Work Zone Safety & Mobility Performance Measures: Implementation Guide

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16. Abstract

Performance monitoring allows transportation agencies to continuously track and analyze work zone safety and mobility impacts throughout a project's lifecycle. By establishing clear, actionable performance measures, agencies can quantify operational impacts to increase accountability, efficiently allocate resources, and evaluate how well existing policies and procedures function in the field. To assist agencies in achieving these benefits, this implementation guide provides practical guidance for establishing and managing continuous work zone performance monitoring programs in alignment with Federal Highway Administration (FHWA) 23 CFR 630 Subpart J rulemaking. The document emphasizes a "data-first" approach, helping practitioners inventory existing work zone activity, safety, mobility, and exposure data, including data sources like crash databases and crowdsourced probe data alongside emerging datasets such as connected vehicle telematics. Building upon this data availability, the report outlines how to select and calculate practical project- and program-level performance measures to meet minimum compliance and operational goals. To assist in this selection, the guide presents safety and mobility performance measures, detailing their specific benefits and limitations, and outlines available calculation options ranging from in-house data development to leveraging open-source tools and multi-state platforms. Furthermore, the report provides actionable recommendations for agencies to establish a foundational program using commonly available data, including crash data and the National Performance Management Research Data Set (NPMRDS), along with potential advanced analysis using higher resolution data sources. Finally, the guide provides an annual reporting template, offering a structure agencies can use to easily incorporate their findings into their 5-year programmatic review.

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List of Acronyms

AADT	Annual Average Daily Traffic
API	Application Programming Interface
ATIS	Advanced Traveler Information Systems
ATMS	Advanced Traffic Management Systems
ATR	Automatic Traffic Recorder
BTI	Buffer Time Index
Caltrans	California Department of Transportation
CFR	Code of Federal Regulations
CV	Connected Vehicle
CWZ	Connected Work Zone
DMS	Dynamic Message Sign
DOT	Department of Transportation
FHWA	Federal Highway Administration
HPMS	Highway Performance Monitoring System
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LCS	Lane Closure Systems
LOTTR	Level of Travel Time Reliability
LRC	Lane Requirement Charts
NHS	National Highway System
NPMRDS	National Performance Management Research Data Set
MAP-21	Moving Ahead for Progress in the 21st Century Act
MPO	Metropolitan Planning Organization
ODOT	Ohio Department of Transportation
PDO	Property Damage Only
PeMS	Performance Measurement System
PET	Post Encroachment Time
PLCS	Permitted Lane Closure System
PM3	Third Performance Management Rule
PTI	Planning Time Index
RITIS	Regional Integrated Transportation Information System
TCP	Traffic Critical Projects
TMA	Truck Mounted Attenuator
TMC	Traffic Management Center
TMC	Traffic Message Channel
TSMO	Transportation Systems Management and Operations
TTC	Time to Collision
TTI	Travel Time Index
TxDOT	Texas Department of Transportation
SWZDI	Smart Work Zone Deployment Initiative
VMT	Vehicle Miles Traveled
WIM	Weigh-in-Motion
WZDx	Work Zone Data Exchange
WZPR	Work Zone Process Review

1 Introduction and Purpose

Performance monitoring allows transportation agencies to track and analyze work zone safety and mobility impacts throughout the entire lifecycle of a work zone by continuously collecting, analyzing and reporting performance measures. Central to this monitoring are performance measures which are quantifiable metrics used to evaluate work zone safety and mobility such as crash rates and travel time delay. These measures are critical tools used for quantify the safety and operational impacts of construction activities on travelers, businesses, and workers. By establishing clear, actionable performance measures, agencies can increase accountability, efficiently allocate resources, and evaluate how well their existing policies, processes, and procedures are functioning in the field.

While the use of performance monitoring has expanded since the early 2010s, a persistent challenge for many agencies has been the availability of data and the ability to implement a program to compute actionable metrics. Furthermore, while foundational guidance materials currently exist, they do not always incorporate the expanded and emerging data sources available to agencies today. Datasets such as connected vehicle telematics, crowdsourced probe data, and camera analytics now offer widespread analytical capabilities without the need for proactively planned infrastructure or labor-intensive manual data collection.

Translating this raw data into practical safety, mobility, and exposure metrics improves an agency's understanding of how decisions made during planning, design, and construction directly affect active work zone operations. Successfully utilizing these metrics empowers agencies to communicate impacts to the public, better predict the benefits of traffic mitigation strategies, and transition toward proactive work zone management. Instead of reacting after the fact, practitioners can continuously monitor safety and mobility measures to identify and mitigate issues before a severe crash or congestion occurs.

However, while the theoretical benefits of performance monitoring are thoroughly documented, this implementation guide does not focus on the why behind performance measures; rather, it is focused on the how.

1.1 Purpose of this Document

To assist agencies in bridging the gap between raw data collection and strategic application, this document provides practitioners with implementation guidance for actively establishing and managing a performance measurement program. Designed as a companion to the Federal Highway Administration (FHWA) 2011 primer, *A Primer on Work Zone Safety and Mobility Performance Measurement* (FHWA-HOP-11-033), this updated guidance focuses on repeatable, program- and system-wide monitoring.

This document aligns with the FHWA rulemaking Code of Federal Regulations (CFR) Part 630 Subpart J on Work Zone Safety and Mobility. It establishes practical pathways for agencies to achieve compliance and calculate meaningful metrics while documenting data sources readily available as well as emerging datasets, such as connected vehicle telematics, probe data, and camera analytics, to enhance proactive work zone management.

The selection of which work zones to monitor, the specific metrics chosen, and the frequency of that monitoring will ultimately depend on Federal rules, agency priorities, and available resources. Federal guidance emphasizes that agencies should use available data for their performance monitoring and provides options for reviewing a representative sample of work zones. With this, agencies select a few (at least one safety and one mobility) highly effective measures based on their unique needs and track them "clearly, seriously, and consistently."

Specifically, these safety and mobility performance measures selected should:

- Directly relate to the agency's overarching safety and mobility goals and objectives.
- Consistent with the measures used during impact assessment efforts for work zone planning and design analyses.
- Able to accurately characterize the different facets of physical and operational impacts that are occurring.
- Capable of allowing practitioners to evaluate alternative strategies to mitigate work zone impacts.
- Compatible with other system-wide performance measures the agency is already utilizing to evaluate its overall network.

1.2 What This Guide Helps You Do

By focusing on a few carefully selected, high-value metrics, this guide translates broad operational goals into actionable practices. It provides a step-by-step approach to help practitioners:

- **Identify existing data and determine needed information:** Balance existing resources with what your agency may need to acquire by mapping out required work zone activity, safety, mobility, and exposure data. This involves leveraging traditional data alongside emerging sources to support the selected metrics without the need for proactively deploying data collection devices.
- **Select performance measures:** Choose at least one safety and one mobility measure tailored to agency goals, and clearly document their definitions so that all stakeholders understand what is being measured and why.
- **Implement a repeatable annual monitoring workflow:** Create a programmatic cycle to ensure the selected metrics are tracked "clearly, seriously, and consistently" annually. Use these aggregated results to conduct data-driven, holistic programmatic reviews for the continuous improvement of work zone processes and procedures.
- **Expand organically:** Evolve from a foundational set of baseline metrics to more advanced, proactive management strategies as data maturity and quality improves and agency staff become more proficient in computing and interpreting complex measures over time.

1.3 Guide Organization

This document is deliberately structured to bridge the gap between high-level theory and on-the-ground execution. To guide practitioners from initial planning to full program deployment, the report follows a sequential path. It begins by establishing the Federal regulatory drivers, then takes a "data-first" approach by helping agencies inventory their available data before selecting specific safety and mobility metrics. Finally, it transitions from theoretical measurement to practical action, detailing how to implement reporting pipelines and highlighting real-world success stories from peer agencies. To execute these phases, the guide is organized into the following chapters:

Chapter 2: Regulatory Context and Background

Establishes the foundational need for work zone performance measures. This chapter details the Federal requirements outlined in FHWA rulemaking (specifically CFR Part 630 Subpart J) and provides the context for why continuous monitoring is critical to modern traffic management.

Chapter 3: Data Sources

While many industry reports identify performance measures first, this guide recognizes that execution is entirely dependent on data availability. Therefore, this chapter precedes metric selection to help agencies identify what data they actually have access to. It covers the primary sources for work zone activity data, mobility data, safety data, and exposure data.

Chapter 4: Performance Measures

Building directly upon the available data identified in Chapter 3, this section details the specific safety and mobility metrics agencies can realistically collect. It outlines what goes into calculating these performance measures at both the project and programmatic levels.

Chapter 5: Implementation and Reporting

Focuses on putting the data and metrics to work. This chapter discusses operational strategies for implementing performance measures, evaluating system health, and utilizing the various tools and platforms available to agencies to support continuous, automated reporting.

Chapter 6: Agency Examples and Resources

Concludes the core guidance by showcasing real-world success stories. This section highlights practical examples from State DOTs currently executing work zone performance monitoring in the field, alongside a curated list of external resources for further reading.

1.4 Additional Resources

This implementation guide is designed as an agile companion rather than an exhaustive textbook. While the original FHWA primer *A Primer on Work Zone Safety and Mobility Performance Measurement* (FHWA-HOP-11-033) focuses on why performance measures matter, defines core terminology, and provides theoretical frameworks, this guide intentionally summarizes those broader concepts to prioritize actionable, modern deployment strategies.

Specifically, this guide builds upon the primer's foundation by focusing strictly on implementation, demonstrating:

- **Identifying** available data sources
- **Choosing** a minimum compliance set of measures
- **Building** a repeatable annual monitoring and reporting process.
- **Expanding** the program organically over time to calculate improved, higher-resolution performance measures.

For readers seeking a deeper foundation on performance measure derivation, or historical context regarding work zone impacts, the original FHWA primer remains the definitive resource. Practitioners are highly encouraged to reference the primer alongside this guide for a comprehensive, full-spectrum understanding of work zone analytics.

The full FHWA primer can be accessed at: https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop11033/index.htm.

2 Regulatory Context

This chapter summarizes the regulatory context and key concepts needed to interpret work zone performance measures and reporting expectations. It translates Federal requirements into practical, implementation strategies for State and local agencies.

2.1 Work Zone Rule context (23 CFR 630 Subpart J)

This guide aligns directly with Subpart J's emphasis on a data-driven assessment of work zone safety and mobility performance. The foundational anchor for this approach is found in 23 CFR 630.1008 (State-level processes and procedures). The overarching purpose of this regulation is to establish requirements and provide guidance for systematically addressing the safety and mobility impacts of work zones, and for developing strategies to help manage these impacts on Federal-aid highway projects

Rule tie-in

Definitions and Data Types: To ensure consistent application, Subpart J officially defines **Mobility** as the ability to move road users efficiently through or around a work zone area with minimum delay compared to baseline travel when no work zone is present, while not compromising the safety of highway workers or road users.

To measure this effectively, Subpart J (§ 630.1008) requires that agencies use field observations and various available data types to monitor and manage work zone impacts for specific projects and perform programmatic reviews. The rule provides examples of these key data types, including:

- **Work Zone Crash data**: Fatalities, injuries, and crashes.
- **Safety surrogate data**: Speed differentials, hard braking, and other data from connected and autonomous vehicles
- **Operational information**: Speeds, travel times, queue length, and queue duration.
- **Exposure data**: Number of projects, number and length of lane closures, and vehicle-miles traveled (VMT) through work zones.

2.2 Work Zone Performance Measure Needs

The same performance measure can often be useful at different decision levels, but agencies must be able to clearly distinguish between project-level and program-level applications. Project-level measures are typically easier to identify, as they directly evaluate the impacts of a single, specific work zone to support day-to-day operational management and active work scheduling (e.g., triggering real-time alerts or adjusting lane closure windows). In contrast, program-level (or systemwide) measures require a broader view. They are most commonly generated by aggregating project-level metrics across the entire network to support high-level monitoring, long-term trend reporting, and the agency's periodic programmatic review cycle.

The key to a successful monitoring program is matching the right measure to the specific decision your agency needs to support, as outlined in Table 1.

Table 1. Project-Level vs. Program-Level Measurements.

Level	Typical Questions	Typical Outputs	Applicable Measures
Project-Level	Is traffic control working? Are queues forming? Should lane closure timing change?	Daily/weekly dashboards for individual project, alerts, closure adjustments	Number of crashes, average delay, number of queueing events, congestion hours
Program/ Systemwide	Are work zones improving over time? Which work zones are high-impact? Where should policy/training change?	Annual monitoring summary, trend plots, representative sample review outputs	Percent of projects exceeding thresholds, vehicle-hours of delay, reliability indicators, crash counts/rates

Rule tie-in

Work Zone Programmatic Reviews: When assessing program-level needs, Subpart J formalizes the concept of a work zone programmatic review, a data-driven, systematic, and holistic analysis using multiple data sources to assess safety and mobility performance to identify improvements to an agency's processes and procedures.

Crucially, the rule specifies that States shall monitor performance annually to ensure continuous assessment. Furthermore, the programmatic review must assess a representative sample of the State's significant work zones over a 5-year period, with the sampling approach properly documented based on factors like land use, roadway type, and extent of impacts

2.3 Policy Requirements

Subpart J specifies that a State's work zone safety and mobility policy must explicitly identify the safety and mobility performance measures it uses to manage work zone performance (§630.1006(b)). States should ideally institute this policy using a multi-disciplinary team and in cooperation with the FHWA. Crucially, the rule specifies that States shall monitor performance annually to ensure continuous assessment. Furthermore, the programmatic review must assess a representative sample of the State's significant work zones over a 5-year period, with the sampling approach properly documented based on factors like land use, roadway type, and extent of impacts (§ 630.1008(e)).

Rule tie-in

Requirements (see § 630.1006): The policy shall identify at least one safety and one mobility performance measures used to manage work zone performance. The rule provides the following examples that agencies should consider. Additional performance measures for consideration are included in Chapter 4.

- Number of fatal and injury crashes occurring in a work zone.
- Percent of projects that exceed a preestablished crash rate in the work zone.
- Number of highway worker fatalities and injuries experienced.
- Highway worker fatality and injury rate per hours worked.
- Percent of projects that experience queues above a predefined threshold.
- Percent of time when speeds in a work zone drop below a predefined threshold.

2.4 Annual Performance Reporting Template

In accordance with the updated 23 CFR Part 630 Subpart J rulemaking, States are required to monitor the selected safety and mobility performance of their work zones on a continuous, annual basis. While this annual summary does not need to be formally submitted to the FHWA, it may be requested by the FHWA local division office. Ultimately, establishing this repeatable annual reporting cycle allows agencies to systematically incorporate annual performance data into the mandatory five-year work zone programmatic review.

More importantly, these annual summaries form the building blocks for the 5-year programmatic review. By consistently documenting performance year over year, agencies can seamlessly incorporate their annual data into the 5-year review to assess long-term systemic trends and identify process improvements.

To assist agencies in standardizing this annual reporting, a template has been developed as part of this guide which is included in Appendix A. It should be noted that this specific template is not included or mandated in the rulemaking; rather, it is provided as a practical example that agencies can use to highlight and satisfy the core requirements of the annual performance measure reporting. The following outlines the content of the template to capture all necessary regulatory elements and actionable insights.

Summary and Methodology

This section provides an overview for the report, providing executive leadership with a high-level summary of the agency's monitoring efforts for the year.

- **Program Overview**: A high-level summary of the report, aligning the performance measurement effort with the agency’s overarching work zone safety and mobility policy.
- **Data Sources Utilized**: A brief description of the data used to compute the measures (e.g., probe data for mobility, statewide crash databases for safety, incident logs, or contractor exposure data).

- **Representative Sample Selection**: The rulemaking specifically requires that performance review at a minimum the representative sample of the State's significant work zones. This section should document the approach used for selecting this sample if applicable based on factors such as land use (urban vs. rural), roadway classification, type of work zone, and the extent of the impacts. Detailing how many work zones were included and how they were chosen belongs in this section.

Safety Performance Measures

This section outlines the specific safety performance measures monitored during the year, discusses historical data trends, and evaluates system-wide performance against the agency's established safety targets.

- **Safety Measure Overview**: A brief definition of the specific safety metrics evaluated for the year (e.g., crash rates per million vehicle-miles traveled, worker injury counts, or safety surrogate data like hard-braking events).
- **Summary of Results and Trends**: An analysis of the program level safety performance measure. This should discuss how the safety performance trended compared to previous years, or how crash rates in work zones compared to expected pre-construction baselines.
- **Performance Targets**: If an agency has defined performance targets, an evaluation of the performance measure against the agency's established safety goals (e.g., tracking the percentage of projects that exceeded a pre-established "acceptable" crash rate or the number of work zone crashes below a threshold annually).

Mobility Performance Measures

This section outlines the specific mobility performance measures monitored during the year, discusses operational data trends, and evaluates overall traffic impacts against the agency's established mobility targets and policy thresholds.

- **Mobility Measure Overview**: A brief definition of the specific mobility metrics evaluated (e.g., total vehicle-hours of delay, maximum queue lengths, or travel time reliability indices).
- **Summary of Results and Trends**: A discussion of the program level mobility impacts. This subpart should discuss the mobility performance measure and compare the current year's mobility trends to previous years or historical baselines.
- **Performance Targets**: If an agency has defined performance targets, an evaluation of how well the work zones complied with agency mobility policies. For example, reporting the "percent of time when speeds dropped below a predefined threshold" or the "percent of projects that experienced queues above a predefined 1.5-mile limit".

Conclusion, Action Plan, and/or Assessment

This section focuses on using the year’s performance data to actively apply these insights and improve future operations. This section can summarize the overall trend of safety and mobility and document any insights or actions the agency may be taking to improve.

- **Overview of Insights**: A synthesis of the key successes, localized challenges, and emerging trends identified in the safety and mobility data over the past year.
- **Annual Observations**: Briefly note any observations on how the data reflects current project planning, design, operations, permitting, or training. Documenting these thoughts annually makes it significantly easier to conduct the formal, cross-division assessment required during the 5-year programmatic review.
- **Immediate Action Items**: If the year's data highlights areas needing immediate attention, document the specific mitigation steps taken or planned. While a comprehensive assessment is part of the 5-year programmatic review, tracking yearly adjustments helps maintain operational health. When noting these steps, it is helpful to include:
    - The specific operational or policy adjustments planned to achieve improvement.
    - The State divisions or offices coordinating the response.
    - An estimated timeframe for when the adjustments will be evaluated.

3 Data Sources

When establishing a work zone performance monitoring program, identifying data sources is a foundational first step. The data an agency has access to directly dictates which performance measures can be calculated, the granularity of the analysis, and the ultimate level of actionable insight gained. Before selecting specific metrics, practitioners should first take inventory of their existing data pipelines to understand what is feasible.

A critical tenet of the FHWA rulemaking (23 CFR 630 Subpart J) is the emphasis on utilizing available data sources. The regulatory intent is clear: agencies are not required to proactively procure costly new data sources to satisfy programmatic monitoring requirements but encourages the use of available data. Instead, agencies should utilize resources that your agency generates, subscribes to, or has access through partners. By leveraging existing assets, such as traffic management center (TMC) sensors, commercial probe vehicle data, crash databases, connected vehicle feeds, or standard lane closure permits, agencies can build a robust performance monitoring program using the tools already available. While agencies may still choose to collect additional, specialized data for specific high-impact projects, relying on scalable, readily available data for your program-wide foundation will significantly minimize implementation costs and effort.

At the core of any work zone performance monitoring program are four primary categories of data. Figure 1 provides an overview of these core sources, which are detailed throughout this chapter. Among these, work zone activity data serves as the overarching foundation required to contextualize all other metrics. While this graphic and document focus on the minimum data sources required to establish a baseline safety and mobility monitoring program, agencies may eventually incorporate additional datasets such as weather conditions, incident logs, detour routing, etc. However, while these supplemental sources are valuable for refining advanced analyses, they fall outside the scope of minimum compliance and will not be a focus of this implementation guide.

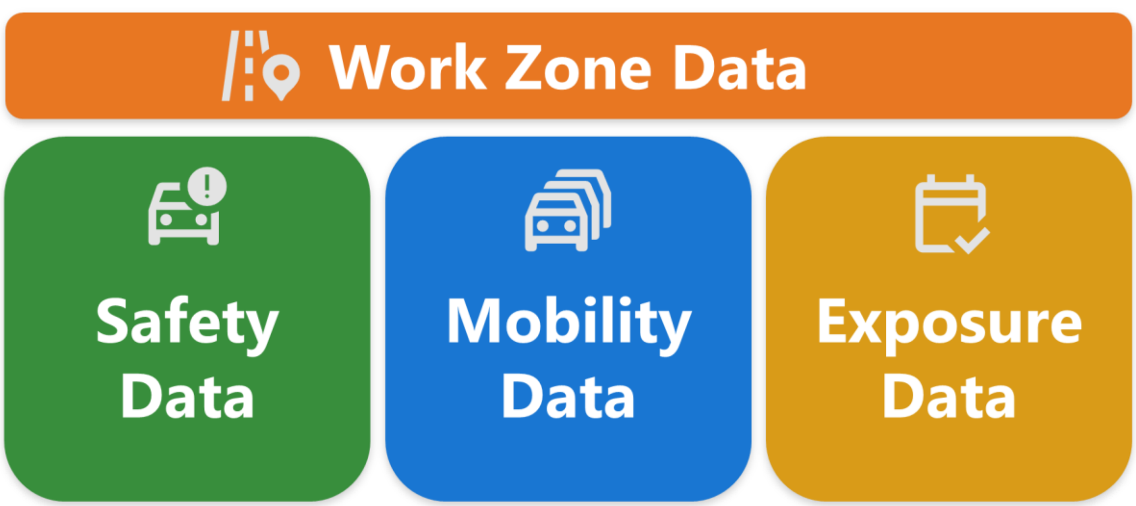


Figure 1. Core Data Sources for Work Zone Performance Program.

