IDENTIFY BEST LOCATIONS FOR NEW FLEX-ROUTE PROJECTS THROUGHOUT THE STATE OF MICHIGAN

Authors

Peter T. Savolainen, Timothy J. Gates, Nischal Gupta, Akinfolarin Abatan,
Matthew Hill, Andrew Ceifetz, Ali Zockaie, Ehsan Kamjoo, Mehrnaz Ghamami

Sponsoring Organization

Michigan Department of Transportation

Performing Organization

Michigan State University
Department of Civil and Environmental Engineering
428 South Shaw Lane
East Lansing, MI 48824

June 2025

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
SPR-1751	N/A	If applicable

4. Title and Subtitle Identify Best Locations for New Flex-Route Projects Throughout the State of Michigan	**5. Report Date** June 2025 **6. Performing Organization Code** N/A
7. Author(s) Peter T. Savolainen, Timothy J. Gates, Nischal Gupta, Akinfolarin Abatan, Matthew Hill, Andrew Ceifetz, Ali Zockaie, Ehsan Kamjoo, Mehrnaz Ghamami	**8. Performing Organization Report No.** N/A
9. Performing Organization Name and Address Michigan State University Department of Civil and Environmental Engineering 3546 Engineering East Lansing, Michigan 48824	**10. Work Unit No.** N/A **11. Contract or Grant No.** Contract 2023-0458
12. Sponsoring Agency Name and Address Michigan Department of Transportation (MDOT) Research Administration 8885 Ricks Road P.O. Box 33049 Lansing, Michigan 48909	**13. Type of Report and Period Covered** Final Report, 6/14/2023 - 6/14/2025 **14. Sponsoring Agency Code** N/A

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MDOT research reports are available at www.michigan.gov/mdotresearch.

16. Abstract

Part-time shoulder use (PTSU) has emerged as an effective lane-use strategy to mitigate both recurrent and non-recurrent congestion. Given the operational and safety benefits associated with the US-23 Flex Route, this research project focused on evaluating the feasibility of PTSU on selected freeway corridors in Michigan that are prone to such congestion. An initial list of 16 candidate freeway corridors was identified based on a review of congestion patterns and consultation with the Michigan Department of Transportation (MDOT). A series of comprehensive operational and safety assessments were conducted for these corridors. Delay trend maps were developed to visualize congestion patterns, and a macroscopic operational analysis was performed using the Highway Capacity Software (HSCS) Freeway Module to forecast the impacts of implementing PTSU on various operational measures of effectiveness. Results indicated that PTSU generally improved travel times and reduced vehicular delay and associated costs. Similar analyses were conducted to quantify the level of safety performance in terms of congestion-related crashes along these same corridors. A spreadsheet tool was developed to compare these performance measures across corridors. The performance measures were normalized, and an overall ranking score was assigned to prioritize candidate corridors for future PTSU implementation. The findings from this study provide a data-driven framework for identifying freeway corridors best suited for PTSU, enabling MDOT to make informed decisions for future implementation.

17. Key Words	18. Distribution Statement
Part-time shoulder use, hard shoulder running, flex-route, network screening	No restrictions. This document is also available to the public through the Michigan Department of Transportation.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	121	N/A

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

Identify Best Locations for New Flex-Route Projects throughout the State of Michigan

FINAL REPORT

June 15, 2025

Principal Investigator
Peter T. Savolainen, PhD., P.E.
MSU Foundation Professor

Co-Principal Investigator
Timothy J. Gates, PhD., P.E., P.T.O.E.
Professor

Ali Zockaie, PhD.
Associate Professor

Mehrnaz Ghamami, PhD.
Associate Professor

Authors
Peter T. Savolainen, Timothy J. Gates, Nischal Gupta, Akinfolarin Abatan, Matthew Hill, Andrew Ceifetz, Ali Zockaie, Ehsan Kamjoo, Mehrnaz Ghamami

Sponsored by
Michigan Department of Transportation

A report from
Michigan State University
Department of Civil and Environmental Engineering
428 South Shaw Lane
East Lansing, MI 48824

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER

This publication is disseminated in the interest of information exchange. The Michigan Department of Transportation (hereinafter referred to as MDOT) expressly disclaims any liability, of any kind, or for any reason, that might otherwise arise out of any use of this publication or the information or data provided in the publication. MDOT further disclaims any responsibility for typographical errors or accuracy of the information provided or contained within this information. MDOT makes no warranties or representations whatsoever regarding the quality, content, completeness, suitability, adequacy, sequence, accuracy or timeliness of the information and data provided, or that the contents represent standards, specifications, or regulations.

ACKNOWLEDGEMENTS

The research team would like to acknowledge the Michigan Department of Transportation (MDOT) for sponsoring this research. The efforts of the research advisory panel (RAP) and other MDOT staff were also very helpful over the course of the project, including in the provision of data and assistance in various quality assurance and quality control procedures.

EXECUTIVE SUMMARY

Traffic congestion remains a consistent problem, both nationally and in the state of Michigan. The average American loses 43 hours to traffic congestion every year. However, traditional methods of reducing congestion, such as adding travel lanes, are expensive and may not be feasible in many cases. Consequently, roadway agencies are increasingly considering alternate methods to reduce congestion. Part-time shoulder use (PTSU), also referred to as hard shoulder running (HSR) is one strategy aimed at reducing recurring congestion, particularly on freeway corridors. This strategy allows for the use of the inside or outside shoulder as a temporary travel lane during periods of elevated congestion. PTSU can be static, wherein the shoulder is opened for a fixed pre-determined schedule, or dynamic where the shoulder is opened to traffic in response to traffic conditions. The US-23 Flex Route was the first example of PTSU in Michigan when it went into operation in 2017. Prior research sponsored by the Michigan Department of Transportation (MDOT) has shown operational and safety benefits on US-23, as well as positive road user perceptions. Consequently, MDOT sought to identify additional corridors where PTSU or other similar lane-use strategies may be implemented. This study aimed to identify such locations along the Michigan freeway network using a series of operational and safety analyses.

As an initial screening step, the entire Michigan freeway network was investigated to identify potential candidate locations for PTSU. This included collecting various segment-specific data, including probe vehicle speeds and travel times, historical traffic volumes and crashes, and roadway geometric information. The latter data included the widths of the median, inside and outside shoulders, and the number of interchanges and bridges along the corridors. Speed trends along each freeway segment were examined by time-of-day and heat maps were created to identify locations that were experiencing recurring congestion. Based on several rounds of consultation with MDOT regional staff and research advisory panel members, 16 candidate corridors were identified and investigated in greater detail for potential PTSU implementation.

Detailed operational and safety analyses were conducted along these corridors. Delay trends based on direction of travel and time of day were plotted as heat maps. Similarly, crash trends were investigated along each corridor. This included comparisons based on crash type, time-of-day, and direction of travel. The results showed significant variability in delay and crash rates across corridors (based on direction and time-of-day). Subsequently, the 16 candidate corridors were analyzed at a macroscopic level using the Highway Capacity Software 2024 (HCS2024) freeway facility module. Various operational measures of effectiveness were compared under three scenarios: (1) existing conditions; (2) a 24-hour shoulder use condition; and (3) a 24-hour shoulder use with 10% induced demand. Separate analyses were conducted for the entire 24-hour operation period, and only AM and PM peak periods. Under certain assumptions, the results showed that the implementation of PTSU would result in significant operational benefits in terms of reduced travel time, delay and road user costs.

Based on the output of the operational and safety analyses, the candidate corridors were ranked to generate a priority list for MDOT to implement the PTSU strategy. One of the 16 corridors (M-39 from I-94 to the John C Lodge Freeway) was excluded from this exercise due to its unique congestion challenges. Various operational, safety, and geometric parameters were summarized for the remaining corridor by direction and then normalized using min-max scaling. The parameters were assigned weights and then ranked based on a normalized score.

The final ranking scheme allows for data-driven prioritization of corridors where PTSU would be most beneficial, balancing operational improvements with safety and feasibility concerns. The method and the assigned weights were flexible and can be modified based on priorities and constraints identified by MDOT.

1 INTRODUCTION

In 2024, an average driver in the United States lost 43 hours due to congestion, costing nearly $771 per person in lost time and productivity (INRIX, 2025). Nationwide, this adds up to $74 billion in lost time. Historically, this congestion has been addressed by adding capacity in the form of additional travel lanes. However, these large-scale projects are often cost-prohibitive, and it is important to note that the majority of such congestion is limited to select time periods, particularly the AM and PM peaks. Consequently, road agencies have started introducing alternative strategies, such as managed lanes, to reduce congestion during these periods.

Furthermore, in light of widespread concerns regarding infrastructure conditions and the increased cost of new construction projects, it is important for states to explore strategies aimed at retrofitting existing infrastructure with cost-effective and innovative active traffic management systems to address transportation issues associated with congestion and safety effectively. Moreover, the consideration of right-of-way concerns, which stem from the high cost of land acquisition in urban areas and legal issues arising from new road construction, emphasizes the need for states to develop inventive approaches that optimize existing right-of-way while simultaneously reducing traffic congestion and enhancing transportation reliability on the highway.

Part-time shoulder use (PTSU), also referred to as hard shoulder running (HSR), is one such strategy that aims at reducing congestion, particularly during specific time periods. PTSU allows the use of inside (left) or outside (right) shoulder as a regular travel lane during peak periods. There are primarily three types of PTSU – bus on shoulder (BOS), static part-time shoulder use (S-PTSU), and dynamic part-time shoulder use (D-PTSU). BOS allows only authorized buses to travel on the shoulder. Static and dynamic PTSU generally allows all or most vehicles to use the shoulder when open. The primary difference between the two strategies is that static shoulder use is opened to traffic based on a fixed pre-determined schedule (e.g., during AM peak and PM peak), while dynamic shoulder use opens the shoulder for use in response to traffic conditions along the corridor.

Several states across the US have implemented PTSU strategies. This includes the state of Michigan, which opened its US-23 Flex Route corridor in 2017. This corridor utilizes the 11-ft inside shoulder as a temporary travel lane during peak traffic periods (Figure 1) and to address crashes and other forms of non-recurrent congestion.

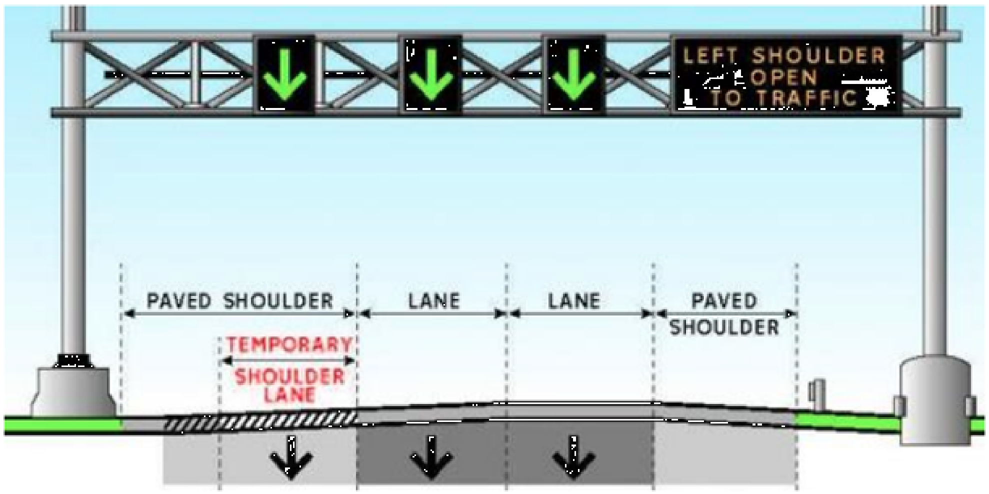


Figure 1 Cross-section of US-23 Flex Route with Inside Shoulder as a Dynamic Lane

1.1 Problem Statement and Study Objectives

The US-23 Flex Route is an 8.5-mi corridor that utilizes active traffic management (ATM) systems, including variable speed limits and queue warning systems, to manage congestion in real-time. These strategies add capacity and address non-recurrent congestion due to traffic crashes or other incidents. A prior study investigated the operational and safety performance of this corridor (Kassens-Noor et al., 2022). That study assessed various metrics, including average travel time and travel time reliability, as well as crash frequency and severity. The results generally showed significant improvements in these metrics, particularly in the southbound direction. While improvements were also evidenced in the northbound direction, these benefits were less pronounced due to congestion that was shifted downstream where the corridor was reduced from three to two lanes up to the interchange of US-23 and I-96 (Kassens-Noor et al., 2022).

These results suggest that PTSU may be a promising strategy to reduce delay and mitigate congestion on other corridors in a manner that is more economical than the construction of new travel lanes. To that end, further research is warranted to assess the MDOT freeway network in order to identify candidates that may be feasible for PTSU or other types of managed lane strategies (e.g., high-occupancy vehicle lanes).

