMC and public websites. JamLogic can provide users with email or text alerts of incidents.

JAMLOGIC FEATURES

- Scalable, flexible and customizable system
- Speed data from multiple sources
- Interactive GPS device mapping and listings
- Transparent logging and history data
- Automated email and text traffic alerts
- Streaming video with PTZ control
- Unlimited users / various levels of access
- Optional public website

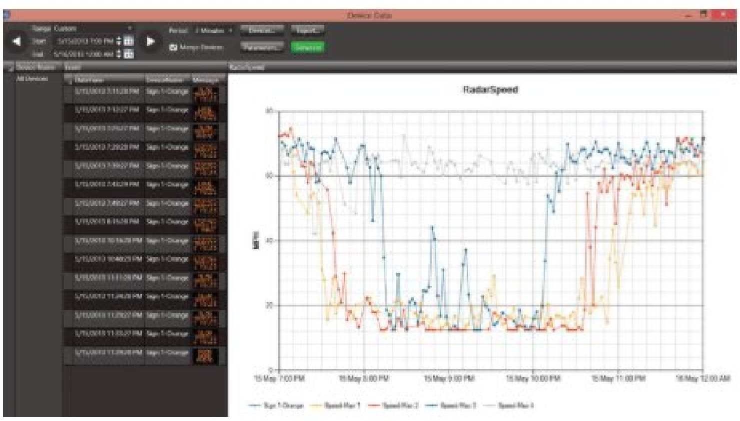
https://public.jamlogic.com/zone/ct-waterbury

JAMLOGIC BENEFITS

- Increased traveler and worker safety
- Cost savings due to reduced incidents
- Better information to motoring public
- Quicker incident response and improved mobility
- Real-time project visibility
- Data analysis at your fingertips
- Better understanding of traffic conditions
- Meets the requirements in the FHWA's Section 1201 Final Rule

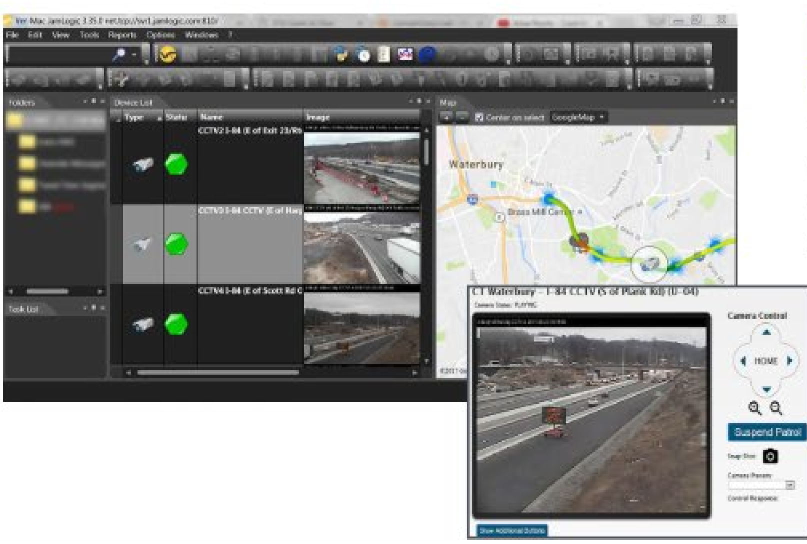
JAMLOGIC PROJECT LIST AND MAP VIEW

- Interactive map and list view
- Color-coded speed data
- Real-time message display
- Communication and battery status diagnostic



JAMLOGIC DATA REPORTS

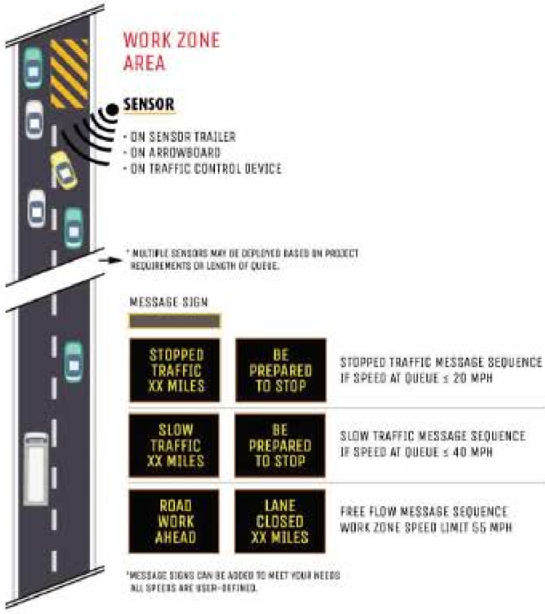
- Quick and easy custom reports, graphs and data exporting
- Sensor, sign and event history
- Monthly, weekly, daily, hourly
- 24/7 access to all real-time and historical data
- Export to Excel



JAMLOGIC PTZ CAMERA

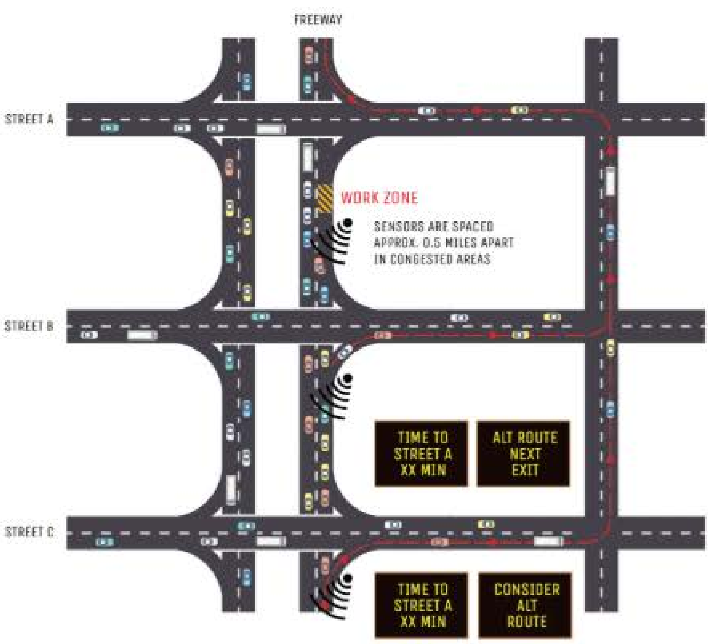
- Stream live video of work zone
- Pan, tilt and zoom (PTZ)
- Unlimited viewer access
- Video recording available

·····› JAMLOGIC MOST COMMON APPLICATIONS



AQW (AUTOMATED QUEUE WARNING)

Based on real-time traffic data, Queue Detection and Warning Systems automatically inform travelers of the presence of downstream stop-and-go traffic with the use of message signs positioned upstream. The benefit is that motorists can anticipate the upcoming situation and the result is reduced rear-end collisions. Successful applications have seen a reduction of up to 45% in rear-end collisions.



TRAVEL TIME / ALTERNATE ROUTE

Travel Time and Alternate Route applications are continuously updated automatically to provide current travel time or length of delay time between the driver's location and a specific destination downstream. The benefit is the motoring public is informed and can make alternate route decisions. It also prevents long unexpected backups and potential rear-end collisions.

OTHER POPULAR APPLICATIONS :

- ZIPPER MERGE (LATE MERGE)
- VARIABLE WORK ZONE SPEED LIMITS
- TRUCK ENTRY WARNING SYSTEMS
- WEATHER CONDITION SYSTEMS

CONTACT US FOR ANY CUSTOM APPLICATIONS

VER-MAC

SPEED-MAC PORTABLE SENSOR

- Radar, modem & GPS packaged in barricade light
- Robust/economical speed data gathering system
- Ideal for SWZ and traffic studies
- Attach to any traffic control device

END-OF-QUEUE WARNING SYSTEMS

Ver-Mac's Speed-Mac is designed to be set up quickly for daily lane closures, maintenance activities or nighttime asphalt paving applications. Simply attach to any traffic control device with power and point towards traffic and the Speed-Mac instantly begins gathering speed data.

The Speed-Mac will automatically autolocate other Speed-Macs to begin to sequence speed data. With an algorithm preprogrammed into JamLogic, the system will instantly begin automating messages.

Speed-Mac combined with JamLogic is a quick and simple way to provide queue warnings and inform the motoring public of unexpected delays.

INVEST IN JAMLOGIC FOR THE SAFETY OF YOUR WORKERS AND MOTORISTS.

YOUR LOCAL DISTRIBUTOR

US OFFICE

4590 SCOTT TRAIL, SUITE 209, EAGAN, MN 55122, USA

HEADQUARTERS

1781, BRESSE STREET, QUEBEC, QC, G2G 2V2, CANADA

888.488.7446

VER-MAC.COM

VER-MAC®

PCMS-1210

TRAILER-MOUNTED MESSAGE SIGN

Ver-Mac's PCMS-1210 is a trailer-mounted portable changeable message sign that displays 3 lines and 8 characters (18 in.) per line.

This unit comes equipped with Stealth Technology, an NTCIP-compliant V-Touch Controller, V-Sync Wi-Fi communication and JamLogic® Fleet Management Software.

The PCMS-1210 combines cutting-edge technology, energy-efficient design and high-quality construction to provide the most reliable, cost-effective and safe to operate message sign on the market. It is the perfect 3-line model for highway construction projects.