With the overarching structure of the data ecosystem established in Figure 1, the next step is understanding exactly what information resides within each of these categories. To help structure the data inventory process, the following breakdown details the scope of the four core data sources needed to drive a comprehensive monitoring program:

- **Work Zone Activity Data**: The foundational project data that defines the physical and temporal footprint of the work zone, helping to identify exactly when and where impacts are occurring. This includes essential operational details such as the location, active working hours, lane closure configurations, roadway classification, and the type of construction activity taking place.
- **Safety Data**: Metrics used to evaluate risk and crash history within the project limits. This encompasses traditional indicators (such as state crash data and worker injury reports), proactive safety surrogate measures (such as hard-braking, low time-to-collision, or swerving events captured via telematics or traffic simulation), as well as emergency and service patrol dispatches.
- **Mobility Data**: Information used to quantify how the work zone impacts traffic operations and travel times. Sourced from traditional ITS infrastructure, commercial probe data, vehicle telematics, Bluetooth point-to-point tracking, or even manual observations. Speed is the most common attribute derived from these sources, providing the ability to track real-time traffic flow, travel time delays, travel time reliability, and the formation and duration of queues.
- **Exposure Data**: Information used to capture who or what is being affected by a work zone, allowing practitioners to contextualize and normalize safety and mobility impacts. By capturing overall traffic volume, person-trips, the extent of lane closures, or total worker-hours in the field, exposure data provides the denominator necessary to establish rate-based comparisons across vastly different work zones.

This chapter introduces common work zone activity, safety, mobility, and exposure data sources so an agency can inventory what they have and identify feasible acquisition options.

Guide Map

In this chapter you will:

- Recognize the main data sources used for work zone performance measurement
- Identify which sources you already have (and what you are missing)
- Understand common gaps and realistic alternatives

3.1 Work Zone Activity Data

Work zone activity data is the foundational element of a performance monitoring program. It serves as the master index that allows agencies to confidently connect safety incidents, mobility delays, and exposure metrics back to a specific project. By linking these operational metrics to specific activity logs, practitioners can target exactly how performance was affected during distinct construction phases or specific time periods.

Without accurate activity data, agencies cannot separate a work zone queue from standard, recurring daily congestion. At its core, this data provides the digital description of the when, where, and how of a work zone deployment.

3.1.1 Common Sources for Work Zone Activity Data

Agencies do not need to build entirely new databases to track this information. Most practitioners can extract the necessary location, time, and closure details from systems already in use. Common repositories of work zone data within an agency include:

- **Lane Closure Systems (LCS) / Permitting Software**: Some agencies may have an internal repository for planned work zone schedules, project limits, and approved lane configurations. If available, this is the most accessible starting point for using as part of the work zone performance monitoring.
- **Advanced Traffic Management Systems (ATMS) & Traveler Information Systems (ATIS)**: These systems are the operational platforms used by TMCs to monitor the road network. These systems often contain active work zone logs used to trigger 511 websites, mobile alerts, or Dynamic Message Signs (DMS).
- **Work Zone Data Exchange (WZDx) / Connected Work Zone (CWZ) Feeds**: An agency may maintain a WZDx/CWZ feed which can serve as an ideal, ready-to-use activity index that provides a uniform language for broadcasting real-time activity to third-party navigators and automated vehicles. These feeds are intended for real-time usage so practitioners should work to either archive this data or go to the source of the feeds to access the archive.
- **Third-Party & Field Telematics (Waze, Connected Arrow Boards, Smart Cones)**: External data sources can be used but may be limited in the details and completeness of work zone data. These dynamic sources can help bridge the gap between "planned" work and "verified" work. Connected field devices (like arrow boards) automatically ping their location and status when turned on, while platforms like Waze or vendor dashboard partnerships offer crowdsourced validation of active work zones in the field.

A frequent challenge when utilizing legacy lane closure systems or ATMS logs is the discrepancy between the planned database entries and the actual, real-world conditions of the work zone in the field (e.g., a contractor leaving a lane closed two hours longer than permitted, no work activity due to weather). While agencies should openly recognize this gap and actively make it a programmatic goal to improve data accuracy, the imperfect data should not limit an agency's ability to launch a performance monitoring program. The regulatory goal is to establish a repeatable workflow using the available data today. Agencies can start by automating baseline metrics, and continuously refine the inputs over time. Specific strategies and recommendations for improving activity data accuracy from the field will be detailed later in this section.

3.1.2 Minimum Data Requirements

To successfully link safety and mobility data to a specific project, an agency must establish a baseline of activity data. This baseline represents the minimum information about a work zone required to launch a performance monitoring program. To establish a functional work zone activity index, the minimum data fields required include:

- **Start and End Location**: The geocoordinates (latitude/longitude) for the project boundaries. This can also include the route name and mileposts to further validate the location. This can also be represented as a line representing the work zone.
- **Start and End Time**: The planned or actual timeframe of the work activity.
- **Direction of Travel**: Specifying which directions (e.g., Northbound vs. Southbound) are actively impacted.
- **Work Type**: A basic classification of the project (e.g., surface work, roadside work, maintenance).

This information establishes the location and duration of the work zone, allowing practitioners to associate the work zone with corresponding safety and mobility data to generate project-level performance measures. While "work type" is not strictly required simply to match a work zone to safety and mobility data, it is included in this minimum set because it immediately empowers agencies to begin understanding how different categories of work impact safety and mobility.

As an agency's data capabilities mature, often through the adoption of WZDx feeds or connected field devices, the work zone activity data should ideally expand to capture the full operational footprint. This additional granularity not only improves the accuracy of the performance measures but also enhances an agency's ability to perform additional analytics identifying the operational activities impacting safety and mobility. Areas where agencies can mature their work zone activity data include:

- **Dynamic Lane Status**: The exact number of lanes closed, shifted, narrowed or open, as well as the physical length of the closure. Capturing lane status accurately can be difficult when lanes are closed in a staggered sequence over the course of a work shift, especially at night. If dynamic, minute-by-minute tracking is currently unfeasible, agencies should default to logging the maximum restriction implemented during the shift.
- **Work Zone State & Phasing**: Distinguishing between a planned event, an active static work zone, or a short-duration moving operation. Furthermore, documenting the specific dates of major construction phase changes allows analysts to evaluate why mobility impacts might suddenly shift mid-project.
- **Worker Presence**: Tracking the number of workers present during specific activity hours or defining specific "active work" timeframes. This is highly valuable for accurately evaluating worker exposure and calculating localized safety metrics.

- **Restrictions and Detours**: Documenting associated speed limit reductions, the presence of temporary concrete barriers in close proximity to travel lanes, designated construction vehicle access points, and mapped detour routes.

3.1.3 Work Zone Data Location

Before calculating any metrics, practitioners should understand what the underlying work zone activity data actually represents and how it was collected in the field. Work zone practitioners are likely not collecting the data themselves but instead relying on databases managed by traffic operations centers, IT departments, permitting offices, or field inspectors. To build an accurate performance monitoring program, agencies must collaborate directly with these internal groups to correctly interpret the attributes that are provided. As an example, a database field simply labeled "Start Location" might mean very different things between agencies.

A specific attribute which should be coordinated is the location or geographic footprint of the work zone. Simply querying the start and end coordinates of a project is only the first step. If the spatial definition of the work zone in the database is misaligned with where the actual traffic impacts occur, the resulting safety and mobility metrics will be fundamentally flawed. There are multiple ways agencies log the geographic limits, but two common methods from the connected work zone standard are shown in Figure 2. A description of the two methods is below:

- **Sign Method (Advance Warning)**: The work zone limits are defined by the placement of the static signage. The "Begin Location" is anchored at the first Advance Warning sign (e.g., Road Work 1 Mile), and the "End Location" is anchored at the End Road Work sign.
- **Channelization Method (Traffic Impact)**: The work zone limits are defined by the physical alteration of the roadway. The "Begin Location" starts at the first channelizing device (the beginning of the transition area or taper), and the "End Location" is where the channelizing devices end and traffic returns to its normal path.

Work zone impacts, specifically the formation of queues and the occurrence of rear-end crashes, frequently happen well upstream of the physical lane closure. Depending on which location method your agency uses, agencies may need to adjust the analysis footprint to capture these upstream events. If the data uses the sign method, the work zone extents naturally include the advance warning area. Because this method begins up to a mile or more before the lane closure, it generally captures upstream queues and crashes without requiring additional spatial modifications.

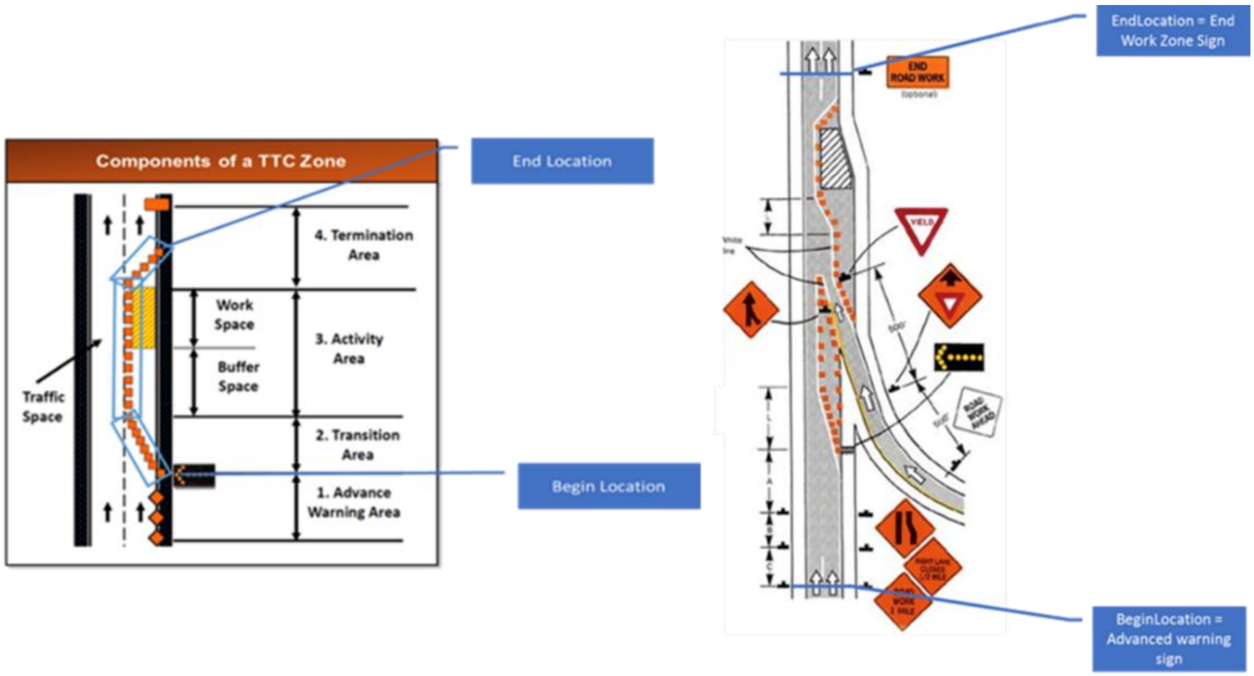


Figure 2. Work Zone Location Method (ITE CWZ Implementation Guide and Standard v01.00)

However, if the data uses the channelization method, the work zone data only covers the physical impacts to the roadway. Bounding the safety and mobility queries to the physical lane closure limits may result in inaccurate performance measures. For example, if a 2-mile queue forms upstream of a lane closure, and a secondary crash occurs at the back of that queue, it is a work-zone-related crash. Calculating safety and mobility performance measures starting only from the taper onward will result in these critical incidents being excluded from an agencies programmatic review, leading to underreporting.

To prevent this, coordination with the provider of the work zone activity data is needed to understand what the location coordinates represent when setting up an agencies program. If an agency's permit system or activity log utilizes the channelization method, a spatial buffer to fully encompass the work zone's impact area will likely be needed. To account for this, an agency can select a standardized upstream distance (e.g., fixed 2 miles or dynamically defined based on roadway classification and speed limit) and append this buffer to the start location of the work zone prior to calculating performance measures. This ensures that the geographic boundaries used to calculate your metrics accurately reflect the true operational footprint of the work zone.

3.1.4 Work Zone Data Accuracy

While agencies are encouraged to launch their work zone performance monitoring programs using existing lane closure databases, a primary goal for continuous improvement should be increasing the accuracy of work zone location and time data. As the fidelity of the work zone activity data improves, the validity and reliability of the resulting performance measures will scale with it. These improvements will likely not be completed as part of a work zone performance monitoring program but structural changes with how the agency manages work zone data. For many agencies, increasing the accuracy of work zone data can be included as an action item for programmatic reviews.

A common implementation hurdle agencies face is the discrepancy between a planned work schedule and the actual active times in the field. Depending on established administrative processes, legacy lane closure databases frequently contain a large number of “phantom” closures which are lane closures that were requested and approved by a contractor but never actually deployed in the field. If these are not identified and removed prior to analysis, they will severely skew performance baselines and erode stakeholder trust in the metrics.

To combat phantom closures and validate field reality, mature monitoring programs will likely increasingly utilize connected temporary traffic control devices. This includes devices such as connected arrow boards, smart cones, or connected smart vests automatically broadcast their location and operational status. When integrated into a central data hub, the activation of these smart devices programmatically verifies that a planned work zone is physically occupying the roadway.

Additionally, emerging mobile applications are allowing field personnel and inspectors to log precise closure coordinates and exact start/end times directly into construction management databases in real time, improving the accuracy of the work zone activity data without incorporating connected devices.

As agencies upgrade their activity data collection, many are aligning their internal databases with the WZDx specification and the CWZ standard. Adopting this harmonized data dictionary not only streamlines internal performance measures calculations but allows the agency to easily broadcast verified, active work zone feeds to third-party mapping companies, automated driving systems, and the traveling public.

Ultimately, capturing high-quality work zone activity data requires more than just new database fields or connected technology; it requires clear operational governance. Establishing reliable reporting workflows, explicitly defining who sends what data from the field, when it must be updated, and how it flows into the central tracking system, is critical to ensuring the performance metrics remain credible. Successfully implementing these data collection protocols requires strong, visible support from an agency’s management, alongside dedicated training to ensure field personnel understand how their accurate reporting directly drives work zone safety and mobility improvements.

3.2 Safety Data

Safety data evaluates the physical hazards introduced by a work zone, addressing the fundamental mandate for any transportation agency: protecting the traveling public and on-site workers. Tracking this data allows agencies to understand how temporary traffic control alters the risk profile of a corridor and measure the direct outcomes of their safety policies.

Agencies have relied heavily on traditional safety sources, such as crash databases, TMC incident logs, and worker safety reports. These foundational datasets are vital for establishing baseline crash rates, identifying long-term high-crash corridors, and satisfying official reporting requirements. They provide the definitive historical record of how a work zone ultimately performed. However, because these traditional sources rely on post-incident analysis, they are inherently retrospective. Formal crash data often requires extensive review and can take months to finalize. As a result of this data latency, a work zone may be entirely dismantled by the time the safety data is available, limiting an agency's ability to make active, mid-project adjustments.

To address this latency and shift toward proactive management, agencies should look toward surrogate safety data, as noted in the examples provided within 23 CFR 630 Subpart J. These "leading indicators", such as speed differentials, hard braking events, and swerving metrics derived from CV data, allow agencies to identify hazardous conditions in near real-time. By utilizing these surrogates, practitioners can correct geometric flaws or confusing advance warning signage before a severe crash occurs.

While agencies can certainly report basic safety impacts using isolated crash or surrogate counts, this data provides significantly more actionable value when it is directly linked to the work zone activity data (discussed in Section 3.1). By precisely overlapping safety incidents with verified active construction windows and specific lane closures, an agency can confidently determine if a spike in crashes or hard braking was genuinely caused by the work zone configuration, rather than an unrelated event on the broader network.

To build a comprehensive safety profile, agencies should evaluate the following safety data sources:

- **State Crash Databases**: The official, definitive record of roadway crashes, severity (fatal, injury, property damage), and contributing factors.
- **TMC Incident Logs & Service Patrol Dispatches**: Near real-time records maintained by TMCs or contracted roadside assistance patrols. These logs capture disabled vehicles, minor fender-benders, and debris removal events that may never generate a formal police report but still heavily compromise the safety of the work zone.
- **Contractor and Inspector Field Logs**: Internal, project-level reports detailing worker injuries, equipment strikes, and documented "near-misses" within the physical workspace. This is beneficial for evaluating internal worker exposure and site-specific safety protocols.
- **Connected Vehicle and Telematics Data**: The emerging standard for proactive safety monitoring. Modern connected vehicles continuously broadcast high-resolution data. Agencies can procure this data to map the leading indicators mentioned above, including hard braking, harsh swerving, or traction-control activations.
- **Video Analytics**: Emerging artificial intelligence platforms that utilize existing roadside camera feeds or drone footage to automatically calculate "Time-to-Collision" (TTC) or "Post-Encroachment Time" (PET) between vehicles and workers.

3.2.1 Comparison of Safety Data Sources

For most agencies, crash data will be the likely safety data source as it is a direct measure of safety. While crash databases provide a highly accessible and definitive baseline, an agency's data needs will naturally evolve as their monitoring program matures from reactive reporting to proactive risk management. Depending on an agency's existing infrastructure, budget, and specific project-level needs, a variety of other safety data sources, ranging from localized TMC incident logs to advanced connected vehicle telematics, can be utilized. To support this progression, the following section provides a comparison of the safety data sources available to practitioners today.

When asking which data source is the "best" for work zone safety performance measurement, the answer ultimately depends on the specific project characteristics and the agency's overarching safety goals. Every data source involves inherent trade-offs between cost, data latency, spatial coverage, and the level of effort required for implementation. For example, while official crash databases provide comprehensive severity and causal data, they suffer from data latency that prevents their use in active work zone management. Conversely, TMC incident logs and contractor "near-miss" reports offer near-real-time operational insights, but they are often geographically limited to major corridors or subject to highly subjective reporting thresholds.

Table 2 provides a decision matrix outlining the key advantages, disadvantages, and practical implementation notes for the most common safety data sources. This matrix is intended to help agencies decide what technologies or datasets to pursue as they build out their safety performance measures. As agencies evaluate these options to determine which source to integrate next, they should consider the following programmatic goals:

- **System-Wide Scalability**: Rather than relying exclusively on piecemeal, highly localized reporting methods (such as project-specific manual field logs), agencies should focus on evaluating data streams, like crash data and connected vehicle telematics, that can be implemented programmatically across entire corridors or networks.
- **Integration with Activity Data**: The ultimate value of any safety data source relies on its ability to be seamlessly linked to the work zone activity data (Section 3.1). Ensure the selected dataset possesses the spatial and temporal granularity necessary to accurately overlap with the reported work zone activity windows. This allows analysts to definitively determine whether a safety incident was driven by the work zone configuration or was simply an unrelated event.

Table 2. Comparison of Safety Data Sources (adapted from FHWA-HOP-11-033 Table 9).

Safety Data Source	Cost & Deployment Effort	Geographic Coverage	Advantage	Disadvantage	Implementation Strategy
State Crash Databases	Low (Existing state data)	System-Wide (All public roads)	The definitive, official record of roadway crashes, severity, and contributing factors.	Suffers from data latency (months to years). Relying on coding of work zone related may result in underreporting.	Utilize primarily for post-project evaluations, annual programmatic reporting, and long-term trend analysis.
TMC Incident Logs & Service Patrols	Low to Medium (Leverages existing TMCs)	Corridor-Specific (Major highways)	Near real-time capture of minor fender-benders, disabled vehicles, and debris not included in crash reports.	Geographically limited to actively monitored routes; reporting thresholds can be inconsistent between operators.	Integrate with activity data for active, daily work zone management and crash prevention.
Contractor & Inspector Field Logs	Medium (Administrative/Training)	Site-Specific	Directly captures internal worker exposure, equipment strikes, and critical "near-misses."	Highly subjective; prone to severe underreporting if the agency lacks a strong, non-punitive safety culture.	Standardize digital reporting forms; mandate the explicit logging of near-misses; train field staff on data value.
Connected Vehicle / Telematics Data	High (Data Procurement and Analytics)	System-Wide	Provides proactive surrogate metrics (hard braking, swerving) before crashes occur.	Requires complex data procurement and advanced analytics; sample size representativeness varies by region.	Continuous, proactive monitoring to identify detailed safety impacts and evaluate operational risk in near real-time.
Video Analytics	Very High (Hardware/Software)	Point-Specific (Camera line-of-sight)	Automatically calculates highly precise surrogate metrics like TTC and trajectory conflicts.	Requires physical camera deployment or drone usage; analytics can be degraded by poor weather or low lighting.	Deploy strategically at known high-risk transition zones to validate complex temporary traffic control designs.

3.3 Mobility Data

Work zone activity data provides the "where and when" of a work zone while mobility data answers the critical question of how much the work zone is affecting travelers. Mobility data quantifies the operational impacts introduced by construction activities on the roadway network, providing the necessary inputs to calculate actionable performance measures. It answers the fundamental questions that agency leadership and the traveling public care about most: How much delay is this causing? How far back does the queue extend? Are travel times reliable?

Before exploring where to get this data, it is helpful to understand what specific elements of traffic flow are being measured. The literature generally divides work zone mobility data into four key subcategories:

- **Speed**: Metrics capturing the vehicle speeds as they traverse the work zone
- **Travel Time and Delay**: Metrics capturing the raw increase in travel time compared to normal, pre-construction baseline conditions.
- **Traffic Queues**: Data on the maximum length, duration, and frequency of traffic backups. This is critical for both mobility analysis and proactive safety assessments (predicting rear-end collision risks).
- **Travel Time Reliability**: Measures that evaluate the day-to-day fluctuations and predictability of trip times through the corridor based on travel time data.

Collecting work zone mobility data historically relied heavily on manual, labor-intensive methods, such as field personnel physically driving through the corridor or manually inspecting travel conditions. As agencies modernized, they began deploying permanent or portable Intelligent Transportation Systems (ITS) such as radar trailers. However, because deploying and maintaining physical infrastructure at every work zone is expensive and geographically limited, comprehensive mobility monitoring was often reserved only for projects anticipated to have significant impacts on mobility.

Today, data sources are available which collect mobility data without the need to deploy any hardware. These improvements to data collection help to satisfy programmatic monitoring requirements efficiently as agencies shift toward ubiquitous probe and telematics data. By leveraging data generated directly by the vehicles moving through the work zone, agencies can monitor network-wide mobility without deploying a single piece of temporary field hardware.