As such, the goal of this study is to assess the current operational and safety performance of the MDOT freeway system to identify candidate corridors for the implementation of such strategies. To accomplish this goal, a methodology is developed to screen and prioritize freeway corridors for managed lanes and temporary shoulder use projects throughout Michigan. Flex routes provide a potentially cost-effective alternative for corridors that experience recurrent congestion, but where site-specific factors may inhibit the addition of a full travel lane. Ultimately, the ability to forecast the operational and safety performance of part-time shoulder use and other active traffic management strategies is critical to near- and long-term investment decisions by MDOT. To that end, the specific objectives of this research are as follows:

- Develop an extensive literature review on methods to select candidate locations for PTSU projects.
- Report state of practice on the usage of various PTSUs and other ATM strategies by different state agencies.
- Study temporal and spatial congestion patterns to identify candidate locations for new PTSU applications.
- Study operational and safety impacts of PTSU on identified corridors.
- Derive and provide a methodology for developing statewide congestion distributions to identify the best locations for new PTSU projects throughout the state of Michigan using an open ranking system that can be applied to additional corridors in the future.

1.2 Task Summary

In order to achieve the above stated research objectives, the following tasks were performed. Detailed description of these tasks has been provided in the subsequent chapters of this report.

- <u>Literature Review:</u> A comprehensive state-of-the-art literature review of national and state-level policies on managed lanes, PTSUs, and other related active traffic management (ATM), as well as methods utilized to select candidate locations for PTSU implementation.
- <u>State Agency Survey:</u> A nationwide survey of state DOTs to investigate existing and emerging practices regarding managed lanes, PTSU, and other related ATM strategies.

This will also include a survey to understand the parameters and methods used by each state DOT to finalize the locations and designs for PTSU applications.

- Initial Data Collection and Screening: To determine priority candidate corridors for implementing PTSU and other ATM strategies, a detailed database of Michigan freeways was prepared. This comprehensive data encompassed essential aspects of each freeway, such as geometric characteristics and crash data. Additionally, up-to-date operational information, such as historical travel speeds, traffic volumes, and travel times, were collected from other sources. Based on speed/congestion trends along the entire Michigan freeway network and subsequent discussions with MDOT staff, a list of potential corridors was prepared for subsequent detailed analyses.

- Operational and Safety Analysis: To understand congestion patterns along the selected corridors, analyses of speeds and delays were conducted. This included visualizing speed and delay patterns along the corridors at different times of day. Subsequently, a macroscopic comparison of the potential corridors was conducted to understand the impacts of implementing a PTSU strategy on corridor performance based on various operational performance parameters. Safety analyses were also conducted for these select freeway corridors to understand crash patterns along these corridors. This helped identify corridors experiencing more than average crashes at different times of day.

- Ranking Scheme: This chapter discusses the method of developing a ranking scheme that lists corridors based on priority to implement PTSU or other ATM strategies.

- Conclusions and Future Work: This chapter presents the conclusions of the study, the limitations of the study and venues for future research.

2 LITERATURE REVIEW

In response to the growing pressure to address persistent congestion challenges and do more with less, many transportation agencies are adopting active traffic management (ATM) strategies such as PTSUs, dynamic lane use control (DLUC), and active demand management (ADM) strategies such as managed lanes to improve their network efficiency while making use of the existing right-of-way (ROW). ATM strategies have been used successfully abroad for several decades prior, prompting their introduction into the U.S. Historically, the first U.S. example of PTSU was in the mid-1970s on Seattle's SR 520, which allowed high occupancy vehicles (HOVs) to jump the queue while approaching the city center. Since then, several states have implemented different forms of shoulder use: buses on shoulders (authorized transit to avoid congestion); static shoulders/lanes (open during fixed times of the day); and dynamic shoulders/lanes (opens based on real-time traffic data) (Jenior et al., 2019). The traditional HOV lanes that require passenger vehicles to have a minimum number of passengers have also gradually been converted to high occupancy toll (HOT) lanes that allow vehicles that don't meet the occupancy requirement limits to pay a toll to use the lane. The HOT lanes have proven more efficient than the traditional HOV lanes since they can also be variably priced to ensure reasonable travel and reliable performance within the lane (FHWA, 2020).

Some locations may combine multiple ATM and ADM strategies with several active technologies present to manage traffic. Already existing intelligent transportation systems (ITS) technology can facilitate the deployment of ATM/ADM strategies such as PTSU and managed lanes by providing real-time traffic data, traveler information and roadway performance measures and the reducing cost of implementation. For example, I-70 in Silverthorne, Colorado, uses dynamic speed limits, while I-66 in Northern Virginia utilizes a combination of ATM strategies including dynamic lane use control, dynamic speed limits, hard shoulder running, merge control, and queue warning systems (FHWA, 2023a).

2.1 Guidance on Part-Time Shoulder Use Implementation

The 2016 FHWA publication titled "Use of Freeway Shoulders for Travel – Guide for Planning, Evaluating, Designing Part-Time shoulder Use as a Traffic Management Strategy," also known as the Shoulder Use Guide, provides guidance for transportation agencies regarding the planning, design, and day-to-day operation of shoulder use to provide additional capacity when needed and as a TSM&O strategy for operations and reliability of a particular facility within the transportation network. Another approach could be the staging of PTSU as an interim solution while a long-term solution is being developed and evaluated, although it should not be taken for granted that such a strategy may reduce the support needed for the long-term project. It should be noted that although PTSU may be effective as a TSM&O strategy, the policy of FHWA for constructing and maintaining roadway shoulders along major arterials and freeways requires a formal design exception if minimum design criteria, such as shoulder width, are not met. The guidance does not address the "part-time" use of a shoulder in the case of a work zone nor the permanent, full-time usage of a shoulder as a travel lane, which would constitute "permanent elimination" of the shoulder (Jenior, Dowling, Nevers, & Neudroff, 2016).

The applications of PTSU have used either the inside (left) or outside (right) shoulder for PTSU. Right shoulders may often be easier to implement because they are generally wider than left shoulders. However, right shoulders are also generally the preferred area for emergency stops by road users and law enforcement. As such, using the left shoulder may be less expensive to implement if sufficient width is available. The left shoulder is also infrequently used for emergency stops and by law enforcement and typically introduces fewer conflicts with entrance/exit ramps. Highly "managed" corridors such as those already monitored by a traffic management center (TMC), traffic incident management (TIM) program, and existing or planned intelligent transportation system (ITS) architecture are good candidate sites for PTSU (Jenior, Dowling, Nevers, & Neudroff, 2016). TSM&O strategies supporting PTSU include ramp management, incident management, managed lanes, ATM, traveler information, and commercial vehicle operations and freight management. Planning for the PTSU operations involves integrating management and operations strategies to improve transportation efficiency, reliability, and options, with PTSU considered as a congestion management strategy and bus-on-shoulder (BOS) considered as a bus reliability strategy, and its incorporation into the planning process increases the likelihood of National Environmental Policy Act (NEPA) compliance for implementation.

Preliminary engineering activities typically occur concurrently with NEPA. Kittelson & Associates, Inc. developed a decision tree as a part of an Active Traffic Management Feasibility and Screening Guide as shown in Figure 2 (Neudorff & McCabe, 2015) to assess if PTSU will be feasible for a given facility. In principle, a similar decision tree can be adopted for any ATM strategy as part of the preliminary engineering activities to be carried out. Information gathered during the assessment of the decision tree, together with a region's transportation goals, may dictate the design options, such as whether the PTSU will operate on the left side, the right side, or both sides, what classes of vehicles it will be opened to, the hours of operation and if it would operate as an HOV-lane. However, this decision tree is limited as it does not consider the initial site selection across the transportation network as well as many desired aspects required in selecting candidate locations, such as cost, accessibility, equity, community cohesion, environmental considerations, regional development/economic effects, and regional development/economic goals. Furthermore, Performance-Based-Practical-Design (PBPD) encourages the evaluation of the performance impacts of highway design decisions in relation to the cost of providing various design features PBPD and should consider multiple design and operating solutions, including PTSU and managed lanes to find the solution that best addresses the TSM&O objectives and regional goals.

The Texas Department of Transportation (TxDOT) has also developed a method for carrying out feasibility analysis on candidate sites for PTSU during the peak period. The identification of candidate locations should involve selection of the preliminary sites or corridors that is based on the severity of reoccurring congestion during commuting hours. The initial group of candidate sites can then be screened and simultaneously prepared for deployment by building and running a traffic simulation analysis – both microscopic and mesoscopic simulation have been used. Microscopic simulation like VISSIM (PTV AG) is the preferred tool to study the effects on a specific roadway section in detail. Mesoscopic models like VISTA (VTG Inc.) are less data intensive and can study network level effects but may not account for changes in driver behavior that may occur when the shoulder is open or closed to traffic. Next, infrastructure improvements needed are identified together with the cost benefit analysis of the hard shoulder running operation. Enforcement strategies and public education plans that are required to expose road users to the new road conditions are also identified. Lastly, potential qualitative impacts such as noise, accessibility, equity and community cohesion, environmental considerations, regional development/economic effects, and aesthetics should also be considered (Ferguson et al., 2009).

Shoulder width is one of the controlling criteria that FHWA requires design exceptions for if minimum design criteria are not met. Unless an existing shoulder is at least 22 feet wide in the case of the right shoulder or 16 feet wide in the case of the left shoulder on a 4-lane freeway, a design exception will be required. AASHTO standards require a minimum freeway lane width of 12 feet and a minimum shoulder width of 10 feet, except for 4-lane freeways, where the minimum left shoulder width is 4 feet. Additionally, legal issues may arise from PTSU operations. For example, in some jurisdictions, driving on the shoulder is prohibited by law. Hence, state and regional statutes may need to be amended prior to implementation.

Part-time use also requires that the shoulder be restored to its original purpose as a shoulder, except during peak or congestion conditions and traffic incidents. Candidate highway corridors that are monitored by a traffic operations center (TOC) and supported by a traffic incident management (TIM) program (i.e., generally, highly managed corridors) are more viable candidates. PTSU is also viable if congestion reduction or transit service improvements (e.g., bus use on shoulders) are desired and traditional improvements are not feasible.

Typically, a state DOT will be the agency tasked with the responsibility of identifying, planning, and evaluating the feasibility of PTSUs and other ATM strategies within the network. As soon as the determination is made, a working group of stakeholders can be incorporated. This will likely involve interdisciplinary collaboration that will include planning, operations, design, maintenance, and executive leadership staff within a DOT; law enforcement, emergency responders, the fire department, bus operators; MPO staff; and FHWA Division Offices staff (Jenior, Dowling, Nevers, Neudorff, et al., 2016). Stakeholder involvement and education is an ongoing process that should continue during the early years of the PTSU implementation.

