U.S. Department
of Transportation
Federal Highway
Administration

Measuring Work Zone Mobility Performance Using the National Performance Management Research Data Set (NPMRDS)

Case Study: Application to the Texas Department of Transportation GO I-10 Project

July 2021

Notice

Quality Assurance Statement

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HOP-20-029	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Performance Using the National Performance Management Research Data Set (NPMRDS) Case Study: Application to the Texas Department of Transportation GO I-10 Project		5. Report Date July 2021 6. Performing Organization Code:
7. Author(s) Alan Pate, Param Sankar, Filmon Habtemichael		8. Performing Organization Report No.
9. Performing Organization Name and Address Battelle 505 King Avenue Columbus, OH 43201		10. Work Unit No. 11. Contract or Grant No. DTFH61-16-D-00049 / 693JJ318F000184
12. Sponsoring Agency Name and Address United States Department of Transportation Federal Highway Administration 1200 New Jersey Ave. SE Washington, DC 20590		13. Type of Report and Period 14. Sponsoring Agency Code HOP
15. Supplementary Notes Jawad Paracha (FHWA – HOTO)		

16. Abstract

FHWA is engaging with State Departments of Transportation (DOTs) and conducting research to understand work zone mobility performance measurement best practices, challenges, and opportunities. The information will be used to increase awareness on data, tools, and methods for systematic work zone performance measurement across all stages of project development including planning, design, construction, and post-construction. Topics of interest include use of probe data and mainstreaming performance measures into agency policies and processes, including work zone process reviews and incorporating work zones into transportation system management & operations (TSMO) initiatives. This case study is one of a series of resources on work zone mobility performance measurement. It demonstrates how the National Performance Management Research Data Set (NPMRDS) can be used to measure work zone mobility performance. The NPMRDS contains probe-vehicle-based speed and travel time data for major highways and roadways across the United States. A real-world road construction project (Texas DOT's GO I-10 Project in El Paso, TX) is used to illustrate a simple, repeatable process that State DOTs can use to measure work zone mobility performance.

17. Key Words Work zone mobility performance measurement, NPMRDS	18. Distribution Statement No restrictions.		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 50	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

List of Figures

List of Tables

List of Abbreviations and Acronyms

AADT	Average Annual Daily Traffic
Caltrans	California Department of Transportation
DOT	Department of Transportation
FHWA	Federal Highway Administration
MPO	Metropolitan Planning Organization
NHS	National Highway System
NPMRDS	National Performance Management Research Data Set
ODOT	Ohio Department of Transportation
TMC	Traffic Message Channel
TOC	Traffic Operations Center
TSMO	Transportation System Management & Operations
TxDOT	Texas Department of Transportation
WZAD	Work Zone Activity Data
WZDI	Work Zone Data Initiative

Overview

This case study demonstrates how the National Performance Management Research Data Set (NPMRDS) can be used to measure work zone mobility performance.[1] The NPMRDS contains probe-vehicle-based speed and travel time data for major highways and roadways across the United States. The Federal Highway Administration (FHWA) provides the NPRMDS free of cost to State Departments of Transportation (DOTs).[2] A real-world road construction project (Texas DOT's GO I-10 Project in El Paso, TX) is used to illustrate a simple, repeatable process that State DOTs can use to measure work zone mobility performance.

The National Performance Management Research Data Set and Work Zone Mobility Performance Measurement

Performance measures enable agencies to monitor their transportation system and identify improvements or mitigation strategies as needed. They serve as indicators for the effects of any changes to the transportation system, such as the introduction of a work zone. Key work zone mobility performance measures include travel time, speed, delay, queues, throughput, travel time reliability, and road user costs.[3]

Traditionally, transportation agencies have struggled to accurately measure and monitor the mobility performance of their work zones due to a lack of data —both mobility data and accurate work zone activity data. One solution to a lack of mobility data is the NPMRDS, which provides mobility data collected anonymously from a fleet of probe vehicles (i.e., cars and trucks) equipped with mobile devices. Using time and location information from probe vehicles, the NPMRDS generates speed and travel time data aggregated in 5-minute, 15-minute, or 1-hour increments. The variable data granularity offered by the NPRMDS allows users to customize their analyses according to their desired level of granularity. The data are available across the National Highway System (NHS), with a spatial resolution defined by Traffic Message Channel (TMC) location codes. A TMC represents a unique, directional roadway segment that is about half a mile to a mile long in urban and suburban areas and could be as long as five to ten miles long in rural areas. The NPMRDS covers more than 400,000 TMCs and includes several billions of speed and travel time observations across the NHS for both freeways and arterials. The NPMRDS has been available since 2013, with freeway data dating back as far as 2008. Please

[1] Note on work zone safety – This document focuses on work zone mobility performance measurement and management. The authors recognize that work zone safety is paramount and that safer work zones contribute to better mobility performance. However, safety performance measurement and the interplay between safety and mobility is not a focus of this document.

[2] https://npmrds.ritis.org

[3] As the phrase is used in this document, "performance measures" do not refer to those performance measures required under FHWA regulations. Rather, "performance measures" refer to mobility performance measures that are widely accepted and used by State and local practitioners and industry.

refer to the accompanying NPMRDS fact sheet for details on using NPMRDS data for work zone performance management.[4]

An example of how State DOTs can use NPMRDS data to systematically measure work zone mobility performance using a 10-step process is shown in figure 1. The process draws upon existing FHWA resources on transportation and work zone performance measurement but is specifically customized to using the NPMRDS as the data source. NPMRDS travel time and speed data are the foundational mobility metrics for this process. Using these foundational metrics as a basis, State DOTs can calculate a variety of performance metrics (e.g., work zone travel time, speed, delay, travel time variability, and road-user costs). The process provides for a systematic, repeatable, inexpensive, and easy-to-adopt process for work zone performance measurement. A detailed discussion of the 10 steps is provided in the Appendix.

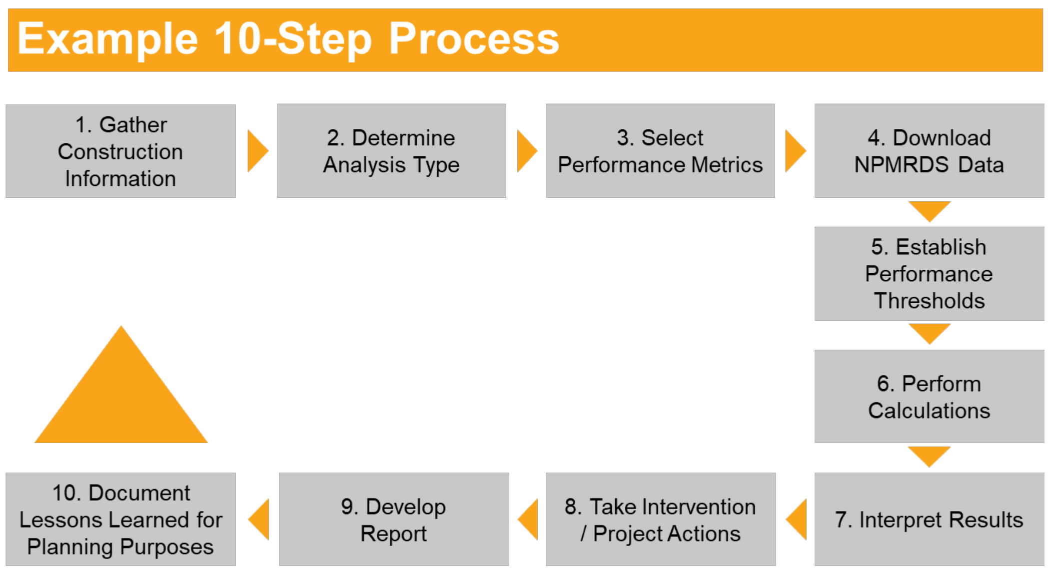


Figure 1. Chart. Example process for estimating work zone mobility impacts using the National Performance Management Research Data Set
Source: FHWA

[4] The National Performance Management Research Data Set (NPMRDS) and Application for Work Zone Performance Measurement, FHWA-HOP-20-029, https://ops.fhwa.dot.gov/wz/decision_support/perf_meas_examples.htm

Agencies can use NPMRDS data to systematically analyze work zone mobility performance, take appropriate remedial actions, and better manage the mobility performance of their work zones[5], including:

Managing and Monitoring the Performance of Individual Projects

- Developing a baseline of system performance prior to implementation of the work zone
- Estimating work zone mobility impacts during planning and design
- Conducting ongoing[6] and post-hoc work zone mobility performance measurement and management

Corridor-, District-, and/or Agency-Level Work Zone Reporting and Management

- Aggregating work zone performance at the corridor, network, region/district, and agency-wide levels
- Comparing and trending across different projects, project types, and work zone activity types
- Incorporating work zone performance measures into annual mobility reports and broader Transportation System Management & Operations (TSMO) efforts
- Incorporating work zone performance measures into the Congestion Management Process as part of a cause of congestion (non-recurrent)

Incorporating Work Zone Performance Measures into Bi-Annual Work Zone Performance Reviews

- Using quantitative NPMRDS measures to supplement and substantiate qualitative process review findings
- Correlating measured performance against agency actions and improvements
- Comparing performance across years, identifying cause and effect, and taking improvement actions

[5] The work zone safety and mobility provisions under 23 CFR 630 Subpart J (https://www.ecfr.gov/current/title-23/chapter-I/subchapter-G/part-630/subpart-J) require States to continually pursue improvement of work zone safety and mobility by analyzing work zone crash and operational data from multiple projects to improve work zone processes and procedures.
[6] Applicable to projects that last longer than a month. NPMRDS data are updated monthly; the prior month's data are usually available by the fifth of every month.

GO I-10 Construction Project Overview

GO I-10 was a 5.75-mile design-bid-build project along I-10 in El Paso, Texas, as shown in figure 2.[7] The project lasted about four years, with an estimated cost of $158 million. Due to the geographical constraints of the work zone site, there were limited alternate routes where traffic could be diverted while construction activities were in progress.

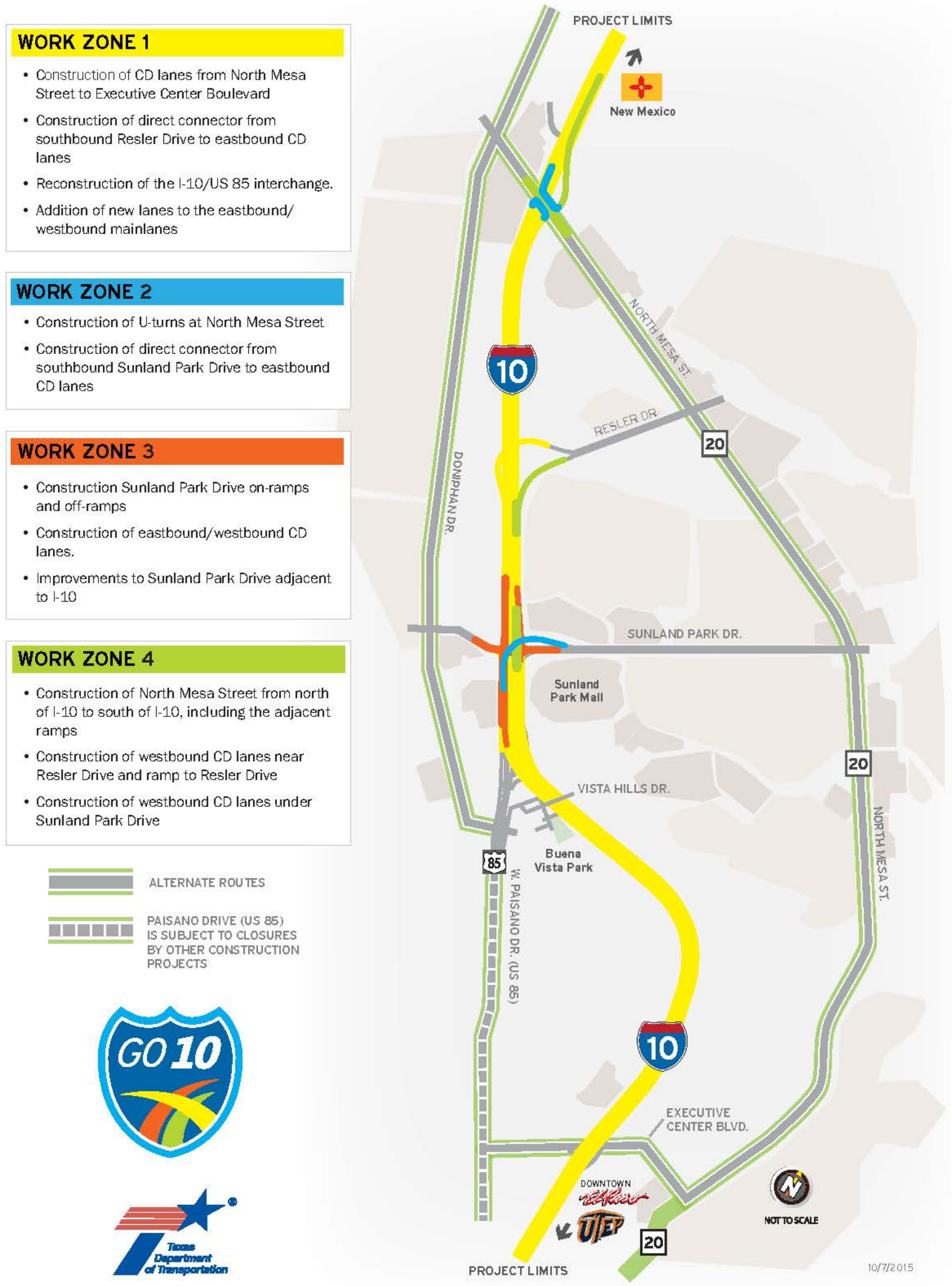


Figure 2. Map. Advanced, Work Zone, and Transition Areas of GO I-10 Project
Source: Texas Department of Transportation

[7] Project communications with Texas Department of Transportation.

The Texas Department of Transportation (TxDOT) performed the following improvements as part of the I-10 reconstruction:

- New collector-distributor lanes through the corridor
- Direct connection with US 85 and the Border West Expressway
- Intermittent addition of lanes to I-10 in both directions
- Reconfiguration of ramps and overpasses
- Upgrades to frontage roads, such as improved turning lanes, drainage, and turnarounds

TxDOT continuously shared work zone information with the public through different media channels to improve public awareness about the project, communicate work activity and lane closure information, increase traveler satisfaction, eliminate surprises, minimize any negative publicity, and encourage travelers to use alternative routes. This publicly available work zone activity information was a key reason why FHWA chose the GO I-10 project for this case study.

Case Study Analyses

The case study analyses, performed according to the previously described 10-step process, are presented in the following subsections.

Construction and Project Information

Given that the GO I-10 project involved both major rehabilitation efforts and new infrastructure construction, the TxDOT El Paso District undertook a comprehensive effort to inform the public about actual and cancelled construction activities through an extensive media campaign. The TxDOT El Paso District issued press releases with information on each lane closure three weeks in advance. As a result, extensive project and work zone information was available for this case study.