To build a comprehensive mobility profile, agencies can now draw from a mix of traditional infrastructure and emerging datasets. When inventorying the available mobility data, agencies can focus on the following primary sources:

- **Commercial Probe Data:** Widely adopted as the primary data source for system-wide performance monitoring, probe data provides continuous speed and travel time metrics across defined road segments. This information is aggregated directly from commercial fleets, mobile applications, and connected vehicles.
    - *Common Sources*: INRIX, HERE, TomTom, and the National Performance Management Research Data Set (NPMRDS).

- *Implementation Note*: The NPMRDS is available to State DOTs and MPOs at no direct cost for the National Highway System, making it an ideal, readily available starting point for baseline mobility monitoring.

- **Agency Fixed or Temporary Sensors**: Utilizing permanent infrastructure (e.g., side-fire radar, induction loops, toll tag readers) or portable deployments (e.g., radar speed trailers), these sensors provide high-fidelity, high-frequency volume and speed data.
  - Implementation Note: While highly accurate, physical sensors are geographically constrained. They offer significant analytical value when a work zone is located within an actively monitored ITS corridor; however, relying exclusively on physical hardware is generally cost-prohibitive and difficult to scale system-wide for rural or secondary road projects.
- **Connected Vehicle (CV) / Telematics Feeds**: Representing the next evolution in mobility monitoring, telematics feeds provide high-resolution trajectory data from individual vehicles rather than aggregated speeds over a predefined segment. The data typically includes vehicle speed and heading every few seconds to minutes.
  - *Implementation Note*: This highly granular data allows analysts to pinpoint the exact locations of vehicle deceleration. This capability makes telematics an exceptionally accurate source for identifying the precise start, end, and maximum length of a work zone queue.
- **Bluetooth / Wi-Fi Re-identification**: Utilizing temporary or permanent roadside detectors, this method anonymously captures a mobile device's unique identifier at an upstream location and re-identifies it downstream to calculate accurate corridor travel times.
  - *Implementation Note*: While this method requires the physical deployment of hardware, it is highly effective for tracking precise trip durations through complex, multi-phase urban work zones.

3.3.1 National Performance Management Research Data Set

For agencies that currently have limited to no physical mobility sensors in the field, the prospect of monitoring work zone delays can seem challenging. However, the NPMRDS provides an immediate, ready-made solution. If an agency currently has no other mobility data available, the NPMRDS is the highly recommended starting point for establishing a work zone performance monitoring program.

Funded by the FHWA to support MAP-21 regulations, the NPMRDS provides field-observed travel time and speed data collected anonymously from a fleet of probe vehicles (both passenger cars and freight trucks). State and local transportation agencies can access this dataset for free through portals such as the Regional Integrated Transportation Information System (RITIS). The NPMRDS is a comprehensive dataset derived from these crowdsourced probes, providing representative travel times across all segments of the National Highway System (NHS).

A summary of the core technical aspects of the NPMRDS includes:

- **Temporal Resolution**: Data is aggregated into 5-minute, 15-minute, or 1-hour increments, available for all hours of the day and all days of the year.

- **Spatial Resolution**: Data is geographically referenced by Traffic Message Channel (TMC) location codes. A TMC represents a unique, directional roadway segment that is typically 0.5 to 1 mile long in urban and suburban areas, and up to 5 to 10 miles long in rural areas.
- **Metrics Provided**: Speed, travel time, reference speed, and historical speed.
- **Data Updates**: Data is available with a one-month lag (i.e., populated monthly for the previous month).

Utilizing the NPMRDS offers several distinct advantages for agencies looking to develop a monitoring program:

- **Universally Available**: Provided to all State DOTs and Metropolitan Planning Organizations (MPOs) at no direct cost, the dataset eliminates the initial financial barrier of obtaining mobility data.
- **Regulatory Alignment**: Because this is the same dataset federally mandated for the FHWA PM3 Level of Travel Time Reliability (LOTTR) performance measures, agency staff are likely already highly familiar with its structure, segmentation, and data processing workflows.
- **System-Wide Scalability**: Because it relies on ubiquitous crowdsourced probe data rather than localized physical hardware, it is instantly scalable. Agencies can use the exact same dataset to evaluate a massive urban interstate reconstruction and a rural highway paving project.
- **Stepping Stone to Advanced Analysis**: The standard NPMRDS data is perfectly suited for baseline programmatic monitoring. Once an agency establishes this analytical workflow, they can easily mature their capabilities by procuring higher-resolution probe data directly from commercial vendors to conduct highly detailed traffic analyses.

The NPMRDS is highly recommended as the foundational starting point for establishing a work zone monitoring program. While it presents an exceptionally low barrier to entry, the dataset does possess inherent operational limitations that should be recognized. Table 3 summarizes the primary advantages and challenges of utilizing the NPMRDS that agencies should understand before baselining their metrics. As agencies mature their programs and seek to improve the accuracy of their mobility performance measures, they can begin to identify and integrate additional data sources. The following section compares these alternative technologies, which can provide the higher-resolution data and detailed analytics necessary to support advanced practitioner needs. Additionally, because the NPMRDS is managed as an ongoing FHWA program, practitioners should anticipate that future iterations of the dataset may include enhancements that directly address these current limitations.

Table 3. Summary of NPMRDS Benefits and Challenges for Work Zone Monitoring.

Category	*Benefits & Advantages*	*Limitations & Challenges*
Availability & Coverage	**Universally available**: State DOTs and MPOs can access at no direct cost, eliminating the financial barrier of deploying field hardware. **Scalability**: System-wide coverage across the entire NHS, allowing agencies to evaluate almost any NHS work zone without prior hardware planning.	**Restricted Network**: Coverage is limited to the NHS. It cannot be used to examine mobility impacts on local or non-NHS arterial routes.
Data Timeliness	**Historical Data**: Provides a rich, continuous historical record (binned down to 5-minute increments). **Analysis:** Excellent for monthly or annual performance reporting, and before/during/after trend analysis.	**Data Latency**: Operates with a one-month lag. Data are populated for the previous month which does not allow for real-time traffic monitoring, alerting, or active incident management.
Granularity & Completeness	**Data Sources**: Captures passenger and freight truck probe data for all hours of the day and all days of the year. **Consistency**: Aligns perfectly with existing Federal PM3 rule reporting (LOTTR), meaning staff are likely already familiar with the data structure.	**Segment Length**: Rural TMC segments can be 5–10 miles long. A short 1-mile queue could be "washed out" or misrepresented over the length of a long segment. **Missing Data**: Speeds are only registered if a probe vehicle actually traverses the segment. Data may be left blank (not imputed) for rural, low-volume roads or during nighttime operations.
Tooling & Processing	**Low Entry Barrier**: The data serves as a perfect stepping stone. Once workflows are established, agencies can seamlessly upgrade to higher-resolution vendor data for greater detail.	**Analytical Tools**: The raw FHWA dataset does not include pre-built tools. Agencies must build their own internal system or tools to process it or work with a third party analytical dashboards to calculate performance measures Tools and resources are included in the Chapter 5.

3.3.2 Comparison of Mobility Data Sources

While the NPMRDS provides a highly accessible baseline, an agency's data needs will naturally evolve as their monitoring program matures and requires higher-resolution analytics. Depending on an agency's existing infrastructure, budget, and specific project-level needs, a variety of other mobility data sources, ranging from physical ITS spot speed sensors to commercial probe data, can be utilized. To support this progression, the following section provides a comparison of the primary mobility data sources available to practitioners today.

When asking which data source is the "best" for work zone mobility performance measurement, the answer ultimately depends on the specific project characteristics and the agency's goals. Every data source involves inherent trade-offs between cost, accuracy, spatial coverage, and the level of effort required for implementation. For example, while Bluetooth readers provide highly accurate point-to-point travel times, their sample sizes depend heavily on the market penetration of Bluetooth devices in the traffic stream. Conversely, manual data collection requires minimal technology investments but is highly labor-intensive and only captures a small snapshot of the work zone's true impact.

Table 4 provides a comparison outlining the key advantages, disadvantages, and practical implementation notes for the most common mobility data sources. This matrix is intended to help agencies decide what technologies or datasets to pursue first. As agencies evaluate these options to determine which source to utilize, they should consider the following programmatic goals:

- **System-Wide Scalability**: Rather than relying exclusively on piecemeal, project-by-project hardware deployments, data streams should be prioritized that can be implemented programmatically across entire corridors or statewide networks.
- **Integration with Activity Data**: The ultimate value of any mobility data source relies on its ability to be seamlessly linked to the foundational work zone activity index (Section 3.1). Ensure the selected technology possesses the spatial and temporal granularity necessary to accurately overlap with the reported work zone activity windows.

Table 4. Comparison of Mobility Data Sources (adapted from FHWA-HOP-11-033 Table 9).

Mobility Data Source	Cost & Deployment Effort	Geographic Coverage	Advantage	Disadvantage	Implementation Strategy
NPMRDS	Low (Free, No Hardware)	System-Wide (NHS Only)	Broad coverage for urban and rural analysis with built in baseline data including historical and reference data.	Segment lengths in rural areas likely extend beyond work zone extents limiting accuracy of performance measure. Monthly data updates may limit monitoring capabilities.	Low barrier of entry for developing performance measures.
Commercial Probe Data	Medium to High (Procurement)	System-Wide	Offers significantly higher spatial resolution with near-real-time options available. Provides baseline historical and reference data.	Recurring data licensing costs. Additional resources needed for analysis. Rural areas may be impacted by lower penetration rates.	Increased granularity of data temporally and spatially compared to NPMRDS for refined performance measures.
Connected Vehicle/ Telematics	High (Procurement and Analytics)	System-Wide	Captures individual vehicles to precisely calculate performance measures in work zones. Raw vehicle data expands performance measure capability.	High cost for data and requires advanced analytics to extract performance measures. Penetration rates will likely vary by region.	Highly granular data which provides flexibility to calculate a variety of safety and mobility performance measures based on individual vehicles but requires increased analysis efforts
Fixed ITS Sensors	Medium (Sunk cost, but high maintenance)	Point-Specific (Fixed Corridors)	Provides ground-truth, high-frequency volume and speed data directly at the sensor location.	Coverage is limited and highly subject to maintenance gaps and hardware outages.	Utilize for major corridors with strong existing coverage; explicitly report data completeness and outages.
Portable ITS Sensors	Medium to High (Labor/Hardware)	Site-Specific (Temporary)	Targeted directly to the active workspace with same advantages as fixed sensors.	Deployment requires significant physical effort. Usage is often inconsistent across different projects.	Reserved for significant projects; standardize device configuration and reporting requirements. Often does not include baseline data unless deployed before work zone.
Bluetooth / Wi-Fi	Medium (Hardware)	Corridor-Specific	Highly accurate for calculating precise corridor travel times through complex work zones.	Requires physical infrastructure; subject to ID sampling bias (only captures active devices).	Useful for specific high-profile corridors.
Manual Observation (Field Logs)	Very High (Labor)	Site-Specific	Works with zero technology barriers; easily captures queue duration and physical length.	Highly labor-intensive; limited temporal coverage (only captures data while the observer is present).	Use primarily as a validation tool or fallback method.

3.4 Exposure Data

Previous literature often grouped work zone activity data discussed in section 3.1 under the broader umbrella of 'exposure.' This report separates the two. As part of this guide, exposure data refers specifically to the traffic volumes and vehicle-miles traveled through the work zones while the activity data in section 3.1 focused on the location and duration of work zone impacts.

Traffic volume is generally not treated as a performance measure on its own. Instead, it serves as the critical denominator required to normalize safety and mobility performance measures, allowing for comparisons across different projects, corridors, and time periods. For example, knowing that a work zone experienced five crashes in a month provides an incomplete picture without knowing whether 5,000 or 50,000 vehicles passed through it. Similarly, looking at year-over-year trends, a decrease in annual crashes is less meaningful if there was also a corresponding drop in exposure, just as maintaining a steady number of crashes alongside increased exposure can actually indicate a safety improvement. By integrating exposure data, agencies can translate raw counts into actionable, normalized rates such as crashes per VMT for safety or total vehicle-hours of congestion for mobility. Incorporating exposure is beneficial as part of programmatic reviews to ensure long-term evaluations reflect the true system performance rather than fluctuations in traffic demand.

It is important to note that gathering independent exposure data is primarily required when an agency relies on safety databases or non-sensor-based mobility data (such as the NPMRDS). Traditional, physical ITS sensors (like side-fire radar or induction loops) inherently collect volume and speed data simultaneously. However, because the industry is shifting toward probe data, which provides speeds but not raw vehicle counts, agencies must consciously pair their safety data and probe speeds with an independent volume source to quantify the true scale of the impact.

To normalize performance measures, agencies typically draw from the following exposure data sources:

- **Historical AADT and HPMS Data**: Annual Average Daily Traffic (AADT) and Highway Performance Monitoring System (HPMS) data represent the most universally accessible volume sources for State DOTs.
    - *Implementation Note*: While readily available for almost all state routes, AADT provides a generalized daily average. To calculate precise impacts (like peak-hour vehicle delay), agencies must apply standardized hourly distribution factors to the AADT to estimate the time-of-day volumes during the active work zone window.
- **Permanent Automatic Traffic Recorder (ATR)**: Fixed continuous count stations and Weigh-in-Motion (WIM) sites maintained by the agency's traffic data division.
    - *Implementation Note*: These stations provide highly accurate, hour-by-hour volume and vehicle classification (passenger vs. freight) data. Geographic coverage is often limited but provide highly accurate vehicle counts.

- **Agency Fixed or Temporary Sensors**: Utilizing permanent infrastructure (e.g., side-fire radar, induction loops, toll tag readers) or portable deployments (e.g., radar speed trailers), these sensors provide high-fidelity, high-frequency volume and speed data.
    - *Implementation Note*: While highly accurate, physical sensors are geographically constrained. They offer significant analytical value when a work zone is located within an actively monitored ITS corridor; however, relying exclusively on physical hardware is generally cost-prohibitive and difficult to scale system-wide for rural or secondary road projects.
- **Connected Vehicle / Telematics Feeds**: Representing the next evolution in mobility monitoring, telematics feeds provide high-resolution trajectory data from individual vehicles which can be used to estimate traffic volumes.
    - *Implementation Note*: The CV data represent only a percentage of the vehicles traveling through a work zone but could be used to estimate traffic volumes. The process to estimate traffic volumes should be verified with ground-truth sensors before adopting.
- **Estimated Commercial Volume Profiles**: An emerging capability from commercial probe data and telematics vendors. Rather than just providing speeds, some vendors now offer estimated traffic volumes and trip analytics derived from their fleet penetration rates.
    - *Implementation Note*: While this eliminates the need for physical sensors, agencies must carefully validate the vendor's volume estimation methodologies against physical ground-truth sensors before adopting them for official programmatic reporting.

3.5 Data Source Recommendations

Every transportation agency is unique, operating with distinct resources, technological capabilities, and strategic objectives. Because of these variations, there is no single "one-size-fits-all" approach to building a work zone performance monitoring program. However, by leveraging ubiquitous, easily accessible data sources as a starting point, agencies can establish a foundational program today and gradually upgrade their data as their program grows, staff become more proficient, and the need for higher-resolution performance measures increases.

To assist agencies in building a foundation for performance monitoring, this section provides recommendations for identifying the work zone, safety, and mobility data already available within their internal systems.

3.5.1 Work Zone Activity Data Recommendation

Collaborate internally for authoritative work zone activity data. Practitioners should work closely with internal groups (such as construction, TMC, Information Technology, or permitting offices) to identify where existing work zone activity data is housed. Pulling this information directly from internal systems ensures the data comes from an authoritative source. Establishing this reliable baseline is critical, as it allows agencies to confidently link safety and mobility impacts to physical work zones, and enables leadership to easily select a representative sample of projects for required programmatic reviews if a comprehensive statewide analysis is not initially feasible. Ideally, work zone activity data can be provided in the WZDx/CWZ format, which allows for easier integration with tools designed to calculate work zone performance measures.

3.5.2 Safety Data Recommendation

Official crash databases are the recommended starting point because they are the most direct indicator of work zone traffic safety, are free to use, and readily available statewide. Most agencies already possess established workflows for analyzing this data. However, crash data is a lagging metric; reports can take weeks, months, or even years to be finalized, processed, and published. Additionally, the accuracy of coding a crash as "work zone-related" is highly subjective and depends entirely on the investigating officer's interpretation at the scene. Police reports frequently lack specific details regarding work zone features and activities, which consistently results in a systemic underreporting of true work zone crashes.

A significant leap forward in safety performance measurement is the adoption of CV and telematics data. Instead of relying on manual police reports, CV data provides near real-time, direct measurements from the vehicles themselves. Agencies can use this to calculate proactive surrogate safety measures (such as hard braking, maximum deceleration rates, or sudden swerving) on a daily or weekly basis. On the downside, procurement is expensive, and extracting usable performance measures from massive amounts of raw trajectory data requires intensive technical resources. Furthermore, this data is highly dependent on regional market penetration rates, meaning sample sizes may be low in rural work zones. Finally, because these are surrogate measures, practitioners must rely on evolving industry research to fully verify their direct correlation to actual crash likelihood and overall work zone safety.

3.5.3 Mobility Data Recommendation

It is highly recommended to begin mobility monitoring with the NPMRDS. It presents an exceptionally low barrier to entry, is free to agencies, and offers ubiquitous coverage across the NHS. The primary drawbacks to the NPMRDS are data latency (monthly updates) and spatial resolution. The long length of TMC segments, which can be up to 5 to 10 miles long in rural areas, can occasionally "wash out" short queues and negatively impact the accuracy of localized work zone performance measures, as the work zone may represent only a small portion of the segment. To note, NPMRDS is managed as an ongoing FHWA program and practitioners should anticipate that future iterations of the dataset may include enhancements that directly address the current limitations.

If an agency has the budget or already procures commercial probe data for other purposes, transitioning to this source represents a significant programmatic improvement. Commercial feeds provide the same coverage as the NPMRDS but often utilize much shorter segment definitions and offer lower aggregation data in near real-time. This drastically improves the accuracy of mobility measures and supports active, daily monitoring. However, this upgrade requires recurring procurement costs and more advanced internal analytical resources or third-party tools to process the highly granular datasets. Probe data does have limitation in rural areas that have lower penetration rates which may impact the accuracy and reliability of performance measures.

4 Work Zone Performance Measures

Once safety and mobility data sources are established, the next critical step is transforming that raw data into actionable performance measures. When developing these metrics, it is helpful to categorize them by their operational scope: project-level versus program-level.

Typically, transportation agencies find it relatively easy to conceptualize project-level performance measures. Because engineers and field staff manage site-specific challenges daily, measuring the direct impacts of a single work zone, such as monitoring queue lengths or crash increases at a specific lane closure, feels intuitive and immediately useful for active traffic management.

The greater challenge lies in elevating these localized metrics to create robust program-level (systemwide) performance measures that evaluate the health of the entire roadway network. To achieve this, careful consideration must be given to how data can be aggregated. In most successful frameworks, project-level metrics serve as the building blocks for program-level insights. For example, "delay per mile" can be calculated for an individual project, and then aggregated across the state to establish an agency-wide "average work zone delay per mile." Alternatively, an agency can use those project calculations to set a programmatic threshold, reporting a metric such as: “85% of all work zones successfully maintained less than 3 minutes of delay per mile.”

Conversely, not all program-level performance measures strictly require project-level aggregation. Some agencies opt to report broad, system-level metrics, such as "total work zone-related crashes statewide." Calculating this total does not require associating each individual crash with a specific project footprint. However, this top-down approach comes with significant analytical limitations.

Broad system totals often fail to account for exposure factors, such as the total number of active work zones or total project miles in a given year. If total crashes increase, an agency utilizing only top-down metrics cannot definitively say whether work zone safety has worsened, or if there was simply twice as much construction activity. Most importantly, disconnected program measures rarely yield actionable insights. By bypassing the project-level link, an agency severely limits its ability to drill down into the data to identify which specific work zones, contractor practices, geometric designs, etc. are actually driving the safety or mobility outcomes.

To maximize the value of a performance monitoring program, agencies should strive for a cohesive framework where tactical project metrics seamlessly feed into strategic program evaluations. Table 5 summarizes the typical questions, outputs, and applicable measures at both operational levels.

Table 5. Project vs Program Level Performance Measures

Level	Typical Questions	Typical Outputs	Measures that Fit
Project-Level	Is traffic control working? Are queues forming? Should lane closure timing change?	Daily/weekly dashboards for individual project, alerts, closure adjustments	Number of crashes, average delay, number of queueing events, congestion hours
Program/ Systemwide	Are work zones improving over time? Which work zone are high-impact? Where should policy/training change?	Annual monitoring summary, trend plots, representative sample review outputs	Percent of projects exceeding thresholds, vehicle-hours of delay, reliability indicators, crash counts/rates

4.1 Performance Measure Overview

While the concepts of project and program-level measures provide a framework for how data is aggregated, the actual selection of performance measures requires a tailored approach. Every transportation agency is unique, and what constitutes a "successful" work zone will vary based on regional goals, available resources, and facility types. The idea of implementing a work zone performance measurement program can seem daunting if an agency thinks it must measure all work zones all the time; however, agencies can gain highly useful information by strategically focusing on a few targeted measures.

Because work zone impacts affect a wide array of users, the selection of these measures should ideally be determined by a diverse, multi-disciplinary set of stakeholders. This group, which may include traffic operations personnel, design engineers, safety inspectors, public information officers, and contractor representatives, should collaborate to identify measures that directly relate to the agency's overarching safety and mobility goals, are compatible with existing system-wide metrics, and clearly communicate performance to both technical staff and the traveling public.

When selecting performance measures, practitioners should carefully balance precision with practicality. Some of the factor's agencies should consider include:

- **Understandability and Alignment:** Performance measures should be clear and easily understood by a broad audience, including executive leadership and the traveling public while directly aligning with the agency's strategic goals. A metric that is too complex will require continuous explanation and lose its impact; conversely, a metric that is overly generalized may fail to capture the specific operational or safety focus areas the agency needs to improve. Measures that are applicable at a project level and can also translate well to program level performance can assist in understanding the performance measure.
- **Ease of Calculation and Data Needs:** Agencies must evaluate the technical burden of generating the performance measures. While combining multiple data sources can yield

highly precise insights, it also increases calculation complexity, introduces new opportunities for data errors, may limit the applicability to all work zones and makes the methodology harder to explain.