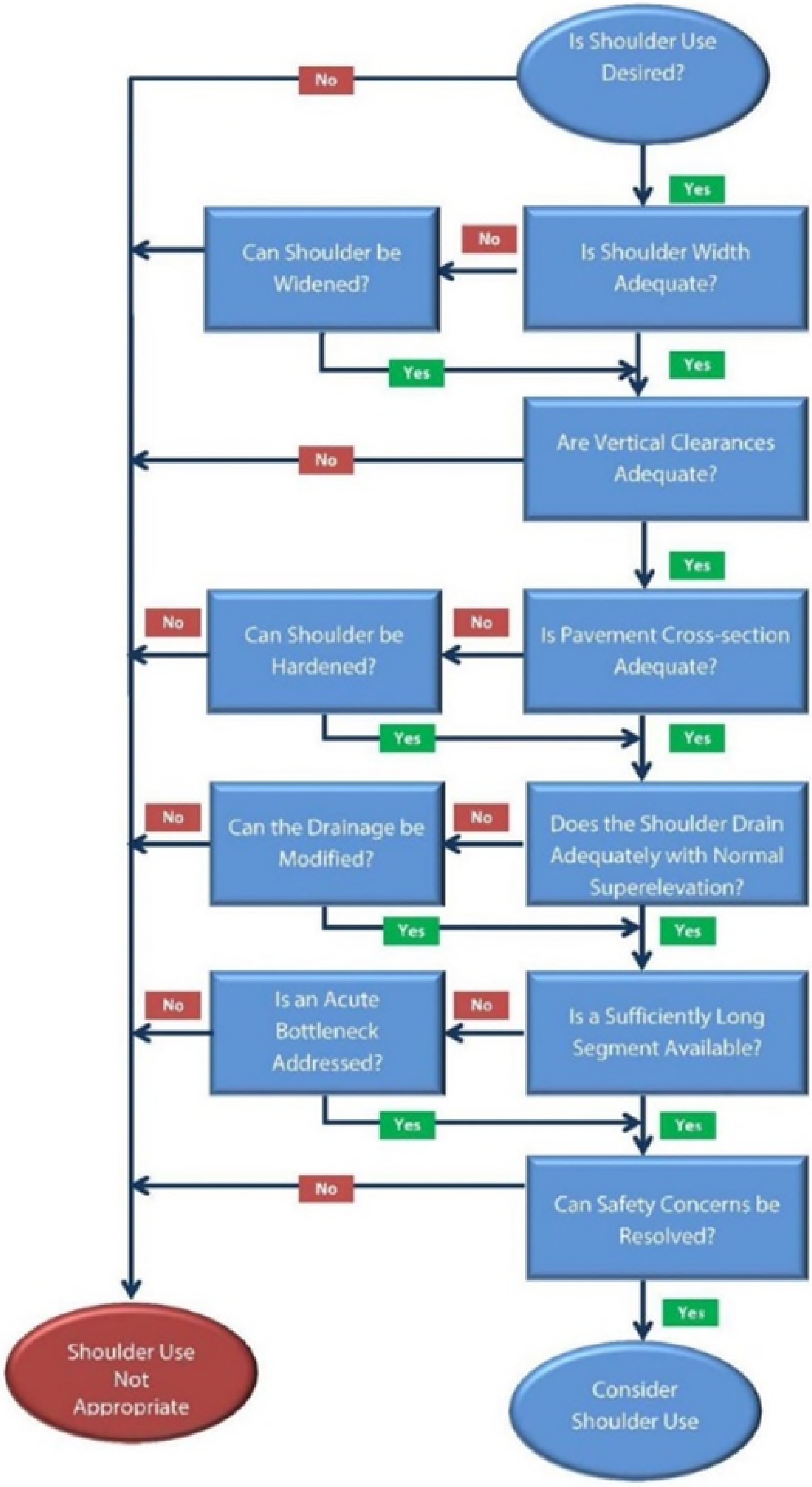


Figure 2 Part-Time Shoulder Use Screening Decision Tree *(Neudorff & McCabe, 2015)*

Education and outreach efforts designed for stakeholders and the driving public would be similar to other innovative transportation projects. Public outreach conducted during planning a PTSU should utilize a diverse range of media outlets such as local newspapers, television, and public meetings and emerging new digital media such as social media and podcasts or other interactive digital experiences.

2.2 Decision Guidance for Implementation of PTSU

The decision to implement S-PTSU, D-PTSU, or BOS depends on various factors, including transportation goals, roadway conditions, and available budget. D-PTSU, being traffic-responsive, offers greater flexibility compared to S-PTSU, which operates on a fixed schedule. D-PTSU can effectively manage recurring congestion, such as peak period traffic, and non-recurring congestion caused by special events, construction work zones, and traffic incidents.

D-PTSU is often integrated with other ATM treatments and ITS solutions, which may result in higher initial costs compared to S-PTSU. These additional ATM treatments may include ramp metering, dynamic lane assignment (using green arrow and red X), dynamic speed limits, etc., usually managed by the Traffic Management Center (TMC). The life cycle associated with D-PTSU may include the initial capital cost, operating cost, and maintenance costs of the ATM treatments, although S-PTSU may also include several ITS solutions, but are often not at the scale of D-PTSU and still tend to be more cost-effective than D-PTSU or conventional road widening (Jenior et al., 2019).

S-PTSU has been successfully implemented and operated using static signs for many years. However, there is a growing trend towards incorporating dynamic signs into these facilities as well. While still maintaining a fixed schedule for travel on the shoulder, certain well-established S-PTSU areas have incorporated dynamic signs, such as changeable message signs (CMS), in addition to their existing static signs. These dynamic signs aim to offer drivers clearer and more immediate information about the current operating conditions of the shoulder. Hence, both S-PTSU and D-PTSU locations may include dynamic signs, either as warning or regulatory signs, providing essential information to drivers about the shoulder's operation or current conditions (Jenior, Dowling, Nevers, & Neudroff, 2016).

Some states have upgraded their S-PTSU to D-PTSU as a corridor improvement to account for non-recurrent traffic and enhance travel time reliability. For instance, I-66 in Fairfax County, Virginia, was an S-PTSU from 1992 to 2015 but has now been transformed into a traffic-responsive D-PTSU with variable speed limit signs. When planning such upgrades, several factors need to be considered:

- Driver expectancy – drivers have become familiar with the shoulder being either closed or open during specific hours of the day, certain days of the week, and during special events and seasons.

- Underutilization – drivers have adaptation concerns and are not using the facility even though it is open.

- Overutilization – drivers use the shoulder even when it is closed to traffic because they are already accustomed to using them for travel during specific periods.

BOS may be used on both freeways and arterial roads to improve bus travel time and reliability. The BOS concept allows authorized buses to use shoulders on freeways and major arterials to bypass traffic in the general-purpose lane during peak congestion periods. A typical transit bus is 8.5 feet wide, excluding mirrors, and about 10 feet wide with outside mirrors, and some bus drivers have expressed safety concerns about narrower shoulder widths (Martin & Levinson, 2012a). BOS may be implemented as an interim solution pending when an improvement to the transit network can be implemented or has a long-term transit solution for the corridor (Martin & Levinson, 2012b). Ideally, this would involve collaborative effort with the transit authorities and the city's traffic and highway engineering departments. BOS operation is typically limited to static ground mounted signs without the need for ITS devices. As a result, BOS is a cost-effective strategy to improve transit travel time reliability on congested corridors (Jenior, Dowling, Nevers, & Neudroff, 2016).

2.3 MUTCD Guidelines on PTSU

The FHWA's Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) establishes a national standard for traffic control devices on all public highways. The 2009 edition of the MUTCD provides national standards for transportation agencies regarding the design and operation of traffic control devices on roadway facilities. Although this version contains traffic control standards for ATM strategies, such as preferential lanes and managed lanes, it does not include standards for PTSU/HSRs. The standards for lane shift unto the shoulder in this older version of the MUTCD are not particularly useful for PTSU/HSR as they are intended for lane shift in a work zone that uses the shoulder. However, the latest edition of the MUTCD (i.e., the 11th edition) incorporates recent technological advances and innovations and contains traffic control standards for PTSU (FHWA, 2023b). This section describes the warning signs, regulatory signs, pavement markings, and lane-use control strategies as discussed in the 11th edition of the MUTCD.

The regulatory signage for part-time shoulder use is detailed under Section 2G.21 of the MUTCD. As a standard in this section, it states that signs and plaques should be in place to notify drivers of the periods of operation that travel on a shoulder is allowed. FHWA proposes the use of PART-TIME TRAVEL ON SHOULDER OPERATION sign (R3-51) and PART-TIME TRAVEL ON SHOULDER VARIABLE OPERATION sign (R3-51d) to give road users signage that distinguishes between fixed period and variable operation, as well as beacons to signal when shoulder use is permitted for variable operation (FHWA, 2023b). In addition, FHWA recommends using the TRAVEL ON SHOULDER BEGINS 1/2 MILE sign ahead of the location where part-time travel on the shoulder first begins, followed by the DO NOT DRIVE ON SHOULDER sign, which should be spaced appropriately downstream. If certain classes of vehicles are prohibited to use the PTSU during hours of operation, then selective exclusion plaque (R3-51aP or R3-51bP) shall be mounted below the R3-51 or R3-51d sign.

FHWA similarly mandates using TRAVEL ON SHOULDER ENDS (R3-52a) sign half mile upstream of where shoulder use ends. Locations where transition from shoulder travel to permanent highway occurs shall have END TRAVEL ON SHOULDER (R3-52) sign installed. After this transition, DO NOT DRIVE ON SHOULDER (R4-17) sign is to be installed (FHWA, 2023b). As guidance, FHWA also recommends the BEGIN EXIT LANE, the EMERGENCY STOPPING ONLY sign, and the TO TRAFFIC ON SHOULDER plaque to be used at the start of deceleration lanes where vehicles are allowed to enter during periods when shoulder travel is prohibited, at turnouts provided for emergency stops during periods when shoulder travel is permitted, and below YIELD signs where vehicles on an entrance ramp are required to yield to traffic using the shoulder, respectively (FHWA, 2023b).

The warning signage for part-time shoulder use is detailed under Section 2G.22. As guidance, FHWA recommends using the TRAFFIC USING SHOULDER sign (W3-9) at freeway and expressway entrances where part-time shoulder travel is permitted to provide ample warning to approaching traffic.

Furthermore, FHWA allows using overhead lane-use control signals to indicate whether a shoulder is available or closed to travel to ensure drivers are aware of lane-use restrictions. These signals should comply with signals guidelines as laid out in the MUTCD (FHWA, 2023b). FHWA suggests the overhead lane-use control signals should be installed, evenly spaced about 1/2 mile or less, and centered over the shoulder to indicate whether a shoulder is available or closed to travel. Specifically, MUTCD proposes "the use of the green down arrow during times when travel is allowed on the shoulder, a yellow X just before the shoulder is to be closed to travel, and a red X when shoulder travel is discontinued." When the temporary shoulder is open, a yellow X should be displayed about 1/2 mile before the location where the part-time shoulder ends. A red X should always be displayed at the location where part-time shoulder use ends. To allow for additional flexibility if advance warning of a lane closure is necessary, a steady yellow X signal should be displayed on one or more lane-use control signals in advance of the location where it is required (about 1/2 mile in advance of the location where the part-time shoulder ends). FHWA suggests lane-use control signals be spaced at 1/2-mile intervals or closer if certain geometric conditions exist or when intervening interchange ramps are not adequately served by 1/2-mile spacing. Along with lane-use signals, MUTCD also allows the use of TRAVEL ON SHOULDER ALLOWED WHEN FLASHING signs (R3-51d) and TRAVEL ON SHOULDER ON GREEN ARROW ONLY signs (R3-51e). However, MUTCD states that combining lane-use signals with overhead signs should be minimized to reduce the informational load on drivers and avoid miscommunicated messaging (FHWA, 2023b).

2.4 Lessons Learned from the US-23 Flex Route in Michigan

The implementation of the US-23 Flex Route by MDOT and its subsequent evaluation have provided valuable insights for selecting additional PTSU locations within Michigan. The overall consensus from the prior project is that it enhanced performance and safety along the corridor, with drivers expressing general satisfaction. Northbound and southbound traffic experienced significant reductions in congestion and operational improvements, although a bottleneck was introduced in the northbound direction due to lane drop.

Despite a general reduction in traffic crashes along the corridor, the lane drops mentioned earlier led to an increase in northbound traffic crashes (Kassens-Noor et al., 2022). To address these challenges, the planned extension of the Flex lane from its current endpoint at M-36 (9-mile Road) to the I-96/US-23 interchange just outside Brighton was proposed for Phase 2 of the project. Additionally, MDOT intends to add an auxiliary lane along the southbound U.S. 23, between the eastbound I-96 on-ramp and the Lee Road off-ramp, to enhance traffic operations between Lee Road and US-23 (MDOT, 2025b).

As noted in these two cases, when identifying and implementing new Flex route locations, it is essential to consider potential bottlenecks on the PTSU route, how to start or terminate the Flex route corridor, and relevant signage along the corridor. In addition, the impact of the Flex route on alternative routes and adjacent roadway infrastructure, such as freeway interchanges and ramps, needs to be investigated when selecting new candidate locations, especially if they will be starting or terminating at an interchange ramp. This thorough evaluation can lead to more successful and cost-effective PTSU implementations.

As noted earlier, the perception of the Flex route was generally positive among road users, and a similar reaction can be expected when the system is expanded to other parts of the state. However, its cost-effectiveness compared to road widening was rarely mentioned on social media as a benefit, even though this was a significant reason for MDOT selecting the Flex route system over traditional road widening. The estimated benefit-cost ratios of the Flex route for both directions at 10 years and 20 years design period were 2.20 and 3.01, respectively, compared to a typical road widening by MDOT to add a lane (Kassens-Noor et al., 2022). Negative comments concerning the Flex routes more often reflected annoyances, such as some drivers demanding that capacity be increased by adding a permanent travel lane. Consequently, additional efforts need to be expended in demonstrating to road users that the Flex lane is a more cost-effective solution compared to a permanent lane. Table 3 summarizes the best practices for planning, roadway design, signage, traffic control devices, traffic operations, traffic monitoring, cost-benefit analysis, and public perceptions of the US-23 Flex route.