PRO SERIES FEATURES

STEALTH TECHNOLOGY
Maintenance-free batteries
Anti-theft hidden battery compartment

V-SYNC WI-FI TECHNOLOGY
Change messages using your smartphone
Safely change messages away from traffic

ROBUST TRAILER DESIGN
Large footprint for greater stability
Diamond plate maintenance platform
Tongue wheel jack for safe and easy set up
Controller located away from the road
Rugged indexed rod mast brake

FULLY-INTEGRATED CELLULAR 4G LTE MODEM
No 3G upgrade needed
10-year fleet cell service
SWZ upgrade (optional)

JAMLOGIC® SOFTWARE
Hourly automated refresh and battery/GPS alerts & reports
Interactive map & list view of all equipment
Project folders to organize equipment
Logs date/time of all activated messages

APPLICATIONS

- Highway construction
- Smart Work Zones
- Special events

4 WAYS TO CHANGE A MESSAGE

ON THE SIGN
Using our V-Touch Controller

NEAR THE SIGN
Using our V-SYNC Wi-Fi

REMOTELY
Using JamLogic® on your computer

REMOTELY
Using JamLogic® web on your smartphone or tablet

PCMS-1210 PRO SERIES

ENERGY-EFFICIENT DESIGN

HIGH-CONTRAST ELECTRONIC CARDS
Create bold and bright characters with greater angularity

SOLAR PANELS
Provide maximum solar recharging year-round

- Designed to run 12 months in most regions without manual charging
- Optional tilt & rotate solar panels

SOLAR REGULATOR
Protects the batteries against overcharge, over-discharge and short circuits

V-TOUCH CONTROLLER

NTCIP COMPLIANT

EASY-TO-READ
7-inch (178 mm) color LCD touchscreen display

USER-FRIENDLY
One-click icon-based menu items

TIME-SAVING
Create your own library of messages

SIMPLE TO OPERATE
Intuitive point-and-go icons make displaying and editing messages quick and easy to display

Transport position

DISPLAY

- Display panel: 75 x 132 in. (1917 x 3343 mm)
- 4 LEDs per pixel
- 3 lines of 8 characters per line
- 5 x 7 pixels (18 in.) characters
- Display sign rotates 360 degrees for perfect set up
- Improved plug-and-play display modules for simplified maintenance

DIMENSIONS AND WEIGHT

- Operating height: 165 in. (4179 mm)
- Overall length: 183 in. (4637 mm)
- Traveling height: 106 in. (2690 mm)
- Traveling width: 87 in. (2197 mm)
- Weight (approx.): 790 kg (1,740 lb.)
- Axle/suspension: 1588 kg (3,500 lb.)

OPTIONS

- Battery charger
- Radar
- Statistics (radar required)
- Fixed camera
- Tilt-and-rotate solar panels

Other options are available to meet your needs.

WARRANTY

- 1 year on complete trailers
- 2 years on electronic components manufactured by Ver-Mac

CERTIFIED BNQ ISO 9001:2015 SYSTEM

VER-MAC®

QUEBEC, CANADA OFFICE: 1781 BRESSE STREET, QUEBEC CITY, QC, G2G 2V2, CANADA
CONROE, TX OFFICE: 3479 POLLOK DRIVE, CONROE, TX, 77303, USA
T: **418-654-1303** TF: **888-488-7446** F: 418-654-0517
VER-MAC.COM

CT-2020-MW
MICROWAVE SENSOR TRAILER

The CT-2020-MW comes with a side-fire microwave sensor that provides bi-directional lane data, per-lane volume, speed - 85th percentile, occupancy and classification information in up to 16 user-defined detection zones. The CT-2020-MW also comes with a high-speed modem with GPS which allows to gather data remotely using our JamLogic® Software. The CT-2020-MW is the perfect equipment to integrate to your smart work zone project or for your traffic studies.

FEATURES AND BENEFITS

20 FT SENSOR HEIGHT
Retractable mast for easy transport

FIXED SOLAR PANELS
Allows for battery recharging and system autonomy

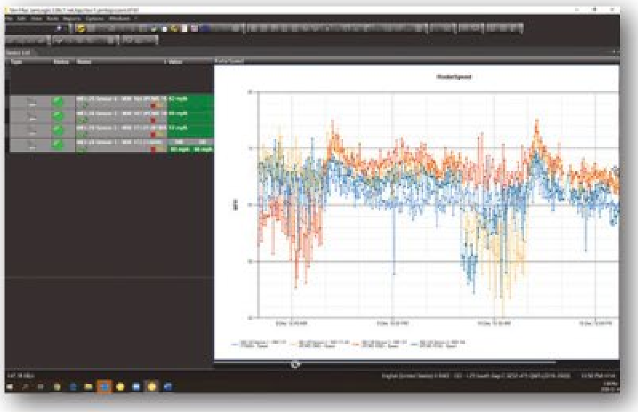
ENVIRONMENTALLY FRIENDLY
No generator, noise and pollution

COMPACT DESIGN
Deploy in 10 minutes and is easy to tow and store thanks to its removable tongue

WIRELESS COMMUNICATION*
Remote equipment health monitoring with a high-speed 4G LTE modem*, remote data retrieval and optional text/email alerts using our JamLogic software

MICROWAVE SENSOR TRAILER APPLICATION

CT-2020-MW



JAMLOGIC® SOFTWARE

CT-2020-MW comes with Ver-Mac's high-speed 4G LTE modem with GPS to maximize your productivity, efficiency and profitability – all remotely from your office or home!

- Get an Interactive list of your equipment and map view
- View speed data on a single screen
- Generate speed data graphs (export to Excel)
- Get communication status and battery voltages
- Integrate with PCMS and cameras

STEALTH TECHNOLOGY

CLEVERLY HIDDEN BATTERY COMPARTMENT
Deter thieves from stealing batteries

LONG-LASTING SEALED BATTERIES
No maintenance required

HIGH-QUALITY CONSTRUCTION

POWDER COATING SUPERIOR FINISH
Impact, humidity, salt spray and rust resistant

4 AJUSTABLE SWIVEL JACKS
For stabilization, sensor leveling and easy transportation

MANUAL LIFT MECHANISM
For quick deployment

HEAVY DUTY PLASTIC FENDERS
For durability

PLASTIC BATTERY BOX
To minimize battery corrosion

LOCKABLE CONTROL BOX
For security

DIMENSIONS & WEIGHT

- Overall length: 132 17/32 in (3,366 mm)
- Operating width: 70 3/8 in (1787 mm)
- Operating height: : 240 in (6096 mm)
- Travelling height: 92 1/2 in (2350 mm)
- Travelling width: 70 3/8 in (1787 mm)
- Axle/suspension: 2000 lb (910 kg)
- Weight (approx): 820 lbs (370 kg)

WARRANTY

- 1-year warranty on complete trailers
- 2-year warranty on electronic components manufactured by Ver-Mac

* Restrictions may apply

VER-MAC®

1781, BRESSE STREET, QUÉBEC, QUÉBEC, G2G 2V2, CANADA
T: **418-654-1303** TF: **888-488-7446** F: 418-654-0517
VER-MAC.COM

SpeedLane® Pro

Houston Radar SpeedLane® Pro

The Houston Radar SpeedLane® Pro is a state of the art **true dual-beam, low-power side-fire radar**. It is designed to **replace in-ground dual loops** by accurately detecting lane, speed, and class of individual vehicles, and computes lane volume, average speed, 85th percentile speed, occupancy, gap, and headway parameters.

Features and Benefits

- Patented (US Patent: US10317525 and EU Patent: EP3117235) true dual beam "speed trap" technology inherently provides accurate measurements without the need for in situ calibration.
- 255 feet (78m) detection range allows flexible deployments.
- World's lowest power usage, highly integrated multi-lane traffic measurement radar.
- FCC and CE approved for full 250MHz operation to suit variety of application requirements.
- Mounts on the side of the road for non-intrusive traffic data collection and works in all weather and lighting conditions.
- Simultaneously measures all vehicles in 16 user-defined lanes.
- All traffic measurements are on per-vehicle, per-lane basis, available in real-time and stored in device memory.
- Lane-by-lane vehicle counts, vehicle counts by user-defined speed bins, length-based class by user-defined length bins, average and 85th percentile speeds, occupancy, headway and gap measurements.
- 1 million individual vehicle memory allows uninterrupted data storage even in the event of communication outages.
- Houston Radar's StatsAnalyzer software provides intuitive GUI to set all configuration parameters, display real-time plots of targets and view snapshots and streaming HD video. Smartphone and tablet app for setup and camera view ease field setup and maintenance.

Specifications and Recommended Operating Conditions	
Specification	**Recommended Condition**
Type	True dual beam side-fire FMCW traffic measurement radar
Vcc	12 to 24VDC Nominal 9 to 28VDC Max
Icc@12VDC (typical)	Ethernet Off: 71mA (0.9 W) Ethernet On: 97mA (1.2W) Streaming HD video: 183mA (2.2W) With 4G or GSM Modem Option: On Line: 97 mA (1.2W) Upload New Data: 108mA (1.3W)
Reverse Power	Protected w/ auto resettable fuse
RF Power	5 mW maximum each radar
Occupied Band	24.020 GHz to 24.230 GHz
Modulation Type	Frequency with linear ramp
Beam Angle	7°x74°
Beam Polarization	Linear
Speed Accuracy	Average per lane: +/- 1% Average per direction: +/- 1% Per Vehicle: +/- 6% for 90% of vehicles
Volume Accuracy	Per Direction Typical: 98 to 99% Per Direction Minimum: 95% Per Lane Typical: 98 to 99% Per Lane Minimum: 90%
Length Class Accuracy	+/-5.7ft (1.7m) or 15% whichever larger for 90% vehicles
User Defined Lanes	Up to 16
User Defined Length Class	Up to 8
Max Detection Range	255 feet (78 m)
Minimum Setback	6 feet (1.8m)
Sample rate	500 Hz x 2 Radars
Certification	FCC, CE, IC, NCC

702 Julie Rivers Dr, Sugar Land, TX 77478
https://Houston-radar.com
Toll Free: 1-888-602-3111

Additional Features and Benefits

- Electronic gyroscope for tilt and level measurements ease setup
- Built-in long-range Class I 2.1+EDR Bluetooth, RS232 / RS485 port
- 512 Mbytes of on-board storage plus uSD card expansion slot
- Built-in 1.3MP HD video camera for sighting makes setup a snap and allows convenient remote monitoring of traffic
- Comprehensive Houston Radar protocol, C and C# SDK
- Powerful SQL based query interface for historical data
- Optional built-in Ethernet port
- Optional integration with Tetryon Cloud Server to aggregate data from multiple devices provides quick and seamless dashboard view.
- Optional built-in UPS with rechargeable battery keeps unit running for up to 96 hours after loss of external power
- Optional MPPT solar charger and built-in 96Whr LiFePO4 battery for temporary or solar installations
- Optional 4G or GSM cellular modem for remote access (country dependent)
- Native support for RTMS file protocol
- Only side-fire radar with optional native NTCIP 1209 v2 compliance