- **Baseline Data Requirements:** Measuring work zone performance inherently involves comparing active construction conditions against normal operations. Complexity often scales with the need to collect pre-construction baseline data and the subjective difficulty of defining what constitutes an appropriate baseline for a rapidly changing corridor.
- **Actionability:** A measure is only valuable if the agency can act on it. Selected metrics should directly inform decisions, whether that means adjusting lane closure windows in the field or updating statewide temporary traffic control policies.

To assist agencies in navigating this selection process, the following sections provide a library of safety (Section 4.2) and mobility (Section 4.3) performance measures. Each section features summary tables designed to help practitioners evaluate which metrics best fit their program. These tables provide a short description of each measure, the pros and cons associated with it (which relate back to why an agency would choose to select or avoid that specific metric), the difficulty involved in calculating the measure, and practical examples of how the performance measure can be reported at the program level. The tables of performance measures are not comprehensive and multiple measures can be adjusted based on a variety of factors. The tables provide some of the common measures found in literature or reported by agencies currently.

While navigating this selection process, it is important to distinguish between minimum Federal compliance and holistic performance management. The FHWA rulemaking establishes a baseline requirement: agencies must select and report on at least one safety and one mobility program-level performance measure. While an agency should officially designate a primary measure in each category to satisfy this requirement, relying exclusively on two singular metrics rarely captures the full operational reality of a state's transportation network. To truly understand and mitigate work zone impacts, it is highly recommended that an agency develops a broader suite of supplementary measures for internal use. By tracking multiple metrics, such as pairing an overarching "average delay" requirement with a more granular tracking of "maximum queue lengths", an agency can build a comprehensive, multi-dimensional view of its work zone performance, ensuring that critical safety and mobility issues are not masked by highly aggregated data.

4.2 Safety Performance Measures

Work zone safety data addresses the most critical mandate of any transportation agency: protecting the lives of the traveling public and on-site workers. Whenever temporary traffic control alters a roadway's normal alignment it inherently increases the physical risk for all users. Safety performance measures evaluate these work zone impacts, allowing agencies to understand how their work zones influences crash frequency and overall safety risk.

Agencies should carefully select safety metrics that balance formal historical reporting with proactive risk management. To achieve this, safety performance measures can be organized into two primary groups:

- **Safety Measures:** Traditional metrics that rely on historical, post-incident data, such as formal crash counts, crash severity, and worker injuries. These metrics are primarily outcome based results and typically have lagging reporting methods (i.e. weeks or months to report)
- **Safety Surrogate Measures:** Proactive, preventative metrics that utilize telematics, smart work zone sensors, or field audits to identify hazardous conditions before a crash may occur. These metrics are surrogate safety measures as they do not measure crashes or injuries but have direct relationships to the overall safety of a work zone.

Crash-based performance measures are likely the most common metrics agencies will rely on when establishing a safety monitoring program. They are the most straightforward and universally understood measures of a work zone's direct impact on public safety. Because official crash records are routinely collected by law enforcement and maintained in established statewide databases, the data is relatively easy to obtain. Furthermore, crash metrics are highly scalable, allowing agencies to easily report on safety performance at both the granular project level and the broader program level. For these reasons, crash based measures are an obvious and necessary foundational choice, and this section will document how agencies can effectively utilize crash-based safety data for performance analysis.

However, while historical crash data remains the definitive baseline for evaluating work zone safety, relying exclusively on it presents significant programmatic challenges. Severe crashes are relatively rare and random events. Waiting for a statistically significant number of crashes to accumulate before identifying a safety hazard means an agency is fundamentally reacting after the damage is done. Furthermore, official crash databases often suffer from data latency, sometimes taking months or even years to be finalized and processed.

To transition to a proactive safety management approach, modern monitoring programs are increasingly adopting leading, surrogate safety performance measures. Surrogate safety measures are often derived from other data sources such as connected vehicle data or camera analytics which provide performance measures that have been shown through research to have a direct relationship with safety. Surrogate measures, such as hard-braking rates, swerving events, and speed differentials, offer several distinct operational benefits:

- **Proactive Risk Mitigation:** Surrogates measure can capture metrics such as near-misses and evasive maneuvers. This allows practitioners to identify and correct hazardous temporary traffic control conditions (such as a confusing lane shift, inadequate taper length, or poorly placed advance warning signs) before an actual crash occurs.
- **Near Real-Time Actionability:** Because surrogate data is often derived from CV telematics, smart work zone cameras, or radar sensors, the metrics are available daily or weekly. This completely bypasses the lagging crash metrics, enabling mid-project corrections.
- **Robust Sample Sizes:** Because harsh braking, sudden deceleration, or speeding events occur exponentially more often than actual crashes, surrogate measures provide a much larger, more statistically stable dataset. This allows analysts to confidently evaluate the true safety risk of a corridor much earlier in the project lifecycle.

To assist agencies in selecting the right mix of metrics for their monitoring programs, the remaining section provides a list of safety and safety surrogate performance measures. Table 6 and Table 7 summarizes traditional crash and injury based metrics (such as crash counts and severity rates), outlining their benefits, limitations, and examples of program-level reporting. For agencies ready to adopt proactive risk management, Table 8 and Table 9 details safety surrogate measures, highlighting how these leading indicators can be leveraged to prevent crashes before they occur.

Table 6. Safety Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Crash Frequency	Raw counts of total, fatal, injury, or property-damage-only (PDO) crashes by year or project. May include a subset of work zone coded crashes	Low	Direct measurement of safety outcomes; utilizes existing statewide crash report databases.	Lagging metric (often by months); strongly influenced by traffic volume differences; heavily reliant on subjective officer coding.	Total number of work zone crashes statewide per year or the average number of crashes per work zone
Crash Rate	Crash counts normalized by exposure data, often compared to a pre-construction baseline	High	Improves comparability across sites; allows for accurate comparison between high-volume and low-volume work zones.	Requires integration of traffic data as well as identifying a baseline time period for comparison	The percentage of projects statewide that exceed a pre-established "acceptable" baseline crash rate.
Crash Characteristics (Type Shares)	Percentage of crashes by specific types (e.g., rear-end, sideswipe) or contributing factors.	Low	Supports direct countermeasure targeting (e.g., adding advance warning for rear-ends).	Interpretation can shift wildly with volume and work zone mix; sample sizes per project may be too small to be statistically significant.	The percentage of total work zone crashes that involve rear-end crash
Crash Costs	Combines crash frequency and severity to assign a financial impact relative to normal conditions.	Medium	Provides a highly quantifiable financial metric to justify safety investments and mitigation strategies.	Requires assigning monetary values to injuries/fatalities; needs cost assumptions, baseline data, and exposure context.	Total annual cost of work zone crashes
Secondary Crashes	Crashes that occur as a direct result of a previous incident or the resulting queue within the work zone.	Medium	Highlights the effectiveness of incident management and end-of-queue advance warning systems.	Difficult to accurately identify and code; relies heavily on the precise spatial and temporal correlation of crash data.	Percentage of total work zone crashes classified as secondary crashes statewide.
Worker Injury & Fatality Metrics	Raw counts or rates of injuries/fatalities for agency or contractor personnel.	Medium	Directly measures the physical risk and safety outcomes for the most vulnerable population within the work zone.	Contractor data can be sensitive; rates require tracking of hours worked; rare events make statistical trends difficult to track.	Statewide worker injury rate per 200,000 construction hours annually.

Table 7. Safety Performance Measures Continued

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Emergency Medical Services & Service Patrol Dispatches	Tracking the frequency of emergency or service vehicles sent to the work zone.	High	Provides a faster signal than crash data; catches minor incidents (disabled vehicles, debris) that evade police reports.	Data may include non-crash events; requires strong interagency data sharing agreements and consistent reporting thresholds.	Number of EMS/Service Patrol Dispatches
Incident Clearance Time	The average time required to clear a primary crash or disabled vehicle from the active work zone.	Medium	Rapid clearance directly correlates to a massive reduction in the risk of secondary, often more severe, crashes.	Overlaps with mobility metrics; often included in crash data or from TMC based incident reports	Average incident clearance time for all work zones crashes or incidents

Table 8. Safety Surrogate Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Speed Metrics (Compliance & Differentials)	Measuring 85th percentile speeds, speed limit compliance, and speed differences between vehicles.	Medium	Leading indicator linked directly to conflict risk	Overlap with mobility metrics, requires individual vehicle such as from CV or sensors to accurately calculate	Percentage of work zones where 85th percentile speeds exceed the posted limit by 10+ mph.
Hard Braking	Frequency of vehicles suddenly braking or exhibiting maximum deceleration. Can also be calculated as a rate measured per 1,000 vehicles.	Medium	Highly correlated to rear-end crash risk; provides a near real-time safety alert before a crash happens.	Extracting this from CV data requires advanced analytics; highly dependent on market penetration rates.	Aggregate rate of hard-braking events per 1,000 vehicles across all monitored work zones or average hard brakes per work zone.
Conflict Metrics (TTC & PET)	Minimum TTC or PET between vehicles/workers.	High	Excellent proactive risk detection; highly effective for predicting safety during the planning phase via simulation models.	Requires advanced video analytics or trajectory data in the field; high effort to extract	Average TTC or PET across all work zones or percentage of work zones with a TTC less than a threshold
Erratic Maneuvers & Intrusions	Tracking sudden lane changes, path conflicts, or vehicles physically entering the closed workspace.	High	Directly observes risky behavior caused by poor temporary traffic control or driver confusion.	Typically requires labor-intensive manual video observation or deployment of advanced AI cameras, making it hard to scale.	Percentage of work zones reporting zero work zone intrusions

Table 9. Safety Surrogate Performance Measures Continued

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Worker Near-Misses & Device Strikes	Internally logged incidents of vehicles narrowly missing workers or striking temporary devices (e.g., channelizers, TMAs).	High	Direct, proactive worker hazard monitoring; catches driver confusion and taper design flaws early.	Requires a strong, non-punitive reporting culture and clear definitions; typically underreported by contractors	Total number of near-misses or device strikes
Safety-Related Public Complaints	Number of public complaints specifically citing confusing signage, dangerous merges, or near-misses.	Low	Crowdsources safety data; catches driver confusion early before it translates into a severe crash.	Highly subjective; often skewed by general public frustration with delays rather than true, actionable safety hazards.	Total number of safety complaints across all work zones or average number of safety complaints per work zone
Inspection & Audit Scores	Systematic rating scores of work zone features (setup quality) and the volume of total inspections performed.	High	Proactive, leading indicator; tracks program activity compliance; easy for agency staff to collect during routine field reviews.	Scoring can be highly subjective; more inspections alone do not guarantee a safety improvement	Percentage of projects statewide achieving a "good" or "excellent" inspection score.

4.3 Mobility Performance Measures

Work zone mobility performance measures answer a fundamental question: how significantly is construction activity impacting the traveling public? Mobility performance measures are designed to quantify this operational impact of a work zone, capturing everything from minor, localized speed reductions to severe, network-wide delays. Tracking these impacts is essential for maintaining public trust and economic efficiency. By actively measuring mobility, agencies can verify that their temporary traffic control strategies are functioning as intended and ensure that traveler delays remain within acceptable, policy-driven thresholds.

To systematically evaluate these diverse impacts, the industry generally categorizes work zone mobility into six operational areas as illustrated in Figure 3. The remainder of this section will summarize the mobility performance measures by these areas include a table highlighting possible performance measures for each.

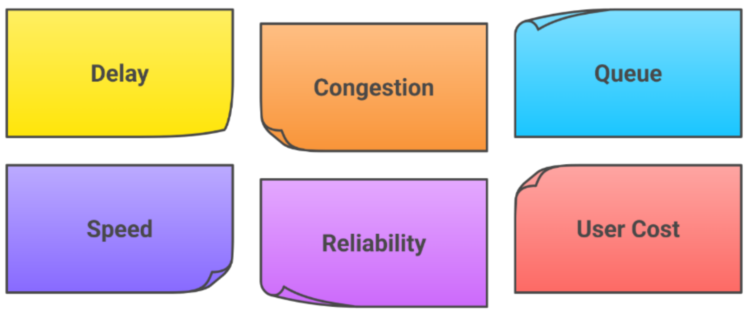
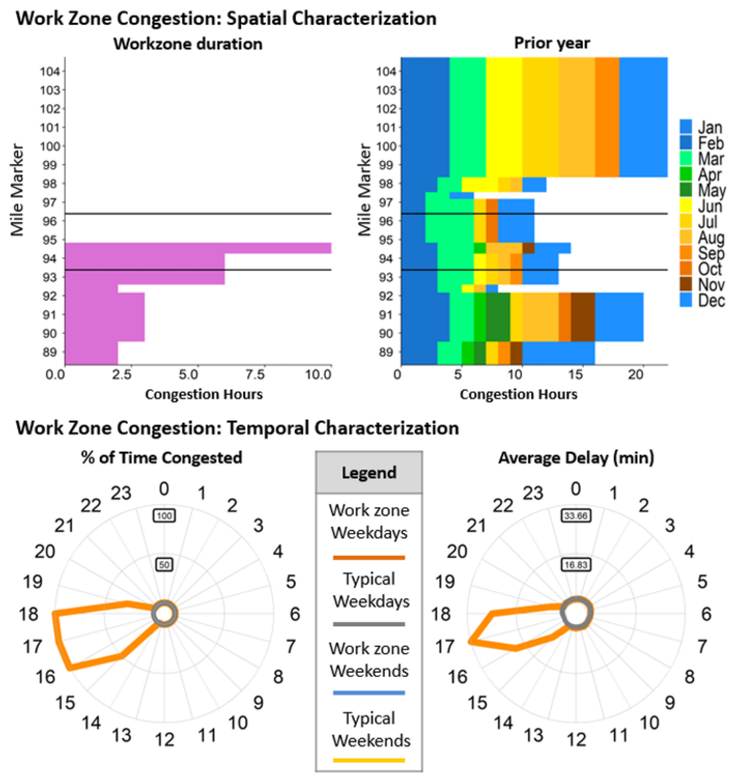


Figure 3. Categories of Mobility Performance Measures.

While the primary focus of this guide is to equip agencies with the framework needed to meet the program-level reporting requirements of 23 CFR Part 630 Subpart J, it is important to emphasize that these metrics are not strictly for high-level summaries. Many of the performance measures discussed in the following sections can be broken down to provide granular, project-level insights.

Instead of evaluating a metric as a single average across an entire construction season or time period, practitioners can slice the data based on specific spatial attributes along the work zone corridor, time of day, day of the week, or active construction phasing. This level of detail transforms a broad programmatic metric into a highly actionable diagnostic tool for day-to-day operations.

For example, Figure 4 demonstrates how breaking down data spatially and temporally can isolate the exact source of operational impacts. By visualizing performance on a segment-by-segment and hour-by-hour basis, an agency can immediately identify whether congestion is originating at the advance warning taper, a specific off-ramp, or a downstream work area. This allows traffic managers to execute precise, mid-project corrections rather than waiting for post-construction evaluations.



Delay & LOTTR Metrics

Stats	AM	Mid	PM	Weekend	Total
Avg Delay(min)	0.1	0.3	20.5		0.1
Max Delay(min)	0.8	25.6	41.1		41.1
Total Delay(min)	28.8	324.5	2908.5		3317.8
LOTTR	1.0	1.1	1.3		1.3

Queueing Metrics

Stats	Queue
Max Duration(min)	245.0
Total Duration(min)	715.0
Max Length(miles)	6.5
# of Queues	8.0

Figure 4. Example of Project Level Mobility Performance (12)

4.3.1 Delay Performance Measures

Delay is one of the most highly relatable and easily understood performance measures for both the traveling public and agency stakeholders. These measures quantify the raw increase in travel time compared to normal, pre-construction baseline conditions. Because delay represents the additional travel time needed to traverse a work zone or detour, calculating these measures often requires a baseline. In locations that already experience recurring congestion, establishing this baseline prior to the start of construction is essential to isolate the specific impacts caused by the work zone itself. When agencies establish performance thresholds or targets for acceptable delay, they should clarify whether they are evaluating total cumulative delay or only the incremental delay experienced over usual, pre-existing congestion.

Fortunately, this baseline is easily quantifiable when utilizing data sources such as commercial probe data or the NPMRDS, which natively provide reference speeds (indicating ideal, free-flow conditions) as well as continuous historical speeds (indicating the normal, recurring speeds for a given section of roadway). Alternatively, agencies can use the pre-construction regulatory speed limit to establish a baseline. Because delay translates a work zone's impact into a universal metric of time, it allows for seamless comparisons of mobility impacts between vastly different work zones. Table 10 summarizes specific delay performance measures, detailing their benefits, limitations, and calculation difficulties.

4.3.2 Congestion Performance Measures

While closely related to delay, congestion measures specifically evaluate the presence, extent, and severity of capacity failures within the active work zone. Unlike delay, these measures do not necessarily require pre-construction baseline data, but baseline data can be highly beneficial for defining exactly what "congestion" means for a specific facility. Because congestion depends heavily on a variety of factors, such as the posted speed limit, facility type, and normal traffic demand, agencies must make a decision to define when congestion is officially occurring.

Some agencies accomplish this by defining a fixed speed threshold (e.g., congestion is any speed below 45 mph). However, fixed thresholds are not always applicable to all work zones. Using a dynamic threshold, such as 60% of the posted speed limit or historical reference speed, provides a flexible and scalable definition. Once defined, agencies can simply aggregate the total minutes a work zone experienced speeds below the threshold to calculate total congestion duration. While "congestion" is a concept well understood by most stakeholders, it can invite questions over how it is defined. Utilizing a dynamic threshold allows agencies to standardize that definition and accurately compare congestion severity across different work zones. Table 11 outlines specific congestion performance measures to help practitioners weigh their specific pros, cons, and data requirements.

4.3.3 Queue Performance Measures

Traffic queues are the physical storage of vehicles that occurs when traffic demand exceeds the work zone's capacity. These measures track the maximum length, duration, and frequency of traffic backups. Similar to congestion, calculating queue metrics does not strictly require historical baseline data. Instead, agencies can use the same logic applied to congestion, defining the presence of a queue whenever speeds drop below a predefined threshold.

When utilizing crowdsourced probe data, practitioners can analyze every time-aggregation period (e.g., 5-minute bins) to identify exactly which segments are experiencing queueing conditions. By summing the physical length of the congested segments during each time period, agencies can calculate the maximum queue length or average the length over a defined time period. From a stakeholder perspective, the understandability of queuing is similar to congestion; it is a highly visible, physical impact that the public immediately recognizes. Furthermore, queueing metrics are critical because they highlight significant safety concerns, such as the increased risk of rear-end collisions due to high speed differentials. Specific queue performance measures, along with their respective impacts, are summarized in Table 12.

4.3.4 Speed Performance Measures

Speed measures are fairly straightforward and focus on the operating speeds of vehicles traversing the work zone. These metrics calculate the percentage of time speeds fall below acceptable thresholds, or evaluate the speed differential as vehicles transition from the advance warning area into the active workspace.

These measures do not typically require historical baseline data to compute, yet they provide immediate, actionable context regarding the actual operational impacts occurring in the field. While speed metrics are extremely easy for the public and law enforcement to understand, they are not always ideal for comparing performance across different work zones, as an average speed alone does not quantify the total time lost without factoring in the physical length of the project. Table 13 details common speed performance measures and provides examples of how they can be reported at the program level.

4.3.5 Reliability Performance Measures

Travel time reliability measures evaluate the predictability of travel times, capturing the variation in mobility from day to day or over the entire duration of the work zone project. Roadways with highly variable travel times force motorists to "buffer" extra time into their trips to ensure they arrive at their destinations on time.

There are multiple reliability metrics that utilize the distribution of travel times through the work zone. While these are excellent measures for comparing performance across different work zones since they are typically formulated as ratios normalized by travel times, they can often be difficult for non-expert audiences and the general public to understand unless worded strategically. A summary of specific travel time reliability measures and their calculation difficulties is provided in Table 14.

4.3.6 User Cost Performance Measures

User cost measures translate the operational impacts of a work zone into a financial metric. These measures typically utilize delay and congestion data, but incorporate exposure data (traffic volumes) to calculate the total vehicle-hours of delay. This total is then quantified by multiplying the delay hours by standard, assumed monetary hourly rates for passenger cars and commercial freight.

These are powerful measures that provide a definitive, economic cost stakeholders can easily understand. They are highly effective for justifying the cost of mitigation strategies or contractor incentives. However, practitioners must be aware that user cost metrics will naturally skew heavily toward work zones with higher AADT (traffic volumes) or massive, long-duration projects compared to rural or low-volume work zones, simply due to the sheer number of vehicles exposed to the delay. Table 15 outlines specific user cost performance measures, evaluating their relatability against calculation complexity.