Table 1 Best Practices for Shoulder Use: Lessons Learnt from US-23 Flex Route *(Kassens-Noor et al., 2022)*

Guidelines	Best Practices: Shoulder Use
Roadway/Path design	• Terminate the Flex route into the deceleration lane, at system interchanges, or into auxiliary lanes near interchanges to improve safety and operations. • Start the Flex lane near the entrance ramp or the conclusion of an acceleration lane to provide a smooth transition. • Terminate future flex lane on flat, tangent section where possible to allow sufficient stopping sight distance (SSD) • Locate a crash investigation site on the opposite side of the freeway near merge points to allow space for enforcement and emergency pull over for vehicles after crashes.
Signage and traffic control devices	• Locate merging sign message for lane drop on gantries further upstream • Shorten the distance between emergency median crossings • Use TRAVEL ON SHOULDER BEGINS1/2 MILE ahead sign ahead of flex route • Use MERGE 1/2 MILE AHEAD sign and MERGE 1 MILE AHEAD sign instead of yellow-X in the transition out of the Flex route to reduce driver confusion • Set Flex routes advisory speeds to the prevailing speed limit or blanked out to minimize confusion • Provide safety caution messages such as "slow down" or "be prepared to stop," advising of speed reduction on incident displays rather than very low reduced speed limits • Change lane marking from solid to dashed lines on stretches where lane switching is allowed.
Traffic operations	• Extend Flex route hours to accommodate Fridays, long weekends, holidays, and special events. • Educate the public on the proper zipper merge method and enforce compliance when merging from the left.
Traffic monitoring	• Constantly monitor new Flex lanes going into operation as morning and afternoon peak hours may shift. The location of traffic crashes may also shift upstream or downstream.
Cost-benefit analysis	• Split the cost-benefit analysis of Flex routes into three separate analyses: one for each direction and one combined.
Public perceptions	• Promote the utilization of Flex lanes and establish them as a cost-effective alternative to permanent lanes through effective public outreach.

2.5 Literature Summary

Implementation of part-time shoulder use (PTSU) with or without some combination of other active traffic management strategies (ATM) is gaining popularity in the US as an efficient treatment to reduce congestion. The FHWA provides some guidance on the implementation of PTSU. Generally speaking, corridors that are already "actively managed" are good candidates for PTSU. Kittelson & Associates, and Texas DOT also developed methods to determine PTSU feasibility. While the Kittelson Method was purely decision tree based and did not consider initial site selection within the network, nor it considers several important factors such as cost, accessibility, environment, etc., the method by TxDOT is more data-driven through simulation analysis. Shoulder width is the primary controlling criteria for design of PTSU and the FHWA minimum recommended width of right or left shoulder for PTSU implementation is 22 ft and 16 ft, respectively. The most recent edition of MUTCD (11^{th} edition) also provides traffic control standards for PTSU. This includes regulatory signs, warning signs, pavement markings, and lane-use control strategies. The US-23 Flex route in Michigan provides several important insights from design, planning, implementation, and management perspectives. The implementation of dynamic PTSU on US-23 in Michigan resulted in both operational and safety benefits and was perceived positively by the road users. The success of US-23 Flex route motivates further implementation of PTSU along additional corridors in the state of Michigan.

3 STATE-OF-THE-PRACTICE SURVEY

As a part of this project, a questionnaire was sent to State DOT personnel members of the AASHTO Committee on Design. The purpose of this survey was to request assistance in: (a) developing strategies for identifying part-time shoulder use or hard-running shoulder (PTSU/HSR) locations; (b) documenting available data that may be obtained for use in this project; and (c) detailing pertinent design practices and issues related to PTSU/HSR. The survey was conducted online and administered via Qualtrics with a launch date of September 15, 2023, and a suggested 2-week return period. A total of 40 state DOTs and District DOT responded to the survey. The non-responding states were Florida, Hawaii, Louisiana, Mississippi, Nebraska, Nevada, New Mexico, New York, Rhode Island and West Virginia.

The survey primarily consisted of four sections. Before being shown the questions, pertinent information about the survey objective was presented. The first section of the survey introduced the goal, which was to support MDOT "flex route" and PTSU/HSR programs by assessing the national state-of-the-art and state-of-the-practice regarding PTSU/HSR and other related strategies. In the next section of the survey, respondents were asked to voluntarily provide their contact information for further follow-up, as necessary. The third section of the survey was related to questions regarding ATM strategies implemented by state agencies that were supplementary to or alternatives to PTSU/HSR and why PTSU/HSR may not have been selected for implementation. Finally, respondents who have implemented PTSU/HSR were asked questions about their implementation of PTSU/HSR. The questions were largely related to the PTSU/HSR implementation type, operations and design, traffic control, and performance measures. A full-text version of the survey questionnaire is provided in Appendix A.

3.1 Implementation of PTSU, HSR and Other ATM Strategies

Respondents were asked about whether their states have implemented PTSU/HSR or any other ATM strategy in the past. In general, states indicated at least one ATM strategy, with some agencies indicating multiple ATM strategies. Besides PTSU/HSR being investigated, several agencies have implemented alternative or complementary ATM strategies to mitigate road congestion and improve safety and operation. In addition, such strategies could be designed to support or enhance PTSU/HSR operations. Table 2 summarizes the ATM strategies operating in each state identified from the survey responses. 18 out of 41 responding DOTs indicated the presence of PTSU/HSR on one of their roadway corridors. In addition to the common ATM strategies in Table 2, some state agencies have implemented other ATM strategies – Colorado, Maryland, and Washington DOTs have implemented destination travel time displays, Tennessee has implemented active freeway lane control, and New Jersey DOT operates a real-time work zone alert with stopped queue messaging.

Table 2 State-by-State Implementation of ATM Strategies

State DOTs	PTSU	HOV	HOT	EXP	RL	RM	VSL	VAS	CP	TRN
Alabama										
Alaska										
Arizona						X				
Arkansas	X	X								
California	X	X	X	X	X	X			X	X
Colorado	X	X	X	X	X	X	X	X	X	X
Connecticut										X
Delaware							X			X
Florida										
Georgia	X	X	X	X	X	X	X			
Hawaii										
Idaho										
Illinois	X				X	X				
Indiana						X	X			
Iowa										
Kansas	X	X		X		X				X
Kentucky					X					
Louisiana										
Maine	X	X								
Maryland	X			X	X	X				
Massachusetts	X	X		X	X			X		X
Michigan	X	X		X		X		X		
Minnesota	X	X	X		X	X		X		
Missouri					X	X	X	X		
Montana							X			
Nevada										
New Hampshire	X	X								
New Jersey	X	X		X		X				X
New Mexico										
New York State										
North Carolina			X	X		X				
North Dakota										
Ohio	X	X		X		X	X			
Oklahoma							X			
Oregon					X			X		X
Pennsylvania						X	X			

State DOTs	PTSU	HOV	HOT	EXP	RL	RM	VSL	VAS	CP	TRN
Rhode Island										
South Carolina										X
South Dakota										
Tennessee							X			X
Texas	X	X		X		X			X	
Utah			X	X	X	X	X			X
Virginia	X	X	X	X	X	X	X		X	X
Vermont										
Washington State	X	X	X	X	X	X	X	X	X	X
Wisconsin	X	X				X				

Note: *PTSU: Part-time Shoulder Use; HOV: High Occupancy Vehicle lane; HOT: High Occupancy Toll Lane; EXP: Express lanes; RL: Reversible lanes; RM: Ramp metering; VSL: Variable speed limits; VAS: Variable advisory speed; CP: Congestion pricing; TRN: Bus Rapid Transit (BRT) or Transit only*

A follow-up question asked the DOTs about the type of PTSU they had implemented. Figure 3 shows a map of states that indicated to have implemented static or dynamic PTSU/HSR, while Figure 4 shows a map of states that have implemented BOS as a transportation systems management and operations (TSMO) strategy in the U.S. Colorado, Texas, and Virginia have implemented only S-PTSU. On the other hand, New Hampshire, Ohio, and Wisconsin have implemented only D-PTSU. Several states indicated the operation of multiple types of PTSU/HSR as a TSMO strategy. For example, Arkansas, Georgia, Maine, and Michigan indicated S-PTSU and D-PTSU, while Washington operates all three types (i.e., S-PTSU, D-PTSU, and BOS).

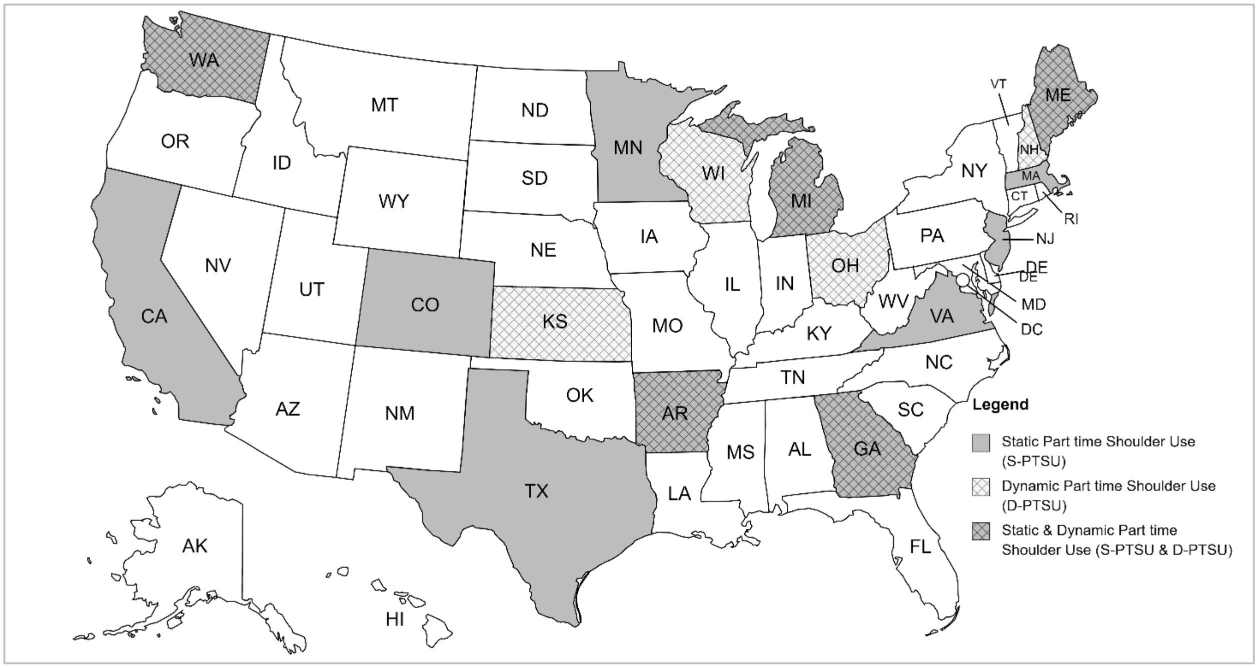


Figure 3 Map of Static and Dynamic Part-Time Shoulder Use or Hard Shoulder Running Locations in The U.S., 2023.

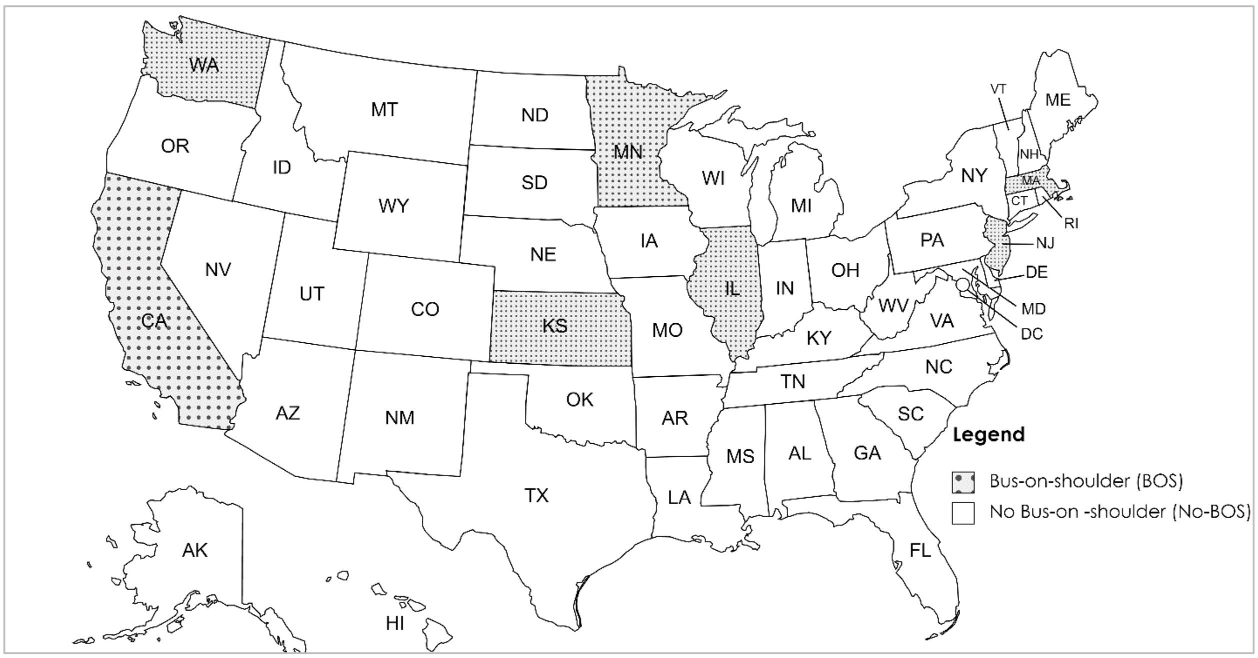


Figure 4 Map of Bus on Shoulder (BOS) Locations in the U.S., 2023.