Image from built-in HD video camera

Specifications and Recommended Operating Conditions	
Ethernet	Optional: 100 BaseT Half/Full Duplex auto polarity detect
Power Over Ethernet	Optional: 802.3af. Mode A/ Type 1 (power over data pairs)
Rechargeable Battery	Optional built-in 96WHr LiFePO4
Solar Kit	MPPT charger, 30W or larger solar panel, depending on location
Storage Capacity	Speed, lane and class for last 1,000,000 vehicles. Per lane counts in user defined speed bins, length based class in 8 user defined bins, average speed, 85th percentile speed, occupancy, gap, headway for last 3 months
Sighting Camera	1.3MP HD video over Ethernet or cellular, or HD snapshots. 60° field of view 1280x960, 800x600, 640x480, 320x240 (800x600 10fps video)
Bluetooth	Ultra low power 800+ feet Class I 2.1+ EDR 460KB baud rate for setup, download and camera
Smartphone/Tablet App	Android smartphone or tablet ver. 4.0.3 and higher. Bluetooth and TCP/IP access.
Remote Access	Optional built-in ultra-low power 4G or GSM modem (country dependent)
GPS	Included with optional built-in cellular modem
Operating °F (°C)	Without battery: -40F (-40C) to +185F (+85C) With LiFePO4 battery: -4F (-20C) to +130F (+55C)
Dimensions without mounting bracket	26”length x 3”diameter (670mm x 76mm Diameter)
Weight	Without battery: 4.6lb (2.1 Kg) With battery: 6.4lb (2.9 Kg)

702 Julie Rivers Dr, Sugar Land, TX 77478
https://Houston-radar.com
Toll Free: 1-888-602-3111

Digi IX30

Intelligent 4G LTE router designed for critical infrastructure and industrial applications

Digi IX30 is an intelligent 4G LTE router designed for optimal performance and reliability across a wide range of critical infrastructure and industrial applications. This complete solution is fully integrated with software and security, providing a secure, reliable connection to industrial controllers, process automation equipment, and smart grid assets on third party sites or remote locations — easy to deploy and centrally managed via Digi Remote Manager® (Digi RM), which is included in your Digi 360 solution. (See page 2.)

Gain critical insights into your deployed devices and manage your network with Digi RM — the command center for your deployment. Digi RM is a cloud-based solution that facilitates easy setup, mass configuration, maintenance, and visibility into the health of your network, whether you deploy dozens or thousands of devices. In the event of a primary network interruption, Digi RM also provides secure terminal access for out-of-band management of edge devices via serial port and command-line interface.

Software-defined, multi-carrier networking and global LTE and HSPA+ options make it easy to get connected. This drop-in connectivity gives operators a way to reduce downtime and service calls and also increase revenue by bringing distributed sites online faster. With its hardened components and low-power feature, it can be configured and installed anywhere — in the harshest conditions, and in applications where power is limited or unavailable.

The Digi IX30 router also offers a FirstNet Capable™ LTE-Advanced model designed to meet the critical demands for emergency communications. Additional industrial use case applications include building and process automation controllers, IP cameras and access controllers, remote data loggers, flow meters, sensing equipment, telco infrastructure, and traffic and obstruction lighting.

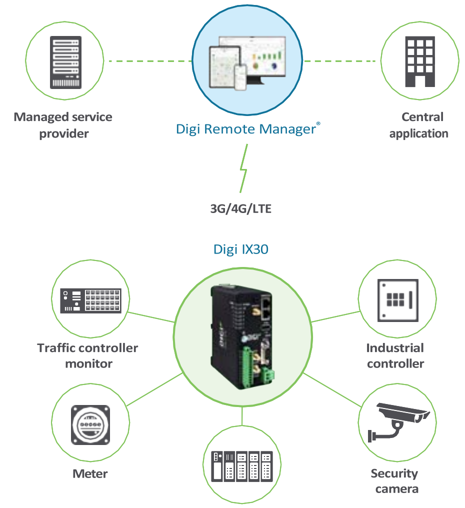
Related Digi industrial IoT software and solutions

Digi IX10 | Digi IX20 | Digi IX40 | Digi IX15 | Digi Remote Manager®

Key features, benefits, and applications

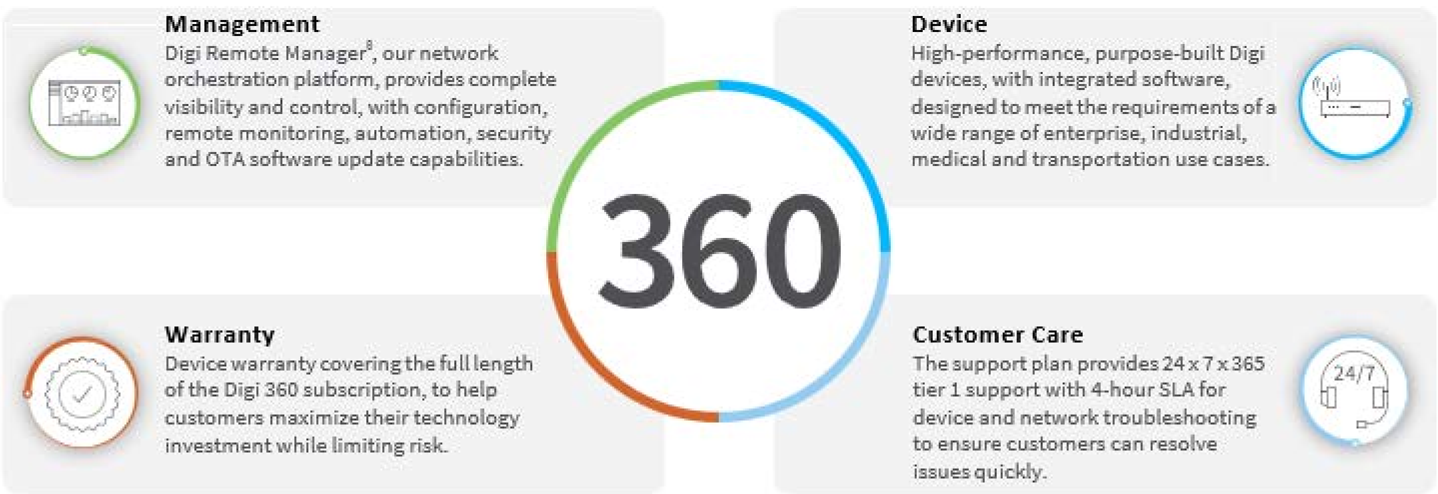
- Global LTE and HSPA+ support and certification on major carrier networks around the world
- Ethernet, serial I/O and Modbus bridging
- Low-power feature can be easily configured for remote and off-grid applications
- Extremely resilient cellular connection through Digi's patented Digi SureLink®, VRRP+ protocol and dual SIM slots
- GNSS receiver for GPS, GLONASS, BeiDou and Galileo
- License-free enterprise software: VPN, firewall, logging and authentication
- Rugged enclosure, optimized for DIN rail or shelf mounting
- C1D2 and ATEX rated; NEMA TS2 temperature rated
- Includes the Digi 360 solution with warranty, customer care and Digi Remote Manager cloud management, enabling easy setup, mass configuration, and management
- Value-added services include Digi Containers to enable powerful, cost-efficient applications and Digi WAN Bonding for WAN aggregation and immediate failover

Application example



Digi 360

Digi 360 offers comprehensive IoT packaged solutions, including purpose-built devices, software and services to help customers optimize their IoT investments and maximize ROI. These solutions are designed to simplify IoT complexity, and ease the challenges enterprises face in configuring, deploying, and managing their IoT initiatives. Your Digi 360 subscription is included with the purchase of Digi IX30, complete with Digi Remote Manager, warranty, and customer care. Learn more at digi.com/digi360.



Value-Added Services

Digi Containers

Digi Remote Manager enables deployment of custom applications via containers

Digi Containers simplify and centralize the process of building, deploying, and running custom applications on devices managed with Digi Remote Manager as the central portal. Containers with custom programs or Python applications can be loaded via Digi RM on any device running the Digi Accelerated Linux operating system (DAL OS).

As an add-on service to Digi Remote Manager, Digi Containers are a powerful capability implemented via Lightweight Linux Containers (LXC). LXC tools enable developers to package up a custom application, with its dependencies and configuration, into a lightweight, portable bundle that shares only the running kernel with the host device.

Digi WAN Bonding

Resilient connectivity and maximum performance across multiple connections

Digi WAN Bonding combines multiple connections into a seamless and resilient connectivity solution that ensures optimal performance and maximum uptime anywhere around the world.

Digi devices provide a range of connectivity options including cellular failover with features such as Digi SureLink, policy-based routing and interface bonding. These features are excellent at preventing any external network failures from causing downtime.

*Digi Containers and Digi WAN Bonding are available as value-added services with Digi Remote Manager.

DIGI IX30 WITH DIGI 360

Digi 360 Management and Security

Digi Accelerated Linux (DAL OS)

DAL OS is Digi's standard operating system integrated into Digi Enterprise (EX), Industrial (IX) and Transportation (TX) routers, console servers and USB-connected devices. Developed for speed and simplicity, DAL OS enables advanced capabilities that support today's demanding applications. Learn more at digi.com/DAL.

Digi Remote Manager (Digi RM)

Digi Remote Manager is a proven technology platform that brings networks to the next level, empowering networks — and the people who manage them — to work smarter. Digi RM transforms a multitude of dispersed IoT devices into a dynamic, intelligent network. It's easy to deploy, monitor and diagnose thousands of mission-critical devices from a single point of command on a desktop, tablet, or phone. All the while, software-defined security diligently safeguards your entire Digi ecosystem. Learn more at digi.com/digi-remote-manager.