Analysis Type

The objective of this case study is to present an analytical procedure for measuring actual work zone performance. Therefore, the analysis presented herein is descriptive and exploratory, rather than predictive or prescriptive, which are both better suited for predicting and managing future performance. The case study presents two different applications of the process:

- **Scenario 1 – A hypothetical scenario for measuring work zone performance during construction as though the GO I-10 project is currently underway.** This scenario illustrates how agencies can monitor and manage work zone mobility performance during the construction phase.
- **Scenario 2 – Post-hoc work zone performance measurement for a longer time period.** This scenario illustrates how agencies may conduct post-hoc mobility performance measurement using NPMRDS data.

Table 1 and table 2 provide the analysis parameters used for the two scenarios, respectively.

Table 1. Analysis parameters for GO I-10 Scenario 1

Analysis Purpose	Work zone mobility performance measurement during construction (hypothetical, illustrative)
Analysis Tool	Microsoft® Excel • Excel is the most commonly used data analysis software, plus the monthly NPMRDS data volumes are manageable. • As the coverage time period (and data granularity) increases, the file sizes can grow too big for Excel, in which case other tools such as SAS®, Tableau®, or R may be better suited.
Baseline Period	Two years prior to construction start
Work Zone Data Period	November 2015 to April 2016 • Incremental monthly work zone performance is calculated for a six-month period

Source: FHWA

Table 2. Analysis parameters for GO I-10 Scenario 2

Analysis Purpose	Post-hoc work zone mobility performance measurement
Analysis Tool	R statistical analysis software • Because the data extend across two years (including the baseline), R was used to speed up and automate the analysis process.
Baseline Period	Two years prior to construction start
Work Zone Data Period	November 2015 to December 2017

Source: FHWA

Performance Metrics and Visualizations

The case study project team calculated the following performance metrics for Scenarios 1 and 2 mentioned above:

- Average travel time and speed for baseline and work zone conditions
- Number of underperforming instances (hours) when observed travel time was higher than the threshold, and the average travel time for each underperforming hour
- Average speeds for baseline and work zone conditions
- Travel time reliability metrics – Travel Time Index and Planning Index
- Road user costs

The case study project team developed the following charts using the metrics:

- Heat maps showing speeds for the different work zone areas
- Line graphs showing average travel time and speeds by month, day of week, and hour
- Box plots showing hourly, daily, and seasonal travel time variation
- Line graphs showing travel time index and planning time index
- Bar graphs and line graphs showing aggregated delays

NPMRDS Data Download

The following are the data download parameters chosen for the GO I-10 case study:

- **Work zone area of interest.** This case study included only the mainline I-10 corridor in the work zone area of interest; frontage roads, nearby arterial streets, or other network elements were not included. The advance area was four miles upstream of the work zone, and the termination area was two miles downstream of the work activity area. This allowed the analysis to capture both queue buildups and discharges. When mapped to NPMRDS Traffic Message Channel (TMC) segments, the resultant corridor consists of 30 TMC segments.
- **Data aggregation (averaging).** A one-hour aggregation interval was used because it offers a good balance between analysis granularity and data volume. As a general guide, agencies may start with a one-hour aggregation interval and graduate down to lower levels of granularity depending upon the specific analysis needs and work zone characteristics. for example, more granular data aggregations are generally more appropriate for more detailed and micro-level simulation and queuing analyses to study specific highway sections or localized congestion problem spots.[8]
- **Data elements.** Average observed travel times, speeds, and the reference speeds (free flow speeds) were downloaded for each of the 30 TMCs for the baseline and work zone periods. The case study project team cleaned the downloaded data by imputing missing and incomplete entries, thereby avoiding bias in calculating average travel time. This analysis uses only passenger vehicle data (i.e., does not include truck data).

Performance Thresholds

Travel time was the analysis focus for this case study. A threshold of 25-percent increase from the average travel time was used to identify instances where the corridor underperformed (i.e., users experienced unacceptable delays). The case study project team applied the 25-percent threshold independently for the baseline and the work zone periods, represented by the following formulae:

- Baseline Threshold Travel Time = 1.25 x (Average Travel Time during baseline period)
- Work Zone Threshold Travel Time = 1.25 x (Average Travel Time during work zone period)

This approach of calculating threshold travel times independently for the baseline and work zone periods accounts for adjusted travel time expectations that the traveling public may have for the work zone period (i.e., they may expect some increase in travel time due to the work zone).

This case study focuses on travel time, so it did not apply thresholds for any of the other measures. Agencies may choose to apply thresholds for other metrics including speed, travel time reliability, and road-user costs.

[8] Additional resources and examples of different types of work zone analyses are available on the FHWA's Work Zone Performance Measurement website at https://ops.fhwa.dot.gov/wz/decision_support/perf_measurement.htm.

Calculations and Results: Scenario 1 – Hypothetical Scenario as though the GO I-10 Project is Currently Underway

Corridor travel time and corridor speed are two foundational metrics for mobility performance. The simplest way to aggregate travel times across multiple, sequential TMCs is to sum the individual TMC travel times at a given time of day to calculate the average travel time for the corridor. Average corridor speed at a given time of day is computed by dividing the length of the corridor by the travel time. Refer to Step 6 in the appendix for additional details on methods to calculate these metrics.

The case study project team used the Estimated Travel Time method to calculate the average corridor travel time, and then divided the travel time by the corridor length to calculate the average speed. Then, the impact of the work zone activities for the six-month construction period was compared with the baseline traffic conditions observed in the preceding one year before construction.

The following steps were taken for the analysis:

- Determined the average hourly travel times for the baseline and work zone periods
- Applied the 25-percent threshold to identify underperforming instances for both the baseline and work zone periods (i.e., hours when the corridor travel time exceeded 125 percent of the average travel time)
- Tallied the total number of underperforming hours and the magnitude of underperformance

This section focuses on a trend analysis of traffic operations during the baseline period and when the GO I-10 project was underway. Trends on corridor performance, average daily travel time, travel time variability, and average delays are presented below.

Corridor Performance Trends

Table 3 and table 4 summarize the average travel time, threshold travel time, and the count of instances (i.e., one-hour interval) when traffic underperformed both in the baseline period and during work zone conditions in the eastbound and westbound directions of travel, respectively.

The following are the key takeaways from the metrics presented in table 3 and table 4:

- Overall, the average travel time for the corridor increased marginally during the first six-month work zone period when compared with the baseline period. However, in some months the average underperforming travel time during work zones was lower compared to the baseline (e.g., in January 2016).
- In general, the work zone impacts in the eastbound direction were comparatively higher than those in the westbound direction.
- On average, the count of underperforming instances during the work zone activities increased by 37 percent and 15 percent in the eastbound and westbound directions, respectively, compared to the baseline period. However, the count of underperforming instances during work zone activity in January 2016 was lower compared to the baseline condition. The extent of the underperforming instances (in terms of average

underperforming travel times) was highest in November 2015 and April 2016 in the eastbound direction during work zone period. Similarly, in the westbound direction, the extent of the underperforming instances was highest in December 2015 and March 2016, while the travel time in the other months was actually less than the baseline condition.

- The average travel time during the work zone period in the winter months was lower than what was observed in the one-year baseline period. However, when the travel times in these months were compared to the travel times in the same months of the previous year, there was a marginal increase.

Table 3. Scenario 1 - Underperforming instance counts and average travel times in eastbound direction

Condition	Time Period	Average Travel Time (min)	Threshold Travel Time (min)	Count of Underperforming Instances	Average Underperforming Travel Time (min)
Baseline	Nov-14 to Oct-15	10.6	13.3	616 (~51 per month)	20.5
Work Zone	Nov-15 to Apr-16	11.0	13.8	422 (~70 per month)	21.7
	Nov-15	11.1	13.9	62	22.9
	Dec-15	11.2	14.0	80	21.4
	Jan-16	10.1	12.6	39	17.7
	Feb-16	10.6	13.3	57	19.5
	Mar-16	11.5	14.4	92	21.5
	Apr-16	11.8	14.7	92	24.3

Source: FHWA

Table 4. Scenario 1 - Underperforming instance counts and average travel times in westbound direction

Condition	Time Period	Average Travel Time (min)	Threshold Travel Time (min)	Count of Underperforming Instances	Average Underperforming Travel Time (min)
Baseline	Nov-14 to Oct-15	10.3	12.9	774 (~65 per month)	17.6
Work Zone	Nov-15 to Apr-16	10.4	12.9	422 (~75 per month)	17.4
	Nov-15	10.2	12.7	65	16.8
	Dec-15	10.5	13.2	82	18.6
	Jan-16	9.9	12.4	57	15.9
	Feb-16	10.2	12.8	70	16.5
	Mar-16	11.1	13.9	105	19.6
	Apr-16	10.2	12.7	71	15.6

Source: FHWA

Hourly Average Travel Time Trends

Figure 3 and figure 4 show the trend of the hourly average travel time by day of week in the eastbound and westbound directions, respectively, during the first six months of construction. For example, the hourly average travel times on Monday in November is calculated by averaging the travel times of all Mondays in November by hour of day. In the eastbound direction, travel time was the highest during the morning peak hours and is sustained through afternoon and evening hours. As discussed earlier, the month of January did not experience excessive increase in travel time compared to the other months, while April experienced the highest increase in travel time. Saturday experienced the highest variability in travel time, followed by Monday and Wednesday, while Sunday experienced the least variability. On the other hand, in the westbound direction, travel time was the highest mostly in the afternoon peak hours. The highest travel time was experienced in March, while the lowest was in January.

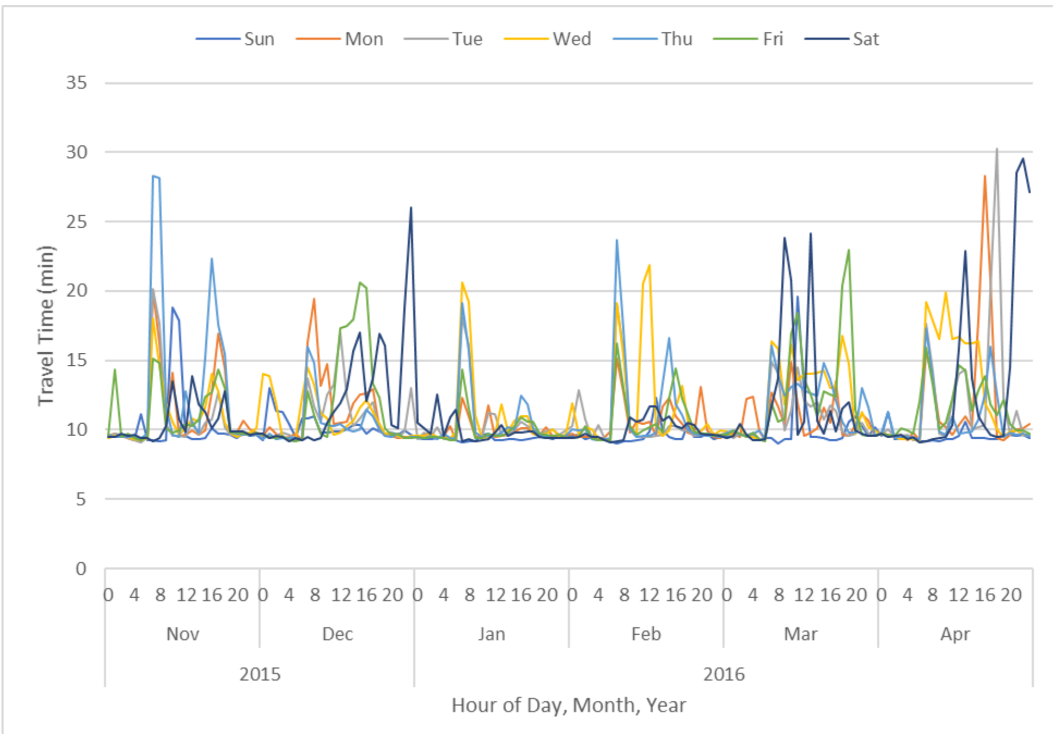


Figure 3. Graph. Scenario 1 - Average hourly travel times during the first six-month construction period in eastbound direction

Source: FHWA

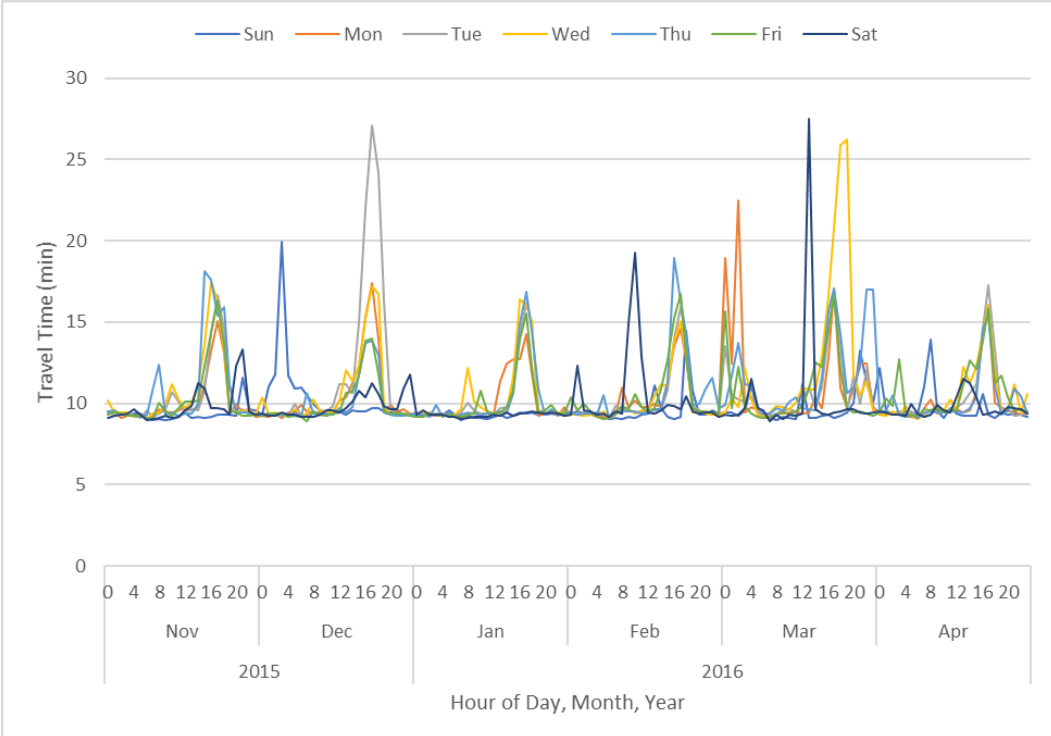


Figure 4. Graph. Scenario 1 - Average hourly travel times during the first six-month construction period in westbound direction

Source: FHWA

Travel Time Variability When Traffic Underperformed

Figure 5 and figure 6 show the variability of travel time in the first six-month construction period when traffic underperformed (i.e., when the observed travel time was higher than the threshold travel time) in the eastbound and westbound directions, respectively. The boxplots show the distribution of travel time in different months, which provide some insight into the travel time variability. In the eastbound direction, March experienced the highest travel time variability followed by December and November. January and February experienced the least variability in travel time. Conversely, travel time variability was fairly stable in the westbound direction except in March when it was slightly higher compared to the other months. In comparison to the eastbound direction, the westbound direction experienced lower variability in travel time.