Table 10. Delay Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Average Delay	The specific delay experienced per entering vehicle, queued vehicle, or peak-period vehicle.	Low	Motorists are highly sensitive to individual delays, making this very intuitive for the public	Averaging can sometimes hide extreme delays experienced by a small subset of drivers	Average delay across all work zones or percentage of projects which exceed a delay threshold (i.e. 4 minutes)
Maximum Delay	The longest individual delay experienced during a project or specific work shift. Can also use metrics like 95^{th} percentile to remove outliers.	Low	Highly effective for understanding the "worst-case scenario" and responding to public complaints	Can be easily skewed by external, non-work-zone events like severe weather or a major crash	Average or maximum of the maximum delay across all work zones or percentage of projects which exceed a maximum delay threshold (i.e. 10 minutes)
Delay/Mile (Unit Travel Time)	The time or delay it takes to travel one mile through the work zone (e.g., min/mile). Commonly calculated by average delay divided by length of work zone	Low	Best suited to standardize work zones by the lengths. Can also be used to calculate delay/mile/hour as alternative calculation method	Rates can be difficult for communicating impacts and can result in low delay/mile values	Average delay per mile across work zones or the percentage of projects with an average delay per mile over a threshold (i.e. 1.5 minutes/mile)
Percentage of Vehicles Delayed	The percentage of total drivers who experience delay greater than an agency-defined acceptable limit.	High	Excellent for tracking exactly what portion of drivers are being unacceptably impacted and factoring in the traffic volumes	Requires exposure data which will likely need to be integrated from a different data source or estimated using AADT	Percentage of work zone travelers statewide experiencing delay over a threshold
Total Vehicle-Hours of Delay	The cumulative delay experienced by all vehicles over a work period, peak period, or work zone.	High	Essential for calculating total road user costs and quantifying the overall economic impact.	Requires exposure data which will likely need to be integrated from a different data source or estimated using AADT	Total annual vehicle-hours of delay accumulated across all statewide construction projects or the average vehicle hours of delay per work zone

Table 11. Congestion Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Percentage of Time Congested	The proportion of time the work zone operates under congested conditions or conversely, the time it operates at free-flow speeds.	Low	Allows agencies to quickly identify work zones with high amounts of congestion relative to how long the work zone is active.	Not as useful for measuring impacts on projects that already experienced heavy recurring congestion prior to construction.	Average percentage of time work zones are congested or the percentage of work zones that exceed an amount of time with congestion. (i.e. 20% of time congested)
Congested Hours	Measures the total duration of congestion by summing the minutes or hours when any portion of work zone is defined as congested	Low	Captures the temporal footprint of the congestion, answering how long the facility was impacted rather than just how slow it got.	Does not factor in the magnitude of the congestion	Average congestion duration across work zones or the percentage of projects with congestion lasting more than a defined threshold (i.e. 20 congested hours)
Congested Mile-Hours	The number of hours any portion of the work zone is congested multiplied by the length of the segments congested	Medium	Provides a spatial component to congestion quantifying the length of work zone impacted by congestion	Requires granular probe vehicle data for accurate results, not easily comparable between various work zone types, and can be difficult measure for general users	Cumulative congested mile-hours across all work zones or percentage of projects exceeding a congested mile-hour threshold (i.e. 100 congested mile-hours)

Table 12. Queue Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Average Queue Length	The average length of traffic backups over a specific interval.	Low	Better characterizes the "typical" conditions of a work zone than the maximum length.	Does not factor in severity or duration of queue and can be impacted by segment length of probe data	Average queue length across work zones or percentage of projects over threshold (i.e. 0.5 miles)
Maximum Queue Length	The maximum distance of a queue over the duration of a specific time period. Can also use 95th percentile to remove outliers	Low	Directly relates to severe safety risks (rear-end crashes); easy to grasp for stakeholders.	Focuses on the severe impacts which may not encompass the entire impacts of the work zone	Percentage of work zones experiencing a maximum queue length greater defined threshold (i.e. 1 mile)
Number of Queuing Events	The number of times a queue was generated	High	Understandable metric that documents the frequency of queuing in a work zone	Requires determination of queue start and end times and does not factor in the duration	Total number of queueing events, average number of queue events per work zone, or percentage of work zones with more than a defined threshold (i.e. 10 queue events)
Days / Periods with a Queue	The frequency count of days or periods that experienced at least one queuing event.	Medium	Distinguishes between occasional, unpredictable backups and frequent, systemic capacity failures.	Should also be factored by the duration of the work zone	Percentage of projects with more than a threshold of days with queue or a percentage of project days with queuing
Percentage of Time Queue Exceeds Threshold	The proportion of time a queue is longer than a predefined distance (e.g., 0.75 miles).	Medium	Combines frequency, duration, and severity into a single, highly actionable metric.	Focuses on severe queuing and may not capture overall impacts. May also be impacted by segment length of probe data	Percentage of project where queue exceed a threshold (i.e. 20% of time with a queue over predefined distance)

Table 13. Speed Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Average Speed	The mean speed of vehicles traveling through the work zone.	Low	Easily collected via spot sensors, radar, or probe data.	Speed alone does not quantify total delay without factoring in the length of the work zone or the work zone speed limit	Percentage of projects maintaining an average speed within 10 mph of the posted limit.
Speed Differential / Drop	The reduction in the 85th percentile or average speed from the advance warning area into the active workspace.	High	Identifies any abrupt speed changes which could serve as a leading indicator for rear-end crash risk.	Requires determining the segment or sensor upstream and inside the work zone and not easily comparable between work zones.	Percentage of work zones exhibiting a speed drop greater than 15 mph.
Speed Variance/ Standard Deviation	The dispersion of vehicle speeds around the average operating speed within the work zone.	Low	Can highlight turbulent, unstable traffic flow with large difference in vehicle speeds.	Harder for general users to understand and will likely show limited results with aggregated probe data only reporting average speeds instead of individual vehicle speeds.	Percentage of work zone segments with standard deviation greater than 10 mph.
Percentage of Time at Free-Flow Speed	The proportion of time the work zone speeds are at free flow speeds	Medium	Positively frames mobility by measuring how often the work zone is operating optimally	Not useful for projects that already experience heavy recurrent congestion prior to construction.	Average percent of time at free-flow speeds or percentage of projects in free flow over a threshold (i.e. 90% of time)
Percentage of Time Speed below Threshold	The proportion of time speed is lower than a predefined speed (e.g., 15 mph).	Low	Similar to congestion measure but using a fixed speed threshold focusing on frequency of severe slowdowns	Treats all speeds below the threshold equally and not factoring spatial impacts; limited in comparison between work zones	Percentage of work zones exceeding a percentage of time (i.e. 20% of time below speed threshold)

Table 14. Reliability Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Travel Time Index (TTI)	The ratio of the actual average travel time to the ideal free-flow travel time.	Medium	The ratio provides an easy metric to compare across work zones and easily understood once explained (e.g., TTI of 1.5 means 50% longer).	Can be misleading in low-speed urban environments where free-flow speeds are already low	Average TTI across all work zones
Level of Travel Time Reliability (LOTTR)	A metric defined by comparing the 80th percentile travel time to the 50th percentile.	Medium	Aligns with Federal MAP-21/PM3 reporting requirements using standard NPMRDS data.	Can be difficult for the general public to understand compared to basic delay metrics.	Average LOTTR metric for work zones or percentage of work zones with a LOTTR over a threshold
Buffer Time Index (BTI)	The extra time (as a percentage) driver must add to their average time to ensure 95% on-time arrival. (i.e. value of 50% indicates drivers must add 5 minutes to a free flow travel time of 10 minutes)	Medium	Easily understood metric indicating how much extra travel time is required to navigate work zone from baseline time period and metric is normalized for comparison between work zones	May require some explanation to general users of what the value means	Average BTI across all work zones or percentage of work zones where BTI exceeds a threshold (i.e. exceeds 30% extra time needed)
Planning Time Index (PTI)	Provides an index of the total time a driver must allow to ensure 95% on-time arrival (i.e. value of 1.6 indicates drivers must allow 16 minutes for a free flow travel time of 10 minutes)	Medium	Metric normalized by the 50^{th} percentile or free flow travel time to show the total time required to traverse work zone	May require some explanation to general users of what the value means	Average PTI across all work zone or percentage of work zones where PTI exceeds a threshold (i.e. index exceeds 1.5)

Table 15. User Cost Performance Measures

Performance Measure	Short Description	Level of Effort	Benefits	Downfalls / Limitations	Example of Program-Level Reporting
Road User Costs (Passenger & Freight)	The monetary value assigned to the vehicle-hours of delay, often segmented by vehicle class.	High	Provides a highly quantifiable financial metric to justify the cost of mitigation or contractor incentives.	Requires generalized financial assumptions for traveler value-of-time and accurate exposure data.	Total road user costs
Emissions / Fuel Consumption	Estimated tons of excess emissions or gallons of fuel burned	High	Translates mobility impacts into environmental impacts; useful for sustainability reporting.	Requires complex modeling based on speed profiles; not a minimum compliance need.	Total estimated excess carbon emissions attributed to work zone delays statewide.

4.4 Performance Measure Recommendations

While the previous sections outlined a library of potential safety and mobility performance measures, selecting exactly where to start can be challenging. Because every transportation agency is unique, each must ultimately determine which specific metrics best align with its regional goals, available data, and facility types. However, to assist agencies in establishing a performance monitoring program, this section outlines recommended performance measures for both safety and mobility. These specific recommendations were selected because they prioritize a critical balance: low calculation effort, high relatability for stakeholders, the ability to obtain actionable insights, and the capacity to seamlessly aggregate data for the annual Subpart J program-level reporting. To note, Subpart J requires agencies to select one safety and one mobility performance measure but agencies can report multiple measures for use within their agency.

4.4.1 Recommended Safety Performance Measures

Total Work Zone Crashes is a recommended safety performance measure. It represents a direct, indisputable measure of safety and is universally understood across all stakeholders. The primary advantage of this metric is ease of reporting. Crash data is readily available through established law enforcement and State DOT databases. By filtering for work zone-coded crashes, agencies can easily compile this data for annual programmatic reporting without needing to aggressively monitor project-level safety on a daily basis. Agencies may also consider limiting total work zone crashes to fatal and serious injury crashes as they are often the most targeted crash severities for safety improvements. However, restricting the analysis to high severity crashes can lead to limited data for smaller agencies which reduces the amount of consistent data available for effective performance monitoring.

However, as a lagging indicator, total crash counts provide very little actionable insight for active work zones. Furthermore, this metric is heavily influenced by exposure. An increase in total work zone crashes may not mean the agency's temporary traffic control is failing; it can be a direct result of an increase in overall work zone activity or the fact that projects were heavily concentrated in high-volume areas during that specific construction season. Taking the next step of associating crashes to work zones can provide project-level reporting and assist agencies in understanding which types of work zones impact safety.

As an alternative surrogate measure, hard braking events is a recommended safety measure based on its ability to move from reactive to proactive monitoring. Previous literature and safety studies have demonstrated that hard braking events have a direct, strong correlation with work zone crashes. The advantage of hard braking is fidelity. It allows for near real-time monitoring (daily or weekly), empowering agencies to proactively identify and correct safety hazards before an actual collision occurs.

The primary limitations of this leading indicator are cost and complexity. Extracting hard braking events from raw CV telematics data and accurately associating them with specific work zone coordinates requires a moderate to high level of data processing effort. Additionally, while hard braking is an excellent surrogate for rear-end collisions, it may not encompass all aspects of work zone safety, such as sideswipes or worker incursions.

4.4.2 Recommended Mobility Performance Measures

Delay Per Mile is a recommended mobility performance measure. This measure calculates the difference between actual travel times and a historical or free-flow reference travel time, effectively isolating the extra delay caused specifically by the work zone while controlling for normal, recurring congestion at that location.

Using Delay Per Mile is advantageous because it requires relatively low effort to calculate, especially when leveraging preferred probe data sources like the NPMRDS. Furthermore, by dividing the total delay by the physical length of the project, this metric normalizes the data across all types of work zones. Normalizing the data prevents massive, multi-mile projects from completely overshadowing smaller work zones in the data, making it superior to "average delay" or "maximum delay" for comparing performance across an agency's entire network. At the program level, an agency can easily aggregate this by calculating the average delay per mile across all active work zones for the year or define a threshold to report the percentage of work zones exceeding the delay per mile threshold.

The primary limitation of Delay Per Mile is that it can dilute the severity of short, localized impacts. Because a work zone typically operates with zero delay for the vast majority of the day, averaging the delay over a 24-hour period can mask a severe capacity failure that only occurs for 30 minutes during rush hour. Additionally, like many mobility metrics, it does not inherently weight or account for differences between high-volume urban corridors and low-volume rural routes.

Percentage of Time with a Queue is another strong mobility performance measures which can be used by agencies. This metric tracks the duration that a work zone experiences severe backups. Like delay, queuing is a concept that stakeholders and the public immediately understand. It also normalizes data temporally, allowing for highly effective program-level reporting. For example, an agency could report the "average percentage of time with a queue across all work zones," or establish a policy threshold and report "the percentage of work zones that experienced queuing for more than 10% of their active lane closure time."

The downfall of this measure is that it only captures the duration of the impact, not the magnitude. It does not factor in traffic volumes, nor does it distinguish between a half-mile queue and a five-mile queue; both are simply recorded as "time with a queue."

5 Implementation, Reporting, and Continuous Improvement

While previous chapters established the foundation by defining what data sources and performance measures can be calculated, this chapter shifts the focus to how to measure it. Selecting the right performance metric is only the first step. Transforming those theoretical measures into a functional, sustainable monitoring program requires technical execution, strategic data integration, and a clear institutional commitment to actively using the results. This chapter serves as a practical guide for agencies ready to operationalize their work zone data.

Building a successful monitoring program requires navigating several institutional and technical hurdles. This chapter will discuss various implementation pathways available to agencies, ranging from developing in-house calculation methods to leveraging open-source tools and transportation pooled funds. Successfully executing these pathways requires more than just selecting a software tool; it involves organizing available data effectively and coordinating across agency divisions. To support this, the following sections provide actionable guidance on bringing data sources together, ways to move from program level to project level results and areas for improvement in the future.

Ultimately, effective implementation is about closing the loop between data collection and field-level change. This chapter details how agencies can generate program-level summaries required by the 23 CFR Part 630 Subpart J programmatic review, while simultaneously building the capability to drill down into project-level diagnostics for active management. By understanding how to move from high-level target setting to daily operational adjustments, agencies can expand far beyond minimum regulatory compliance to create a continuous, data-driven framework for improving work zone safety and mobility.

5.1 Implementation Approach

The FHWA rulemaking requires transportation agencies to calculate at least one safety and one mobility program-level performance measure. However, as discussed in previous chapters, one of the primary challenges agencies face is defining program-level metrics that are both meaningful and actionable. A single, aggregated annual number satisfies reporting requirements, but it does not inherently tell an agency how to improve its temporary traffic control.

To capture the true spirit of the rulemaking, agencies should adopt a structured philosophy for performance monitoring. A mature monitoring program requires rolling localized project data up into comprehensive program-level metrics to evaluate overall system health, while simultaneously preserving the ability to drill down into the data to solve specific field issues.

To effectively achieve this balance, an agency's performance measurement strategy can be visualized as a hierarchical pyramid (Figure 5). At the highest level, leadership needs broad, aggregated summaries to evaluate the overall health of the transportation network. At the lowest level, field practitioners need highly granular data to manage the day-to-day operations of individual work zones. The critical component of this approach is the middle layer, a system of targets and thresholds that connects the two, allowing an agency to identify systemic trends and flag problematic work zones or types of work zones that need attention or intervention. This structure creates a seamless flow of information, ensuring that executive-level reporting directly drives field-level or program improvements.

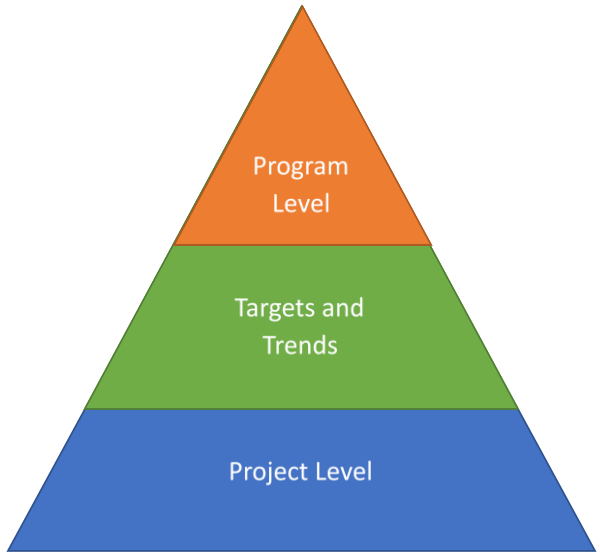


Figure 5. Performance Measure Pyramid

- **Program Level**: This tier encompasses the overall safety and mobility footprint of all work zones within an agency's jurisdiction. Common methodologies for calculating these executive summaries include:
    - System-Wide Averages: Calculating the mean metric (e.g., average delay per mile) across all active work zones.
    - Target Compliance: Reporting the percentage of total work zones that successfully met a defined agency target (e.g., "90% of projects maintained queues under 1 mile").
- **Targets and Trends**: This middle ground bridges the "strategic gap." Program-level measures are excellent for executive direction but lack the granularity to fix field issues; conversely, project-level measures are too voluminous for leadership to review individually. By stratifying the program-level data by relevant factors, such as roadway classification (interstate vs. arterial), work activity type (paving vs. bridge repair), or project duration, agencies can identify trends and deficiencies. This layer can establish target thresholds that act as flags for work zone outliers and identifying specifically which work zones are deficient and require further evaluation.
- **Project Level**: Once the middle layer identifies a poorly performing work zone, practitioners can use project-level measures to understand why it is failing. This granular data empowers field staff to make actionable, localized improvements to address the performance issues, whether through immediate operational changes, updated planning, or revised physical design.

5.1.1 Monitoring Frequency

The ultimate goal of a performance measurement program is to identify which work zones are negatively impacting safety and mobility so the agency can learn, adapt, and implement improvements. While the FHWA rulemaking requires annual reporting of program performance measures, this represents minimum compliance. Waiting a full calendar year to analyze data inherently restricts an agency to a reactive posture. As agencies build out and mature their programs, they should look toward operationalizing these performance measures. By calculating and reviewing metrics on a quarterly, monthly, weekly, or even daily basis, agencies transition from simply reporting historical data to maintaining a continuous, proactive focus on optimizing work zone safety and mobility.

5.2 Implementation Methods

Developing performance measures requires transitioning from theoretical definitions to active data processing. Because agencies possess varying levels of internal expertise, technical resources, and familiarity with complex data integration, there is no single "correct" way to build a monitoring program. Some agencies are well-equipped to develop these measures using existing internal staff, while others will benefit from collaborating with consultants, university partners, or third-party platforms.

To help agencies understand the different methods of implementation, the following section explores the ways agencies are currently approaching work zone performance monitoring and highlights the available methods across a few general categories.

5.2.1 In-House Tool Development

Building an in-house framework allows an agency to directly leverage data it already collects and manages, such as integrating existing lane closure systems and TMC sensors. Because it utilizes existing internal access, this approach can reduce long-term software costs and allows the agency to tailor the performance measures and dashboards to its highly specific operational goals. For example, the California Department of Transportation (Caltrans) successfully uses its own in-house Performance Measurement System (PeMS) (Chapter 6.4) to estimate work zone impacts, manage traffic during construction, and evaluate post-construction mobility.

Agencies do not have to tackle this entirely on their own; many successfully partner with university research centers or consulting firms to establish the initial data architecture, writing the scripts that internal staff will later maintain and operate.

- **Key Considerations:** Agencies choosing this route must clearly define their operational requirements upfront. Practitioners need to evaluate how frequently the performance measures must be calculated (e.g., daily automated dashboards versus annual manual analysis) and assess the technical realities of accessing their data (e.g., connecting directly to a live database application programming interface (API) versus manually exporting flat files from a legacy system).

5.2.2 Open Source Analytical Tools

As an offshoot of the in-house method, agencies can leverage open-source tools developed by the broader transportation community. This provides an established framework on data processing without requiring the agency to write complex code from scratch.

For example, through the Smart Work Zone Deployment Initiative (SWZDI), researchers developed an open-source analytical tool for work zone performance. The tool is designed to simplify the workload for practitioners: users upload work zone activity, safety, and mobility data in standard formats, and the tool automatically handles the complex data integration and calculates the core performance measures. It is available as an online web interface or can be downloaded as an R script for customization.

- **Key Considerations:** If utilizing a tool like the SWZDI application, agencies must figure out the logistics of identify the data needs using the commonly available standard formats required by the tool. If downloading the R codebase, the agency must decide if they have the IT infrastructure and permissions to run the tool locally and connect it directly to their internal databases for continuous, automated uploads.

5.2.3 Transportation Pooled Funds and Multi-State Platforms

For agencies seeking the lowest barrier to entry, participating in multi-state initiatives, such as the Eastern Transportation Coalition or the Work Zone Data Analytics Pooled Fund, provides a streamlined implementation path. This method is highly efficient because these platforms already ingest and process the massive commercial probe data like NPMRDS and connected vehicle datasets for mobility calculations. To generate the metrics, the agency typically only needs to coordinate the sharing of its localized work zone activity data.

For example, RITIS, developed by the University of Maryland Center for Advanced Transportation Technology (CATT) Lab, provides a dynamic interface for practitioners to calculate metrics. Users can select an active work zone and physically adjust the start and end locations on the map to ensure they are capturing the upstream approach queue (Chapter 3.1.3). The tool then automatically calculates performance measures for congestion, speed, and delay. It generates individual project summaries featuring visual charts that track the work zone's performance against agency-defined target thresholds.

- **Key Considerations:** While these third-party platforms currently excel at high-fidelity, project-level monitoring, they are continually evolving. Until native program-level dashboards are fully integrated, agencies utilizing these platforms may need to export their project-level results and aggregate the data themselves to fulfill their annual programmatic reporting requirements.

5.3 In-House Calculation Methodologies

If an agency chooses to calculate metrics internally, a systematic data filtering and aggregation process is required. While every agency's data architecture is unique, and some may utilize existing internal systems or resources that automate portions of this process, the general methodology follows a consistent path from raw data to actionable insights. Figure 6 outlines a high level overview of the workflow, demonstrating how agencies can move from initial data identification through to target setting and continuous monitoring.

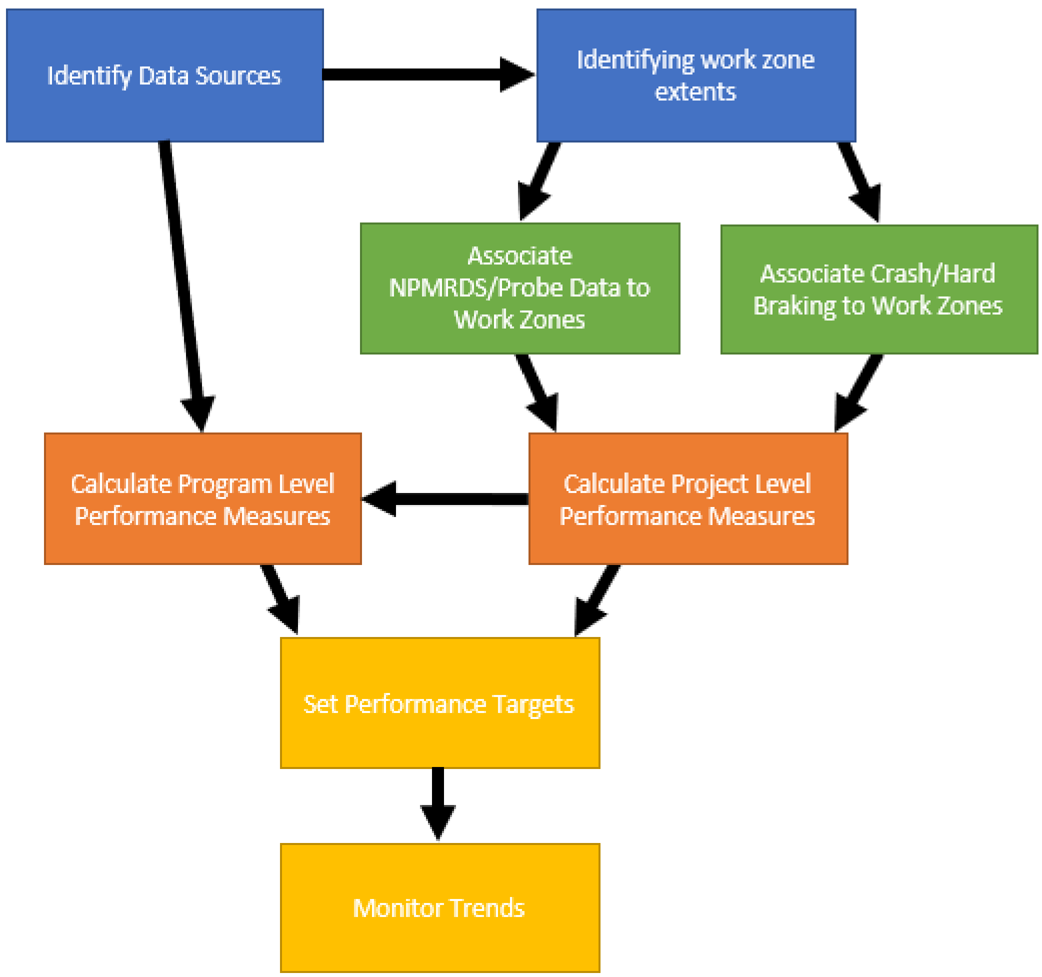


Figure 6. General Workflow for Calculating Performance Measure.