Table 3 summarizes corridors where PTSU/HSRs have been implemented in the U.S. as of 2023. About 18 corridors featured PTSU/HSR on the right side, while about 15 had these lanes on the left side. Consequently, there was no clear overall preference for either the right or left side for the placement of PTSU/HSR lanes. This suggests that site-specific conditions and state DOT design policies likely determine the selection of the shoulder side for PTSU/HSR. On the other hand, 32 of the corridors with PTSU/HSR were reported as permanent solutions to alleviate congestion, while only 5 were reported as temporary solutions. It was noted that some of the temporary solutions were intended to transition to more permanent measures once suitable, long-term strategies are identified. Furthermore, a few of these temporary measures were initially initiated as pilot programs being investigated.

Although PTSU/HSR projects may be more cost-effective than providing an additional lane on the corridor, the resources required to plan, design, and implement them may make it financially prohibitive as a temporary solution. There is also a concern that the PTSU/HSR may not operate as intended, resulting in the subsequent addition of a full lane. California, Georgia, Minnesota, Texas, and Wisconsin indicated running PTSU/HSR corridors as temporary solutions. Interestingly, these same 5 states reported previously removed a PTSU/HSR installation. These removals could be related to a shift in state DOT practices, safety or operational issues resulting in adding a permanent full lane. Most reasons for PTSU/HSR removal are related to adding a permanent lane, suggesting PTSU/HSRs as an interim congestion alleviation strategy until a permanent lane can be planned, designed, and constructed. Table 4 summarizes the state DOTs that have removed a PTSU/HSR in the past and the reason the installation was removed.

Table 3 Summary of corridors with PTSU/HSRs in the U.S

Location	Corridor	Shoulder side	Duration
Little Rock, Arkansas	I-430 between Hwy 10 and Hwy 100	Right shoulder	Permanent
City of Pismo Beach, California	US 101 in San Luis Obispo County	Left shoulder	Permanent (7-year Pilot)
Richmond-San Rafael Bridge, California	I-580 Between Richmond and Marin County	Right shoulder	Temporary (7-year Pilot)
N.V. State Lane to the Agricultural Inspection Station, California	I-15	Right shoulder	Permanent
Colorado	I-70 from M-232 to M-243	Left shoulder	Permanent
Colorado	I-70 Eastbound and Westbound MM 230 to MM 242		
Georgia	SR 400 north of I-285	Right shoulder	Temporary
Georgia	I-85 between Jimmy Carter and Indian Trail Rd	Right shoulder	Permanent

Location	Corridor	Shoulder side	Duration
Kansas	I 35 from MO/KS state line to 119th Street	Right shoulder	Permanent
Maine	I-95 on the bridge between the border of Maine and New Hampshire		Permanent
Maryland			
Michigan	US-23 from M-14 to M-36	Left shoulder	Permanent
Michigan	US-23 from M-36 to I-96	Left shoulder	Permanent
Michigan	I-96 from I-275 to Kent Lake Rd	Left shoulder	Permanent
Michigan	US-131North of Grand Rapids	Left shoulder	Permanent
Michigan	I-94 from US-23 to State St	Right shoulder	Permanent
Minnesota	I-35W	Left shoulder	Temporary
Minnesota	Twin cities - Citywide		Permanent
New Hampshire	Blue Start Turnpike I-95 from M-14.4 in New Hampshire to M-3.0	Right shoulder	Permanent
New Jersey	U.S Route 1	Right shoulder	Permanent
New Jersey	NJ 129	Right shoulder	Permanent
Old Bridge Township, New Jersey	US 9 between Spring Valley Road and Cindy Street	Right shoulder	Permanent
Old Bridge Township, New Jersey	US 9 between Phillips Drive and Perrine Road	Right shoulder	Permanent
Old Bridge Township, New Jersey	Between Perrine Road and Ehlers Lane	Right shoulder	Permanent
Old Bridge Township, New Jersey	Between Cindy Street and Spring Valley Road	Right shoulder	Permanent
New Jersey	Route 495		Permanent
New Jersey	Route I-80 (HOV on shoulder)	Left shoulder	Permanent
New Jersey	Route I-287 (HOV on shoulder)	Left shoulder	Permanent
Columbus, Ohio	IR-670 from MM 5 to MM 9	Left shoulder	Permanent
Cincinnati, Ohio	IR-275	Left shoulder	Permanent
Columbus, Ohio	IR-71	Left shoulder	Permanent
Texas	SH 161 from John Carpenter Fwy to Airport Fwy	Left shoulder	Temporary
Virginia	Interstate 264 from mile marker 15 – 18	Right shoulder	Permanent
Virginia	Interstate 64: Mile marker 266-284	Left shoulder	Permanent
Washington State	S.R. 16 from MP 15.35 to 15.40, Ramp 16		Permanent
Washington State	U.S 2 from MP 0.65 to 2.20	Right shoulder	Permanent
Lynwood, Washington State	I-405 Lynwood area	Right shoulder	Permanent
Lynwood, Washington State	I-405 from Kirkland to Lynnwood	Right shoulder	
Lynwood,	I-5		Permanent

Location	Corridor	Shoulder side	Duration
Washington State			
Wisconsin	US 12/18 Madison Beltline Highway	Left shoulder	Temporary (10-15 year) solution

Table 4 PTSU/HSR Removals in the US

State DOTs	Reason for PTSU/HSR removal
California	A permanent lane was added
Georgia	Major construction work eliminated the shoulder
Minnesota	A permanent lane was added
Texas	A permanent lane was added
Virginia	A permanent lane was added, and other ATM or TSMO strategies were implemented.
Wisconsin	Unknown

In addition to providing information about implemented PTSU/HSR corridors within their states, several state DOTs indicated PTSU/HSR at different stages of planning, design, or construction. Indiana DOT indicated a PTSU/HSR project at the design stage for the I-80/94 Expressway from I-65 into Illinois, which will be a D-PTSU on the left side shoulder with a current plan to handle the traffic control with active traffic management and dynamic message signing along the corridor. Iowa DOT has a D-PTSU project in the design phase programmed to begin operation on I-35/80 in Polk County in Iowa around 2025 or 2026. The Iowa DOT seeks to change the Iowa driving code to allow for driving on the shoulder and support its integrated corridor management (ICM) approach for this corridor. Maryland DOT has an S-PTSU (sign only, no gantry) planned on a local M.D. route on the left shoulder and a D-PTSU under construction on 18 miles (both directions) of I-695 Baltimore Beltway and on the left shoulder. In addition, several other corridors have been considered at various locations at the planning level by PennDOT. PennDOT is proposing D-PTSU on both directions of I-76 and indicated full-time shoulder conversions of I-78/SR22 in Lehigh County and SR 222 & S.R. 12 interchange in Berks County on the right shoulder. It should be noted here that a full-time use of the shoulder or part of its cross-section with a full-time travel lane – known as shoulder elimination could increase capacity- is not considered PTSU according to the FHWA guidelines (Jenior, Dowling, Nevers, Neudorff, et al., 2016). However, this response highlights one of the many options that may be considered by state DOTs when deciding whether to implement PTSU/HSR or another ATM strategy, such as adding a permanent lane or using the shoulder as a travel lane full-time.

On the contrary, about ten State DOTs have considered PTSU/HSR for implementation in the past but have not implemented PTSU for a myriad of reasons. State DOTs that have considered PTSU/HSR but are yet to implement them as a TSMO strategy are summarized in Table 5.

Table 5 Summary of Reasons for Not Implementing PTSU/HSR

State DOTs	Reason for not implementing PTSU/HSR as a TSMO strategy
Alabama	Lack of coordination and understanding. Shoulders do not have sufficient buildup to sustain the projected traffic loads.
Arizona	Geometric and operational considerations did not support proceeding with PTSU.
Connecticut	Concerns were based on experience from other states and the potential for increased crashes. Past concerns include planning public outreach and traffic control strategy. Additional issues were related to shoulder design, cross-slope modification, and operational impacts on speed change lanes.
Delaware	The shoulder was eliminated and reconstructed as a full-time travel lane.
Missouri	Building and maintaining lane-quality shoulders and expensive ITS equipment will be too costly. Prioritizing adding a lane
North Carolina	Bus on shoulder concept is still being considered.
Oklahoma	In the process of setting up needed legislation and locating appropriate locations
Oregon	Geometry and technology limitations, although the agency is still investigating
Tennessee	Cost to implement. Shoulders are not full-depth pavement, and Some bridges are not wide enough to accommodate PTSU/HSR operations.
Utah	Safety considerations and ITS infrastructure limitations were a concern when PTSU/HSR was considered many years ago. Advancements in technology and ITS infrastructure may suggest further investigation.

3.2 PTSU-Related Policies and Guidance

The next section of the survey involved asking State DOTs if they had formal policies or guidance regarding road conditions (such as traffic volume ranges, available right-of-way, and geometric conditions) under which PTSU may be considered or design guidance and policies. Total 8 out of the 18 state DOTs operating PTSU/HSR corridors (California, Colorado, Kansas, Maine, Michigan, New Jersey, Ohio, and Washington) indicated that they had such guidance. On the other hand, 6 out of 18 state DOTs with PTSU/HSR corridors (Arkansas, California, Colorado, Minnesota, Ohio, and Washington) indicated they have a formal design policy for PTSU/HSR.

Respondents from state DOTs were also asked what minimum width they consider for implementing PTSU/HSR. Figure 5 shows a summary of these responses. As shown in the figure, most DOTs (6 out of 18) considered a minimum width of 12 feet for the travel lane. Several states have provided below 12 feet. Colorado DOT and Michigan DOT indicated a minimum shoulder width of 11 feet. Georgia DOT, Kansas DOT, and Minnesota DOT indicated a minimum travel lane width of 10 feet. In addition, some state DOTs provided a range of minimum widths to be considered. Texas DOT provided a range of between 11 to 12 feet, and Washington DOT provided a range of 10 to 13 feet as the minimum width considered. The minimum width considered for the travel lane on the shoulder could depend on site-specific conditions, available right way, or other factors such as whether the shoulder is open to all traffic or buses only. AASHTO standards require a minimum freeway lane width of 12 feet, however, shoulder lanes less than 12 feet may be used with design exceptions. A 12-foot travel lane on the shoulder creates a "shoulder lane" with the same width as the general-purpose lanes on the freeway. In practice, the existing shoulder widths before implementing PTSU/HSR may range from no width to more than 12 feet. Several strategies may be used to resolve these concerns, such as adjusting the posted speed or lateral offset to obstruction. For example, the respondent from Washington DOT indicated that a 10-foot minimum width was used for a posted speed limit of less than 35 mph and a minimum of 11 feet for posted speeds greater than 35 mph. Minnesota's standards for BOS specify a minimum width of 10 feet for the "shoulder lane" and a minimum total shoulder width of 12 feet. This implies the inclusion of a two-foot paved area between the second edge lane and the edge of the pavement. However, a wider lane width of 12.0 feet was mandated for "areas of new construction or reconstruction." As in the case of Washington DOT, buses on 10-foot shoulder lanes were also limited to a 35-mph speed limit in Minnesota.

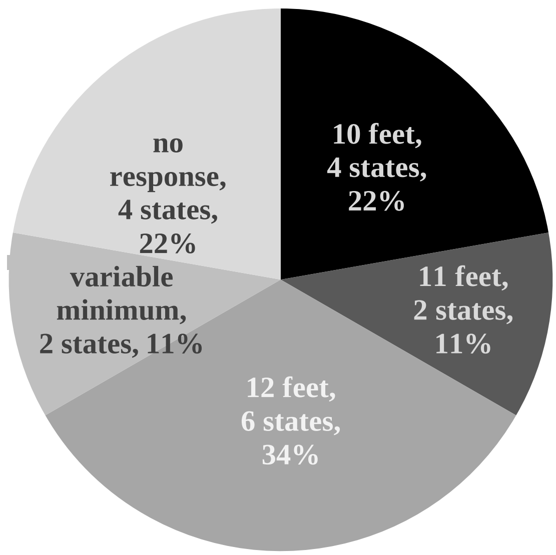


Figure 5 Minimum Travel Lane Widths Considered for PTSU/HSR by Number of State DOTs

Additional information related to the design of PTSU/HSR and specifically the need for cross-slope modifications, drainage modifications, and noise mitigation at PTSU/HSR sites are summarized in Table 6, with noise mitigation seemingly of the least concern when identifying PTSU/HSR locations.