Note: The graphic to the right shows how to interpret the box plots shown in figure 5 and figure 6. A key takeaway from these charts is that the NPMRDS provides a rich history of 24/7 data, which agencies can use for variability and trend analyses that will help them better understand what drives work zone performance.

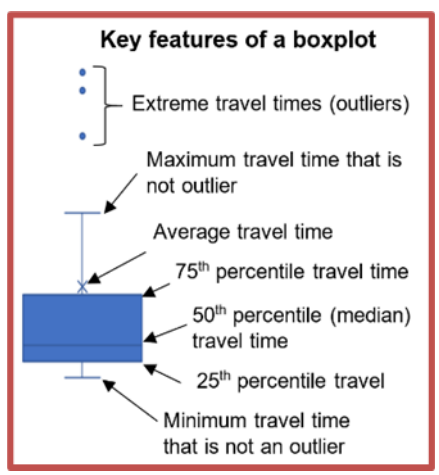


Figure 5. Graph. Scenario 1 - Travel time variability during the first six-month construction period when traffic underperformed in eastbound direction
Source: FHWA

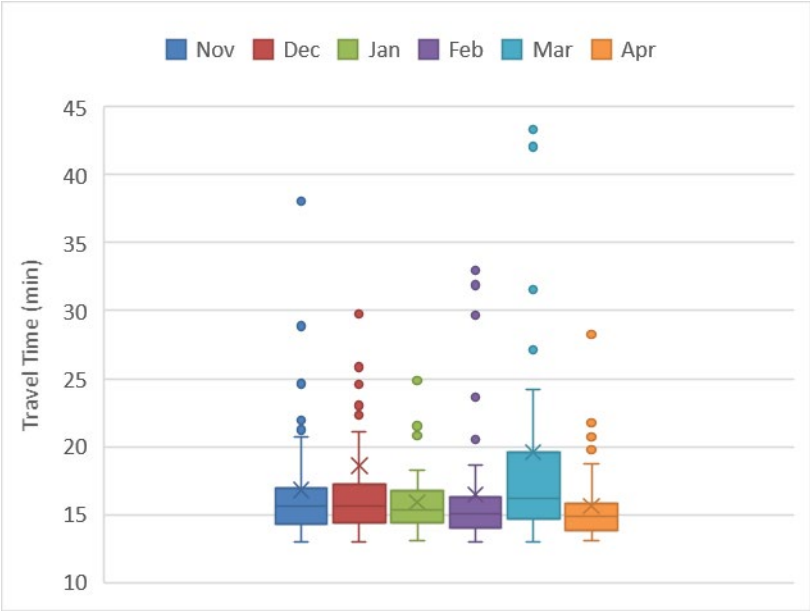


Figure 6. Graph. Scenario 1 - Travel time variability during the first six-month construction period when traffic underperformed in westbound direction
Source: FHWA

Delay Trends

Figure 7 and figure 8 show the total delay by hour of day aggregated on a monthly basis when traffic underperformed (i.e., when average hourly travel times exceeded the threshold travel time) during the first six months of work zone activities in the eastbound and westbound directions, respectively. Delay is computed as the difference between the observed travel time and the travel time threshold.

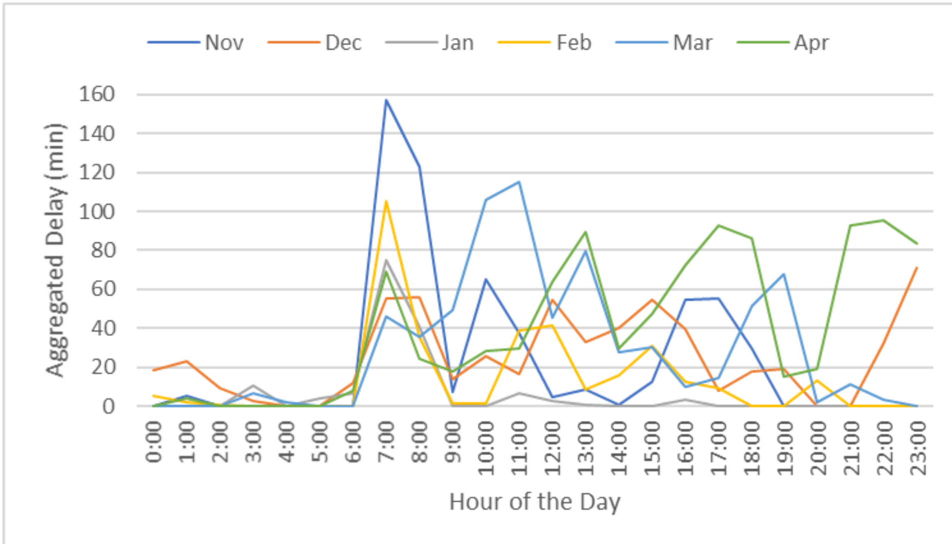


Figure 7. Graph. Scenario 1 - Delay trends during the first six-month construction period in eastbound direction
Source: FHWA

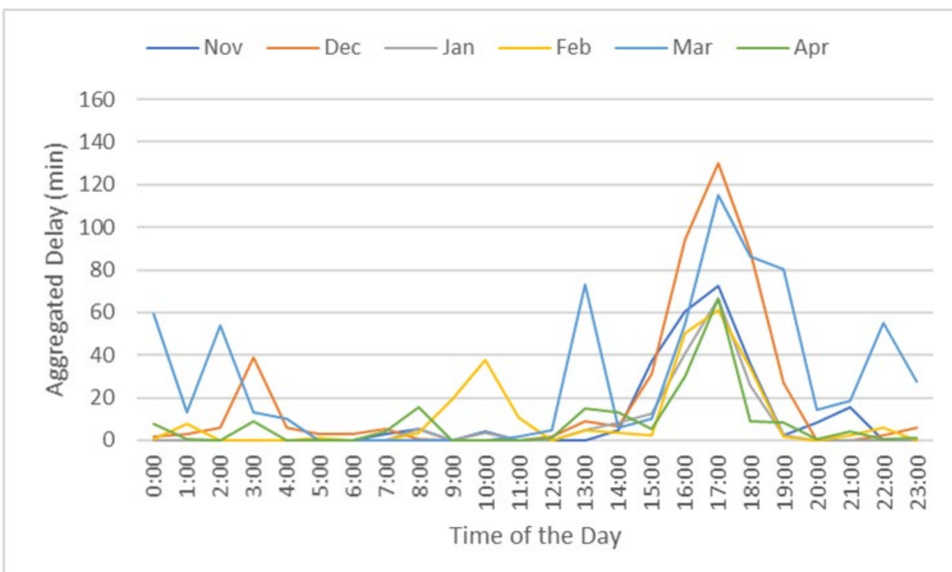


Figure 8. Graph. Scenario 1 - Delay trends during the first six-month construction period in westbound direction
Source: FHWA

These charts help in understanding what hours of the day had the highest total delay for the month, along with how delays trended across the first six months of construction. In the eastbound direction, the pattern of the delay was inconsistent, although typically the delay occurred in the morning peak hours. November had higher delays in the morning peak hours, with some delays in mid-day and late afternoon hours. In December, the delays were concentrated in the morning peak hours and afternoon hours, with some delays around midnight. January saw delays only during the morning peak hours. Most of the delays in February were in the morning peak hours, with some delays around mid-day. The delays in March were mostly experienced around mid-day, with some delays in the evening. April experienced a unique delay pattern, with heavy delays spread across the morning peak, early afternoon, late afternoon, and late evening hours. Conversely, the delays in the westbound direction were relatively consistent in pattern, and most of the delays occurred in the afternoon peak, with some delays in the early night hours. Overall, December and March experienced the highest delays, while January experienced the least. In general, the delay extent in the eastbound direction was higher than the westbound direction.

Using NPMRDS data, agencies can analyze trends across key performance measures to evaluate the impact of work zone activities and try to understand how those impacts evolve as construction progresses. Such trend analyses (coupled with mobility, travel behavior, weather, and other data) could assist agencies to learn which strategies worked well, which did not, and how those strategies can be adjusted in the future. Trend analysis is not only useful for historical performance analysis but also for developing future projections of work zone performance, which can lead to better work zone planning and impact mitigation.

Calculations and Results: Scenario 2 – Post-hoc Work Zone Performance Measurement for a Longer Time Period

Corridor travel time and corridor speed are two foundational metrics for mobility performance. One way to aggregate travel times across multiple, sequential TMCs is to sum the individual TMC travel times at a given time of day to calculate the average travel time for the corridor. Average corridor speed at a given time of day is computed by dividing the length of the corridor by the travel time. Refer to Step 6 in the appendix for additional details on methods to calculate these metrics.

The case study project team used the Estimated Travel Time method to calculate the average corridor travel time, and then divided the travel time by the corridor length to calculate the average speed. Then, the impact of the work zone activities during the first two years of construction was compared with the baseline traffic conditions observed in the preceding two years before construction.

The following steps were taken for the analysis:

- Determined the average hourly travel times for the baseline and work zone periods
- Applied the 25-percent threshold to identify underperforming instances for both the baseline and work zone periods (i.e., hours when the corridor travel time exceeded 125 percent of the average travel time)
- Tallied the total number of underperforming hours and the magnitude of underperformance

The case study project team did not consider the effects of other influencing factors (e.g., incidents, crashes, adverse weather conditions, special events) on corridor performance.[9] Agencies may choose to consider and appropriately discount data points reflective of excessive delays caused by these external factors.

Overall Corridor Performance

Table 5 summarizes the average travel time, threshold travel time, and the count of instances (i.e., one-hour intervals) when traffic underperformed both in the baseline period and during work zone conditions in each direction of travel.

Table 5. Scenario 2 - Underperforming instance counts and average travel times in eastbound direction

Condition	Travel Direction	Average Travel Time (min)	Threshold Travel Time (min)	Count of Underperforming Instances (1-hour periods)	Average Underperforming Travel Time (min)
Baseline	Eastbound	9.7	12.1	1,676	20.1
	Westbound	9.4	11.8	1,611	16.9
Work Zone	Eastbound	10.2	12.8	3,020	21.1
	Westbound	10.0	12.5	2,256	19.5

Source: FHWA

The following are the key takeaways from the metrics presented in table 5:

- The average travel time for the corridor increased marginally during the work zone period when compared with the baseline period.
- For a comparable two-year timeframe, the number of underperforming hours was about 60 percent higher during the work zone period. On average, the extent of the under-performance also was higher during the work zone period (i.e., an increase of 1.0 minutes or 4 percent for the eastbound traffic and 1.6 minutes or 9 percent for westbound traffic).
- The work zone impacts in the eastbound direction were comparatively higher than those in the westbound direction.

The case study project team also calculated the number of days that motorists were exposed to underperforming traffic conditions. Over the two-year construction period, there were 659 days with one or more underperforming instances in the eastbound direction, while there were 598 days in the westbound direction. Comparatively, the number of days with one or more underperforming instances in the baseline period in the eastbound and westbound directions was 538 and 523, respectively.

[9] The case study project team examined incident and crash data from TxDOT (including Dynamic Message Sign messages) but did not use them because not enough background was available to be able to correlate the data with what may have actually happened on a given day. Therefore, the incident and crash data were disregarded.

Average Traffic Speed

The typical delays on the construction site can be represented by the decrease in the average traffic speed along the 10-mile corridor. Figure 9 uses a heat map to illustrate the average speed in the eastbound direction, both in the baseline and work zone conditions, when traffic underperformed. The start and end of the work zone locations are indicated by the dotted lines. The chart also highlights the location of multiple ramps from and to I-10, CanAm Highway Route 85, and Sunland Park Drive (which give access to nearby shopping areas and the border crossing to Mexico). In general, the average traffic speed under work zone conditions was mostly lower than the baseline scenario. In the eastbound direction, congestion was apparent during the day when construction activities were in progress, specifically during the morning peak and early afternoon hours. In addition, most of the congestion due to the work zone activities occurred within the construction site (i.e., traffic was free flowing both upstream and downstream of the work zone).

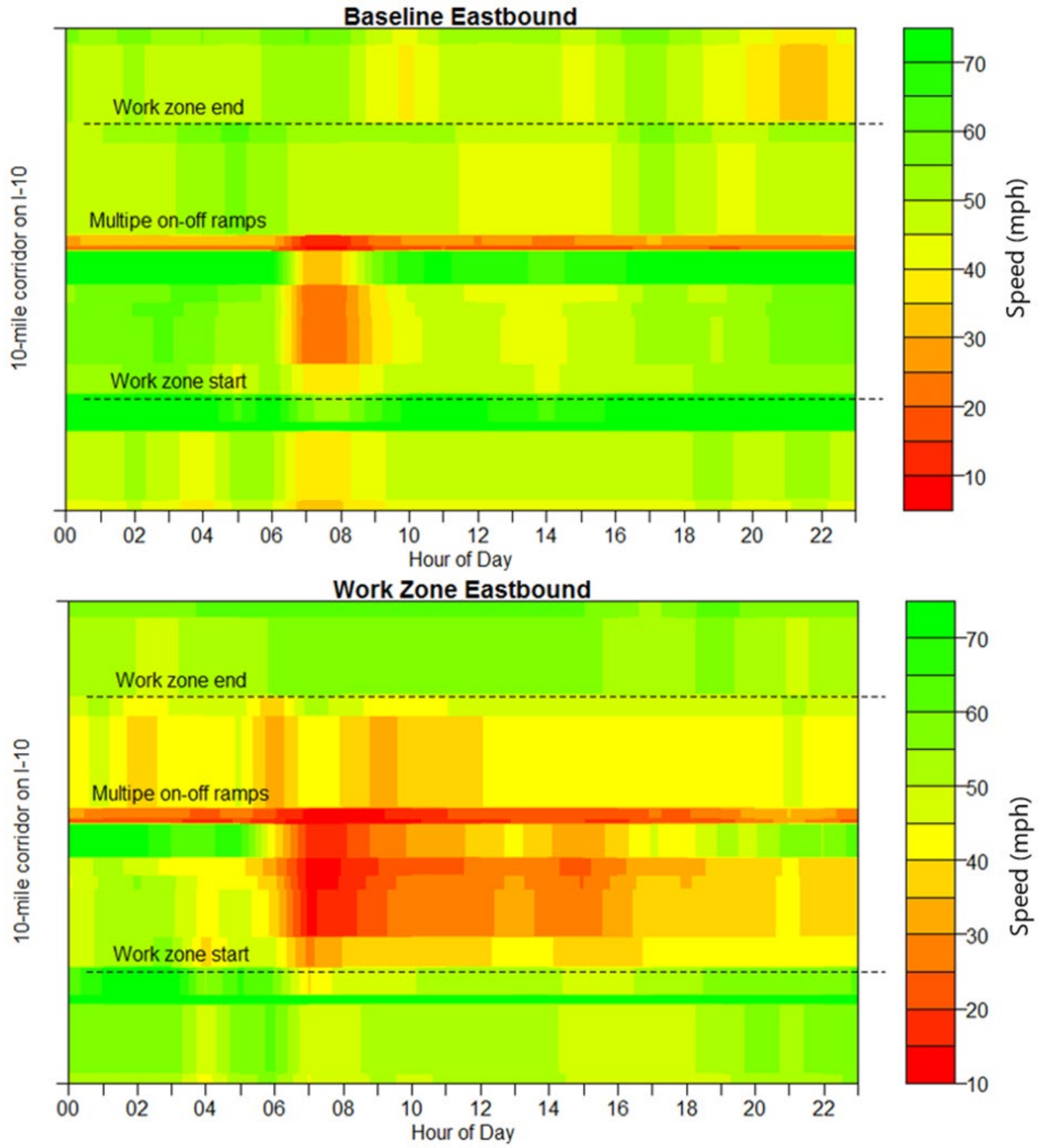


Figure 9. Graph. Scenario 2 - Average traffic speed during baseline and work zone conditions in eastbound direction
Source: FHWA

Similarly, figure 10 shows the average traffic speed along the 10-mile corridor in the westbound direction. The westbound traffic experienced fewer delays compared to eastbound traffic. The typical congestion due to work zone activities occurred during the afternoon peak hours and was located upstream of the construction site. In addition, there was slight congestion in the early morning and late evening hours that occurred at the beginning of the construction site.