Digi RM infrastructure and security

- Hosted in a commercial-grade cloud server environment that meets SOC 1®, SOC 2®, and SOC 3® standards
- Superior availability, operating at 99.9% or greater uptime
- Open APIs are available to support application development
- Comprehensive security controls to protect your data
- Member of the Center for Internet Security® (CIS®)
- Enables compliance with security frameworks like ISO27002, HIPAA, NIST and more
- Earned Skyhigh's CloudTrust™ Program highest rating of Enterprise-Ready

DAL OS and Digi RM capabilities

- DAL OS with Digi Remote Manager: Remote console access, configuration templates, HTTP proxy, device event logs, configurable maintenance window
- Serial: Modbus, serial-over-TCP/UDP
- Customization: Python 3, Python pip, PyCharm integration, shell scripting, containers, MQTT client
- Troubleshooting: iPerf and nuttcp bandwidth testing, Find Me tool
- GNSS: NMEA/TAIP location forwarding to servers, geo-fencing
- Activate, monitor, and diagnose your mission-critical devices through a single portal
- Schedule key operations — including firmware updates and file management — on a single device or on a group of devices, keeping your network functionality up-to-date and maintaining compliance standards
- Manage edge devices out-of-band via console terminal access
- Monitor equipment health and connectivity across deployments
- Create detailed reports and real-time alerts for specified conditions
- Integrate device data through open APIs to gain deeper insights and control with third-party applications
- Report and alert on performance statistics, including connection history, signal quality, latency, data usage, and packet loss

Digi TrustFence

The Digi TrustFence device security framework simplifies the process of securing multiple connected devices.

DIGI TRUSTFENCE

Designed for mission-critical applications, Digi TrustFence enables users to easily integrate device security, device identity, and data privacy capabilities into product design.

Digi TrustFence security for IoT devices is designed to grow and adapt with new and evolving threats.

Learn more at digi.com/trustfence.

Built-in Security. Delivered.

- Secure boot: Programs and code running on the device are validated to be from an approved source or manufacturer
- Protected hardware ports: Internal and external I/O ports are hardened and access-controlled to prevent unwanted intrusion
- Authentication: Data authentication and device identity management options, with updated user and password settings
- Secure connections: Latest encryption protocols for data in motion and over-the-air (OTA) transmissions to ensure integrity
- Ongoing monitoring and support: Ongoing threat measurement and monitoring services, with external security audits

DIGI IX30 WITH DIGI 360

Specifications

Manage and configure Digi IX30 with Digi Remote Manager

SPECIFICATIONS	DIGI IX30 WITH DIGI
WIRELESS INTERFACES	
CELLULAR**	
FIRSTNET CAPABLE™ LTE-ADVANCED CAT 7	LTE-Advanced Cat 7— FDD: B2, B4, B5, B7, B12, B13, B14 FirstNet®, B25, B26, B66, B71; TDD: B41, B42, B43, B48; WCDMA: B2, B4, B5; GNSS: GPS, GLONASS, BeiDou, Galileo, QZSS
LTE CAT 4 GLOBAL (SELECT REGIONS/CARRIERS*)	LTE Cat 4 — FDD: B1, B2, B3, B4, B5, B7, B12, B13, B18, B19, B20, B25, B26, B28; TDD: B38, B39, B40, B41; WCDMA: B1, B2, B4, B5, B6, B8, B19; GSM: B2, B3, B5, B8; GNSS: GPS, GLONASS, BeiDou, Galileo, QZSS
LTE CAT 4 AU/NZ	LTE Cat 4 — FDD: B1, B3, B5, B7, B8, B18, B19, B21, B28; TDD: B38, B39, B40, B41; 3G: B1, B5, B6, B8, B9, B19; GNSS: GPS, GLONASS, BeiDou, Galileo, QZSS
CONNECTORS	(3) 50 Ω SMA (2x cellular, 1x GNSS); center pin: female
SIM SLOTS	(2) Mini-SIM (2FF)
SIM SECURITY	Screw-down SIM cover
GNSS	Protocol NMEA 0183 V3.0 Acquisition time — hot start: 1 s; warm start: 29 s; cold start: 32 s Accuracy horizontal: < 2 m (50%), < 5 m (90%); Altitude: < 4 m (50%), < 8 m (90%); Velocity: < 0.2 m/s
SOFTWARE AND MANAGEMENT*	
REMOTE MANAGEMENT	Digi Remote Manager; SNMP v1/v2c/v3 (user installed/managed), SMS
LOCAL MANAGEMENT	WebUI (HTTP/HTTPS); CLI (Telnet, SSH, serial)
MANAGEMENT/ TROUBLESHOOTING TOOLS	FTP, SFTP, SCP; protocol analyzer with PCAP for Wireshark; event logging with Syslog and SMTP; NTP/SNTP
WIRED INTERFACES	
ETHERNET	
PORTS	(2) RJ-45; 10/100 Mbps (auto-sensing)
SERIAL	
PORTS	(1) DB-9 DTE
STANDARD	RS-232/422/485
SIGNAL SUPPORT	TXD, RXD, RTS, CTS, DTR, DCD, DSR, RI
FLOW CONTROL	Software (XON/XOFF), hardware supported
I/O	
CONNECTOR	12-pin screw down terminal block
DIGITAL	0-30 VDC, 200 mA max.; (4) I/O, software-selectable; pulse counter input
ANALOG	(4) analog I/O; 4-20 mA or 0-10 V, software-selectable; 12-bit resolution
USB	
PORTS	(1) USB 2.0 Type A; 5 V 500 mA max
PHYSICAL	
DIMENSIONS (L X W X H)	12.8 cm x 10 cm x 5.2 cm (5.04 in x 3.94 in x 2.05 in)
WEIGHT	0.5 kg (1.1 lb)
STATUS LEDS	Signal strength (5), LTE, power
ENCLOSURE/RATING	Aluminum / IP30
MOUNTING	DIN rail mount

*Includes the Digi 360 solution for Digi IX30 (1-year) with Digi Remote Manager, warranty and customer care.
**Visit digi.com/resources/certifications for latest approvals and updates.

DIGI IX30 WITH DIGI 360

Specifications and Technologies

Manage and configure Digi IX30 with Digi Remote Manager

SPECIFICATIONS	DIGI IX30 WITH DIGI
POWER REQUIREMENTS	
POWER INPUT	9 - 30 VDC, reverse polarity protection, 18 W min power source required
POWER CONNECTOR	Screw down removable terminal block
POWER CONSUMPTION	1.5 W (light traffic flow), 3.5 W (peak data transmission); 1 W (low power mode, idle traffic, no serial/no Ethernet WAN)
ENVIRONMENTAL	
HAZARDOUS (CLASS 1 DIV 2)	Yes
OPERATING TEMPERATURE	−34 °C to 74 °C (−29 °F to 165 °F); reduced cellular performance may occur above 60 °C (140 °F)
STORAGE TEMPERATURE	-40 °C to 85 °C (-40 °F to 185 °F)
ETHERNET ISOLATION	1.5 kV RMS
SERIAL PORT PROTECTION (ESD)	15 kV
RELATIVE HUMIDITY	5% to 95% (non-condensing)
APPROVALS**	
CELLULAR	IX30-00P7: PTCRB, Verizon, T-Mobile, AT&T, FirstNet Capable™; IX30-00G4: CE, RED, UKCA Visit digi.com/resources/certifications for latest cellular certifications and updates
SAFETY	Hazardous locations: ANSI/ISA-12.12.01-2015, CAN/CSA C22.2 NO.213-15 Ordinary locations: UL 62368-1, 2nd Edition, 2014-10-14; UL 62368: 2014, 2nd Edition ATEX standards: Protection method Ex II 3 G Ex nA IIC T4 Gc EN 60079-0:2012+A11:2013, EN 60079-15:2010, DEMKO 15 ATEX 1574X Rev. 1
IECEX STANDARDS	US/UL/ExTR17.0077/00
EMISSIONS / IMMUNITY	CE; RED; FCC Part 15, Subpart B; ICES-003; AU/NZS CISPR32
ENVIRONMENTAL	ROHS3
WARRANTY***	
PRODUCT WARRANTY	1-year

*Includes the Digi 360 solution for Digi IX30 (1-year) with Digi Remote Manager, warranty and customer care.
**Visit digi.com/resources/certifications for latest approvals and updates.
***Product warranty can be extended with Digi 360 extensions or renewals.

ENTERPRISE SOFTWARE	DESCRIPTION
PROTOCOL SUPPORT	HTTPS, TLS, SCP (client and server), SFTP, SNMP (v3), SSH, Telnet and CLI for web management; remote management via Digi Remote Manager; protocol analyzer, ability to capture PCAP for use with Wireshark; DynDNS, Dynamic DNS client compatible with No-IP/Dy-nDNS; Captive portal, Intelliflow; Nagios, DNS server, NTP server, Multicast, mDNS, IPerf
SECURITY	IP filtering, stateful inspection firewall with scripting, address, and port translation; VPN: IPSec with IKEv1, IKEv2, NAT Traversal; SSLv3, FIPS 197, Open VPN client and server; L2TP; VPN tunnels; cryptology: SHA-1, MD5, RSA; encryption: DES, 3DES and AES up to 256-bit (CBC mode for IPsec); authentication: RADIUS, TACACS+, SCEP for X.509; certificates; content filtering (via 3rd party); MAC address filtering; VLAN support
ROUTING / FAILOVER	IP pass-through; NAT, NAPT with IP port forwarding; Ethernet bridging; GRE; multicast routing; routing protocols: PPP, PPPoE, RIP (v1, v2) OSPF, BGP, iGMP routing (multicast); IP failover: VRRP, VRRP+TM; automatic failover/failback to second GSM network/standby APN, Digi SureLink
OTHER PROTOCOLS	DHCP; Dynamic DNS client compatible with No-IP/DynDNS; QoS via TOS/DSCP; Modbus UDP/TCP to serial; Modbus bridging for connecting diverse field assets

*For a comprehensive list of operating system features, please visit digi.com/solutions/by-technology/dal-operating-system/features.