In addition, the survey questionnaire investigated traffic performance measures utilized by state DOTs when identifying PTSU/HSR locations. Figure 6 shows the traffic performance measures state DOTs use to identify new PTSU locations. As indicated in the figure, the assessment of future part-time shoulder use (PTSU) locations by state DOTs predominantly revolves around the use of two primary performance metrics: congestion duration and delay, and total delay. Level of service (LOS), level of travel time reliability (LOTTR), and travel time index (TTI) were also widely used by state DOTs. Other less common performance measures were vehicle miles traveled (VMT) (California DOT, New Jersey DOT, Ohio DOT and Virginia DOT), planning time index (PTI) (Michigan DOT, Virginia DOT, Wisconsin DOT), volume capacity analysis and highway capacity manual analysis (HCM) (Arkansas DOT), volume using shoulder (Georgia DOT), travel time, queuing and speed (Indiana DOT), and transit advantage (Minnesota DOT).

Table 6 Cross-slope Modifications, Drainage Modifications, and Noise Mitigation Required at PTSU/HSR Sites

State DOTs	Cross-slope Modifications	Shoulder Hardening	Drainage Modifications	Noise Mitigation
Arkansas	No	all sites	No	No
California	some sites	all sites	some sites	No
Colorado	all sites	all sites	all sites	No
Georgia	No	some sites	No	No
Illinois				
Indiana	some sites	some sites	some sites	some sites
Kansas	No	No	some sites	No
Maine	No	all sites	No	No
Maryland	some sites	some sites	some sites	No
Massachusetts				
Michigan	some sites	all sites	some sites	all sites
Minnesota	No	some sites	all sites	No
New Hampshire	No	No	No	some sites
New Jersey	all sites	some sites	all sites	No
Ohio	all sites	all sites	all sites	some sites
Texas	No	No	No	No
Virginia	all sites	all sites	all sites	all sites
Washington	No	some sites	some sites	No
Wisconsin	all sites	some sites	all sites	unknown

State DOTs were also asked if they consider state, local police, or emergency services when selecting new PTSU locations. Fourteen out of 18 states consider police and emergency services when selecting new PTSU locations. Only two state DOTs indicated they do not, while two state DOTs did not respond. The availability of resources for emergency response and services and carrying out "sweeps" before opening the shoulder to traffic could be vital to the smooth running or operation of PTSU/HSR and useful in identifying PTSU/HSR locations.

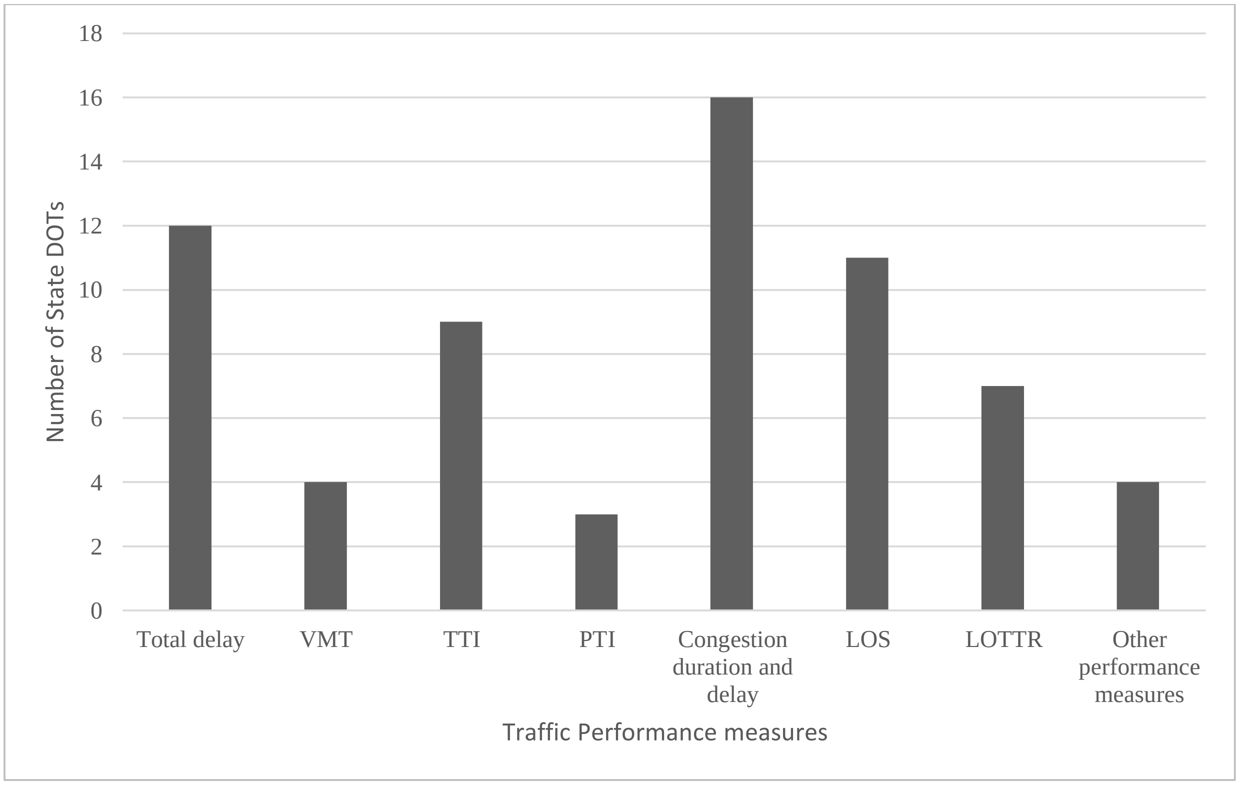


Figure 6 Enumeration of State DOT Preferences for Traffic Performance Measures

3.3 Evaluation of PTSU/HSR

State DOTs were also asked if they had information about the shoulder capacity when PTSU/HSR is active. Six state DOTs responded "Yes" but only four states provided the capacity information, while 13 states did not have this data or did not respond. Table 7 summarizes shoulder capacity ranges when operating PTSU/HSRs. New Jersey suggested a percentage of the capacity of a normal travel lane as a guide, although this percentage was not provided.

Table 7 Estimated Capacity of PTSU/HSR

State DOTs	Shoulder capacity
Colorado	1100 -1600 vphpl
Maine	Not provided
Michigan	1700 vphpl
New Jersey	% of a full lane
Washington	800-1,000 vphpl

State DOTs	Shoulder capacity
Wisconsin	1200-1500 vphpl

Furthermore, state DOTs that have implemented PTSU/HSRs were asked whether they utilized modeling or simulation techniques to evaluate their potential PTSU/HSR locations and which microsimulation software were used. Modeling or traffic simulation could be invaluable tools when identifying PTSU/HSR locations as they can assist state DOTs in identifying traffic hot spots, induced demand, spill-over effects, and highway corridors most likely to benefit from PTSU/HSR implementation. State DOTs were evaluated to understand which of the popular simulation software were used for these evaluations (Aimsum, Freeval, Sumo, and Vissim) and asked to list any other simulation software used besides those listed. Nine out of 18 states indicated using some kind of modeling or simulation technique to evaluate potential PTSU/HSR locations, while 7 states indicated not using any simulation software. The remaining two state DOTs did not respond to the question. Figure 7 illustrates the common traffic simulation software used for these evaluations. VISSIM is the most common choice among state DOTs that utilize simulation software opting for VISSIM. Other options include Transmodeler (Colorado DOT and Ohio DOT), FREQ model employed by Caltrans, and Paramics, used by Wisconsin DOT.

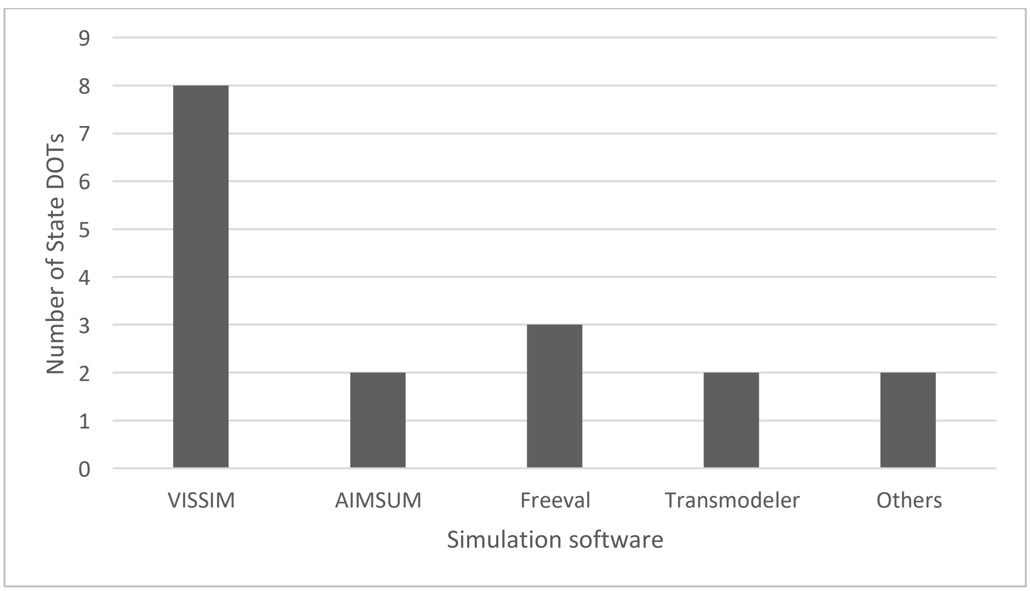


Figure 7 Enumeration of State DOT Preferences for Traffic Simulation Software

3.4 Real-Time Monitoring of PTSU/HSR Corridor

The nature of PTSU/HSRs suggests that the shoulder would be accessible for travel only during specific periods of the day. Consequently, monitoring of the shoulder is necessary to respond to incidents promptly, ensure closure, or provide timely clear-up and emergency services in the event of weather or traffic-related incidents. This could improve operation and incidence response for PTSU/HSR operations. These services may be managed by a Traffic Management Center (TMC) and are often facilitated and coordinated with the police department, incidence response, or a dedicated highway patrol fleet.

Real-time monitoring would often be required for D-PTSU as the shoulder is opened in response to traffic, which could change instantly but may not be necessary for S-PTSU or BOS, where occasional "sweeps" can be carried out on a schedule before opening or closing the shoulder. Table 8 summarizes state DOTs that have real-time monitoring and incident response for their PTSU installations. Thirteen out of 18 state DOTs have real-time monitoring and incident response on all their PTSU/HSR locations, 2 state DOTs (Maryland and New Jersey) have on some of their locations, and one state DOT (Kansas DOT) does not provide real-time monitoring. It should be noted that Kansas operates a BOS, which is only opened dynamically when mainline speeds drop below 35 mph.

As suggested by the FHWA, BOS lanes do not need to be inspected before use, as the bus drivers can make the decision to use the BOS lanes or merge in traffic to avoid incidence, and this information can be passed on to the dispatchers to alert other bus drivers. Hence, the need for real-time incident monitoring on the shoulder may also not be required as the bus drivers carry out this function. Although providing real-time monitoring may not be necessary for S-PTSU or BOS, several state DOTs may still offer such services on their corridors to facilitate the planning and operation of the BOS, although this may come at an increased running cost.

Table 8 State-wise Real-time Monitoring and Incident Response for PTSU Installations

State DOTs	Real-time Monitoring and Incidence Response	S-PTSU	D-PTSU	BOS
Arkansas	All sites	X	X	
California	All sites	X		X

State DOTs	Real-time Monitoring and Incidence Response	S-PTSU	D-PTSU	BOS
Colorado	All sites	X		
Georgia	All sites	X	X	
Illinois				X
Kansas	No		X	X
Maine	All sites	X	X	
Maryland	Some sites	X	X	
Massachusetts		X		X
Michigan	All sites	X	X	
Minnesota	All sites	X		X
New Hampshire	All sites		X	
New Jersey	Some sites	X		X
Ohio	All sites		X	
Texas	All sites	X		
Virginia	All sites	X	X	
Washington	All sites	X	X	X
Wisconsin	All sites		X	

The survey also asked a series of questions related to strategies used by state DOTs to handle traffic incidents and inclement weather along the PTSU/HSR corridor. Figure 8 summarizes the strategies utilized by state DOTs to handle traffic incidents on the shoulder. CCTV cameras, communication equipment, or other ITS devices, such as automatic incident detection, can be installed to facilitate incident detection and response. Thirteen out of the 18 states that have implemented PTSU/HSR have such devices installed. Thirteen out of 18 state DOTs handle traffic incidents on the shoulder through law enforcement and emergency services. In addition, 8 state DOTs have a dedicated fleet of highway patrol, emergency patrol, TMC staff, or incident response vehicles committed to promptly resolving incidents. Furthermore, 10 out of 18 state DOTs responded that they close the shoulder during traffic incidents. If the PTSU/HSR has dynamic lane control signs, this could be used to trigger the lane closure rapidly to prevent secondary crashes. Closing the shoulder clears it of any vehicles and could provide emergency responders, the highway patrol, and state or local police with a clear and uncongested path to address traffic incidents promptly (Jenior, Dowling, Nevers, Neudorff, et al., 2016). Moreover, if the PTSU/HSR has dynamic lane control signs, as in the case of many D-PTSU installations, this could be used to trigger the lane closure rapidly to prevent secondary crashes. Other strategies state DOTs use to handle traffic incidents on the shoulder include providing emergency turnouts, installing additional static or dynamic warning signs at locations that experience high crashes, advance dynamic messages ahead of the incident, and partial lane use.