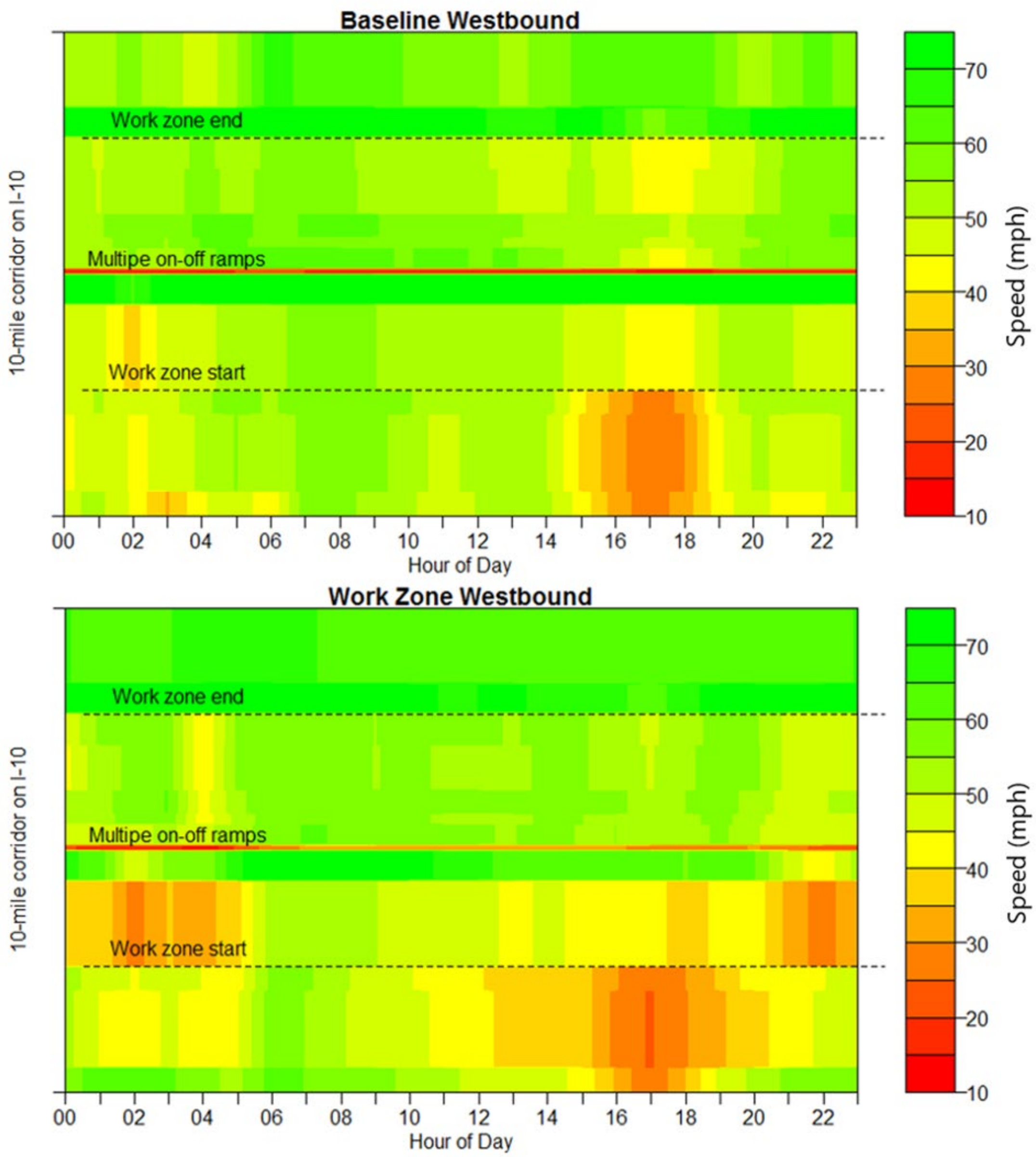


Figure 10. Graph. Scenario 2 - Average traffic speed during baseline and work zone conditions in westbound direction

Source: FHWA

Such figures assist in visualizing where and when congestion occurred and thus can be useful to adjust traffic control strategies to mitigate the impact of work zone activities. Similarly, these observations can help traffic engineers identify an optimal location for placing queue warning systems or dynamic message signs to inform travelers about upcoming traffic conditions.

Hourly, Daily, and Seasonal Travel Time Variability

Traffic is dynamic with different daily, weekly, and seasonal patterns. Examining the distributions of travel time across the hours of the day, days of the week, and months of the year can capture the impact of work zone activities in a variety of traffic patterns. Such analysis will enable agencies to better understand work zone traffic and travel time patterns and appropriately adjust their work zone management strategies. The NPMRDS provides 24/7 data coverage of the entire NHS. It enables engineers and analysts to better understand temporal and spatial variability in transportation system performance and is a rich data resource for performance-driven work zone management.

Figure 11 shows the distribution of hourly travel times during the baseline and work zone underperforming conditions (i.e., when hourly travel times exceeded the threshold travel time) in the eastbound and westbound directions. Note that the baseline condition refers to the two-year time period before construction started (November 2013 through October 2015), and work zone conditions refer to the two-year time period after the construction project started (November 2015 to December 2017). Overall, the hourly travel times during work zone activities were consistently higher than the corresponding travel times in the baseline conditions. Increases in the average hourly travel times due to work zone activities were observed in the morning and afternoon peak hours in the eastbound direction. In the westbound direction, the majority of the increased travel times were observed in the afternoon peak hours and late evening hours. In many cases, the interquartile range of the hourly travel times during the work zone period was higher than the baseline period. This suggests an increase in unreliability of travel time (i.e., higher variability in travel time) during the work zone period. However, there could be confounding variables that the case study project team was not able to control in this analysis because of lack of access to additional information such as weather conditions, work zone activity, work zone traffic management strategies, and incidents, as well as changes in regional travel behavior and options.

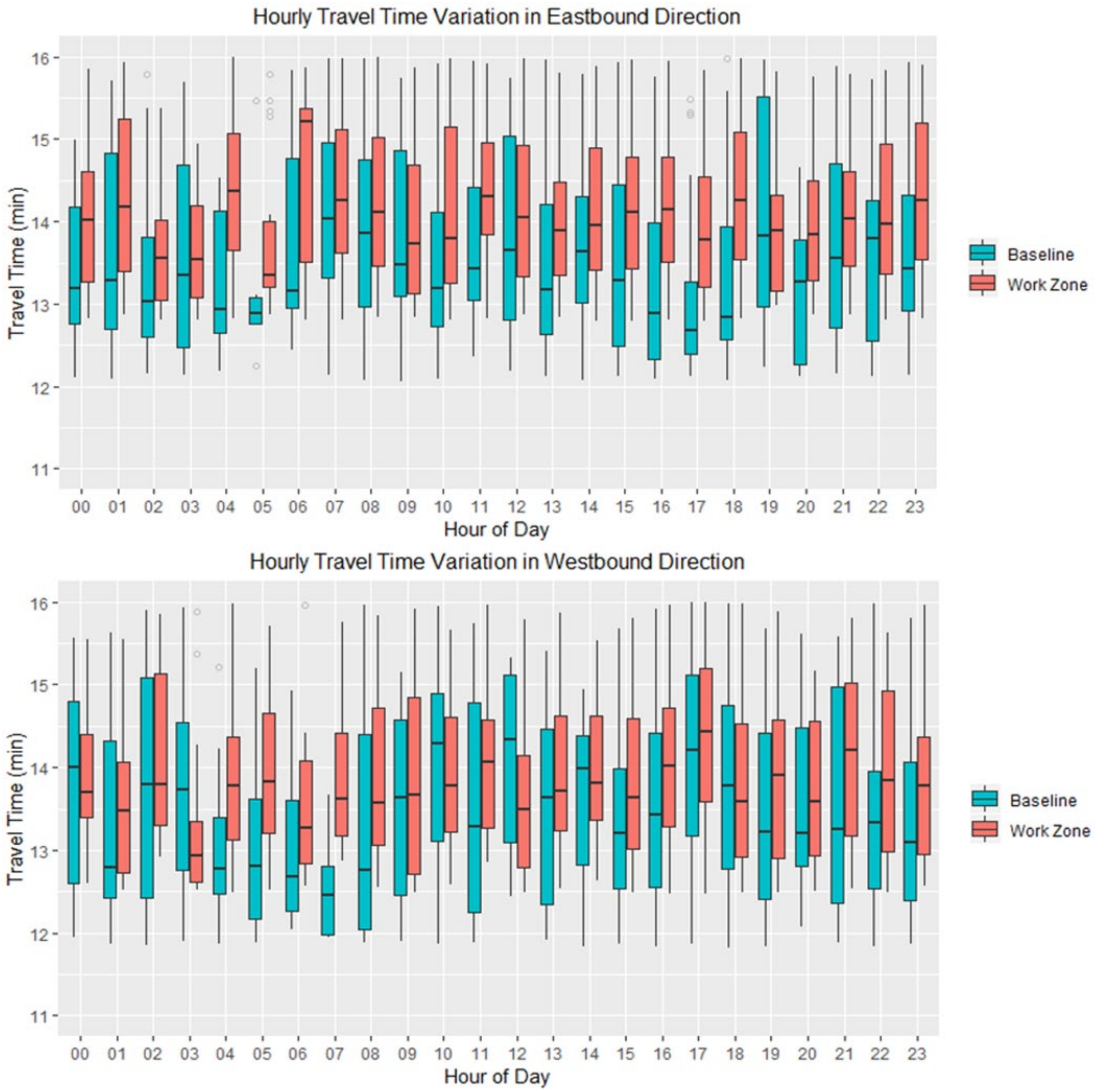


Figure 11. Graph. Scenario 2 - Distribution of hourly travel times during baseline and work zone conditions

Source: FHWA

Figure 12 shows the distribution of travel times in the morning and afternoon peak hours (6:00 a.m. to 9:00 a.m. and 4:00 p.m. to 7:00 p.m.) by day of the week during underperforming conditions. In the eastbound direction, the average peak hour travel time under work zone conditions was consistently higher than the baseline conditions on each day of the week. Most of the increases in peak hour travel times were observed on Fridays and Saturdays, while the least occurred on Tuesdays. In the westbound direction, similar peak hour travel time distributions were observed on Mondays, Tuesdays, and Wednesdays in both the baseline and work zone conditions. However, the increase in the average travel time was significant in the later days of the week and was the highest on Sundays. Overall, the impact of work zone on peak hour travel time variability appears to be little, and this could be due to confounding variables that are not controlled. In addition, a relatively longer time period (i.e., two years) is considered in the analysis – which aggregates total work zone impacts over a longer timeframe. Filtering the data by specific days or time periods may provide a more telling picture of work zone impacts for that particular condition.

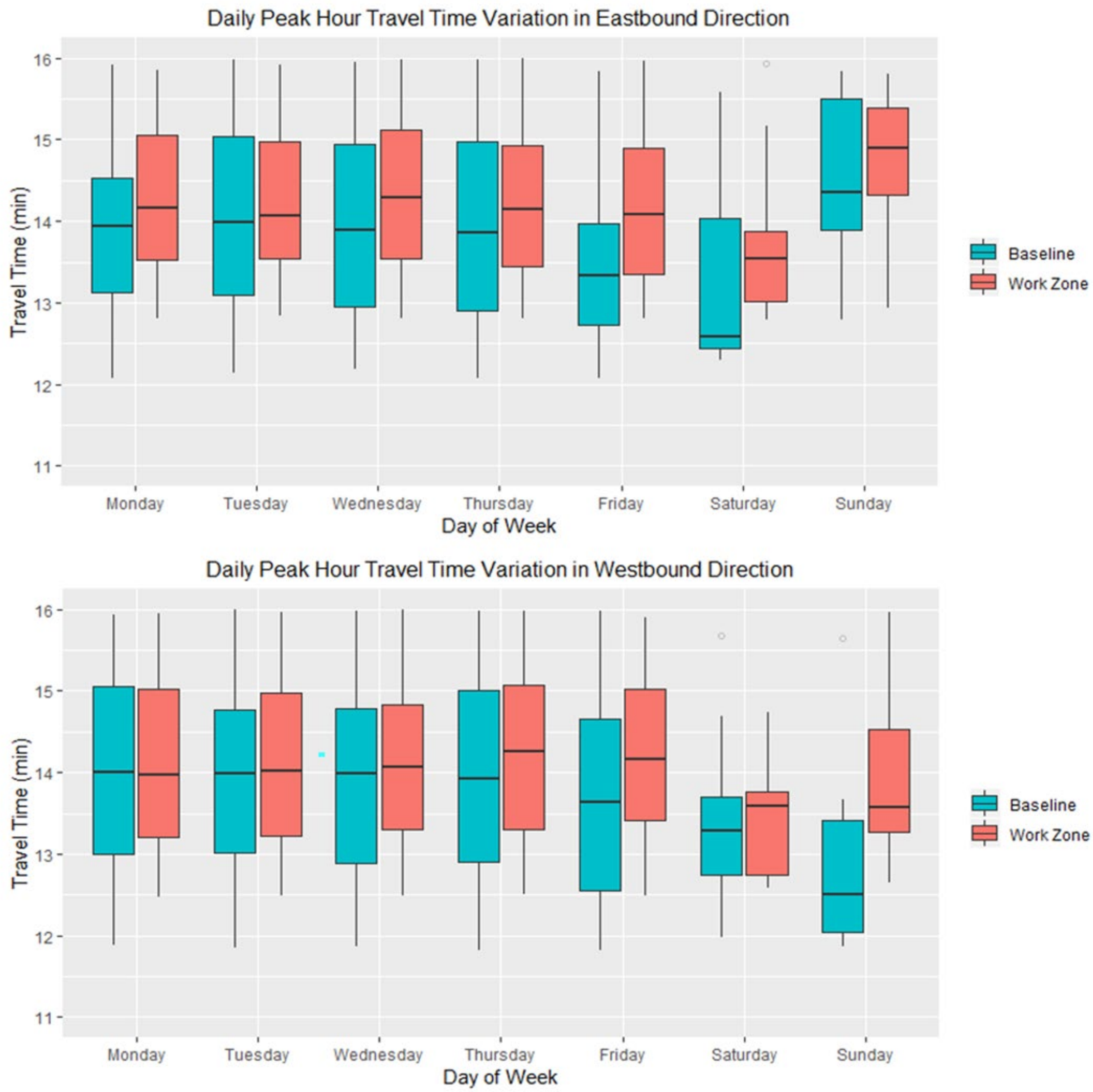


Figure 12. Graph. Scenario 2 - Daily variability of peak hour travel times during morning and afternoon peak hours
Source: FHWA

Figure 13 shows the monthly variability of travel times during the peak hours in the baseline and work zone conditions, enabling the seasonal impact of work zone activities to be examined. In the eastbound direction, the average travel times under work zone conditions were higher in all months of the year than what was observed in the baseline conditions. The increase in the average travel times and its variability was the highest in the months of July, August, and December, and was the least during fall months. Similarly, in the westbound direction, the average travel times during work zone conditions were higher than the baseline conditions in all months of the year, although the impact was lower than the eastbound direction.