Product Photos and Technologies

Product photos

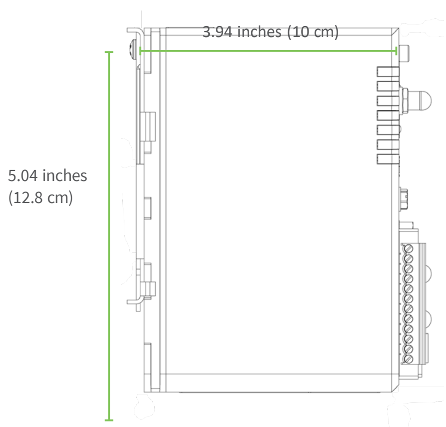
Digi IX30

Digi IX30 — front

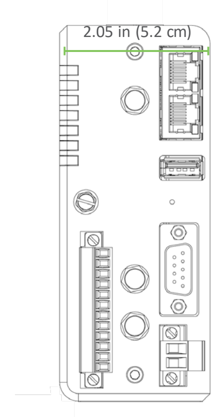
Digi IX30 — lek

Digi IX30 — right

Digi IX30 — left side (with dimensions)



Digi IX30 — front (with dimensions)



Featured Technologies

FIRSTNET.
Built with AT&T

*FirstNet® and FirstNet Ready™ are registered trademarks and service marks of the First Responder Network Authority. All other trademarks are the property of their respective owners.

DIGI IX30 WITH DIGI 360

Part Numbers

PART NUMBERS	DIGI IX30 WITH DIGI
DIGI IX30 — FIRSTNET CAPABLE LTE-ADVANCED CAT 7	
IX30-00P7	Digi IX30 — LTE-A Cat 7 North America, FirstNet Capable, dual Ethernet, RS-232/422/485, GNSS
DIGI IX30 — LTE CAT 4	
IX30-00G4	Digi IX30 — LTE Cat 4 Global (select regions/carriers)**, 3G/2G fallback, dual Ethernet, RS-232/422/485, GNSS
IX30-00A4	Digi IX30 — LTE Cat 4 AU, 3G/2G fallback, dual Ethernet, RS-232/422/485, GNSS

*Includes the Digi 360 solution for Digi IX30 (1-year) with Digi Remote Manager, warranty and customer care.
**Visit digi.com/resources/certifications for latest approvals and updates.

PART NUMBERS	AVAILABLE ACCESSORIES**
76002113	Digi IX30 Accessory Kit — PSU, antennas, Cat 6 Ethernet cable, GPS antenna
76002104	Power supply — 18 VDC, 1 A, wall mount level VI, industrial temperature, changeable plug tips, 2-pin combicon screw terminal plug
76002117	Power supply — 18 VDC, 1 A, wall mount level VI, commercial temperature, changeable plug tips, 2-pin combicon screw terminal plug
76002114	Antenna — 5G/LTE 600 MHz - 6 GHz, swivel, black
76000C54	Antenna base — SMA, 1 m, RG174
76002106	Cable — UTP, Cat 6, 2 m (6 k), black, flat patch cable

**Sold separately, unless otherwise noted.

PART NUMBERS	DIGI 360 EXTENSIONS AND RENEWALS
DIGI360-IX30-EXT-2YR	Digi 360 extension for two additional years for Digi IX30
DIGI360-IX30-EXT-4YR	Digi 360 extension for four additional years for Digi IX30
DIGI360-IX30-REN-1YR	Digi 360 renewal for one additional year for Digi IX30
DIGI360-IX30-REN-3YR	Digi 360 renewal for three additional years for Digi IX30
DIGI360-IX30-REN-5YR	Digi 360 renewal for five additional years for Digi IX30

PART NUMBERS	VALUE-ADDED SERVICES
DIGI-RM-PRM-CS	Digi Containers subscription — 1-year subscription
DIGI-SRV-WB-TIER1-1YR	Digi WAN Bonding subscription with 100 Mbps max throughput — 1-year subscription
DIGI-SRV-WB-TIER2-1YR	Digi WAN Bonding subscription with 200 Mbps max throughput — 1-year subscription
DIGI-SRV-WB-TIER3-1YR	Digi WAN Bonding subscription with 1 Gbps max throughput — 1-year subscription

For more information, please visit digi.com.

For more information about Digi IX30,
visit digi.com/ix30.

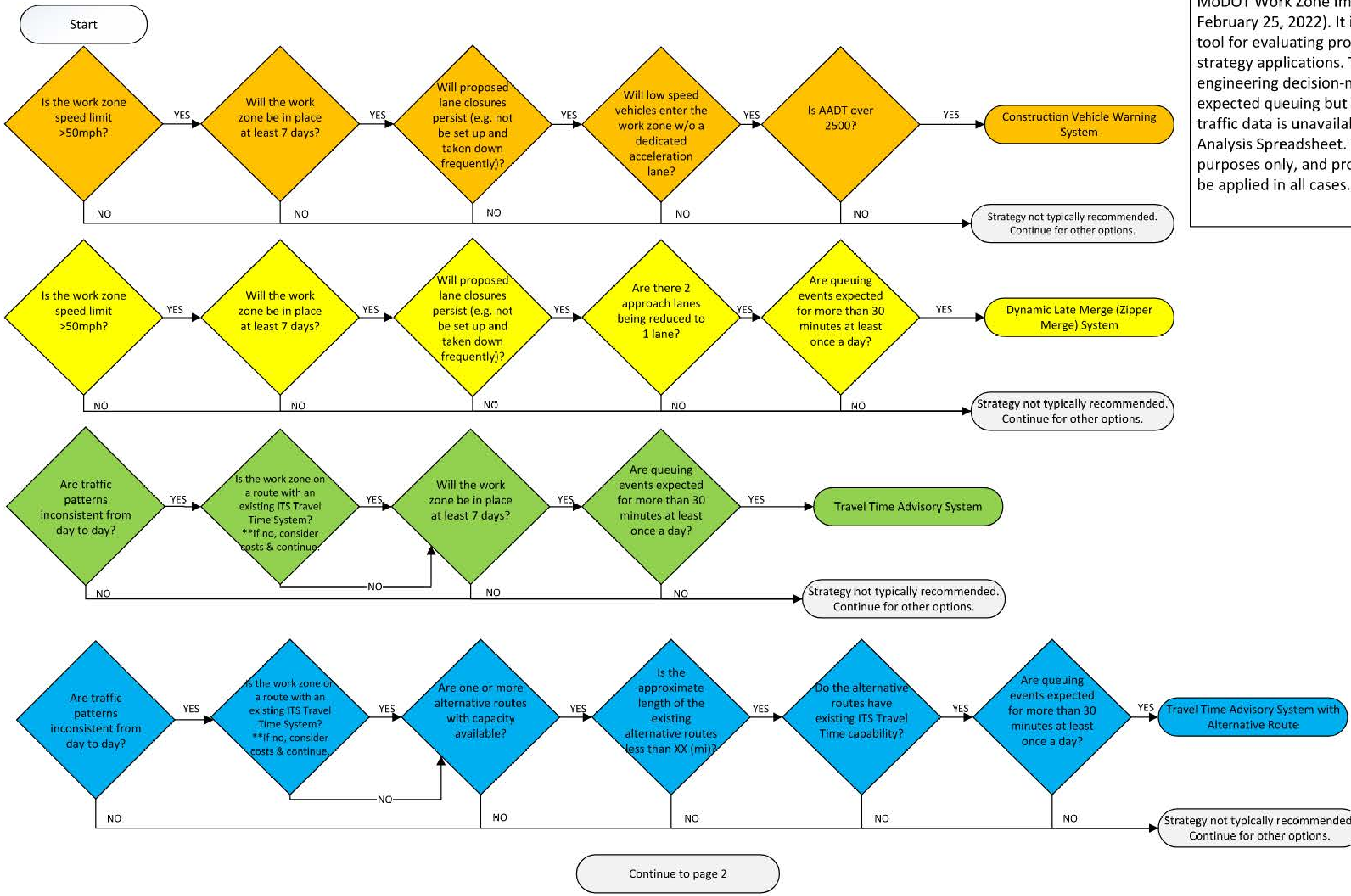
877-912-3444 I 952-912-3444

E1. Appendix E: Advanced WZ Strategy Selection Flow Chart

Use this decision tree quick reference guide to identify potential Advanced Work Zone Strategies for projects on freeways or interstates that will have negative impacts to safety, mobility, or delay.