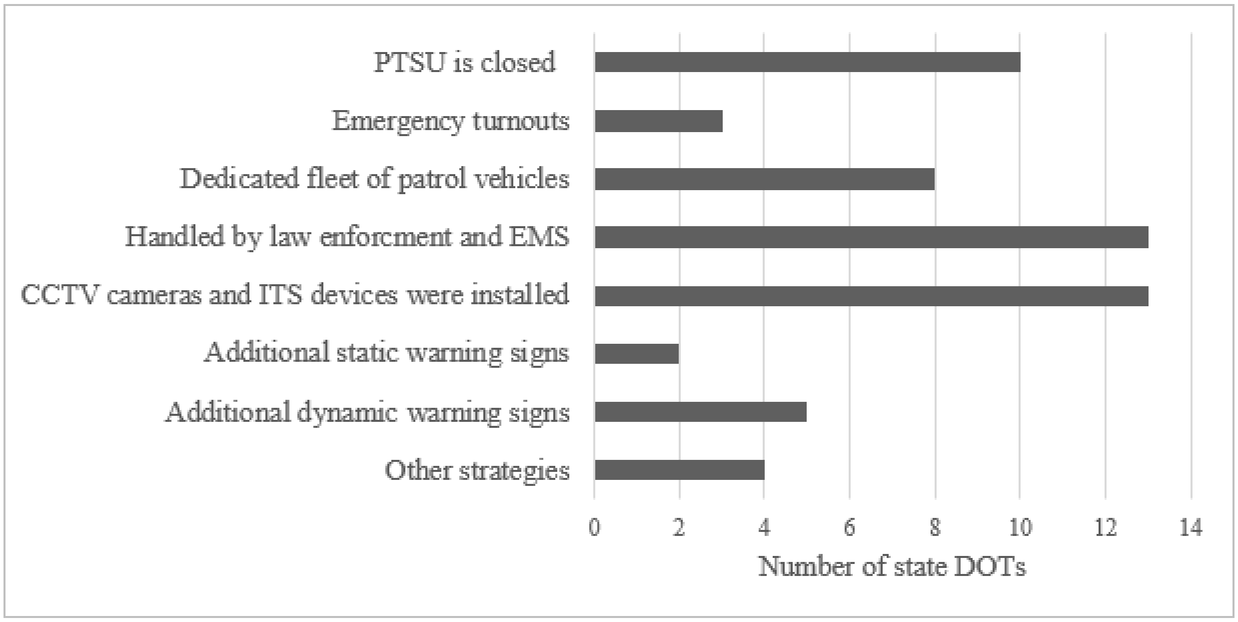


Figure 8 Strategies Utilized by State DOTs to Handle Traffic Incidents on the Shoulder

In addition to traffic-related incidents, the PTSU/HSR corridors can also experience weather-related incidents including ponding water, flooding, reduced visibility due to fog, and snow and ice buildup. Figure 9 summarizes the strategies utilized by state DOTs to handle weather-related incidents on the shoulder. Majority of the DOTs (12 out of 18) may opt to close the shoulder during weather-related incidents, and 10 out of 18 state DOTs plow the shoulder during winter storms for PTSU/HSR. Five out of 18 state DOTs indicated using roadway sensors that can be used to determine shoulder pavement conditions and to decide whether to open or close the shoulder to traffic during snow storms.

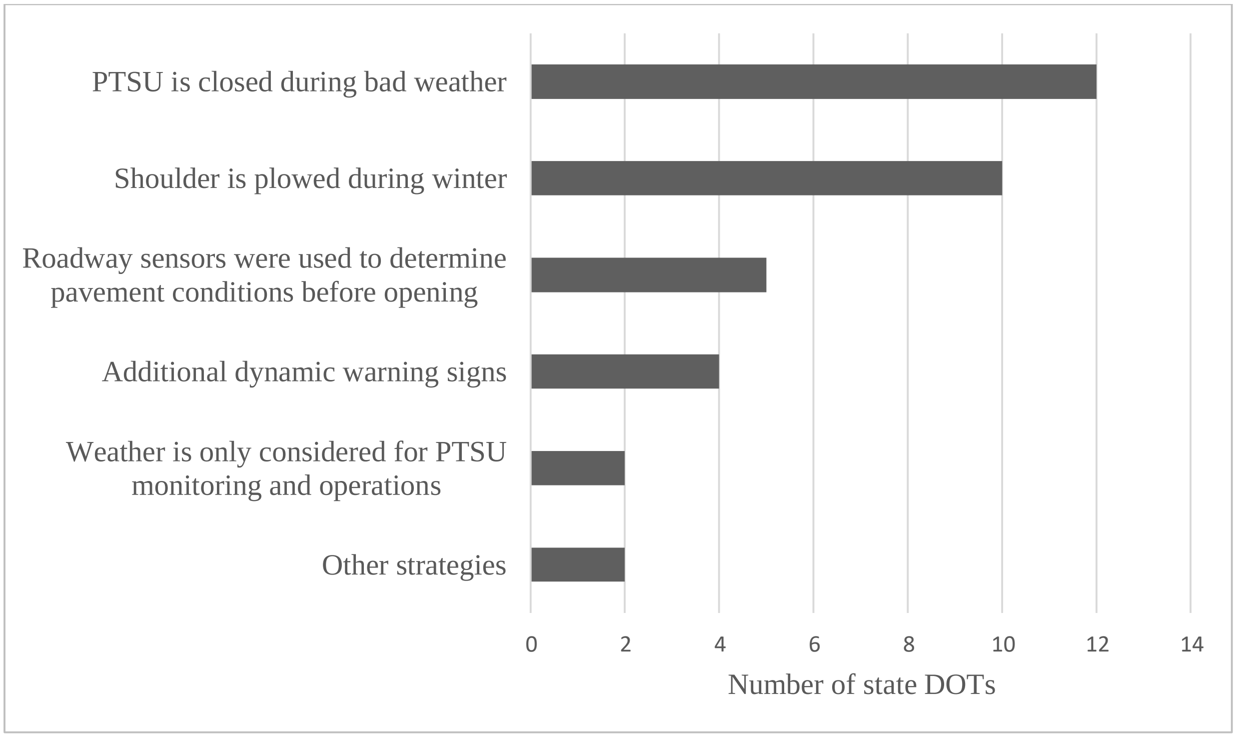


Figure 9 Strategies Utilized by State DOTs to Handle Inclement Weather as Related to PTSU/HSR

3.5 Initiation and Termination of PTSU/HSR

The survey also asked how state DOTs initiate or terminate PTSU/HSR and the traffic control devices utilized to transition into and start PTSU/HSR segments or transition out of and terminate PTSU/HSR segments. Operational and safety considerations suggest that PTSU/HSRs do not begin or end abruptly. Clear instructions are to be given to drivers whenever the shoulder is open or closed for traffic using traffic control devices such as warning signs, regulatory signs, pavement markings, and lane use control signs (LUCS). Figure 10 summarizes how state DOTs initiate PTSU/HSRs. Thirteen out of 18 state DOTs may initiate PTSU/HSR along basic freeway segments by strategically placing signage or pavement markings, while 9 out of 18 states may begin PTSU/HSR segments by adding a lane from an on-ramp. Other strategies utilized by state DOTs to initiate PTSU/HSR segments include starting the PTSU/HSR as an auxiliary lane between adjacent interchanges to mitigate closely space ramps, commencing PTSU/HSR at high-volume on-ramp locations where traffic is merging, and starting them between interchanges to create part-time auxiliary lanes.

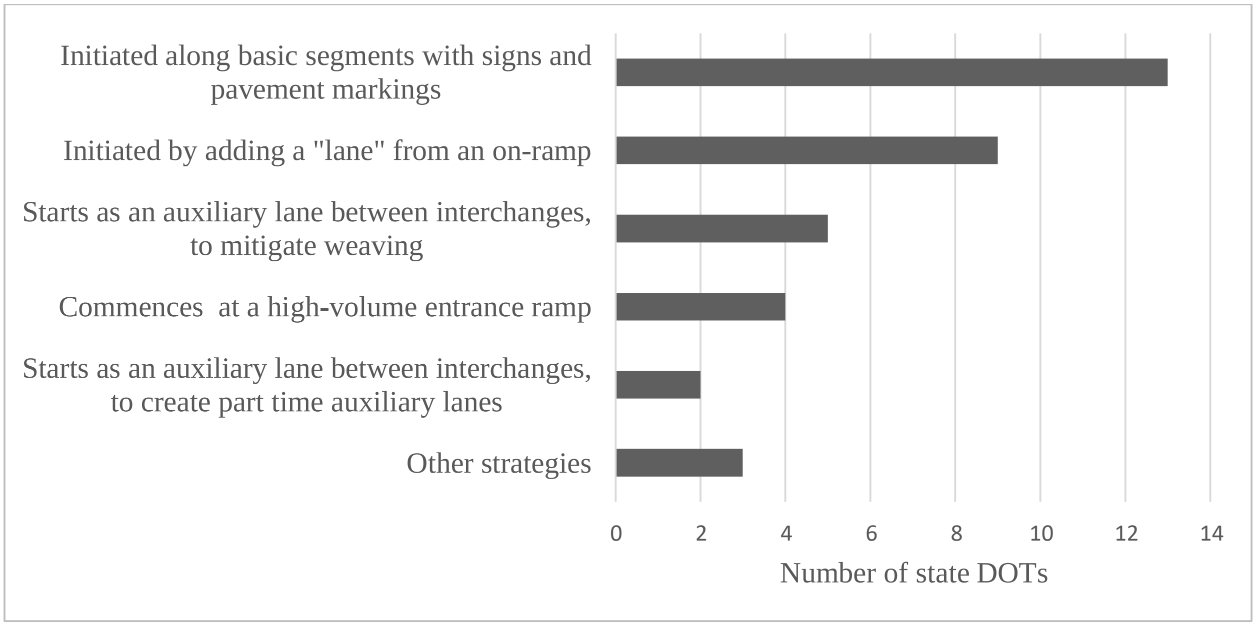


Figure 10 Strategies Utilized by State DOTs to Initiate PTSU/HSR Segments

Figure 11 summarizes how state DOTs terminate PTSUs. Eleven out of 18 state DOTs end PTSU/HSR along basic freeway segments through the strategic place signs and pavement markings, while 8 out of 18 state DOTs end the PTSU/HSR segments at the exit ramps to avoid unexpected lane changes. Other strategies state DOTs utilize include ending the PTSU/HSR segments where a high volume of traffic exits, for example, at the exit ramp of system interchanges or major road forks on the freeway. PTSU/HSRs may also be terminated between interchanges to effectively create part-time auxiliary lanes, which may be used for merging, diverging, and weaving maneuvers.

State DOTs were also asked about the traffic control devices (TCD) utilized to inform or instruct drivers as they transition into corridors where the PTSU/HSR is located and until they exit the PTSU/HSR segments. Table 9 shows an enumeration of state DOTS using each type of traffic control device. The traffic control devices were classified as warning signs, pavement markings, regulatory signs, and lane-use control signs (LUCS). In addition, state DOTs were allowed to include other traffic control strategies in text format when filling out the survey form. Thirteen out of 18 state DOTs have warning signs on the transition into the PTSU/HSR corridor, and 8 out of 18 DOTs provide pavement markings. Some examples of warning signs used include "Watch for buses on the shoulder" and "Shoulder use permitted on green arrow only." These signs could be either static or dynamic. Other traffic control strategies were flashing beacons and variable message boards to alert and instruct drivers along the PTSU/HSR.