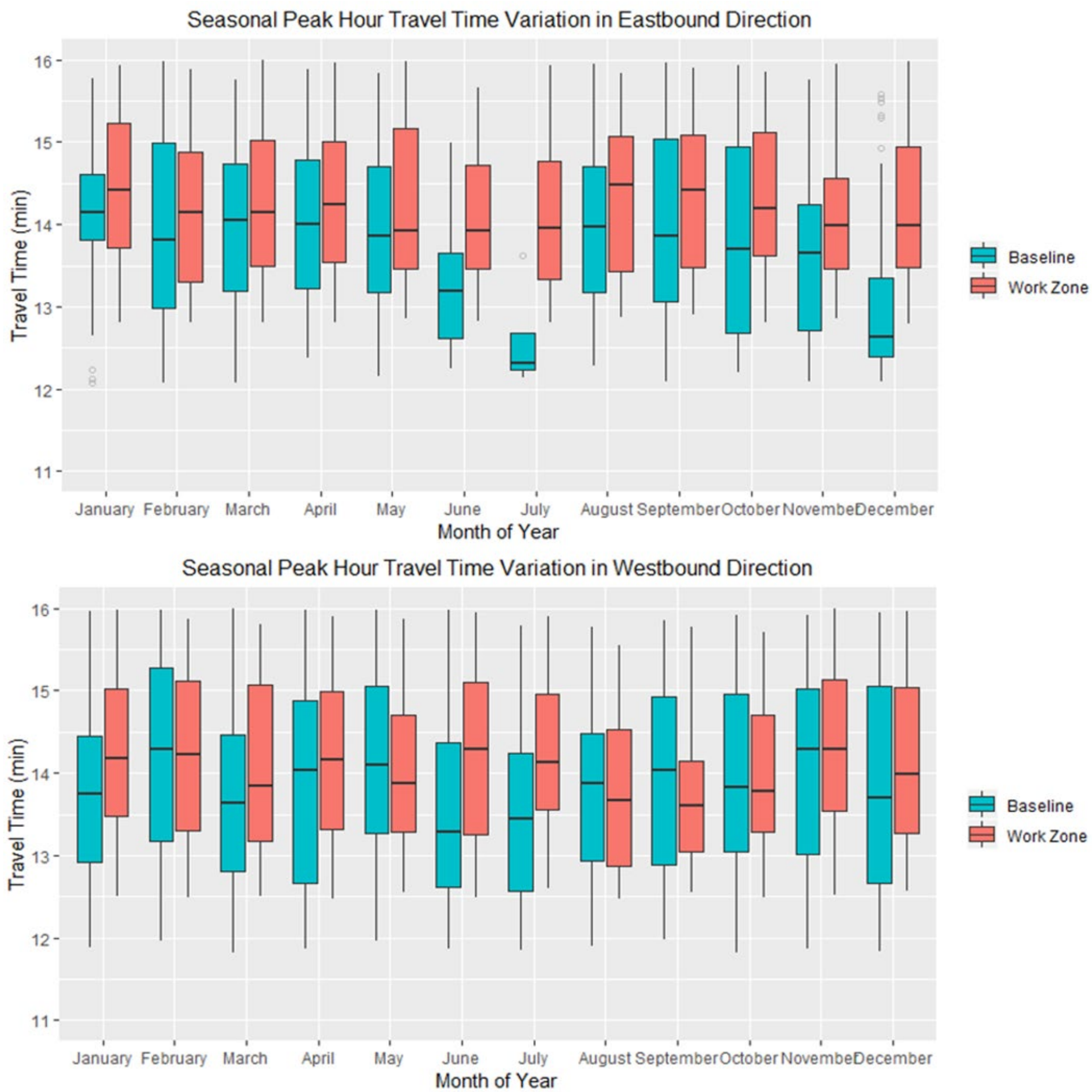


Figure 13. Graph. Scenario 2 - Seasonal variability of peak hour travel times during baseline and work zone conditions

Source: FHWA

Travel Time Reliability

Travel time reliability refers to the consistency, predictability, and dependability of a trip's travel time. It is an important measure to commuters, especially freight traffic for on-time arrival and delivery schedules.

The case study project team calculated the following reliability metrics:

- **Travel Time Index:** The ratio of the observed (average) travel time to free flow travel time
- **Planning Time Index**: The ratio of the 95th percentile of the corridor travel time to the free flow corridor travel time

Figure 14 shows the equations for calculations these indices.[10]

$$Travel\ Time\ Index = \frac{Observed\ travel\ time}{Free\ flow\ travel\ time}$$

$$Planning\ Time\ Index = \frac{95th\ percentile\ of\ the\ corridor\ travel\ time}{Free\ flow\ corridor\ travel\ time}$$

$$Travel\ Time\ Index = \frac{Observed\ travel\ time}{Free\ flow\ travel\ time}$$

$$\text{Planning Time Index} = \frac{95th\ percentile\ of\ the\ corridor\ travel\ time}{Free\ flow\ corridor\ travel\ time}$$

Figure 14. Equation. Travel Time Index and Planning Time Index
Source: FHWA

If the Travel Time Index is greater than one, on average the travel time is expected to be higher than the Free Flow Travel Time, proportional to the value of the index. The Planning Time Index presents how much time needs to be allocated to be on time 95 percent of the time.

Figure 15 and figure 16 show the travel time and planning time indexes, respectively, to traverse the 10-mile corridor in the eastbound and westbound directions under the baseline and work zone conditions (when the traffic underperformed regardless of day of week and hour of day for the baseline period and the work zone period). In general, travel time was less reliable under work zone conditions compared to the baseline conditions. Travel time reliability in the eastbound direction was impacted higher than the westbound direction by the work zone activities.

In the eastbound direction, travel time during the work zone conditions was less reliable during daytime hours, starting from 6:00 a.m. until 7:00 p.m. It was particularly least reliable during the morning peak hours. For example, in the eastbound direction at 7:00 a.m.:

[10] https://ops.fhwa.dot.gov/publications/tt_reliability/ttr_report.htm

- The Travel Time Index was 1.63. This means that the typical travel time observed at 7:00 a.m. when traffic underperformed was 1.63 times the free flow travel time.
- The Planning Time Index was 276 percent. This means that a traveler would have to budget a travel time of 2.76 times the free flow travel time to timely traverse the 10-mile corridor 95 percent of the time.

The westbound direction was less impacted by the construction activities compared to the eastbound direction of traffic. The reliability impacts of the construction activities were observed to start in the late morning hours and peak at late-night hours. The highest Travel Time Index was 1.5, which was observed at 5:00 p.m. Similarly, the highest Planning Time Index was 340 percent, observed at 9:00 p.m.

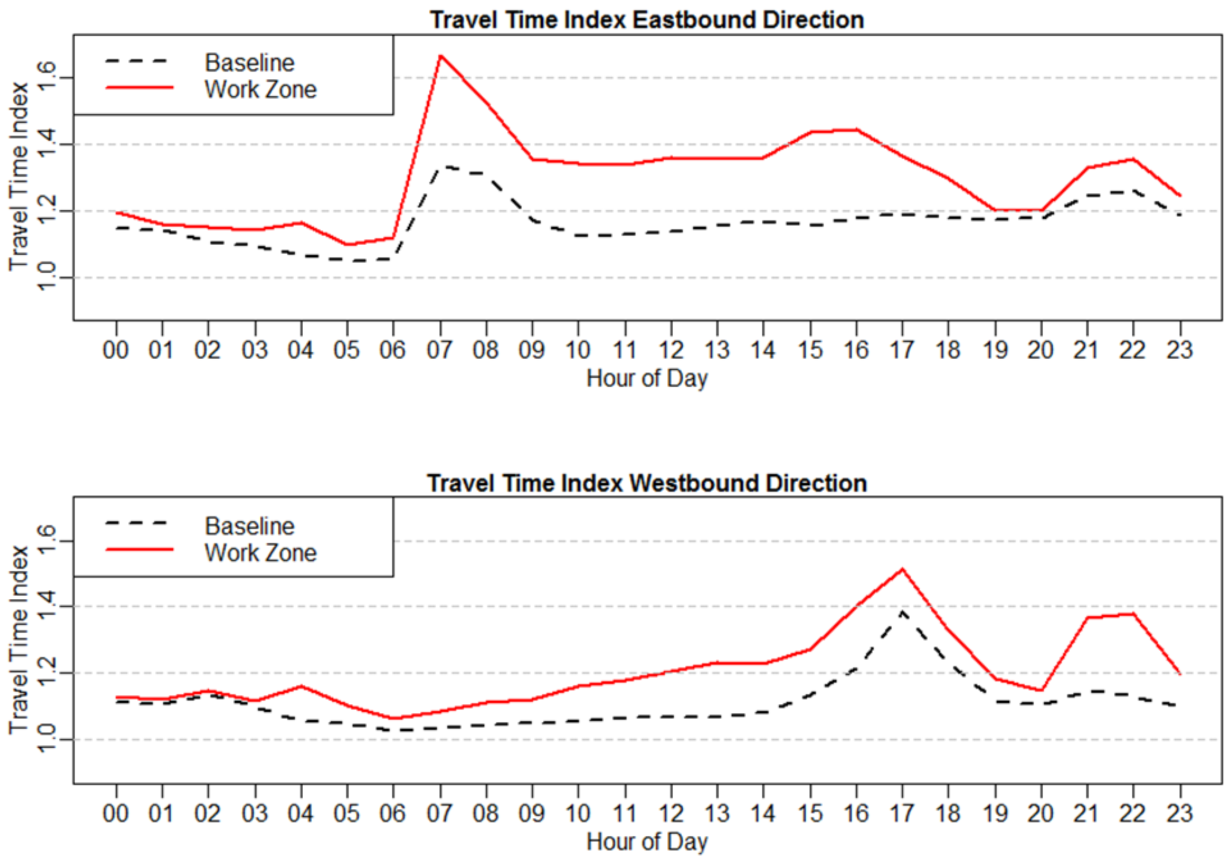


Figure 15. Graph. Scenario 2 - Travel time index during baseline and work zone conditions
Source: FHWA

The impacts on reliability in this analysis were relatively high because only a short trip along the work zone site (i.e., the 10-mile corridor) was considered. If longer trips were considered (e.g., a 30-mile corridor), the impact of the work zone activities on trip reliability would be significantly lower.

The following are some examples of how agencies may use travel time reliability metrics:

- Provide public information during the construction phase of projects, especially those projects that last at least a month and those that are expected to garner significant attention from the traveling public
- Conduct further investigation into what might be driving the variability in travel time—work activity, work zone setup and take down, traffic volume impacts, etc.

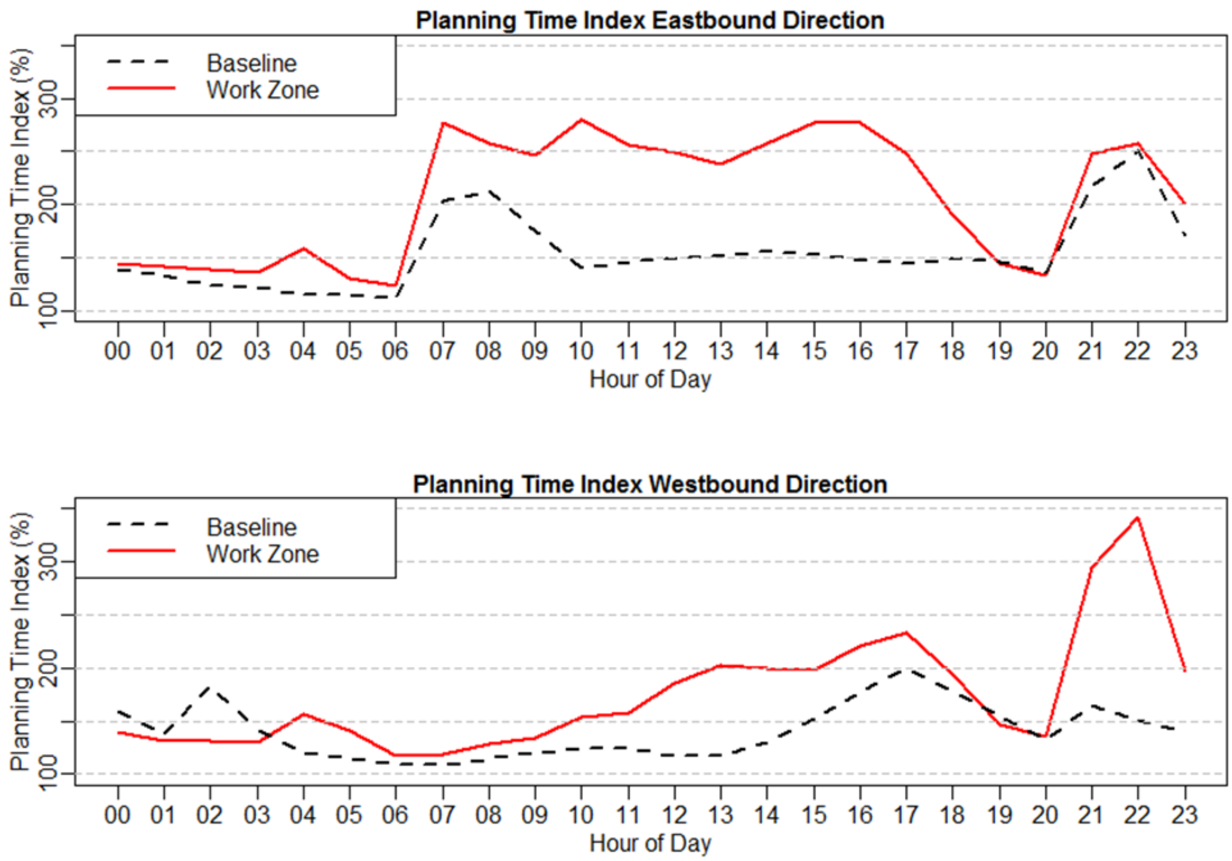


Figure 16. Graph. Scenario 2 - Planning time index during baseline and work zone conditions

Source: FHWA

Road-User Cost Estimation

In addition to examining the average travel time and its variability, the total delay and its monetary value (road-user delay costs) can be estimated. Delay refers to the time difference between the actual travel time and free flow travel time. In this study, as mentioned earlier, only travel times when traffic underperformed are considered (i.e., travel time is 25 percent more than the free flow conditions). Therefore, delay refers to the difference between the actual travel time when traffic underperformed and the threshold travel time. Total hours of delay can be computed by multiplying the calculated delays by the corresponding number of vehicles affected (traffic volume) and the average vehicle occupancy. Volume of traffic represents the number of vehicles that are affected by the delay in each hour of the day. Vehicle occupancy is the average number of occupants of a vehicle during a trip.