The foundational step of any in-house calculation is identifying exactly what data is being used (Chapter 3) and defining the spatial and temporal footprint of the work zone. Accurate calculations depend entirely on knowing exactly where the active work occurred and when the lane closures or impacts were physically in place. The data at this step will include the spatial location of the work zone, the start and end times, a unique identifier for the work zone and any other relevant details about the work zone such as work type, road type, etc.

Once the extents are defined, practitioners must filter the raw safety and mobility data to ensure it accurately reflects the work zone's specific impact. Associating mobility data begins with identifying the specific physical sensors or commercial probe data segments, such as TMC codes, that geographically overlap with the work zone. The results of this step will be a list of sensors or segments that are associated with a given unique work zone. The data from these sensors or segments must then be filtered by the exact start and end times of the work zone. For physical sensors, agencies must collect baseline data prior to construction to establish a "normal" condition, or simply use the posted speed limit to calculate general delay. Commercial probe data inherently includes historical and reference speeds, significantly streamlining the delay calculation. Safety calculations follow a similar spatial and temporal filtering process. Analysts must identify crash records or surrogate safety events, like hard-braking, that fall within the geographic extents of the active work zone. Because work zone impacts often extend upstream of the physical closure, it is a critical best practice to append a spatial buffer to the start location to ensure end-of-queue crashes are accurately captured in the analysis. The results of these steps will be all raw safety and mobility data associated to a unique work zone identifier.

With the data accurately associated, the agency can execute the performance measure calculations. The general processing workflow for project-level measures involves calculating the chosen metric at the lowest available resolution, such as 5-minute bins for mobility data, and then summing or averaging those results across the entire time period of the project. For example, to calculate delay an agency would add the travel time across all probe data segments for a given time period then subtract the historical travel time added across all segments. This would provide the delay for that given time period. The delay could then be averaged across all time periods for the project level performance measures. The results of this step will be project level performance measures at any desired frequency (annual, monthly, weekly, daily, etc.).

Once project-level measures are calculated, they are rolled up and aggregated into system-wide averages to create executive, program-level summaries. The type of aggregation will vary based on the performance measure but can include finding the sum or average across all project level performance measures from the previous step. As an example, an agency can calculate the average delay for each work zone then average the average delay across all work zones for a program level performance measure. An alternative would be to utilize thresholds and report the percentage of work zones meeting or exceeding the threshold. Using the average delay example, an agency can take the average delay for each work zone then calculate what percentage of work zones had an average delay over 10 minutes.

As illustrated in the workflow diagram, a shortcut exists for certain lagging safety metrics. Most performance measures require calculating project-level performance measures then aggregating those results as program level measures. Some measures such as the total number of work zone crashes can often be calculated directly from the initial data sources for program-level reporting without needing to be meticulously associated with individual project extents first. These performance measures were discussed in Chapter 4 and the potential limitations with calculating only program level measures.

Finally, while the steps above fulfill minimum reporting requirements of safety and mobility performance measures, mature programs utilize this data to drive continuous improvement. Once the baseline performance measures are established, agencies should set operational targets like maximum acceptable queue lengths or targeted delay thresholds. These targets require agencies to continuously monitor the performance measures and make changes to work towards those targets. Targets can be developed by evaluating the current work zone performance measures and then identifying targets which align with agency goals. By continuously monitoring trends against these established targets, agencies transition from simply reporting historical data to proactively managing their temporary traffic control strategies.

Ultimately, while this workflow represents a generalized approach that will naturally vary based on an agency's specific architecture and existing software capabilities, it establishes the major milestones required for calculating performance measures. By successfully navigating these core steps, from defining the initial work zone footprint and accurately filtering complex datasets to aggregating project-level metrics into actionable programmatic summaries, agencies can build a robust, scalable framework. Establishing this foundation is what allows an agency to move beyond raw data processing and successfully transform its technical capabilities into measurable improvements for work zone safety and mobility.

5.4 Programmatic Reviews and Continuous Improvement

Regardless of the approach for calculating work zone performance measures, implementing performance measures and calculating program-level data is not the final step. The ultimate goal and spirit of the Subpart J rulemaking is to drive continuous improvement. When assessing program-level needs, FHWA Subpart J formalizes the concept of a work zone programmatic review which is a data-driven, systematic, and holistic analysis using multiple data sources to assess safety and mobility performance to identify improvements to an agency's processes and procedures. The programmatic review goes beyond reporting performance measures but to identify procedures and action items. A successful programmatic review shifts the agency's focus from merely reporting data to actively using it to refine policies, update training, and improve temporary traffic control standards.

To maintain compliance and operational awareness, agencies must understand the dual cadence of performance evaluation:

- **Annual Monitoring:** The rule specifies that States shall monitor performance annually to ensure continuous assessment. This involves establishing a repeatable annual cycle to pull data, compute measures, summarize trends, and document any immediate actions taken. The monitoring does not need to be submitted but can be requested by the FHWA division office.
- **5-Year Programmatic Review:** The programmatic review assesses the work zone safety and mobility performance over a 5-year period of at least a representative sample of the State's significant work zones. This formal review serves as a comprehensive "look-back" at the accumulated annual data to identify long-term systemic trends and to develop an action plan for improving safety and mobility.

5.4.1 Representative Sample

Under FHWA rulemaking, the minimum compliance requirement for a programmatic review is the evaluation of a representative sample of a State’s significant work zones. However, relying on a fractional sample inherently limits an agency's ability to fully capture the true, system-wide impacts of temporary traffic control. To achieve a comprehensive understanding of work zone safety and mobility, it is highly recommended that agencies evaluate all work zones rather than a subset.

If an agency elects to use a representative sample, typically to reduce the time and effort required to calculate performance measures, it must document the methodology (e.g. decision matrix, statistical approach, etc.) used to select those specific projects. To ensure the sample yields insights that are reasonably applicable across the agency's diverse footprint, the selection process must be strategically stratified based on key factors, including land use (e.g., urban vs. rural), roadway classification (e.g., interstate vs. arterial), work activity type, duration of work activity, daytime vs. nighttime, and the anticipated extent of the impacts.

5.4.2 Action Plan

Programmatic reviews are intended to drive specific improvements, complete with designated timelines and responsible personnel. A review that culminates merely in a report without enacting change represents a significant missed opportunity. To successfully "close the loop", the insights derived from safety and mobility performance measures must be translated into a formalized action plan.

To ensure accountability and measurable progress, a robust action plan is required as part of the programmatic review. Below are the elements of an action plan including required and optional elements:

- **Finding/Issue:** A clear description of what needs improvement based on the data.
- **Evidence:** The specific performance measures, data trends, or field observations that highlight the issue.
- **Action:** The concrete policy, operational, or design change that will be implemented.
- **Owner:** The specific individual, office, or division responsible for executing the change.
- **Target Date:** A definitive deadline for implementation.
- **Evaluation:** The specific metric and follow-up timeline used to verify that the action successfully resolved the underlying issue.

By adhering to this continuous improvement cycle, measuring performance, reviewing performance measures holistically, and executing targeted action plans, agencies can confidently ensure their work zone programs are actively reducing delays, mitigating congestion, and protecting the traveling public.

5.5 Role of Exposure Metrics

While the primary focus of this guide has centered on direct measurements of safety and mobility, exposure metrics such as traffic volumes are a critical element of advanced performance monitoring. Incorporating exposure data significantly improves the normalization of performance measures and greatly expands an agency's analytical and reporting capabilities. Metrics such as AADT or lane-mile-hours can be used to normalize both safety and mobility outcomes. While not strictly required for minimum regulatory compliance, this normalization translates raw, absolute numbers into fair, rate-based comparisons, such as crashes per million vehicle miles traveled or user delay costs per vehicle. This normalization is what allows practitioners to accurately and fairly compare the performance of a high-volume urban interstate work zone against a low-volume rural work zone without the data skewing entirely toward the corridor with the highest traffic demand.

Despite these substantial benefits, exposure is not heavily emphasized across the foundational performance measures recommended in this report primarily because of the technical complexity it introduces. Integrating exposure data adds a significant analytical burden to the calculation process, requiring agencies to fuse multiple, often disparate, datasets. Furthermore, unless an agency has access to continuous, real-time volume counts directly at the work zone, these rate-based calculations often rely on broad, historical planning assumptions, such as static AADT figures. Because traffic patterns frequently shift in response to construction, relying on historical volume data can introduce hidden inaccuracies into the metrics. For these reasons, while exposure provides the ultimate context for work zone performance, agencies are generally encouraged to establish and master foundational, non-normalized metrics before layering exposure calculations into their reporting programs. It is anticipated that large scale exposure based data similar to probe data will become available that can improve the access and accuracy of exposure for incorporating into performance measures.

5.6 Expanding Beyond Minimum Compliance

While the strategies discussed thus far ensure an agency meets the minimum compliance of annual Subpart J reporting, mature programs treat these regulatory requirements as a baseline rather than the finish line. As agencies establish their foundational performance measures, they should continuously seek opportunities to enhance their monitoring capabilities. The most immediate avenue for improvement is increasing the quality and fidelity of the underlying data. This begins with improving the spatial and temporal accuracy of the work zone activity logs themselves, ensuring the exact location and duration of lane closures are documented accurately with the real-world conditions. On the safety side, upgrading from traditional lagging crash counts to high-fidelity safety surrogate metrics, such as CV-derived hard braking events, allows an agency to pinpoint the exact locations of operational friction with far greater precision. Agencies can refine their mobility data by transitioning to shorter commercial probe segment lengths and reducing time aggregation intervals, preventing short, localized delays from being "washed out" in broad averages. Furthermore, agencies can adopt highly granular CV trajectory data to evaluate individual vehicle behavior rather than relying solely on aggregated speed bins.

Beyond improving the core safety and mobility datasets, agencies can drastically expand their analytical capabilities by incorporating additional contextual data into their performance monitoring framework. As discussed previously, integrating exposure data significantly improves the normalization of metrics, but the context does not have to stop there. Agencies can layer in real-time weather conditions, active incident reports, detour routing information, and established commuting patterns to better understand the holistic operating environment of the corridor. Advanced field hardware, such as smart work zone camera feeds or LiDAR, can also be integrated into these analytical ecosystems. By fusing these diverse datasets, practitioners transition from simply knowing that a work zone is performing poorly to understanding exactly why the issues are occurring. This context allows an analyst to determine, for example, whether a severe queue was caused by a flaw in the temporary traffic control design or if it was the unavoidable result of a sudden downstream weather event.

Ultimately, expanding beyond minimum compliance requires fundamentally changing how often the data is used. While annual reporting satisfies Federal requirements, agencies should strive to operationalize their performance measures by generating daily, weekly, or monthly insights and embedding them directly into the standard workflows of agency staff. The true value of a performance measurement program lies entirely in its ability to complete the feedback loop. Generating highly accurate, context-rich metrics is only useful if those actionable insights are placed directly back into the hands of the project engineers, traffic management centers, and field inspectors who can physically alter the work zone. By shifting from a culture of annual compliance reporting to one of continuous, localized performance management, an agency ensures that its data actively drives safer, more efficient work zones across the network.

To truly capitalize on the continuous feedback loop, mature agencies can advance how they systematically identify and isolate safety and mobility issues. While minimum compliance dictates reporting just one safety and one mobility measure, a robust program utilizes a comprehensive suite of metrics to evaluate the holistic health of the network. By establishing performance targets and operational thresholds across these multiple measures, agencies can create automated triggers that immediately flag when a specific project falls out of compliance. This capability can allow an agency to successfully bridge the gap between high-level programmatic summaries and granular, project-level interventions. As data programs evolve, agencies can increasingly leverage advanced analytical tools and machine learning processes to automatically detect outlier work zones. Instead of relying on a single metric in isolation, these advanced systems can continuously scan all available performance data to identify complex, multi-variable anomalies that might otherwise go unnoticed which can allow practitioners to make changes impacting the safety and mobility.

6 Agency Implementation Examples

While the previous chapters have established the theoretical frameworks, data requirements, and calculation methodologies necessary for monitoring performance, transitioning from concept to a fully operational system can still present institutional challenges. One of the most effective ways for an agency to navigate this transition and build internal momentum is by examining how peer agencies have successfully deployed these strategies in the field.

This final chapter bridges the gap between guidance and practice by highlighting four real-world case studies. The following sections detail how the Texas, Iowa, Ohio, and California Departments of Transportation have each approached the challenge of work zone performance measurement. While their specific regional goals, available data sources, and internal technical capabilities naturally vary, these examples provide practical ways safety and mobility are monitored across diverse transportation networks.

6.1 Texas DOT: NPMRDS-based Mobility Measurement (GO I-10 case study)

Source study: *Performance Measurement Using NPMRDS – Case Study: GO I-10 Project* (FHWA-HOP-20-029).
https://ops.fhwa.dot.gov/publications/fhwahop20029/hop20029.pdf

The FHWA case study of the Texas Department of Transportation's (TxDOT) GO I-10 mega-project demonstrates how transportation agencies can systematically measure work zone mobility impacts using the NPMRDS. The primary takeaway from this report is that agencies without physical ITS sensors deployed in the field can still establish a robust, repeatable work zone mobility monitoring program by leveraging probe data such as NPMRDS.

Because the NPMRDS provides highly granular, segment-by-segment speed and travel time data, the case study showed how TxDOT could calculate a comprehensive suite of mobility performance measures. The case study showed how the performance measures could be calculated using both spreadsheet or R for this single project. The report focused on extracting the following specific metrics:

- **Speed and Travel Time**
- **Underperforming Instances** – Travel time 25% higher than average
- **Travel Time Reliability**
- **Road User Costs (Delay)**

To calculate these measures, the report outlines a standardized 10-Step Process (Figure 7). The core of this methodology involves associating work zone information with corresponding NPMRDS TMC segments. Once the NPMRDS data are identified for the work zone, the 10-step process establishes baseline performance thresholds (using pre-construction historical data) and performs the calculations to isolate the exact delay and speed reductions directly attributable to the construction activity. The performance measures are then interpreted and documented as part of lessons learned or action plans for the agency.

Figure 7. TxDOT: NPMRDS 10-step process (from FHWA-HOP-20-029).

A major highlight of the report is its ability to visualize complex performance measures. Instead of relying solely on summary tables, the workflow produces diagnostic heat maps, comparisons between baseline and work zone performance measures over time and overall performance measures. The charts such as those in Figure 8 show how mobility performance measures at a project level can provide insights to practitioners and intuitively see where and when the work zone is having mobility issues without needing to decipher raw data tables.

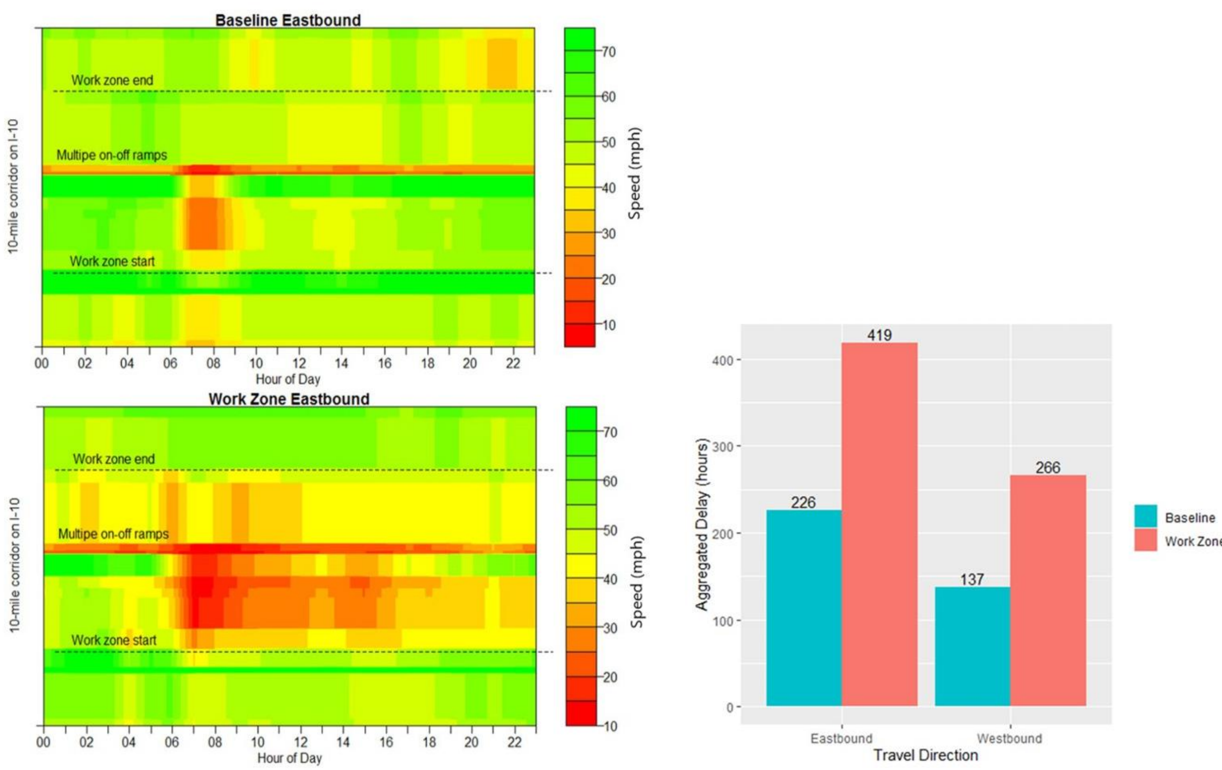


Figure 8. TxDOT: Example Performance Charts (from FHWA-HOP-20-029).

Texas Example Overview

Context	Repeatable work zone mobility measurement using NPMRDS
Measures	Speed, travel time, delay, reliability
Data sources	Work zone location/time definition and NPMRDS
Reporting	A documented analysis workflow producing visuals and summary performance measures.
Key takeaway	**Low Barrier to Entry:** Because the NPMRDS is provided to State DOTs and MPOs at no direct cost, establishing this monitoring workflow requires analytical time, but no new hardware but does have limitations such as the spatial coverage, the latency in reporting and the lack of exposure data. **Scalability:** The standardized 10-step process used for the massive GO I-10 project can be scaled down and applied to almost any work zone located on the NHS. **Actionable Insights:** By systematically monitoring speeds and delays, the case study showed how NPMRDS can provide critical information on the mobility impacts of the work zone

6.2 Iowa DOT: Centralized Work Zone Data Hub

Source study: *Data-driven Work Zone Process Reviews Case Study: Iowa Department of Transportation* (FHWA-HOP-21-052). https://ops.fhwa.dot.gov/publications/fhwahop21052/fhwahop21052.pdf

The Iowa Department of Transportation (DOT) has successfully transitioned from qualitative, point-in-time process reviews to a continuous, data-driven performance management cycle. To systematically evaluate work zone safety and mobility, the agency utilizes an integrated framework that leverages crash reports, traffic sensors, third-party probe data, and digitized field reviews.

A foundational element of this data-driven methodology is clearly defining which work zones are included in the analysis. Rather than evaluating every minor maintenance activity, the agency focuses its primary monitoring efforts on Traffic Critical Projects (TCPs) where sensors and additional mitigation strategies are deployed. TCPs are defined as key construction projects that are anticipated to cause significant safety or mobility impacts to the traveling public. By tracking the total number of active TCPs each season, the agency establishes a critical baseline for its metrics. This contextual data helps analysts understand whether a system-wide spike in crashes or delay is due to a flaw in temporary traffic control strategies, or if it is simply the result of a significant increase in the sheer volume of major construction projects occurring that year.

To evaluate systemic safety performance, Iowa DOT's review focused on all incidents explicitly coded as work zone-related within the state crash database. The data was stratified by roadway facility type (Interstates, U.S. Routes, Iowa Routes, etc.) and crash severity (e.g., Fatal, Possible/Suspected Injury, Property Damage Only). Key Safety Performance Measures Evaluated:

- **Total Number of Work Zone Crashes:** This metric (Figure 9) tracks the absolute frequency of crashes across the network. For example, Iowa DOT noted a 12-percent reduction in total work zone crashes in 2020 compared to 2019, a trend largely driven by the drop in overall vehicle miles traveled (VMT).
- **Number of Crashes at Traffic Critical Projects:** To isolate the impacts of major construction, crashes occurring within a 0.1-mile buffer of TCPs were analyzed. This also included extending the approach area of the work zone to ensure that end-of-queue and advance-warning crashes are accurately captured and not underrepresented.
- **Normalized Crash Rates (Crashes per TCP):** By dividing the absolute crash counts by the active TCPs, the agency calculated the average crashes per project. The data showed 10 crashes per TCP in 2018, jumping to 20 in 2019, and settling at 14 in 2020. This normalization highlights the critical need for tracking comprehensive Work Zone VMT to fully explain the root causes of these rate fluctuations.