Advanced Work Zone Strategies Quick Reference Flow Chart

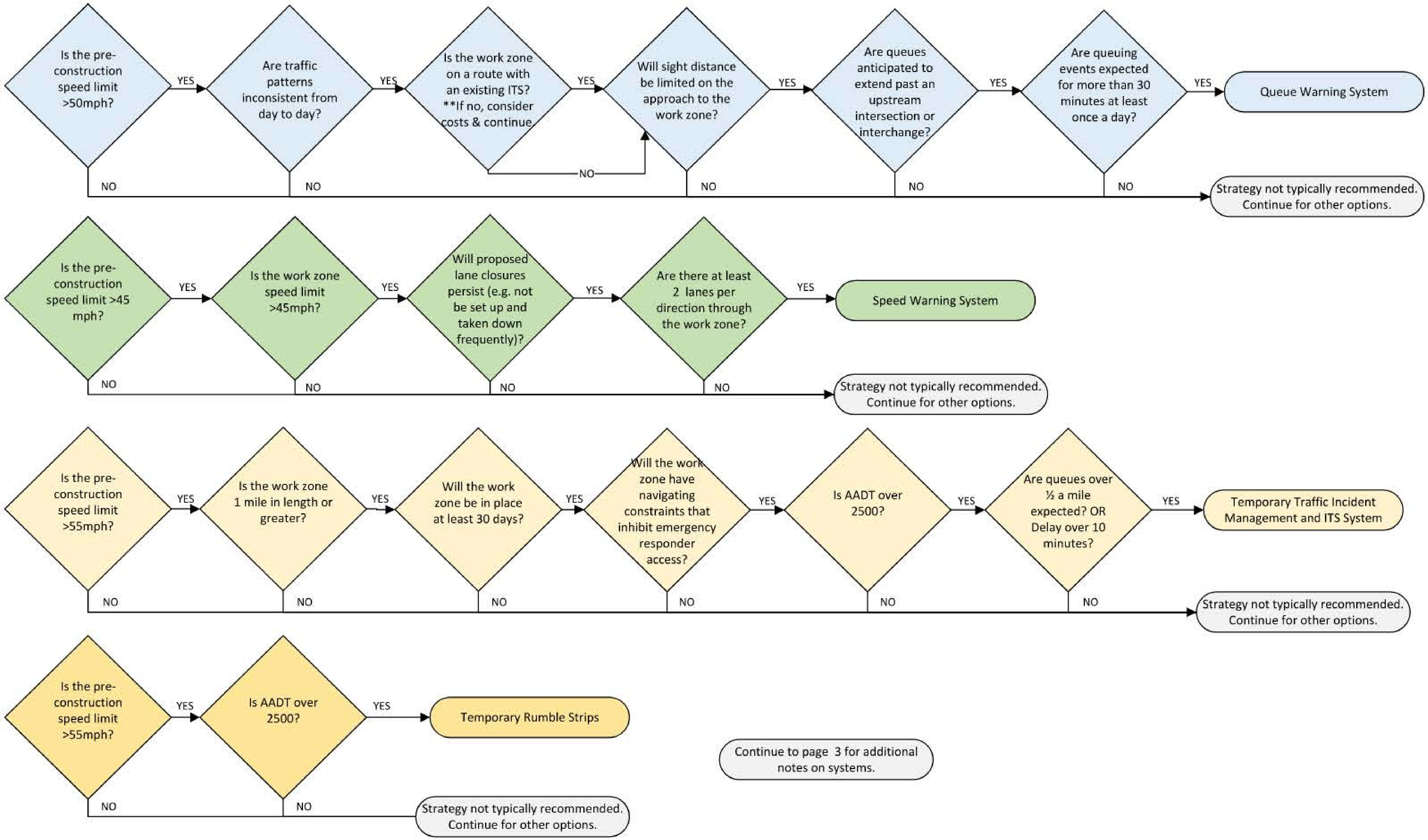
This decision tree was developed using information from the MoDOT Work Zone Impact Analysis Spreadsheet (Revised February 25, 2022). It is intended to serve as a quick-reference tool for evaluating projects for potential advanced work zone strategy applications. The decision tree may be used to support engineering decision-making when modeling results indicate no expected queuing but queuing is anticipated, or when sufficient traffic data is unavailable to apply the Work Zone Impact Analysis Spreadsheet. This guide is provided for informational purposes only, and professional engineering judgment should be applied in all cases.



Continue to page 2

Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

Use this decision tree quick reference guide to identify potential Advanced Work Zone Strategies for project on freeways or interstates that will have negative impacts to safety, mobility, or delay.



Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

Advanced Work Zone Strategies Quick Reference Flow Chart

This decision tree was developed using information from the MoDOT Work Zone Impact Analysis Spreadsheet (Revised February 25, 2022). It is intended to serve as a quick-reference tool for evaluating projects for potential advanced work zone strategy applications. The decision tree may be used to support engineering decision-making when modeling results indicate no expected queuing but queuing is anticipated, or when sufficient traffic data is unavailable to apply the Work Zone Impact Analysis Spreadsheet. This guide is provided for informational purposes only, and professional engineering judgment should be applied in all cases.

Considerations for Construction Vehicle Entering Systems:

- Higher work zone speeds will lead to a higher potential for crashes with entering construction vehicles.
- Lower volumes will permit construction vehicles to enter the roadway with few potential conflicts.

Considerations for Dynamic Late Merge (Zipper Merge System)

- Approach speed must be at least 50 mph. Higher approach speeds increase the probability of conflicts and crashes at the back of a queue.
- Work zone must be in place at least 7 days.
- Because of the work required to set up and calibrate the system, it should not be installed on short term closure.
- System should cost approximately 1.9% of total project cost or a max of $50k per setup.
- Must have 2 approach lanes that reduce to 1 open lane.
- A greater number of hours a queue is present has a greater potential for conflicts and crashes.

Considerations for Travel Time Advisory System

- TT Advisory systems are more useful when traffic is inconsistent.
- If this falls within an existing ITS system, then the setup cost is estimated at 75% lower.
- Assume base cost of $20k/mile of work zone and assume $200/week/mile of WZ+Queue system.
- Queue anticipated a minimum of 30 minutes per day. Longer durations increase the need for a TT Advisory system.
- Min delay of 5 minutes, and longer delays increase the need for a TT system.
- Sensors must be set up to monitor in the queueing area, and portable DMS signs to advise of the travel times.

Considerations for Travel Time Advisory System with Alternative Route

- Variability in traffic patterns increases the value of a TT/Alt Route system.
- An existing ITS system in the project area increases the feasibility for and reduces cost for this system.
- If no alternate routes are available, do not consider this option.
- Cost to outfit alternate routes with ITS devices. **note that this system may increase the mileage needed along the primary route also, but this is not accounted for here because of the added complexity and time needed for a user.
- Assume base cost of $20k/mile of work zone and assume $200/week/mile of WZ+Queue system.
- Assume 75% discount if ITS devices and TT Capability already exist on the routes.
- Queue anticipated a minimum of 30 minutes per day. Longer durations increase the need for a TT Advisory system.
- Min delay of 5 minutes, and longer delays increase the need for a TT system.
- Sensors must be set up to monitor in the queueing area, and portable DMS signs to advise of the travel times.

Considerations for Queue Warning System

- Higher pre-construction roadway speeds increase risk for vehicles approaching the back of a queue.
- Unpredictable traffic patterns increases the value of a queue warning system.
- Existing ITS devices may reduce the cost of detecting real-time queues.
- A Queue warning system has greater value if sight distance issues exist.
- A Queue warning system has greater value if upstream conflicts exist.
- Assume $20,000/mile * max of (queue length and taper length) + $200/mile/week.

Considerations for Speed Warning System

- Applicable in work zones with higher speeds.
- Number of trailers (assuming 1 per every 5 miles) * WZ length. Contractor provided Cost:$10/hour. No additional cost if MoDOT owned trailers are used.
- For use on multi lane routes.

Considerations for Temporary Traffic Incident Management and ITS System

- Assume $150/device/day/mile. Assumes 2 devices (camera/sensor) per mile. Assumes portable DMS are covered elsewhere. Reduce cost for existing sensors/cameras. Add if emergency response units on standby.

Considerations for Temporary Rumble Strips

- Assume 1 set and 1 approach base cost of $2000.

End

Information source: MoDOT Engineering Policy Guide 161.19; MoDOT Work Zone Impact Analysis Spreadsheet. Spring 2026.

F1. Appendix F: SWZ JSP Template_DRAFT Recommendation_V2.3

Work Zone Intelligent Transportation System (WZITS)JSP-Template RECOMMENDATION

1.0 General
Smart Work Zone (SWZ) Systems shall be portable, real-time, automated, solar powered systems that calculate and display warnings and real-time work zone traffic information to the traveling public. The goal of these systems is to provide advanced traffic condition information to motorists at key decision points due to construction activity. Systems shall be in operation 24 hours per day, seven days per week, during the construction period unless otherwise instructed by the Engineer.

*(**Insert the following paragraph/information as needed)*

A qualified Responder will be required on this project that has the capability, experience, and resources required to provide, operate, and maintain SWZ Systems to support road work projects located on Interstates, U.S., and State highways in Missouri.

1.1 Pre-Bid Conference. This contract requires Responders, their Sub-contractors, and key personnel to have specific qualifications and experience with deploying SWZ solutions within work zones. The SWZ system and supplier shall be a proven system provider verifiable by at least one completed deployment of at least ten months. All Contractors/Subcontractors are required to attend a Pre-Bid Conference at the Missouri Department of Transportation office, *(address)*, on *(date)*. This meeting, which is held to clarify the scope of the work for this project, will begin promptly at *(time)*. All contractors will be required to bring proof of prior deployments as well as contact information from prior deployments (names and phone numbers) to this Pre-Bid Conference. The references will be contacted by the Department, and a determination will be made as to whether the Contractor's systems and services meets the requirements and conditions of this specification. The Department reserves the right to reject any bids received from Contractors who do not meet the qualifications and certifications as described here. The decision to reject a bid may be based on information about past performance. Non-attendance of Contractors/Subcontractors at the Pre-Bid Conference may result in rejection of the bid.

1.2 Responder and Sub-contractors. This contract requires Responders and their Sub-contractors and key personnel to have specific qualifications and experience with deploying SWZ solutions within work zones. Responders, including Sub-contractors, must document their companies' qualifications and experience on previous similar projects. Information specific to this project is required. Submittals of standard marketing packages alone may cause the bid to be rejected.

1.3 Description. This item shall consist of submittal and approval of a Smart Work Zone System plan, furnishing, installing, relocating, and operating a portable, automated, solar powered real-time work zone system ("Smart Work Zone System") meeting the requirements noted herein, and providing a system manager to maintain the system throughout the duration of the project. The Contractor shall assume responsibility for any damaged equipment due to crashes, vandalism, adverse weather, etc. that may occur during the system's deployment.

The Contractor shall furnish, install, relocate, operate, maintain, and remove this system for measuring and delivering real-time messages for the work zone.

The Contractor is responsible for coordinating any work in adjacent roadway construction projects. *Provide brief description of how the Contractor can acquire contact information for staff responsible for adjacent project, since adjacent project may be sponsored by a different agency.*

The Contractor will be responsible for relocating the devices as directed by the Engineer. When the equipment is no longer required for this project, the Contractor shall remove it and retain ownership.

1.4 Availability of Equipment. The Responder shall be required to provide the SWZ equipment defined in this JSP. The Responder must be able to provide and maintain sufficient equipment to meet the demands of the Commission. The Responder must have the capability, experience, and resources required to provide, operate, and maintain SWZ systems and components for this project.