The monetary value of the total delays can be estimated by multiplying the total hours of delays by the average value of time. Value of time is a traveler's opportunity cost of time that is spent on the journey. In other words, it represents the amount of money that a traveler is willing to pay to save one hour. Value of time can be different depending on time of day, income, geographic location, and other factors.

Figure 17 shows the aggregated hourly delays in both travel directions of the construction site in the baseline and work zone conditions (without considering the volume of traffic affected by the work zone activities). In general, the eastbound traffic suffered the most delays compared to the westbound traffic, both in the baseline and work zone conditions. Over the two-year period, the eastbound traffic experienced an additional 193 hours of aggregated delays due to work zone activities when traffic was underperforming (i.e., the difference between 419 hours of delays during work zone conditions and 226 hours of delays during the baseline conditions). Similarly, the westbound traffic experienced an additional 129 hours of delays due to work zone activities.

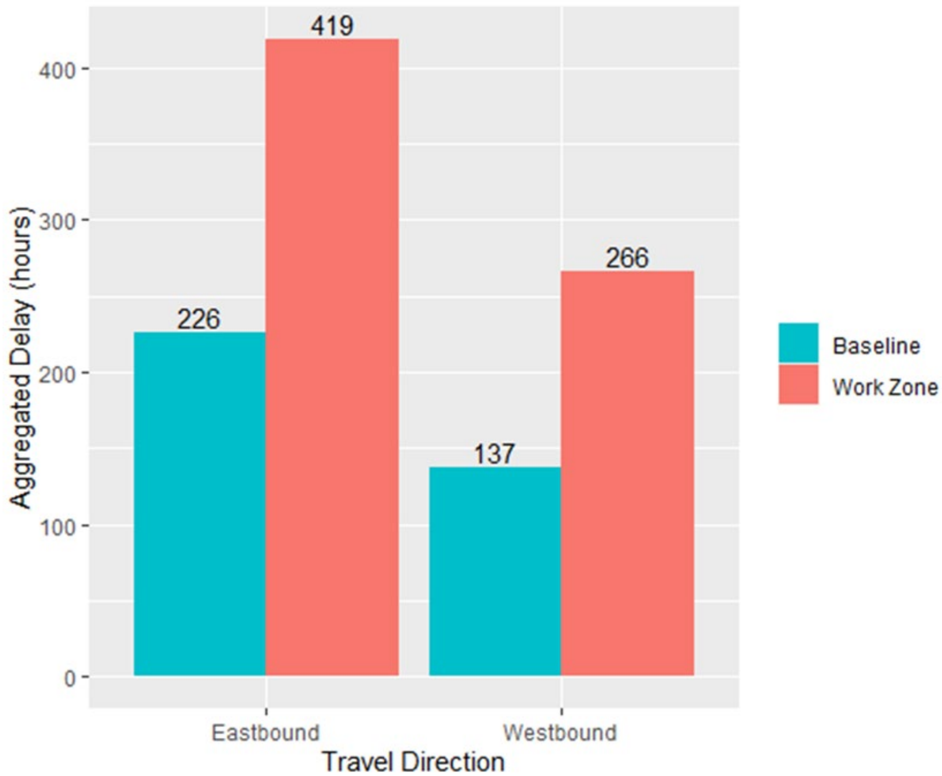


Figure 17. Graph. Scenario 2 - Aggregated delays in the baseline and work zone conditions
Source: FHWA

The breakdown of the aggregated delays by time of day is shown in figure 18. The impact of the work zone during the day can be clearly observed in the eastbound direction. Most of the delays in the eastbound direction occurred in the morning peak hours, particularly at 7:00 a.m., followed by a slight increase in the early afternoon hours. During late night and early morning hours, the delays observed in the baseline and work zone conditions were comparable. In the westbound direction, on average, no additional delays due to work zone activity were observed until after 9:00 a.m. The work zone delays in the westbound direction were the highest during afternoon peak hours, particularly around 5:00 p.m. and late evening hours.

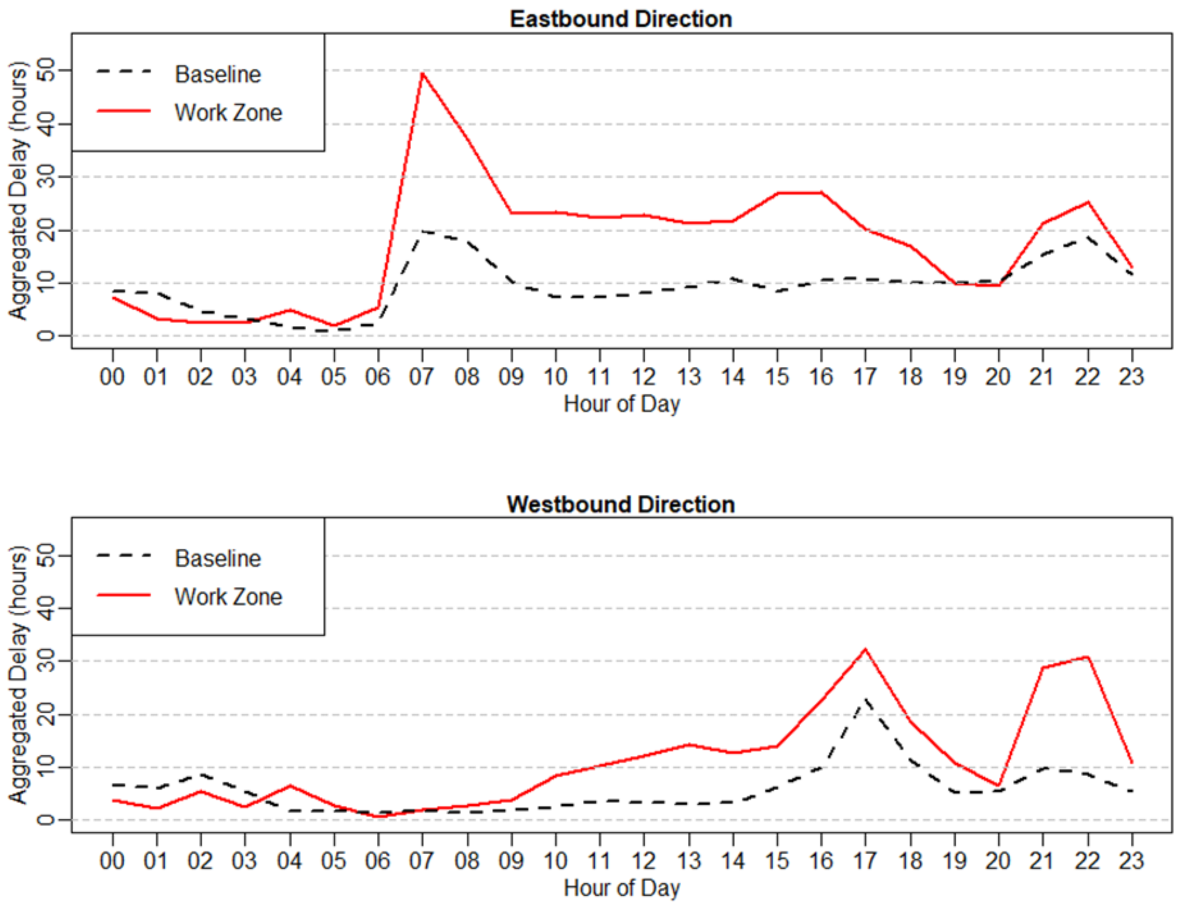


Figure 18. Graph. Scenario 2 - Hourly aggregated delays in the baseline and work zone conditions
Source: FHWA

The hourly aggregated delays can be converted into monetary units by multiplying them by the averages of hourly traffic volume, vehicle occupancy, and value of time of travelers. The case study project team obtained the average hourly traffic volumes for both directions of the 10-mile corridor from the El Paso Metropolitan Planning Organization (MPO). According to the El Paso MPO, the average vehicle occupancy factor in the region is 1.41 persons per vehicle. Similarly, an average value of time of $17.91 per hour was used.[11] In this analysis, it is assumed that traffic is composed of only passenger vehicles. Also, the vehicle occupancy factor and the value of time are the same in the baseline and work zone periods.

Table 6 and table 7 show how the monetary values of delays in the eastbound and westbound directions of I-10 traffic, respectively, were estimated. When traffic underperformed, the monetary value of the total delays in the eastbound direction in the baseline condition was estimated to be $18 million, while in the work zone condition, it was estimated to be $39.3 million. Therefore, the monetary value of the delays due to work zone activities in the eastbound

[11] Ellis, D. (2017). Value of Delay Time for Use in Mobility Monitoring Efforts. Texas A&M Transportation Institute. https://static.tti.tamu.edu/tti.tamu.edu/documents/TTI-2017-10.pdf (accessed in February 2019)

direction is estimated to be $21.3 million. Similarly, in the westbound direction, the monetary values of the total delays when traffic underperformed in the baseline and work zone conditions were $10.5 million and $22 million, respectively. Therefore, the monetary value of the delays due to work zone activities in the westbound direction was estimated to be $11.5 million.

Table 6. Scenario 2 - Estimating the monetary cost of delays in the eastbound direction

Time	Hourly Aggregated Delays (hours)		Hourly Volume (veh/hour)	Vehicle Occupancy (person/veh)	Value of Time ($/hour)	Monetary Value of Delays ($)	
	Baseline	Work Zone				Baseline	Work Zone
0:00	8.4	7.3	476	1.41	17.91	101,275	87,547
1:00	8.1	3.2	333			68,016	26,731
2:00	4.6	2.5	276			31,983	17,296
3:00	3.4	2.4	304			25,728	18,587
4:00	1.6	4.9	569			23,160	70,481
5:00	0.9	1.9	1,609			35,830	77,188
6:00	2.6	5.5	4,217			271,662	582,437
7:00	19.9	49.6	5,603			2,817,082	7,019,945
8:00	17.7	37.0	5,082			2,271,216	4,749,764
9:00	10.2	23.1	4,281			1,098,987	2,496,627
10:00	7.3	23.3	3,841			703,906	2,256,065
11:00	7.3	22.3	3,881			711,403	2,181,158
12:00	8.1	22.8	3,906			798,401	2,247,457
13:00	9.2	21.3	3,950			917,044	2,125,634
14:00	10.8	21.8	4,203			1,146,099	2,311,927
15:00	8.4	26.9	4,465			947,063	3,038,119
16:00	10.5	27.1	4,344			1,152,996	2,978,186
17:00	10.7	20.2	4,087			1,105,213	2,085,301
18:00	10.0	17.0	3,483			880,934	1,496,844
19:00	10.1	10.0	2,610			664,737	659,623
20:00	10.4	9.4	2,234			586,086	532,691
21:00	15.4	21.4	1,897			739,941	1,023,223
22:00	18.6	25.3	1,379			646,207	882,089
23:00	11.7	13.0	926			273,926	304,314
Total						18,018,896	39,269,235

Source: FHWA

Table 7. Scenario 2 - Estimating the monetary cost of delays in the westbound direction

Time	Hourly Aggregated Delays (hours)		Hourly Volume (veh/hour)	Vehicle Occupancy (person/veh)	Value of Time ($/hour)	Monetary Value of Delays ($)	
	Baseline	Work Zone				Baseline	Work Zone
0:00	6.8	3.8	1,463	1.41	17.91	251,428	140,873
1:00	6.0	2.4	826			124,877	49,802
2:00	8.8	5.6	568			125,844	79,956
3:00	5.4	2.5	344			46,651	22,025
4:00	1.7	6.5	312			13,124	51,221
5:00	1.7	2.7	294			12,954	20,364
6:00	1.5	0.7	490			18,021	8,436
7:00	1.6	2.0	1,148			47,814	56,887
8:00	1.5	2.9	2,818			105,991	207,648
9:00	2.0	3.8	3,730			183,703	359,896
10:00	2.5	8.4	3,463			218,576	735,460
11:00	3.5	10.2	3,222			282,680	830,233
12:00	3.3	12.2	3,118			257,658	958,450
13:00	2.9	14.3	3,442			256,339	1,243,703
14:00	3.4	12.7	3,506			299,881	1,122,941
15:00	6.2	14.0	3,754			589,533	1,328,525
16:00	10.1	22.5	3,881			991,839	2,204,046
17:00	22.8	32.3	4,303			2,478,621	3,507,842
18:00	11.3	18.5	4,611			1,311,228	2,159,219
19:00	5.2	10.8	4,786			633,872	1,308,009
20:00	5.4	6.5	4,158			565,442	681,386
21:00	9.6	28.7	3,042			738,896	2,201,500
22:00	8.7	30.9	2,726			595,567	2,124,346
23:00	5.5	10.7	2,191			305,067	594,575
Total						10,455,609	21,997,345

Source: FHWA

For this case study, hourly traffic volumes for the I-10 corridor were obtained from the El Paso MPO. Traffic volume data may not always be available. In such case, agencies can use the NPMRDS-provided Average Annual Daily Traffic (AADT) data. The NPMRDS AADTs can be converted to hourly flow rates by using suitable daily, seasonal, and hourly adjustment factors. More information on this is available at https://npmrds.ritis.org/analytics/help/#npmrds.

Interventions/Actions

This case study presents an example application of NPMRDS data for work zone mobility performance measurement and does not necessarily delve into specific intervention/actions. Identifying when and where work zone traffic congestion occurs and estimating the road-user delays can be useful for implementing appropriate intervention actions to avoid or mitigate future work zone mobility impacts. Such information is crucial for state and local transportation agencies to mainstream their strategies that minimize delays due to work zone activities. Such strategies include regulating lane closure durations, educating construction personnel to consider road-user delays in the construction project management process, and affecting the behavior of road users to manage when and how they travel.