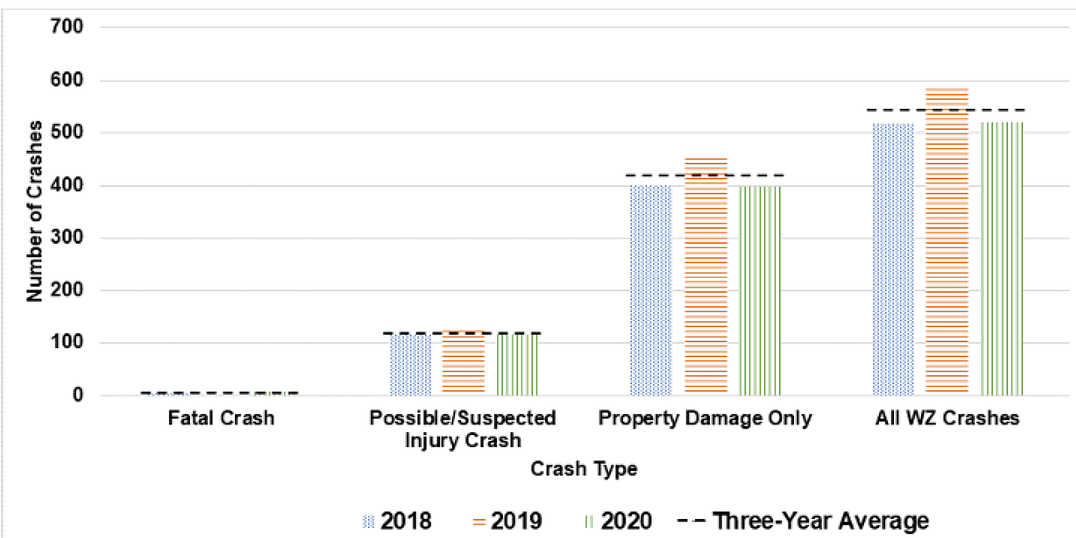


Figure 9. Iowa DOT Crashes by Severity (from FHWA-HOP-21-052).

The mobility assessment focused strictly on the performance of TCPs, utilizing a combination of deployed speed and travel time sensors alongside third-party probe vehicle data. The core objective of the mobility analysis was to evaluate field performance against a defined policy threshold. Iowa DOT is developing guidance that defines a maximum 4-minute delay per vehicle threshold (based on the 95th percentile of work zone delay) to automatically trigger operational mitigations and assist in lane closure planning. Key Mobility Performance Measures Evaluated:

- **Number of Work Zone Traffic Congestion Events:** Defined as instances where sensors detect slow or stopped traffic for more than 5 minutes. While the absolute number of events increased year-over-year from 2019 to 2020, normalizing the data by the number of active projects revealed a 34-percent reduction in congestion events per project in 2020.

- **Average Duration of Events:** This metric tracks how long a work zone remains in a congested state. The data revealed that Interstates were the primary driver of sustained congestion, seeing a 56-percent increase in average event duration in 2019 compared to 2018.
- **Average Queue Length:** This measures the spatial and physical impact of the congestion (Figure 10). System-wide, travelers experienced an average queue of 1.1 miles in 2018, which dropped to 0.8 miles in 2019 and 2020. Evaluating queue length distributions (such as using box plots for limited access freeways) allows the agency to compare the variability of queue lengths, including percentiles and extremes.
- **Percent of Traffic Encountering a Queue:** Calculated as the ratio of traffic experiencing a queue to the total traffic traversing the corridor. This metric translates technical delay into a measure of broader route reliability for the traveling public.

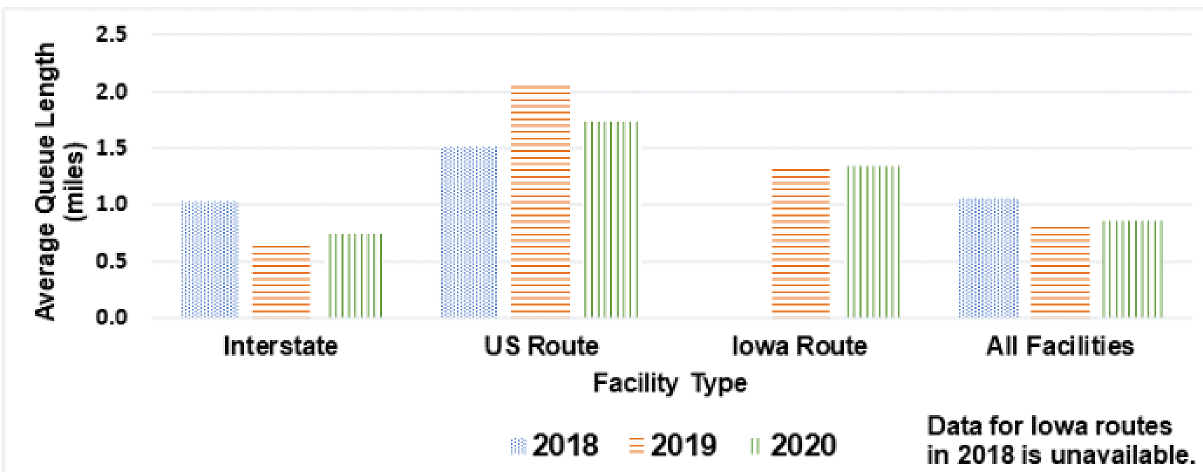


Figure 10. Iowa DOT Average Queue Length (from FHWA-HOP-21-052).

Beyond automated sensor data and crash logs, Iowa DOT emphasizes the necessity of structured, digitized field reviews to understand the contextual reasons behind the performance data. Data was sourced from regular traffic control field reviews and aggregated into an interactive dashboard that allows the agency to adjust granularity from the state level down to specific projects.

Field reviews evaluated various temporary traffic control setups (e.g., lane closures, channelizing devices, temporary signals, transition areas). Specific aspects of these setups (e.g., proper signage, positive closure, retroreflectivity) were graded using a four-tier rating system: Exceptional, Acceptable, Marginally Acceptable, and Undesirable.

By tracking these ratings programmatically, the agency identified systemic, actionable trends:

- Categories related to lane closures frequently received marginally acceptable or undesirable ratings, indicating a direct need to reexamine the lane closure design and implementation processes, specifically emphasizing location/spacing and positive control.
- Conversely, temporary pavement markings and traffic barrier deployments consistently received exceptional ratings, allowing the agency to formally document these successful practices as internal baseline standards.

The ultimate objective of integrating these disparate data sources is to transition the agency from static reporting to continuous operational improvement. By synthesizing safety trends, mobility impacts, and granular field review scores, Iowa DOT can definitively pinpoint the root causes of underperformance. By establishing performance thresholds, continually expanding monitoring metrics, and utilizing interactive dashboards to identify outlier projects, the agency can seamlessly feed actionable intelligence back to design engineers, traffic management centers, and field inspectors to actively drive safer and more efficient work zones.

Iowa Example Overview

Context	Transitioning Work Zone Process Reviews (WZPRs) from static, point-in-time evaluations to continuous, data-driven monitoring.
Measures	Safety outcomes (crash frequency/severity), mobility impacts (speeds/delay), and field review/inspection scores.
Data sources	Permanent and temporary sensors, crash data, third party probe data and qualitative field inspection logs.
Reporting	Continuous aggregation feeding into the federally mandated multi-year programmatic process review.
Key takeaway	**Continuous Monitoring:** Replaces Point-in-Time Reviews: Adopting a "continuum mindset" ensures that performance data is actively tracked year-round. This makes compiling the required multi-year programmatic reviews significantly easier, more accurate, and far more insightful. **Qualitative Meets Quantitative:** Combining hard quantitative data (probe speeds, crash logs) with qualitative field review data (inspector scores and project tracking) provides the necessary context to identify why a work zone is performing poorly. **Repeatable Workflows:** By establishing a standard process for analyzing exposure, safety, mobility, and inspection data, agencies can build a streamlined, repeatable analytical framework that scales across multiple process review cycles.

6.3 Ohio DOT: policy-driven lane closures and performance monitoring

Source study: *A Policy-Driven Approach for Work Zone Mobility Performance Management* (FHWA-HOP-19-034).
https://ops.fhwa.dot.gov/publications/fhwahop19034/fhwahop19034.pdf

The Ohio Department of Transportation (ODOT) utilizes a policy-driven approach to systematically determine, minimize, and mitigate the negative impacts work zones have on mobility. A foundational element of this methodology is the Permitted Lane Closure System (PLCS), which establishes firm traffic volume thresholds for allowable lane closures based on the time of day. During the planning and permitting phases, ODOT evaluates proposed projects for expected mobility impacts. If a project timeline needs to violate the standard PLCS thresholds, a customized queuing analysis is required. ODOT enforces a policy threshold that allows a maximum predicted queue length of 0.75 miles; if the predicted queue remains below this limit, the closure may proceed.

To ensure these planning thresholds hold up in reality, ODOT transitions from predicting queues to actively monitoring them once construction begins. Using commercial probe vehicle data, the agency tracks actual field performance against its models. The core mobility performance metric focuses on identifying real-world queues and systemic bottlenecks by tracking the frequency and duration of times when work zone speeds drop below ODOT's established minimum performance threshold of 35 mph. ODOT actively monitors the field performance of its highest-impact work zones throughout the construction season. For an average of 25 to 30 significant projects each year, the central office work zone team produces detailed monthly performance reports based on the 35 mph speed threshold. Some of the performance reports include:

- **Work Zone Speed Analysis:** By analyzing the probe data, ODOT visually charts the exact number of hours that vehicles traveled at less than 35 mph through the work zone each month (Figure 11). This analysis explicitly quantifies the prevalence of severe speed reductions, allowing the agency to pinpoint the most disruptive bottlenecks and target them for operational adjustments.
- **Average Hourly Speeds by Time of Day:** In addition to monthly tallies, the agency plots the average hourly speeds for each work zone on a month-by-month basis (Figure 12). Originally intended to quantify instances of motorists exceeding the speed limit, these plots evolved into a highly effective diagnostic tool used to investigate exactly why and when actual speeds drop during certain times of the day.
- **Crashes and Bottlenecks:** Crashes and bottlenecks are also reviewed monthly for the work zones to identify any additional trends or insights. The crash report summarizes the current number of crashes in the work zone to the historical maximum and three year average number of crashes.

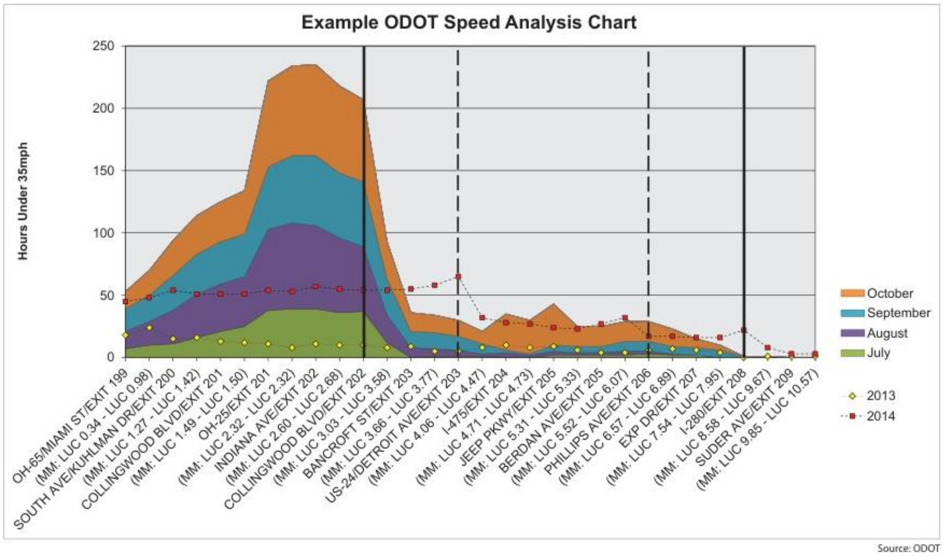


Figure 11. ODOT: Overall Speed Analysis (from FHWA-HOP-19-034).

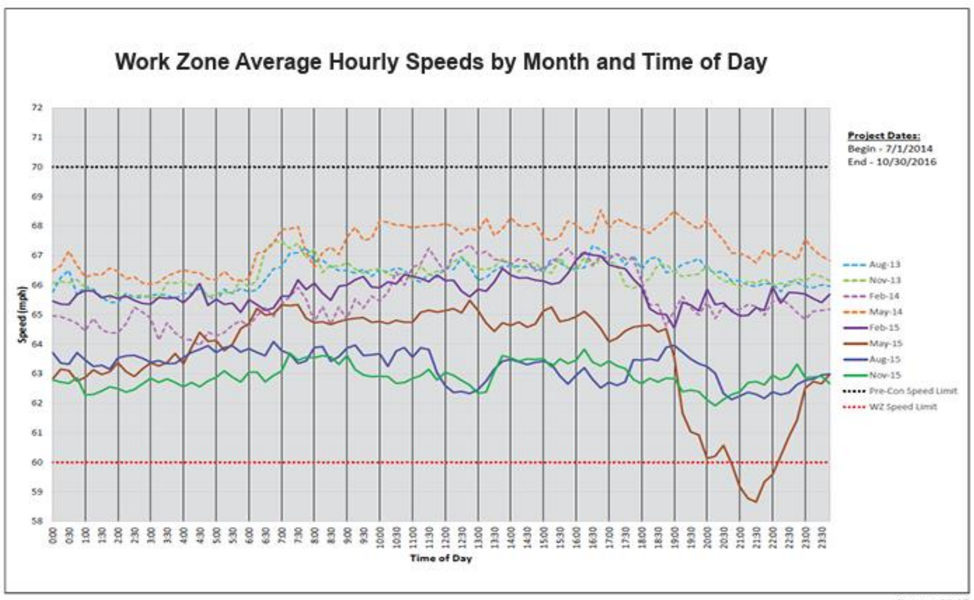


Figure 12. ODOT: Speed Analysis by Time of Day (from FHWA-HOP-19-034).

The ultimate goal of ODOT's program is to leverage probe data and policy thresholds to not only monitor current performance but to conduct research that improves overall management practices. By maintaining centralized, universally understood benchmarks, namely the 0.75-mile queue limit and the 35 mph speed threshold, the central office can effectively monitor and uniformly evaluate work zone performance across all 12 state districts. Furthermore, by rigorously collecting lessons learned and leveraging historical probe data, ODOT continually refines its future practices for work zone planning, design, and construction.

Ohio Example Overview

Context	Utilizing a policy-driven approach to systematically determine, minimize, and mitigate work zone mobility impacts from the initial planning phase through active construction performance monitoring.
Measures	Work zone speed deficits (tracking the frequency and duration of speeds dropping below 35 mph), bottlenecks and total work zone crashes
Data sources	Permitted Lane Closure System volume calculations, commercial probe vehicle data, and crash data
Reporting	Detailed monthly performance reports for the 25 to 30 highest-impact projects, featuring visual speed analysis charts and average hourly speed plots.
Key takeaway	**Policy-Driven Thresholds**: A systematic, policy-based approach allows the agency to apply consistent engineering checks. Policy (like the 0.75-mile queue limit and 35 mph speed) provide a centralized, objective reference to track performance across the entire state. **Leveraging Probe Vehicle Data**: Commercial probe data provides both high-level and in-depth metrics. It serves as a relatively low-cost, high-fidelity method to transition from theoretical planning tools to real-time, granular field metrics. **Bridging Planning and Operations:** By actively monitoring field construction speeds against the initial design thresholds, the agency ensures that theoretical models successfully translate into real-world mobility, effectively closing the feedback loop between design engineers and field operations.

6.4 Caltrans: PeMS Work Zone Monitoring Program

Source study: *Comprehensive Work Zone Mobility Performance Management Across Project Stages* (FHWA-HOP-19-054).
https://ops.fhwa.dot.gov/publications/fhwahop19054/fhwahop19054.pdf

Caltrans utilizes a highly centralized, data-driven framework to proactively manage work zone mobility impacts across every stage of project development. Rather than relying on isolated analytical tools, the agency uses its statewide Performance Measurement System (PeMS) as the primary platform for all work zone planning, monitoring, and evaluation. PeMS fuses an enormous volume of existing in-house data which includes real-time feeds from over 39,000 inductive loops and radar detectors, historical traffic counts, incident logs, and Electronic Toll Collection travel times.

The initial element of this methodology is using this wealth of historical data to conduct rigorous pre-closure planning. Caltrans matches expected traffic demand against roadway capacity within

PeMS to automatically generate Lane Requirement Charts (LRCs). These charts dictate the allowable lane closures by the time of day and day of the week. To fully understand the anticipated impacts, the system models proposed work zones as "incidents" to estimate critical metrics before a project even begins, including total vehicle-hours of delay, maximum individual vehicle delay, maximum expected queue lengths, and estimated road user costs.

Once a project moves from design to construction, Caltrans transitions to actively monitoring the work zone to ensure the field conditions align with the pre-closure models. Every work zone activity on state highways is recorded in the Caltrans Lane Closure System (LCS), which feeds directly into PeMS and updates every five minutes. The real-time mobility performance monitoring includes:

- **Real-Time Closure Dashboards:** Because contractors are strictly required to update the system the moment they set up and take down closures, district traffic managers utilize an interactive map view to see exactly which work zones are active at any given moment across the state.
- **Lane Closure Delay Maps:** PeMS generates real-time delay maps that display the localized delay for each specific work zone, allowing staff to immediately compare current delays against historical day-of-week averages.
- **Detour Route Performance:** Rather than focusing solely on the mainline, analysts use these same mapping tools to monitor the real-time health of designated detour routes on an hourly basis, adjusting traffic control as needed if the detour becomes overwhelmed.
- **Active Operational Thresholds:** These real-time tools are tied to actionable changes. For example, if the traffic management team observes that a work zone is causing an excessive delay exceeding 15 minutes, district engineers actively intervene to modify construction activities or terminate the closure entirely to mitigate excessive queuing.

The final aspect of the Caltrans methodology is a formalized post-construction evaluation that feeds directly into continuous, program-level monitoring. After a project concludes, resident engineers leverage archived PeMS data to validate what actually happened in the field against what was planned. Traffic engineers review these post-closure evaluations to systematically adjust and optimize the Lane Requirement Charts for future projects, creating an immediate feedback loop.

Beyond these individual project-level evaluations, Caltrans expands this data into powerful program-level measures through its Mobility Performance Reporting and Analysis Program. Every district is required to submit comprehensive quarterly and annual summary reports. These summaries aggregate total vehicle hours of delay, track queue durations, and compare current performance against previous quarters.

These district summaries are used to rank work zone bottlenecks based on average queue lengths. By rolling this granular sensor data up into program-level quarterly and annual reports, Caltrans can definitively identify which specific work zones are causing the most severe issues across the network. This systemic ranking allows the agency to pinpoint precise locations for improvement, allocate resources more effectively, and ensure that localized work zone issues are addressed within the state's broader congestion mitigation efforts.

California Example Overview

Context	Sensor-based performance monitoring supporting planning, real-time operations, and post evaluation.
Measures	Total delay duration, maximum individual vehicle delay, maximum queue length, total vehicle-hours of delay, road user costs, and TTI.
Data sources	ITS sensors, incident data and work zone activity data.
Reporting	Real-time delay reporting (every 5 minutes) and post construction analysis including quarterly and annual summary reports for each district
Key takeaway	**Centralized Data Fusion**: By integrating a massive network of existing in-house sensors and historical data into a single platform, the agency eliminates the need for separate analysis software, creating a unified, one-stop ecosystem for all mobility data. **Full-Lifecycle Feedback Loop**: Actively utilizing performance data across every project stage—from generating Lane Requirement Charts during pre-closure planning to post-construction evaluations—ensures continuous operational refinement and directly links field outcomes back to the design engineers. **Mainstreaming Work Zones**: Integrating work zone performance into broader Transportation Systems Management and Operations (TSMO) reporting processes elevates the visibility of work zone impacts and allows the program to organically tap into wider agency resources and funding.

Additional Performance Measure Resources

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3. Pate, A, Sankar, P, Habtemichael, F. FHWA. Performance Using the National Performance Management Research Data Set (NPMRDS) Case Study: Application to the Texas Department of Transportation GO I-10 Project (FHWA-HOP-20-029). July 2021. https://ops.fhwa.dot.gov/publications/fhwahop20029/hop20029.pdf

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13. Ullman, G, Pesti, G, and Klein, R. FHWA. Guidance on Data Needs, Availability and Opportunities for Work Zone Performance Measures. (FHWA-HOP-13-011). March 2013. https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop13011/fhwahop13011.pdf

14. Hallmark, S, Turner, J and Albrecht, C. Synthesis of Work-Zone Performance Measures. Smart Work Zone Deployment Initiative. September 2013. https://ctre.iastate.edu/wp-content/uploads/2018/03/work-zone_perf_msrs_w_cvr2.pdf

15. Basulto-Elias, G, Knickerbocker, S, Hardt, Marie. Development of an Analytical Tool for Work Zone Performance. Smart Work Zone Deployment Initiative. August 2025. https://swzdi.intrans.iastate.edu/wp-content/uploads/2025/08/analytical_tool_for_WZ_performance_w_cvr.pdf

16. Sakhare, R, Desai, J, Overall, M, Mukai, J, Pava, J, McGregor, J, Bullock, D. Work Zone Performance Measures Derived from Connected Vehicle Data for Safety and Mobility Assessment. January 2026. https://doi.org/10.3390/futuretransp6010012

Appendix A: Annual Performance Reporting Template

The following section provides an example template for annual work zone performance reporting. This example illustrates what can be included in an annual report to successfully meet minimum regulatory compliance while effectively positioning a DOT to incorporate these annual findings into their comprehensive 5-year programmatic review.

Please note that this template is not prescriptive; rather, it serves as an illustrative guide to demonstrate how data can be summarized and reported. The example is intended to highlight how agencies can report on their one safety and mobility performance measure but incorporate additional metrics supporting the annual analysis. Each agency will have their own unique operational needs and data availability which can be adapted into the template. This example also works to incorporate action items and continuous improvement that should be evaluated annually that can be wrapped up into the five year programmatic review. For a detailed description of each component included in this template, please refer to Section 2.4.