1.5 System Manager. The Contractor shall employ one (1) qualified System Manager assigned to manage the SWZ systems. The System Manager shall be an employee of the Responder or of a Sub-contractor. The System Manager shall be locally available to maintain system components, maintain the website, move portable devices as necessary, and respond to emergency situations, within four (4) hours of notification. The System Manager shall be responsible for coordinating the placement of devices in the project areas. It is the responsibility of the System Manager to move system components that interfere with construction operations and relocate the components to another area. The System Manager shall supply a local phone number and/or a toll-free number to the Engineer to contact the System Manager or other System Representative at any time. The System Manager shall not perform any other duties on the job site. Any replacement of the System Manager must have prior written approval from the Commission. If a substitute System Manager is proposed during the contract, they should be equally qualified or more qualified than the original System Manager.

The Engineer also reserves the right to require replacement of a System Manager, that is non-responsive or whose performance does not meet contract requirements.

1.6 Required Meetings. The System Manager shall participate in the project kickoff/pre-con meeting and then any additionally held weekly/bi-weekly/monthly meetings or conference calls with the Engineer and others as directed to assess the effectiveness of deployed systems and to address any operational issues or concerns. Project meetings are considered incidental to the daily operation and maintenance of SWZ devices.

2.0 SWZ Device and System Requirements

These requirements apply to all systems, sub-systems, and individual components, including but not limited to changeable message signs (CMS), Sensor Trailers, and Camera Trailers. These requirements apply to all SWZ system components furnished, placed, and maintained to provide for SWZ Systems that are part of this contract.

Unless otherwise required by the Engineer, the Responder will use their own software to operate the SWZ Systems described.

If TMC integration is required, a SWZ Communication Plan that describes how system devices and central computer will communicate with MoDOT's *(Kanas City, St. Louis, Springfield)* Traffic Management Center's must be provided as noted in section 3.2.2.

2.0.1 Cellular Modem Communications

Responder shall provide cellular modems and network service on all of their SWZ equipment or systems as detailed in this JSP. At a minimum, Responder must be able to use the cellular communications to locate, track, and monitor device or system status and condition.

Cellular modems on devices that integrate with Missouri's ATMS Software have the following additional requirements. Cellular modems on all CMS, all Sensor Trailers, and Camera Trailers defined in Section 2.2 shall be capable of providing a minimum bandwidth comparable to a 4G/LTE network for remote communications. The cellular service provider shall have data coverage within the project limits. The IP Address, communication port, software, and any username/password for web interface shall be supplied to the Engineer via a DOT operated web-accessible, password protected spreadsheet. Electronic access shall be protected by a unique username and password that is not the manufacturer's default username and password.

Each cellular modem shall be capable of obtaining its location by global positioning system (GPS) of satellites. Current location from GPS coordinates shall be stored in the cellular modem's memory for retrieval. The modem shall have firewall security protections that limit who and what can communicate to it. The Response shall include details of the security protections the Responder will use to meet this requirement. A static set of coordinates shall be provided in the IP address spreadsheet for each modem.

The DOT expects monthly data usage to be:

- 5 to 50 MB per PDMS
- 50 to 100 MB per Sensor Trailer
- 50 GB per Camera Trailer

2.0.2 Changeable Message Signs (CMS)

SWZ systems shall utilize MoDOT approved portable changeable message signs (CMS) in accordance with Missouri Standard Specifications for Highway Construction section 616 Temporary Traffic Control and 1063 Temporary Traffic Control Devices and Standard Plans for Highway Construction 616.10.

In addition to the MoDOT specifications all CMS system components including the onboard computer, communication devices, solar panels, batteries, and charge controller shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a unique username and password that is not the manufacturer's default username and password. The username and password shall not be recorded on any part of the trailer. The power supply shall be capable of providing continuous service for 10 days without recharging.

2.0.3 Changeable Message Sign with Radar (CMS with Radar)
The CMS with Radar shall meet all requirements of a CMS in Section 2.0.2 and the following:

The radar sensor shall be capable of detecting speeds of oncoming traffic up to 800 feet in advance of the sensor. The margin of error for speed detection of any radar utilized should be less than 5 mph. The radar sensor can be any make and manufacturer capable of meeting the requirements of the JSP.

Each CMS with Radar shall be programed to have an "indicator" pixel that the sign is active, but the radar has not detected a speed to cause a message to be displayed.

2.0.4 Sensor Trailer Portable Non-Intrusive Traffic Sensors
A Sensor Trailer includes the portable non-intrusive traffic sensor, trailer and all components required to operate the sensor including the serial converters, communication devices, solar panels, batteries, and charge controller. All equipment shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a username and password that is not the manufacturer's default username and password. The power supply shall be capable of providing continuous service for 10 days without recharging. These sensors shall be capable of acquiring traffic data from up to *six (6)* lanes of traffic on a lane-by-lane basis. The trailer shall be capable of supporting the system on any typical roadway shoulder including concrete, asphalt, granular or turf. When deployed, the trailer shall present a level appearance. The trailer shall be capable of supporting the sensor at a variable height of 12 to 30 feet above the ground elevation.

Sensor Trailers shall be equipped with cellular modems as specified in Section 2.0.1 and be configured to transmit data as defined by the Commission. Typical data transmittal is per lane data every minute and includes lane-specific speeds, volumes, occupancy and three vehicle classifications.

Sensors are required to provide accurate data with no less than 90% communications uptime as viewed by daily data reporting.

2.0.5 Bluetooth Sensor Trailer
Some projects may require the use of Bluetooth sensors to collect vehicle travel times along a corridor or through a project and to report those travel times to the CMS. A Bluetooth Sensor is defined as all components working together as a system to accomplish the requirements of the JSP. These components include, but are not limited to, non-intrusive traffic detection device,

onboard computer, any third-party software required to convert sensor data into travel times, mounting equipment, solar panels, batteries, charge controllers, etc. Communication will be via cellular modem provided by the SWZ Responder.

Each Bluetooth Sensor shall contain all needed components, be placed on a temporary SWZ trailer, or be physically protected from vehicular traffic or located outside of the clear zone. The power supply shall be capable of providing continuous service for 10 (ten) continuous days without recharging.

Physical access to the onboard computer shall be protected by a padlock or other locking handle mechanism. Electronic access to the onboard computer shall be protected by a unique username and password that is not the manufacturer's default username and password.

Wireless communication for each Bluetooth Sensor is detailed in Section 2.0.1. The SWZ Detector Bluetooth Sensor shall be able to communicate with SWZ central computer and software, and provide travel times, origin and destination, and route choice etc.

2.0.6 Camera Trailer

Camera Trailer includes the camera, portable trailer, and all components required to power and operate the Camera Trailer. Camera must encode video with h.264 codec and be capable of providing two simultaneously configurable video streams consumable via RTSP.

All cameras shall be capable of full Pan-Tilt-Zoom (PTZ) operation. The camera shall be capable of panning 360 degrees, at least 20x optical zoom, at least 4CIF (704 × 576) color video with a user-selectable frame rate (5, 10, 15, 20, 25, 30 frames per second). Responder shall set up on-screen displays including compass direction and a descriptive camera name.

All Camera Trailers shall be capable of recording at least one (1) week of video locally, with the ability to review and download recorded video remotely and in a non-proprietary format.

All system components including the camera, onboard computer, communication devices, solar panels, batteries, and charge controller shall be trailer mounted. The equipment cabinet(s) shall be locked. Electronic access to the onboard computer shall be protected by a unique username and password that is not the manufacturer's default username and password. The username and password shall not be recorded on any part of the trailer. The power supply shall be capable of providing continuous service for 10 days without recharging. The trailer shall be capable of supporting the system on any typical roadway shoulder including concrete, asphalt, granular or turf. When deployed, the trailer shall present a level appearance. The trailer shall be capable of supporting the camera at a variable height of 18 to 30 feet above the ground elevation.

Cellular communications to be provided by the Responder as described in Section 2.0.1.

For Camera Trailers, typical monthly data usage is expected to be up to 50 GB. Data usage shall be monitored and documented by the successful Responder and reported to the Engineer on weekly basis.

2.1 Central Computer and System Software

The central computer and system software shall provide the functionality described below:

General

- Provide a Graphical User Interface that is compliant with Windows standards.
- Communication between the central computer and any device shall be independent and *non-reliant* upon communications with any other CMS or sensor.
- Alerts to MoDOT *TMC or District* staff and the Engineer shall be provided via text and/or e-mail. Alerts shall be sent in the event of device failure or traffic delays over *15* minutes.

Data Processing Software

- The capability to collect, display, and store sensor data.
- The capability to compare traffic data collected from sensors to user-defined thresholds and automatically update one or more CMS's based on the SWZ systems intended purpose.

Data Management

- Storage of speed, volume, occupancy, CMS message history, and travel times as well as appropriate sensor status for each day.
- Ability to view and download (export) data including sensor data, sign logs, and CCTV images in real time or near real time.

Website and Online Access

- The Contractor will be responsible for hosting the SWZ System software and must provide MoDOT *TMC or District* staff and the Engineer with login access. System permissions such as create, read-only, update, and delete (CRUD) will be specified by the Engineer.
- The Contractor will be responsible for hosting a website and obtaining domain names. Possible domain names and overall website design must be submitted to the Engineer for approval prior to it being made available.
- The website shall contain an accurate map of the area affected by the work zone, including state highways or routes that may be used as alternates.
- Icons or hyperlinked text should accurately depict the current location of the system components and give real-time information provided by each component. In the event components are moved to a new location, the website or software must reflect these changes to the system layout.
- Data should be password protected and stored on the website for each day the system is in use, with date and time stamps included.
- Data shall be available to MoDOT staff at all times for the duration of work zone activity.
- An electronic copy of all data, including date and duration of system malfunction, shall be provided to MoDOT staff each day for the previous day if requested.

- An electronic copy of all data, including date and duration of system malfunction, shall be provided to MoDOT staff after all work zone activity is completed and the SWZ system(s) has been removed.
- Device information shall be provided to MoDOT *TMC or District* staff and the Engineer through icons or hyperlinked text representing each device. Detectors should provide real-time speeds at the respective locations and CMSs should provide the current message of each sign, and cameras snapshots of the current project view.
- The website shall be designed and operated to allow up to *20* users to access the site at one time.