Reporting

The analysis and results should be documented in well-written and clearly structured reports. In doing so, the underlying assumptions, data used, and analytical process followed should be clearly documented so that the analysis performed is defendable and reproduceable.

Simple and concise reports that are easily understood by decision makers, stakeholders, and the general public are beneficial. Supporting the analysis results by visual aids, such as tables, charts, and figures, make the findings easy to understand by technical and non-technical stakeholders.

Lessons Learned

Documenting the lessons learned facilitates identifying areas of potential improvements, recommended actions, and best practices. Lessons learned can cut across all areas of work zone management including planning, design, traffic analysis, engineering, contracting, construction, training, and performance and process improvement. Lessons learned should include both the positive and negative experiences of the work zone mobility management efforts. This effort includes identifying strategies that went right, strategies that went wrong, and practices that could benefit from improvements. As mentioned in Step 10 of the appendix, agencies can take advantage of their bi-annual work zone process reviews to document their lessons learned and implement appropriate process improvements using a mindset of continuous improvement.

Conclusion

This case study presents a high-level, data-driven approach for measuring work zone mobility performance using NPMRDS data. The case study project team used a simple methodology without complex modeling approaches and data analysis techniques. Two different analysis tools (Excel and the R statistical analysis tool) were used to illustrate choices that agencies may make in conducting the analyses. State DOTs and other agencies can follow this simple process to measure and manage work zone mobility performance and determine when and where work zone delays occur, what causes those delays, and how those delays can be mitigated or eliminated. The NPMRDS provides a rich foundation of travel time and speed data, which can be used to measure basic travel time and speed impacts of work zones, conduct variability analyses (e.g., temporal, spatial), calculate travel time reliability metrics, and estimate delays and road-user cost impacts of work zones. NPMRDS data can also be used to model work zone queues, but this case study does not calculate queue lengths. The performance measurement data can be used to manage work zone mobility performance across all aspects including policy, process, planning, design, traffic analysis, engineering, contracting, construction, and post construction.

When combined with additional contextual information such as incident, crash, weather, and special event data, work zone performance metrics can be used to further assess cause and effect, draw correlations, and appropriately take systematic and programmatic actions to better understand and alleviate work-zone-related congestion.

Key takeaways from measuring work zone mobility performance using the NPMRDS include:

- **The NPMRDS can be used for work zone mobility performance management purposes.** Usable data are important to work zone performance management. With free access to the NPMRDS, transportation agencies can use these data for work zone impact analysis and performance management. The NPMRDS can be used for analysis of congestion patterns and delays, as well as travel time and its variability. Such analyses can provide critical information toward identifying the spatial and temporal patterns of work zone delays (i.e., where and when work zone delays occurred), as well as the extent of the delays (i.e., how much delay road users experienced due to work zone activities).
- **Simple analysis of NPMRDS data can inform work zone impact analysis and performance management.** Complex modeling approaches sometimes discourage transportation agencies from using mobility analysis tools and datasets. However, simple analysis of NPMRDS data that does not require sophisticated technical and data analysis skills has the potential to provide meaningful insight into work zone mobility impacts and performance management. Such simple analysis is practical and implementable with limited agency resources.
- **Work zone mobility performance management information from the NPMRDS can be used to develop optimal traffic management strategies for work zones.** Quantifying work zone mobility impacts does not necessarily address adverse mobility effects of work zones unless the analysis is coupled with developing a traffic management strategy to mitigate the impacts. Work zone mobility impact performance management using the NPMRDS can be the basis for transportation agencies to identify and implement optimal traffic management strategies for work zones (e.g., limiting road closures during selected hours of the day, providing alternate routes to road users, and delivering more targeted public information campaigns).
- **Combining NPMRDS data with other data can enable richer work zone performance analysis.** Combining NPMRDS data with other work-zone-specific contextual data (e.g., type of work zone activity, weather, incident, enforcement, and traffic volume) can enable a more comprehensive assessment of work zone impacts.
- **The NPMRDS does have its limitations.** The NPMRDS does not cover non-NHS roads, which is a limiting factor. NPMRDS roadway segment lengths can be very long, especially in rural areas, which can lead to an over generalization of performance data over a long roadway segment. NPMRDS data are not available in real-time, which rules out its applicability for real-time use cases. One way to overcome some of these limitations is to purchase more granular probe vehicle data from any of the commercial providers of such data. Different providers offer different packages, including real-time data, extended roadway coverage, and more granular road segment coverage. The NPMRDS does not provide hourly volume data, which is essential for drawing the context between congestion and traffic volume and for estimating road user costs. Agencies can either use the NPRMDS AADTs and convert them to hourly volume estimates or rely upon their own regional data to fill this gap.

Appendix – Example Ten-Step Process for Work Zone Mobility Performance Measurement using the National Performance Management Research Data Set

An example of how State DOTs can use NPMRDS data to systematically measure work zone mobility performance using a 10-step process is shown in figure 19. The process, which is not required under Federal law, draws upon existing FHWA resources on transportation and work zone performance measurement but is specifically customized to using the NPMRDS as the data source.[12] NPMRDS travel time and speed data are the foundational mobility metrics for this process; using those data, State DOTs can calculate a variety of performance metrics (e.g., work zone travel time, speed, delay, travel time variability, and road-user costs). This 10-step process provides for a systematic, repeatable, inexpensive, and easy-to-adopt process for work zone performance measurement. The richness of the NPMRDS data (e.g., 24/7 coverage, intra-hour data granularity, repeatable temporal and diurnal analyses) allows State DOTs to subset and/or combine the data in many ways to suit their specific analysis needs.

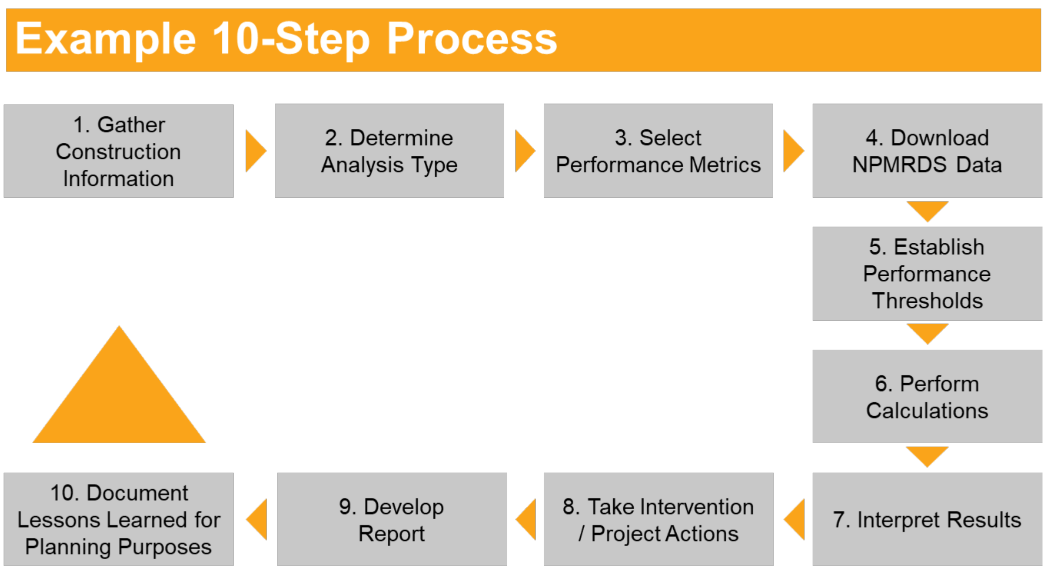


Figure 19. Chart. Example process for estimating work zone mobility impacts using the National Performance Management Research Data Set
Source: FHWA

> **NOTE:** This process is not intended to provide step-by-step assistance on work zone performance management. Rather, it provides a practical approach for using NPMRDS data for work zone performance measurement. For additional detail and explanation on work zone performance measurement concepts, metrics, and methods, please refer to resources available at https://ops.fhwa.dot.gov/wz/decision_support/performance-development.htm.

12 Example FHWA work zone performance measurement resources are available at https://ops.fhwa.dot.gov/wz/decision_support/perf_measurement.htm and overall transportation performance measurement resources are available at https://ops.fhwa.dot.gov/perf_measurement/.

Step 1 – Gather Construction Information

Work zone mobility impact estimation begins with gathering comprehensive work zone activity data (WZAD)[13] on when, where, and how the project is being performed. This information includes work zone attributes such as location, work type, time, impact, duration, lane closures, changes in lane geometry, operational changes, and signage. It also includes contextual information such as alternative routes, immediate transportation network, incident data, and weather data. Having real-time, accurate, comprehensive, and standardized WZAD allows agencies to: 1) provide work zone information to internal and external stakeholders; 2) analyze and manage potential work zone impacts across all stages of project development; and 3) systematically evaluate the performance of past work zone projects.

It is also beneficial to start locating and collecting historical data including traffic volume, safety, mobility, incident, and weather data for the work zone area of interest.

Step 2 – Determine Analysis Type

Analysis type refers to the extent, complexity, scope, and intended use of the performance measurement exercise. The analysis can range from a simple descriptive summary of work zone performance to diagnostic analyses explaining the reason for the performance to more complex predictive and prescriptive analyses. Agencies can start with simple metrics such as average work zone speed and travel time and then graduate to more sophisticated analyses such as queuing, travel time reliability, and road-user cost estimation, coupled with temporal and spatial trend analyses. The analysis scope may range from project-level to corridor-level to district/region-level (e.g., State DOT District-level, metropolitan area level) to statewide-level (i.e., the NPMRDS provides the ability to both drill down and aggregate up).

Agencies may choose different analytical tools based on the analysis type, scope, and complexity. For incremental analysis (e.g., monthly analysis of work zone performance as new data gets uploaded to the NPMRDS), Microsoft® Excel is sufficient and preferable due to easy data manipulation and analysis. For longer analysis periods that lead to larger datasets, as well as for complex analyses, agencies may use more sophisticated tools such as SAS®, R, and Tableau® that provide advanced statistical analysis, data manipulation, and data visualization capabilities.

[13] FHWA started the Work Zone Data Initiative (WZDI) to develop a recommended practice for managing WZAD; to create consistent language by initiating the development of a data dictionary and supporting implementation documents; and for communicating information on work zone activity across jurisdictional and organizational boundaries. The WZDI developed seven standardized and comprehensive WZAD categories, including: 1) Work Zone Planning and Project Coordination, 2) Work Zone Impact Analyses, 3) Construction and Maintenance Contract Monitoring, 4) Real-time System Management/Traveler Information Provision, 5) Safety and Mobility Performance Measurement, 6) Law Enforcement and Emergency Service Providers, and 7) Connected and Automated Vehicles Hardware Needs and System Readiness. FHWA-HOP-18-083. Available online: https://ops.fhwa.dot.gov/publications/fhwahop18083/index.htm.

Step 3 – Select Performance Metrics

The next step in the process is to choose the specific measures to calculate, tied to the analysis type from the previous step. Many transportation agencies use average speed, delay, travel time, and queue length as the main work zone mobility performance indicators. These metrics are easy to understand and good for communicating impacts to transportation professionals, contractors, and the traveling public. Metrics range from simple to complex, based on the effort to gather the necessary data to compute the metrics and the complexity of the calculations:

> The following case studies, available at https://ops.fhwa.dot.gov/wz, showcase the use of probe-vehicle data for work zone performance management:
>
> - A Policy-Driven Approach for Work Zone Mobility Performance Management – Ohio DOT
> - Utilizing Probe-Vehicle Data for Work Zone Mobility Performance – Virginia DOT

- **Simple Metrics – Speed, Travel Time, and Delay.** Work zone speed, travel time, and delay are the most straightforward metrics that the NPMRDS enables. Agencies can calculate average speed and travel time, deduce delay, and extend the analysis to include temporal and spatial performance variations and compare current performance against historical averages or agency-defined speed thresholds. These basic mobility performance measures are easy to calculate and to incorporate into existing work zone mobility performance measurement programs.
- **May Require Additional Data and Modeling – Queue Length.** Although the NPRMDS provides 24/7 speed and travel time data, it provides only AADTs and does not provide intraday traffic volume data. Further, NPMRDS roadway section lengths (i.e., TMC lengths) are sometimes too long (e.g., many miles long in rural areas) to accurately represent the effect of traffic queue buildup and dissipation. Therefore, agencies may need to supplement NPMRDS data with more granular traffic volume and/or additional speed and travel time data so that they can perform accurate queuing and throughput analysis. One option to supplement NPMRDS data is to purchase more-granular probe-vehicle travel time and speed data from third party data providers.
- **Advanced Metrics – Travel Time Reliability, Road User Costs.** The basic NPMRDS travel time and speed data can be used to calculate derived measures such as travel time reliability and road-user costs. These may involve advanced statistical modeling and data processing as well as additional data points such as intraday traffic volume (e.g., hourly, peak period, peak hour volumes), standard values for road user costs (e.g., value of time), and assumptions around travel time reliability expectations.

Now is also a good time to identify visualizations, charts, and graphics to produce. Visualizations may range from simple line and bar charts to more sophisticated visualizations such as heat maps, box plots, and contour plots, depending on the audience. For example, line and bar charts may be best suited for non-technical audiences, while more sophisticated visualizations such as heat maps, box plots, and contour maps are better directed at technical audiences and for deep analysis purposes.

Examples of visualizations used by different State DOTs are available at https://ops.fhwa.dot.gov/wz/decision_support/perf_meas_examples.htm.

The NPMRDS travel time and speed data provide a good foundation to build a variety of work zone mobility performance metrics and charts. For the sake of simplicity in this document, the main measures of work zone mobility performance are speed, travel time, and delay. Because travel time and delay are well correlated with queue lengths, the case study does not focus on estimating queue length. However, agencies may want to estimate queue lengths for various purposes, including examining the impacts of work zones on off-ramp, on-ramp, and adjoining arterial street operations. Agencies can estimate queue lengths using Highway Capacity Manual computational methods with travel time and speed data from the NPMRDS coupled with agency traffic volume data.

Step 4 – Download NPMRDS Data

The NPMRDS Massive Data Downloader allows users to download data from the NPMRDS. A key step in the process is to map the "work zone area of interest"[14] to specific NPMRDS roadway segments (i.e., TMCs). The work zone area of interest generally includes:

- Advance area and transition area
- Work zone activity area
- Post-activity / termination area

Depending on the scope of the analysis, agencies also can include alternate routes, nearby intersections, and the immediate transportation network in their analysis.

The following are the key activities to be performed in this step:

- Select TMC segments
- Select the analysis timeframe, including time period before (baseline), during, and after the work zone
- Choose the units for speed and travel time
- Choose the aggregation (averaging) level: 30-, 15-, 10-, or 5-minute
- Download and import the data into the analysis tool of choice (e.g., Excel, SAS®)

Baseline period is a reference period that represents normal traffic operations without the work zone. The baseline may be a few months to a few years, depending on data availability and road network changes over time.