Annual Work Zone Safety and Mobility Report

Annual Statewide Summary Report | Fiscal Year 2025

1. Executive Impact Summary

This report summarizes the safety and mobility performance of all state-managed work zones for the current reporting year. The purpose of this programmatic review is to align active performance measurement with the Department of Transportation's overarching work zone safety and mobility policies, ensuring continuous improvement in temporary traffic control operations. The agency actively monitored 218 work zones during this reporting cycle. Across these projects, the system-wide average delay was 54 seconds, and 63.8% of projects had crash rates at or below the pre-work zone baseline.

54 Seconds	63.8%	218
Average Delay	Work Zone at or below Pre-Work Zone Crash Rate	Number of Work Zones

Data Sources

To support the development of the performance measures, the DOT integrated operational and historical datasets to evaluate work zone impacts from the following data sources:

- Work Zone Activity: Data was sourced directly from the 511 system, which produces a Connected Work Zone (CWZ) feed for real-time operations.
- Mobility Data: Commercial probe data was utilized, providing high-fidelity speed readings every minute across approximately 1-mile segments. This dataset includes historical reference speeds, which serve as the baseline comparison to accurately capture the excess delay specifically caused by the work zone.
- Safety Data: Statewide crash databases were utilized. To ensure accuracy, the data was filtered to include only crashes coded as work zone-related by responding law enforcement officers.
- Exposure Data: Traffic volumes using the average annual daily traffic (AADT) were used to estimate the traffic impacted by the work zones

Representative Sample

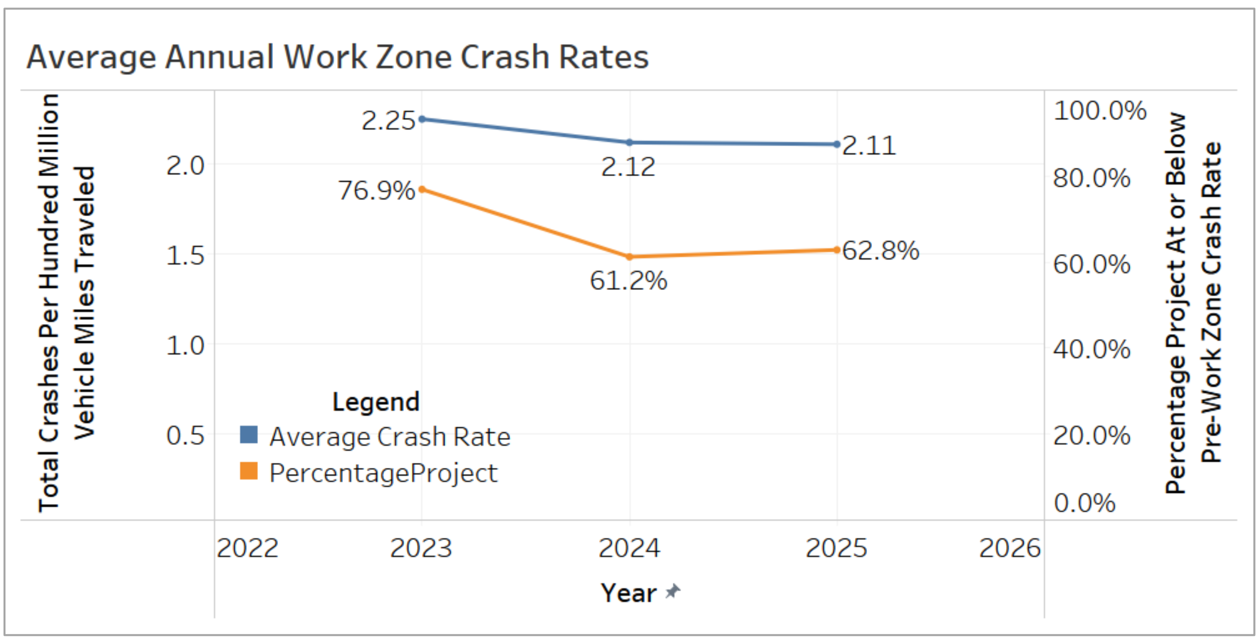
For this reporting cycle, the analysis did not rely on a fractional sample. Instead, the review included 218 work zones, representing all active work zones reported through the 511 system throughout the year.

2. Safety Performance Compliance

The primary safety performance metric evaluated for this annual safety performance review is the crash rate compared to a pre-work zone baseline. This metric provides a direct measure of the physical impacts and crash frequencies occurring within active project limits while also accounting for traffic volumes and length of the work zone. The measure includes all reported work zone crashes included in the DOTs crash database. The identification of a work zone related crashes is coded by the reporting officer and defined as the first harmful event occurs within the boundaries of a work zone or on an approach to or exit from a work zone, resulting from an activity, behavior, or control related to the movement of the traffic units through the work zone. Traffic volumes were estimated by AADT and the reported length of the work zone. The pre-work zone baseline was calculated based on the prior year during the same time period unless a work zone was reported. If a work zone was present then the baseline was calculated based on two years before the work zone.

Safety Trends

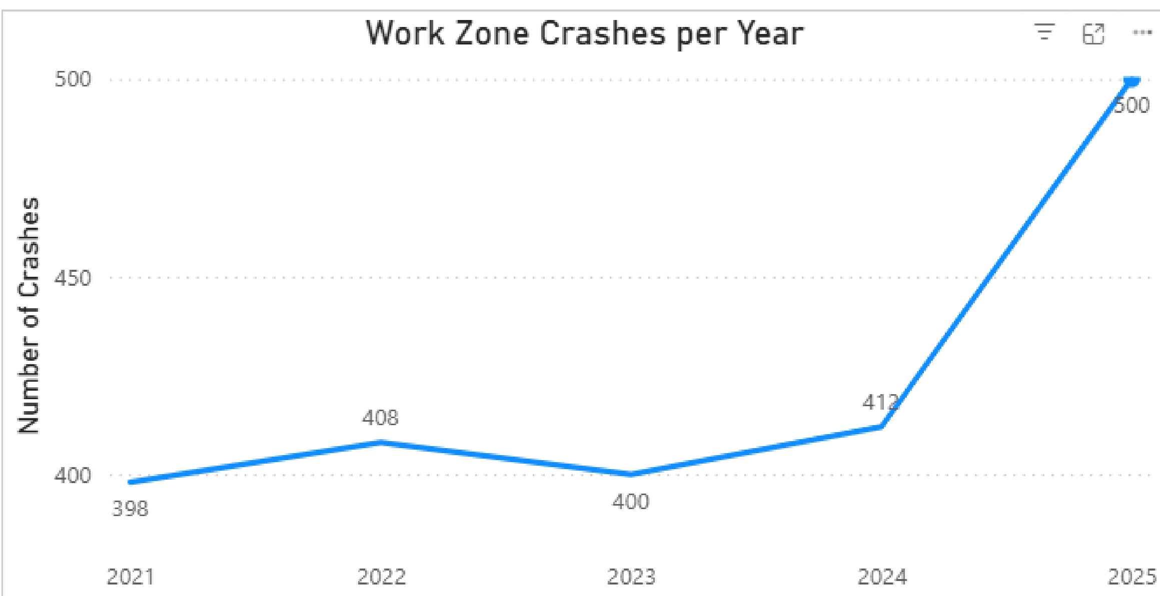
Monitoring the crash rate trends, 62.8% of work zones had crash rates at or below their pre-work zone crash rates which is comparable to the prior year but lower than the percentage of projects in 2023. Overall, the average crash rate continues to decline compared to 2023. This indicates that overall crash frequency is improving even though individual work zones are not meeting their baseline threshold.



The top five work zones with the highest crash rate increases (140% to 241%) all feature extended work zone durations of 90 to 210 days. Consistent with broader transportation studies, prolonged work zones struggle with crash rate compliance compared to pre-work zone baselines. These findings suggest that long-term projects may benefit from dynamic traffic management, mid-project safety reviews, or periodic enforcement campaigns to curb upward crash trends over time.

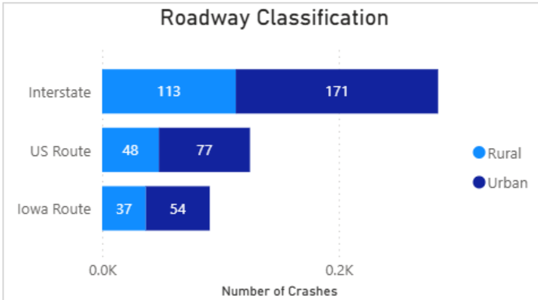
Work Zone	Crash Rate	Pre-Work Zone Crash Rate	Change in Crash Rate	Road Type	Duration
I-35 MM 85-92	2.9	0.85	241%	Interstate	150
US-61 MM 20-25	3.15	1.1	186%	US Route	90
SR-141 MM 5-12	1.35	0.5	170%	State Route	120
I-80 MM 120-135	2.45	0.95	158%	Interstate	210
US-30 MM 150-158	1.8	0.75	140%	US Route	180

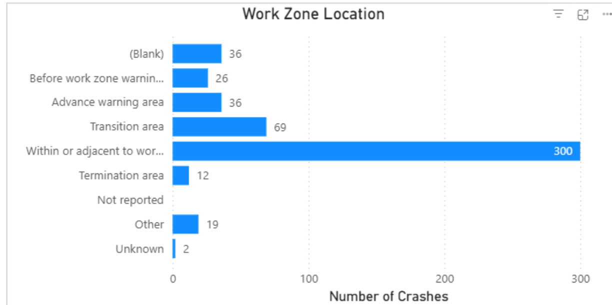
For the current year, there were 500 total work zone crashes including 1 fatal crash and 12 serious injury crashes. This represents an 18% increase in the total work zone reported crashes over the five year average but has been part of a concerted focus on improving reporting accuracy and work zone crash coding by local law enforcement. Because this represents an improvement in data capture rather than a strict impact of safety, the metric is anticipated to stabilize in future reporting years.



A deeper analysis of the 500 reported crashes reveals trends regarding where these incidents are concentrated**:**

- **Roadway & Environment:** Over half of all work zone crashes occurred on the Interstate system, with **61%** taking place in urban environments where traffic density is highest.
- **Work Zone Area: 60%** of crashes occurred directly within or adjacent to the active work area, heavily outweighing crashes in the advance warning or transition areas. This suggests incidents stem primarily from navigating the narrowed geometry of the active workspace itself, rather than sudden upstream queuing.





The DOT continues to monitor specific crash characteristics and contributing factors, as shown below with five-year sparklines illustrating the recent trends for each category:

- **Speeding (342 crashes):** The most prevalent contributing factor.
- **Rear-End Collisions (278 crashes):** The dominant manner of collision.
- **CMV Involvement (117 crashes):** A significant portion of crashes involved commercial motor vehicles.

278 Rear-End Crashes

117 CMV involved Crashes

342 Speeding Crashes

Safety Targets

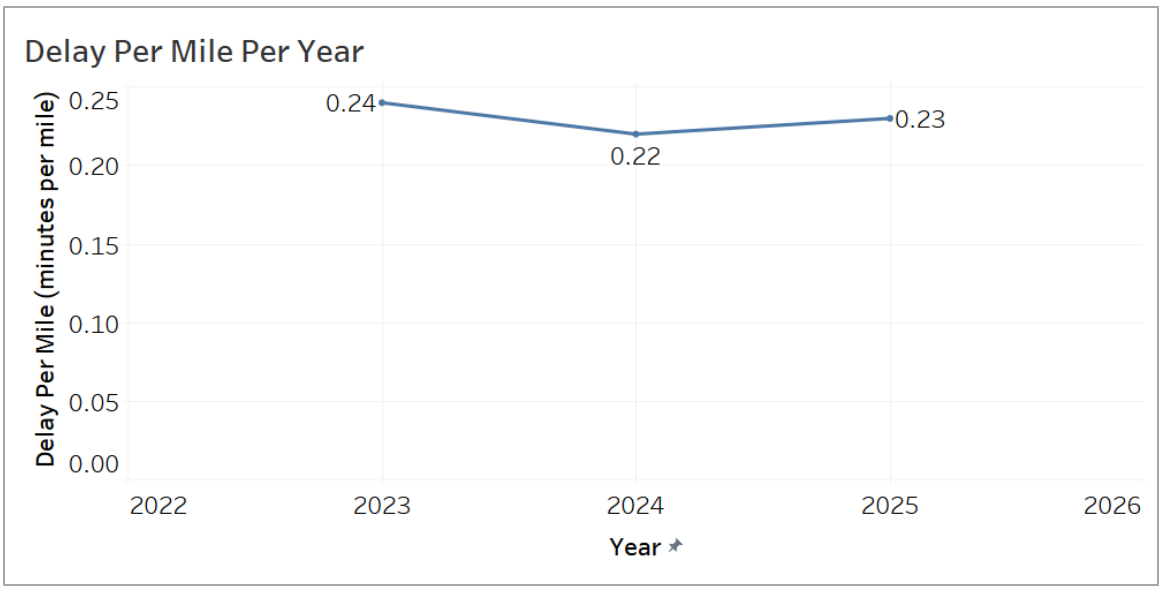
The primary safety performance target for the DOT is for 75% of work zones to operate at or below their pre-work zone crash rates. The agency successfully achieved this benchmark in 2023, with 76.9% of projects meeting the criteria. While recent reporting periods have fallen below this goal, the agency is actively implementing strategies to improve compliance, reverse this trend, and consistently meet or exceed the 75% target in future years.

3. Mobility Performance Compliance

To normalize mobility impacts, the primary metric evaluated is Mean Delay Per Mile. This is calculated by using the probe speed data which is provided every minute for ~1 mile segments through the work zone. The speed data is used to calculate the travel time through the work zones which is then compared to the historical speed and travel times through the area which accounts for any recurring delay. For executive reporting and public relatability, this metric is also converted to an Average Delay assuming a standard 5-mile work zone length.

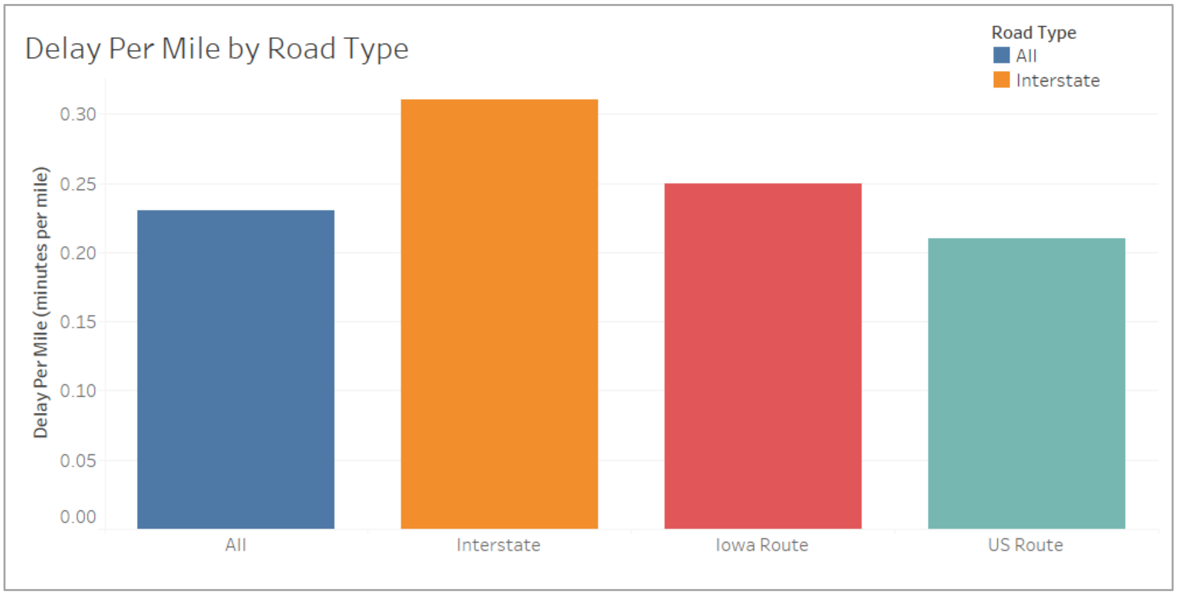
Mobility Trends

System-wide mobility performance remains highly stable. From 2023 through 2025, the overall system average hovered reliably between 0.22 and 0.24 minutes per mile. In 2025, the average was 0.23 minutes per mile (translating to roughly 54 seconds of total delay for a typical 5-mile work zone).



Breaking down the delay per mile by roadway classification reveals that operational impacts are heavily concentrated on high-volume corridors:

- **Interstates (AADT 31,280):** 0.31 minutes per mile (~93 seconds total delay)
- **Iowa Routes (AADT 3,960):** 0.25 minutes per mile (~75 seconds total delay)
- **US Routes (AADT 9,840):** 0.21 minutes per mile (~63 seconds total delay)

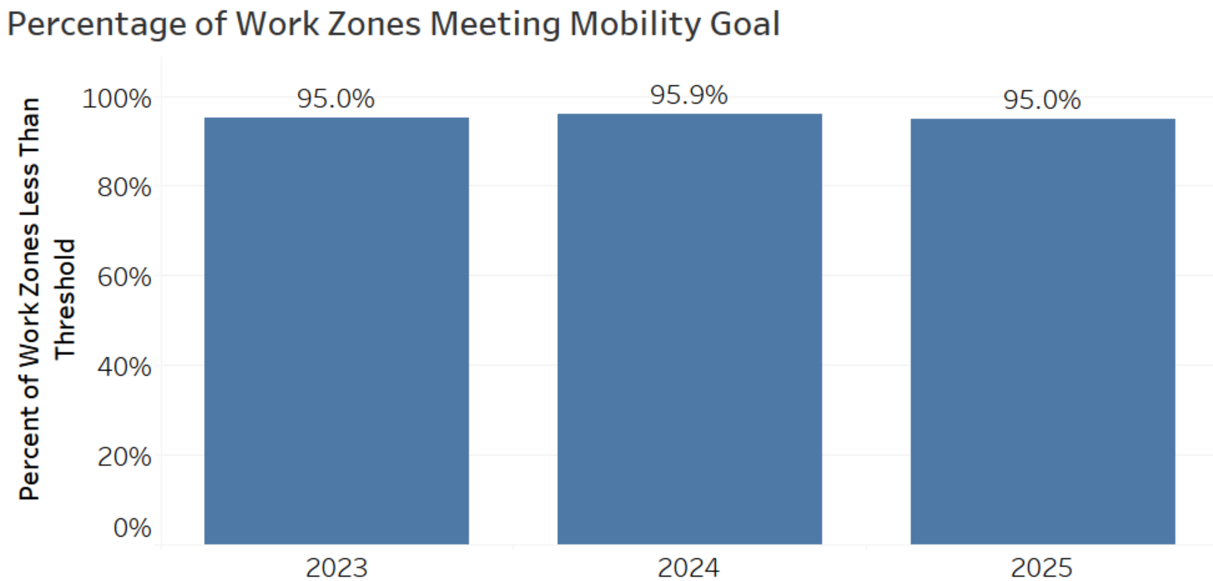


The top five work zones with the highest mobility impacts exceeded the allowable delay threshold, with delays ranging from 0.95 to 1.45 minutes per mile. A notable trend among these outliers is the correlation with high commuter traffic volumes (AADT up to 55,000) and localized bottlenecks. Work zone at I-80 MM 120-135 and I-35 MM 85-92 appear on both the safety and mobility outlier lists, indicating that traffic congestion and extended project constraints on these high-volume interstates impacted both mobility compliance and safety.

Work Zone	Road Type	AADT	Average Delay Per Mile (min)	Est. Total Delay (5-mi basis)
I-80 MM 120-135	Interstate	42,500	1.45	7 min 15 sec
I-35 MM 85-92	Interstate	38,100	1.25	6 min 15 sec
I-29 MM 60-65	Interstate	28,400	1.1	5 min 30 sec
US-218 MM 40-46	US Route	19,500	1.05	5 min 15 sec
SR-22 MM 15-18	State Route	7,200	0.95	4 min 45 sec

Mobility Targets

The DOT established mobility policy sets a maximum threshold of 0.8 minutes of delay per mile (4 minutes of total delay for a 5-mile project). As illustrated below, compliance with this target has remained consistently high over the past three years. In 2023 and 2025, 95.0% of monitored work zones successfully operated below the maximum delay threshold, with a slight peak of 95.9% in 2024. The current system-wide average of 0.23 minutes per mile (and the Interstate average of 0.31 minutes per mile) is operating well below the maximum allowable delay threshold. In future years, the DOT will evaluate establishing additional targets to further minimize delay for targeted work zones.



4. Action Plans

The data from this reporting cycle demonstrates that the agency is successfully maintaining robust mobility through its active construction projects. Delay metrics have remained consistent year-over-year and are operating well within established policy targets. On the safety front, the percentage of projects at or below the pre-work zone crash rate is below the DOTs current goal but overall work zone crash rates have decreased.

Annual Observations

The heavy concentration of total user delay and crash frequency on urban interstates reaffirms that these high-volume corridors require the most rigorous temporary traffic control planning. The use of commercial probe data and historical speed baselines successfully isolated the true operational impact of the work zones from standard recurring congestion.

Action Items

To transition these programmatic findings into actionable operational improvements, the following steps have been taken or will be as part of the annual review:

- **Safety Data Monitoring**: The Safety Office will continue monitoring monthly work zone crash reports to confirm the recent 21% reporting driven increase stabilizes, ensuring no new safety impact are developing on the urban interstate networks. This includes ongoing coordination with law enforcement to improve the accuracy of work zone crash coding.
- **Temporary Traffic Signal Operations**: Performance reporting identified higher mobility impacts on State Routes utilizing temporary signals for mobility impacts. After determining that several projects were using pre-timed, the Construction Office is

actively coordinating with District Resident Construction Engineers to ensure all temporary signals utilize fully actuated control per DOT policy, minimizing unnecessary delay.

- **Improve Exposure Data**: Currently, the DOT utilizes AADT to estimate traffic volumes through work zones which is used in calculating crash rates. Because this does not capture actual traffic during construction, the Construction Office will evaluate additional data sources to improve the accuracy of future safety and mobility performance measures.
- **Deploy Queue Warning Systems**: To actively address safety performance targets, the DOT will prioritize the deployment of Queue Warning Systems on high-volume interstate corridors. These systems are highly effective at reducing crash severity, directly aligning with current crash trends that show a high prevalence of rear-end collisions. To support this deployment, the Operations Office will lead the effort to identify and deploy queue warning systems over the next year.