2.2 SWZ Systems

The following SWZ systems are approved for use by MoDOT as described in the MoDOT Engineering Policy Guide Section 616.13. Note that the Engineering Policy Guide may contain updated information or systems. *Number (X) dependent on SWZ Plan provided by the contractor, unless DOT designed.*

2.2.1 Construction Vehicle Warning System

Provides notification to motorists when a construction vehicle is planning to enter or exit from work zones. Components of a construction vehicle entering system include, but are not limited to:

- *Number (X)* Non-Intrusive Detection System (Presence or IR Beam – To be approved, in writing, by the Engineer)
- *Number (X)* CMS
- *Number (X)* Communication link between the Non-Intrusive Detection System and the CMS
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.2 Dynamic Late (Zipper) Merge (DLM) System

Provides increased work zone safety by reducing queue lengths or temporary traffic control situations where a lane closure reduces the mainline roadway from two continuous lanes to one lane. Components of a dynamic late (zipper) merge (DLM) system include, but are not limited to:

- *Number (X)* Sensor Trailer Non-Intrusive Detection System
- *Number (X)* CMS
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.3 Queue Warning System

Informs travelers about upcoming congested or stopped traffic condition. Components of a queue warning system include, but are not limited to:

- *Number (X)* Sensor Trailer Non-Intrusive Detection System
- *Number (X)* CMS
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.4 Temporary Long Term Rumble Strips

A strategy for reducing distracted driving and achieving MoDOT's work zone safety goals. Design per JSP-13-04C.

- *Number (X)* Preformed rumble strips.

Optional monitoring equipment:

- *Number (X)* Sensor Trailer Non-Intrusive Detection System
- *Number (X)* Camera
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.5 Speed Warning System

Speed displays using intelligent transportation system (ITS) or SWZ technologies that give the driver information about their speed as well as the posted advisory speed. The speed displays are portable and can be used in the work zone wherever excessive speeding is a problem.

- *Number (X)* CMS with Radar or standard speed feedback trailer with comms.
- Communication link between radar and the CMS.
- Communication link between system and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.6 Temporary Traffic Incident Management System

The coordinated, preplanned use of technology, processes, and procedures to reduce the duration and impact of incidents in a work zone.

- *Number (X)* CMS

Optional monitoring equipment:

- *Number (X)* Sensor Trailer Non-Intrusive Detection System
- *Number (X)* Camera
- Communication link between system and SWZ software.

- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.7 Travel Time Advisory System

Provides travel times through a work zone.

- *Number (X)* Sensor Trailer Non-Intrusive Detection System, Bluetooth sensors, or 3rd party data such as INRIX.
- *Number (X)* CMS
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

2.2.8 Travel Time Advisory System with Alternate Routes

Travel time advisory systems both on the route under construction as well as the alternate route.

- *Number (X)* Sensor Trailer Non-Intrusive Detection System, Bluetooth sensors, or 3rd party data such as INRIX.
- *Number (X)* CMS
- Communication link between system devices and SWZ software.
- All equipment shall be equipped with a power supply capable of providing continuous service for ten (10) days without recharging.

3.0 Smart Work Zone Plan, Work Plan, and Test Plan

3.1 General

The Contractor shall submit to the Engineer for approval a detailed written and illustrated SWZ Plan that addresses and meets all requirements of this specification *three (3)* weeks prior to mobilization of any component of the SWZ System. Commission may propose changes or modifications to specific procedures and requirements of the Plans prior to approval.

Approval of the SWZ Plan by the Engineer is required prior to the placement of any SWZ devices. Approval is conditional and will be predicated on satisfactory performance during construction. The Engineer reserves the right to require the Contractor to make changes in the SWZ Plan and operations, at no additional cost, including removal of personnel, as necessary, to obtain the quality specified. The Contractor shall notify the Engineer in writing a minimum of *seven (7)* calendar days prior to any proposed changes in the SWZ Plan. Proposed changes are subject to approval by the Engineer. The Plans shall be executed upon approval from the Engineer.

The Contractor will not be allowed to start any construction activities that will affect traffic on the project until the SWZ Plan is approved by the Engineer and SWZ is deployed and operational, including successful operational testing.

3.2 Content of the SWZ Plan

The SWZ Plan shall include, as a minimum, the following items:

- A detailed plan showing the proposed locations of all SWZ devices and equipment description including make and model.
- A description of all proposed thresholds and proposed CMS messages to be implemented.

3.2.1 Management Plan

- The name and contact information of the SWZ System Manager, Field Technicians, and any Sub-contractors or suppliers.
- The responsibility and authority of each individual on the Responder's team. The relationships between and authority over all individuals on the Responder's team.

3.2.2 Work Plan

The Work Plan shall include, but is not limited to, these major areas:

- SWZ Equipment Availability:
    - Quantities of equipment owned by responder that is available for this contract.
    - Plans for obtaining additional equipment (if needed).
- A detailed description of the proposed methods of communication between SWZ devices, SWZ Central Computer, and SWZ Software.
    - If TMC integration is required provide a communications plan that describes the communications between SWZ Central Computer and the *MoDOT Transportation Management Center (TMC)* or District Office located at *Address*. The data plan should include, but is not limited to:
        - Device Vendor/Manufacture
        - Protocol (NTCIP, Proprietary, Server Interface)
        - Software and current firmware version
        - Communication Ports
        - Integration Plan
        - Initial verification demonstration and testing ahead of deployment.
- How the Responder plans to meet all requirements in Section 1.0.
- How the Responder proposes to accomplish the initial deployment of each system and related components for each individual project in the contract. This shall include minimum advance notice for component delivery and deployment and how this ensures meeting all requirements of the contract, so all systems are operational.
- How the Responder proposes to maintain the system, including availability of spare parts and equipment, response methods, and times, and how the Responder will

ensure all requirements are met to respond to system failures, including damage and equipment failures.

- A detailed description of the Responder company's process to verify that each piece of equipment is in proper working condition including, but not limited to, preventative maintenance schedules, equipment depreciation and replacement schedules, pre-deployment testing procedures, equipment component replacement schedules, and procedures, etc.
- Proposed corrective method procedures including response times and notification process.
- A detailed description of the System Managers plan for daily devices checks, data validation review plan and frequency, and system validation review plan and frequency.

3.2.3 Test Plan

Responses shall include a complete Test Plan that includes, but not be limited to, these major areas:

- A list of items to be tested.
- Test methods and expected minimum results for each item to be tested.
- Test procedures and all forms used to document testing results, including the proposed method for submittal of completed documents.

3.2.4 Additional Devices, Systems or Technologies

Responders are encouraged to propose additional systems, devices, or technologies that the Commission may want to consider for improving safety and operations in work zones. Additional systems may include both devices that can be integrated into ATMS software, or stand-alone devices or systems.

Details about additional devices, systems or technologies may be provided in cut sheets or standard marketing brochures. All of the equipment, processes, software, and operating system information shall be included in these details and the unit costs.

4.0 Operational Test

Once the SWZ is installed, it shall undergo a five-day operational test. The operational test shall include a test of the system in operation during to ensure that all SWZ equipment (including the *changeable message signs, traffic sensors, central computer, communication devices, and website/interface*) is operating in a fully functional manner and in accordance with the Smart Work Zone Plan for a duration of at least *five (5)* consecutive calendar days. The Contractor shall provide for complete operations support from the vendor during the operational test, and the Contractor shall provide verification that the reported data in the work zone accurately reflects actual field conditions. If any equipment malfunctions occur for a combined period of *four (4)* hours or more during this operational test on any day, no credit will be given for that day for the operational test period, and the five-day operational test will reset.

The Contractor shall maintain records of equipment stoppages and resumptions during the five-day operational test for submission to the Engineer for approval. In the event that ten percent or more of the time similar malfunctions occur that affect the proper operation of the SWZ system, the Engineer may declare a system component defective and require replacement of the equipment at no additional cost. When a system component defect is declared, the five-day operational test shall begin again after all defective equipment is replaced and the system is fully operational.

4.1 Operational Test Report

The Contractor shall submit a report to the Engineer detailing the daily activity of the system during the operational test. The report shall indicate the date and time of any activity necessary to maintain operation of the SWZ during the operational test period. Each entry shall include the following information:

- Identity of the equipment on which work was performed.
- Cause of equipment malfunction (if known)
- A description of the type of work performed.
- Time required to repair equipment malfunction

Once the operational test report is received and approved by the Engineer, the SWZ will be considered operational, and the system will be accepted for use.

5.0 Measurement and Payment

All SWZ devices furnished, installed, and maintained by the Responder shall be measured by one lump sum and shall be divided into the following payment schedule:

- 35 percent will be paid when all of the SWZ equipment is delivered to the jobsite.
- 10 percent will be paid when the Engineer approves the Operational Test Report.
- 10 percent will be paid after *30* calendar days of full system operation.
- 45 percent will be paid after work that requires the use of SWZ system has been completed, the Contractor's SWZ equipment has been removed from the project, and historical data has been provided to the Engineer.

5.1 Deduction for Failed System

A percentage of the lump sum will be deducted should the system malfunction for *three (3)* or more consecutive calendar days or any total of *five (5)* calendar days in any one calendar month after the approval of the operational test. This deduction will be based on a ratio of calendar days of unsuccessful operation to total calendar days of operation following the approval of the operational test. This deduction will not reduce the total system payment to less than *60* percent of the lump sum.

System malfunction will be defined as any provided device or component failure that causes the SWZ system it is supporting to provide inadequate information or warning to the motorist. For example: If a Sensor fails causing the Queue Warning System it supports to be inoperable, none of the other Sensors or PDMS for that Queue Warning System shall be considered operable for that time period.

6.0 Basis of Payment

Payment for submittal and approval of a Smart Work Zone System plan, furnishing, installing, relocating, operating, maintaining, testing, monitoring, providing a website, providing daily data and historical data, and removal of the Smart Work Zone System (SWZ), including all items required for proper operation of this installation, will be completely covered by the contract unit price for Item Number *XXX XX.XX*, "Smart Work Zone System," per lump sum.