The data aggregation level describes the granularity of the performance measurement. In most cases, hourly data provide a good understanding of congestion effects of work zones. Further, the data file sizes may be more manageable with hourly data. However, agencies may choose to use more granular aggregation levels if they want to better understand the intra-hour congestion build up and dissipation effects of work zone traffic.

[14] See the Manual on Uniform Traffic Control Devices (MUTCD) for more information on the different areas in a work zone - https://mutcd.fhwa.dot.gov/.

Note on missing data and data cleaning: There may be situations where NPMRDS data are missing (null value) and/or the data may not line up with the rest of the data in the dataset. Missing data are most likely during low volume periods (nighttime) or segments with lower AADT (e.g., rural areas). As a general rule, agencies may choose to ignore data rows with incorrect or missing data but should be cautious in drawing conclusions from periods or segments with sparse data. The NPMRDS help link shown previously provides information on how to handle missing data.

Step 5 – Establish Performance Thresholds

Performance thresholds indicate the acceptable level of performance degradation that the transportation system can handle, or road users can tolerate. While agencies strive to maintain performance under all conditions, it may not be practically feasible to do so, given the capacity constraints that work zones may impose. Performance thresholds allow agencies to set acceptable limits for work-zone-induced delay, speed reduction, or travel time reliability impacts; and consequently, enable agencies to manage the performance of their work zones to those established thresholds. Thresholds may vary from agency to agency, and from project to project, depending on the roadway classification, work type, project duration, work zone length, lane closure hours, etc. Some agencies divide delay thresholds into categories such as minor, moderate, and severe congestion. Agencies may also choose to adjust delay thresholds based on road user expectations—for example, delay tolerance may be lower for work zones in less congested areas and higher for projects on already congested corridors. Agencies may also implement performance thresholds for alternate routes associated with work zone projects.

Examples of performance thresholds include:

- Delay and travel time thresholds
- Speed thresholds
- Queue thresholds
- Travel time reliability thresholds (e.g., acceptable planning index, buffer index)
- Traffic volume and throughput thresholds (though the NPMRDS provides AADT, it does not provide actual traffic volume and throughput data; agencies may need to get these data from other sources)

Figure 20 presents an example of performance thresholds and associated NPMRDS data showing actual performance against established thresholds.

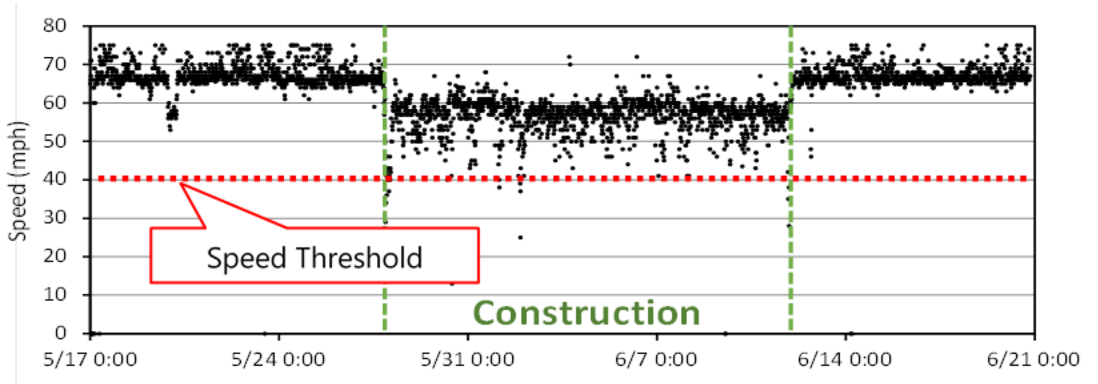


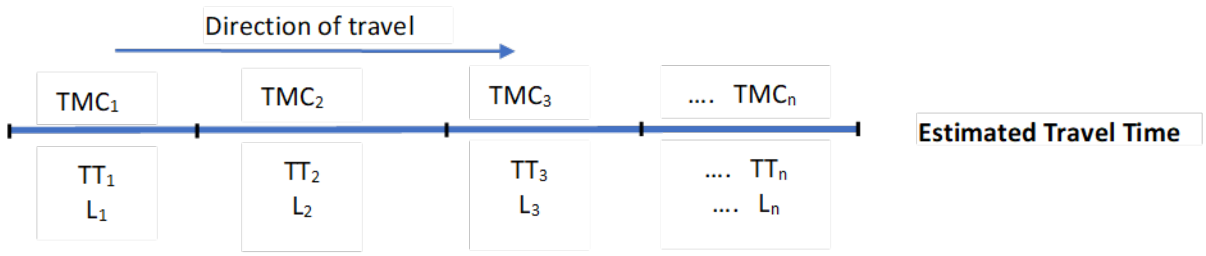
Figure 20. Graph. Example of Performance Threshold
Source: FHWA

The Ohio Department of Transportation (ODOT) uses a policy-driven approach to manage work zone mobility. During project planning, lane closures are allowed on highways only if the volume and queue requirements of the Permitted Lane Closure System are met. The maximum volume threshold is 1,000 to 1,490 vehicles per hour per open lane (depending on truck percentages and terrain), and the allowable queue threshold is 0.75 miles. If the project team estimates queues to be greater than 0.75 miles, the associated lane closure will not be allowed, and the project team must submit an exception request along with appropriate queue and delay mitigation strategies. Similarly, ODOT strives to meet a minimum work zone speed threshold of 35 miles per hour. ODOT staff monitor queues through freeway cameras (where coverage is available) and speeds using probe-vehicle data. The monitoring results are appropriately communicated to the respective ODOT District and project engineers. According to ODOT's processes, the project team takes appropriate action to improve and address performance issues. More information on ODOT's work zone performance management approach is available at https://ops.fhwa.dot.gov/wz.

Step 6 – Perform Calculations

This step involves converting raw data from the NPMRDS into metrics and information for decision-making. Travel time and speed data from the NPRMDS form the basis of all the performance measures to be calculated, using which agencies can calculate average speed and travel time, analyze travel time reliability, and develop speed profiles and travel time trends.

The discussion presents an example of how to aggregate travel times at the corridor-level using NPMRDS TMC data (i.e., multiple TMCs make up a corridor). Refer to the NPMRDS help documents for additional information on calculating other metrics as well as recommended best practice "dos and don'ts". The simplest way to aggregate travel times across multiple, sequential TMCs is to sum the individual TMC travel times at a given time of day to calculate the average travel time for the corridor. This method of travel time calculation is called Estimated Travel Time or instantaneous travel time (figure 21). This method is most commonly used for larger data aggregations (e.g., for NPMRDS data averaged over an hour or more).



$$TT_t = \sum_{i=1}^{n} TT_{i,t}$$

TT_t is the corridor travel time at time t

$TT_{i,t}$ is the travel time of TMC_i at time t

Figure 21. Equation. Estimated Travel Time
Source: FHWA

Average Corridor Speed at a given time of day is computed by dividing the length of the corridor by the travel time. Figure 22 shows the formula for calculating this metric.

$$S_t = \frac{\sum_{i=1}^{n} L_i}{TT_t}$$

S_t is the average corridor speed at time t

L_i is the length of TMC_i

TT_t is the corridor travel time at time t

Figure 22. Equation. Average Corridor Speed
Source: FHWA

In the case of more granular analyses, agencies may choose to use the Actual Travel Time method for aggregating travel times across TMC segments. This approach works especially well when the travel times of individual TMC segments are higher than the aggregation interval itself. Actual travel time at a given time of day is calculated by traversing the corridor through the individual TMC segments while incrementing the date/time stamp for the next TMC segment by the travel time of the previous TMC segment (figure 23). The Average (Actual) Corridor Speed can then be calculated by dividing the Actual Travel Time over the length of the corridor.

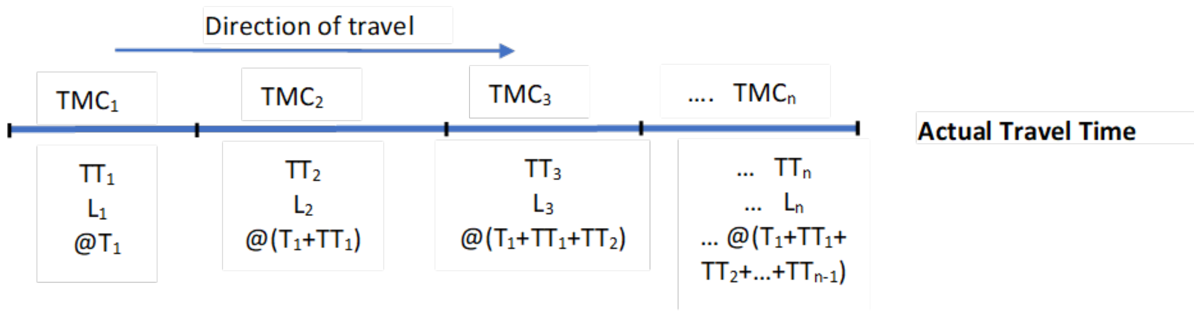


Figure 23. Equation. Actual Travel Time
Source: FHWA

Using the basic travel time and speed data, additional metrics such as travel time reliability and road user costs may be calculated. Additional data will be needed to calculate these measures, including free flow speed and travel time data, hourly traffic volumes, vehicle occupancy, and dollar value of time for road users.

For a quick representation and illustration of the calculated measures, it is best if they are presented using graphical visualizations to demonstrate and understand trends and patterns. Corridor travel times and reliability can be visualized using trend lines, while speed profiles can be visualized using heat maps.

> Additional resources on calculating performance measures using NPMRDS data are available at https://npmrds.ritis.org/analytics/help/#npmrds. Resources on work zone performance measures are available at https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop13011/index.htm. Resources on calculating travel time reliability are available at https://ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm#Whatsteps.

Step 7 – Interpret Results

This step brings together of all the data analysis and calculations. It includes:

- Identifying whether there is a performance issue
- Assessing whether performance thresholds are met
- Conducting root cause analysis:
  - What, why, how, when, who, how much?
  - Correlating with actual construction information
  - Correlating with contextual information – incidents, weather, project team input, public feedback, crash data, etc.
  - Reaching out to the project team, district/regional traffic engineering teams, and traffic operations centers (TOCs) to better understand any project-specific or regional issues that may have an influence on the work zone
- Identifying potential fixes for performance issues:
  - If there is a performance issue, can something be done to fix it – immediately, later, when, how?
  - Is it something that better planning or design could have prevented?

- Setting up recurring checkpoints for reviewing performance with concerned stakeholders (e.g., monthly reviews with work zone mobility steering committee)

The Ohio Department of Transportation (ODOT) produces work zone speed charts on a monthly basis using probe vehicle data. Traffic managers evaluate the speed analysis charts monthly to identify any work zone performance issues. For example, ODOT determined for a particular project that the construction crew was closing lanes an hour earlier than allowed in the plan. ODOT engineers used this information to not only remind the project team about the importance of sticking to the permitted lane closure plans but also to re-emphasize the same message on a broader level to all project teams.[15]

Step 8 –Take Action/Intervention

This is the point in the process where agencies may choose to take action based upon the performance measurement results. Actions can include:

- **Corrective** actions to rectify project and process issues, including changes to project design and construction management (e.g., changing lane closure timings, allowed lane closures, alternate route changes)
- **Investigative** actions to further understand the underlying cause(s) of a performance issue
- **Corroborative/Confirmative** actions that lead to verification of cause and effect, peripheral/external influences, and other factors that may affect work zone performance
- **Informational** actions to communicate the performance measurement results to concerned parties including the traveling public
- **Contractual** actions to enforce existing contract terms aimed at ensuring better work zone performance and to modify contract terms towards delivering better work zone mobility
- **Incentive or disincentive** actions depending on whether performance expectations are met
- **Procedural** actions in response to unmet performance expectations (e.g., actions in response to delays caused by unallowed lane closures)
- **Forward-looking** actions aimed at improving future practices and policies

Step 9 – Develop Report

The purpose of this step is to appropriately document the results of the performance measurement and use them for ongoing process improvement. The reporting should be:

- Actionable
- Relevant
- Written with a learning and process improvement mindset

Step 10 – Document Lessons Learned

This is the final step in performance measurement. Just like in any other analysis and assessment activity, it is important to identify lessons learned and institute any changes or updates to existing

[15] Project communications with Ohio Department of Transportation.

policies and practices. Archiving lessons learned in easily accessible and searchable formats (e.g., checklists, searchable databases) enable practitioners to apply the lessons learned during the regular course of project planning, design, and implementation. In addition to lessons learned around overall work zone management, there may be lessons to apply to performance measurement processes and methods leading to more efficient and effective performance measurement.

Some of the considerations for documenting lessons learned include:

- What to archive:
  - Raw data
  - Curated and processed data
  - Assumptions and contextual information
  - Information and insights
  - Performance results, issues, cause, and effect (root cause)
  - Actions taken and any resultant benefits of the actions
  - Lessons and suggestions for improvement
- What to keep in mind while archiving:
  - Strive for easily searchable and retrievable information
  - Preserve the context of the performance measurement
  - Keep a learning and continuous improvement mindset → living process and artefacts
  - Adapt policy, procedures, and processes based on lessons learned

Incorporating findings and lessons learned in agency process reviews. An effective channel for documenting lessons learned is to incorporate findings from performance management activities into the agency's process reviews. Documenting the findings and actions in process reviews may help agencies to adopt a continuous, systematic approach to performance management by tracking action items across process review cycles and across program areas.

California Department of Transportation (Caltrans) resident engineers regularly conduct post-construction work zone mobility evaluations that document and evaluate the design/construction features of road projects in the context of contractor work windows, traffic delays, contractor claims for insufficient language in the specifications, contract change orders due to deficiencies in their lane requirements charts, and any special project provisions. Incidents in the vicinity of the work zone are evaluated to understand their impact on work zone performance, and any incidents caused by lane closures are appropriately attributed to the work zone. The information from the evaluations is used to identify lessons learned and improvement opportunities for work zone system planning and management. Caltrans districts include work zone performance evaluations in their quarterly and annual Mobility Performance Reporting and Analysis Program reports that cover broader congestion reports and metrics.[16]

[16] Project communications with California Department of Transportation.

For more information on FHWA's Work Zone Management Program, please contact Jawad Paracha, FHWA Office of Operations: Jawad.Paracha@dot.gov

Additional resources on work zone performance management can be found at:
https://ops.fhwa.dot.gov/wz/ and
https://www.workzonesafety.org/swz/

FHWA is engaging with State DOTs and conducting research to understand work zone mobility performance measurement best practices, challenges, and opportunities. The information will be used to increase awareness on data, tools, and methods for systematic work zone performance measurement across all stages of project development including planning, design, construction, and post-construction. Topics of interest include use of probe data and mainstreaming performance measures into agency policies and processes, including work zone process reviews and incorporating work zones into TSMO initiatives. This case study is one of a series of resources on work zone mobility performance measurement.

July 2021 FHWA-HOP-20-029