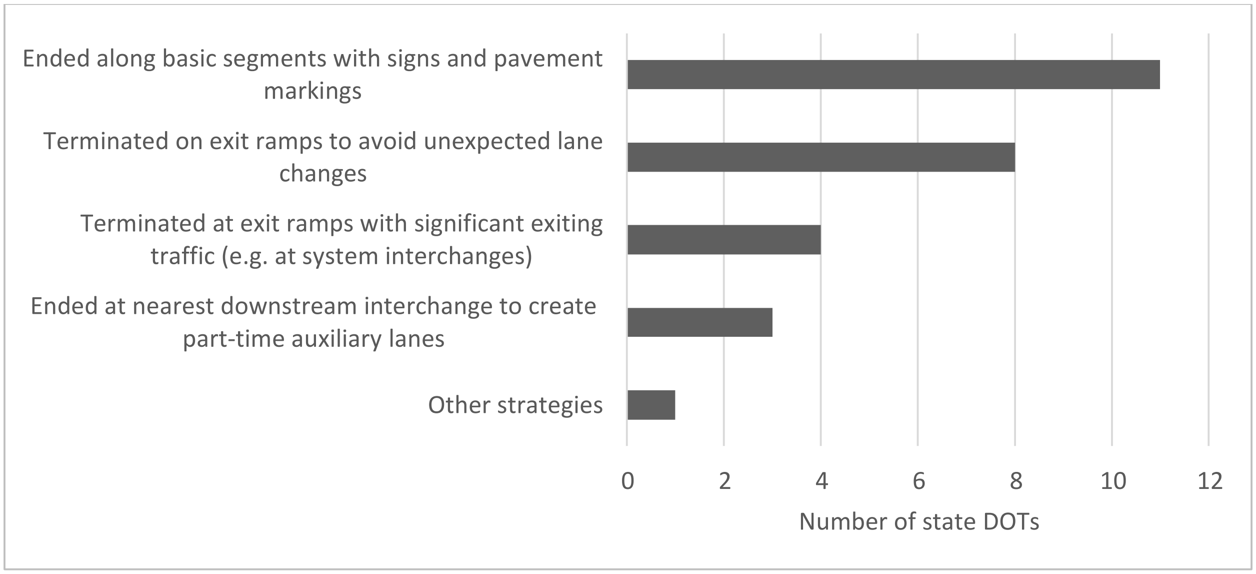


Figure 11 Strategies Utilized by State DOTs to Terminate PTSU/HSR Segments

Table 9 Enumeration of PTSU/HSR States Using Each Type of TCD

Sign Type	Transition into PTSU	At the start of PTSU	Transition out of PTSU	At the end of PTSU
Warning signs	13	10	7	-
Pavement markings	8	12	7	9
Regulatory signs	12	14	11	11
Lane-use control	2	11	10	9
Other strategies	3	1	-	-

By investigating state practices across DOTs, in Table 9 and as simplified in Figure 12, state DOTs appear to prioritize the deployment of traffic control devices at the start and the transition into the PTSU/HSR segments rather than at the transition out of or the end of the PTSU/HSR segments.

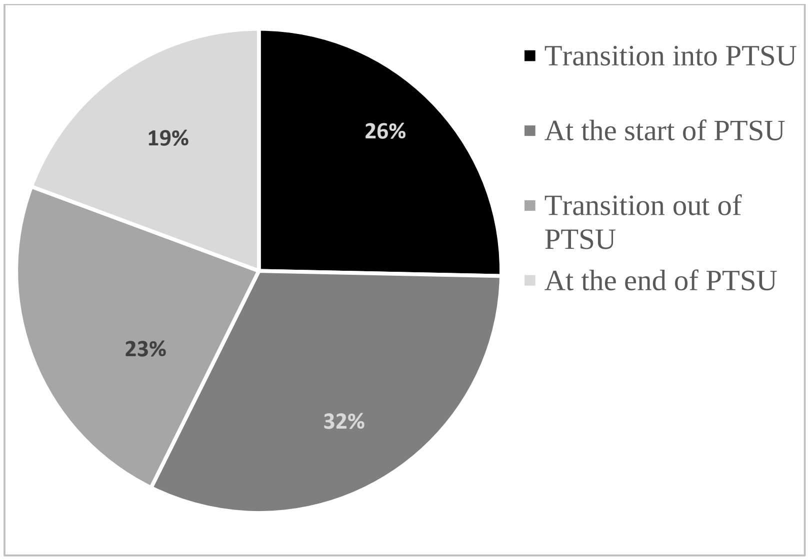


Figure 12 Enumeration of Traffic Control Devices at the Transition Into, Start, Transition Out of, and End of PTSU/HSR Corridors

3.6 Data Availability

Table 10 provides an assessment of the availability of formal policies or guidance as to conditions (e.g., traffic volume ranges, available right-of-way, geometric conditions) and formal policies on the design of PTSU/HSR. State DOTs were asked if they have such policies available, and as a follow-up question, respondents were asked if they were willing to provide access to these documents. Respondents from the state DOTs listed in Table 10 indicated the availability and willingness to provide access to these documents if requested. All the states listed in the table also indicated a willingness to provide access to these policies and guidance documents if requested.

Table 10 Availability of Formal Policies on Conditions under which PTSU/HSR is Considered and PTSU/HSR Design by State DOTs

Formal policies on PTSU/HSR conditions for consideration	Formal policies on PTSU/HSR design
California	Arkansas
Colorado	California
Kansas	Colorado
Maine	Minnesota
Michigan	Ohio
New Jersey	Washington
Ohio	
Washington	

3.7 Summary

The state DOT survey was distributed to gain insights on the current state-of-practice related to identification of potential corridors for PTSU/HSR implementation, and detailing the pertinent design practices and issues. Of the 41 responding states, 18 states currently operate some form of PTSU/HSR on at least one of their corridors. Several of these states operate multiple types of PTSU/HSR (static and dynamic), while Washington state operates static, dynamic PTSU as well as bus-on-shoulder strategy. The data showed no clear preference for operating PTSU on the right or the left shoulder. In majority of the cases, PTSU was implemented as a permanent solution to congestion. Several states also reported not implementing PTSU due to various reasons. Of the 18 states that have PTSU/HSR corridors in their states, 8 state DOTs indicated to have some form of formal policies or guidance regarding identification of candidate corridors or related to design guidance and policies. The assessment of future PTSU locations by state DOTs predominantly revolved around the use of two primary performance metrics, namely, congestion duration and delay, and total delay. Nine of the 18 states also indicated using simulation tool to evaluate potential PTSU/HSR locations. Moreover, 13 of these 18 states monitor their PTSU/HSR corridors in real-time to manage incidents related to weather and traffic. The current state of practice on how DOTs initiate and terminate PTSU segments was also documented. Majority of the states do so by initiating and terminating PTSU segments along basic freeway segments with proper signage and pavement markings. The findings from this survey would be helpful for MDOT and other road agencies in developing/updating their design guidelines related to PTSU/HSR.

4 INITIAL DATA COLLECTION AND SCREENING

The primary focus of this project was to identify candidate limited-access corridors suitable for implementing PTSU strategy in the near future. To that end, a detailed database of Michigan freeways was prepared. This included data related to roadway geometry, operational conditions such as volume and speed, and safety aspects including crash data. The following sections discuss the various data collected and integrated as a part of this project.

4.1 Michigan Freeway Network

The first step in the data collection process was to locate all the limited-access roadways in the state of Michigan. The MDOT sufficiency file was used as the base file for this purpose. The sufficiency file is divided into homogeneous segments of varying lengths. Segments are broken down whenever any roadway characteristics change. Each segment has a physical road (PR), beginning mile point (BMP), and ending mile point (EMP) which can be used to uniquely identify each segment. The sufficiency file includes geometric details of all state-maintained roads in Michigan. This includes information about number of lanes, lane width, type of median and median width, width of left and right shoulders, speed limit, presence of signals, passing lanes, turn lanes, sight restrictions, among others. The "Road_type" attribute was used to identify all limited-access routes within the state. This variable describes the type of road segment. All road segments where Road_type=1 (freeways with full-access control) were filtered for further analyses.

4.2 Speed Data

The speed data for the entire limited-access freeway network identified in Michigan were obtained from probe vehicle data. Probe vehicle data are collected using global positioning system or GPS that are installed in vehicles or are available through devices such as cell phones. The GPS devices send and receive signals from earth-orbiting satellites which are converted to display real-time location and speed data for the probe vehicle. These data were accessed through the Regional Integration Transportation Information System (RITIS) provided by INRIX. RITIS is a secure data platform that integrates existing operational data from transportation agencies and provides speed and travel time information among other datasets at various levels of fidelity.

Unlike the MDOT data which primarily uses PR and mile point information to identify road segments, RITIS uses eXtreme Definition (XD) segment as identification scheme for each of the roadway segment. The XD segment ID for each of the freeway segment identified from the sufficiency file was first determined using GIS tools. These IDs were then imported into RITIS portal and the speed data were downloaded. For the purposes of this project, speed data were downloaded in 15-minute aggregation for entire calendar year 2022.

4.2.1 Initial Screening of Freeway Segments

One of the primary goals of these speed data in the initial stages of the project was to determine locations that experience significant occurrences of recurring congestion over the year and during different time periods of the day. Thus, as an initial step, speed data were filtered for weekdays. Further, three time periods were defined for analyses purposes –

1. AM peak period from 6 AM to 9 AM,
2. PM peak period from 3 PM to 7 PM, and
3. Remaining hours as off-peak period, from 9 AM to 3 PM, and from 7 PM to 6 AM

Once these periods were defined, speed data from RITIS were separated into these three time periods. Thereafter, the speed trends (or congestion trends) along the Michigan freeways were visualized using maps. To that end, the number of hours in the year during which the average speeds on the roadway segment fell below 55 mph was determined for each roadway segment in the roadway file. This was defined as the period of congestion, i.e., if the average hourly travel speeds on any particular segment fell below 55 mph, then the segment was considered as congested during that hour. The percentage of hours in the year 2022 in which the average hourly speed fell below 55 mph on the roadway segment was color coded and plotted on a map. Figure 13 shows an example of such map for all freeway segments in the Grand Region. The map shows percent hours each freeway segment in NB or EB direction was congested (hourly average speed < 55 mph) during PM peak period (3 PM to 7 PM). Similar maps were developed for segments in SB/WB direction of travel, and for each of the other two time periods. These maps were plotted for 5 MDOT regions – Bay, Grand, Metro, Southwest, and University. North and Superior regions were not considered due to lack of sufficient freeway mileage and significantly low levels of congestions. The maps for other regions and time periods can be found in Appendix-B.

The primary purpose of these maps was to identify corridors that were experiencing recurrent congestion. This was because it was not practical to conduct further operational and safety analyses on the entire Michigan freeway network. Thus, the MSU research team met and presented the findings from speed maps to the project Research Advisory Panel (RAP) team members and MDOT staff at Grand and Metro regions to identify corridors of interest for further analyses. The findings from these maps were shared with the remaining three MDOT region offices too to gain feedback. A short survey was also distributed to staff at each of the 5 MDOT region offices which asked the regions if there are any particular corridors that they think would be "good" or "bad" candidates for implementation of PTSU/HSR based on congestion levels, available shoulder widths, etc. Based on these discussions and responses from the survey, a total of 16 freeway corridors were identified as potential candidates for further analyses which are listed below. It should be noted that some of these corridors such as the north and south extension of US-23, US-131 from 1-96 to Post Dr. are already in construction/planning stages for the implementation of PTSU.

1. I-75 near Monroe between Luna Pier and Newport
2. I-94 between Kalamazoo and Battle Creek
3. I-94 from M-14 to US-12
4. I-96 between M-44 and 28th St.
5. I-96 from Kent Lake Rd. to US-23
6. I-96 from Okemos to US-127
7. M-14 from US-23 to I-275
8. M-39 from I-94 to John C Lodge Frwy
9. M-53 from 18 Mile to 27 Mile
10. US-10 in Bay City to I-75
11. US-131 from Center Ave. to US-131 BR Interchange
12. US-131 from I-96 to Post Dr.
13. US-131 from Post Dr to 10 Mile Rd
14. US-23 in Genesee County to I-75 in Flint
15. US-23 North Extension from Barker Rd. to I-96
16. US-23 South Extension from M-14 to I-94

4.3 Traffic Crash and Volume Data

Traffic crash data were obtained from Michigan State Police for years 2021-2023. The crash data included details of each crash such as location and time of occurrence along with crash severity and several other driver, roadway, and environmental related factors. The data also included information about the type of crash, i.e., single vehicle crash, rear-end crash, sideswipe crash, etc.

The traffic volume data for the 16 corridors identified during the initial screening were obtained from MDOT. MDOT collects traffic volume counts through permanent traffic recorder (PTR) stations. These data were provided for entire calendar year 2022 in 15-minute intervals. The volume data through PTR stations were available for all candidate corridors except two – M-14 from US-23 to I-275, and US-131 from Center Ave. to US-131 BR Interchange.

For further macroscopic analyses, traffic volume counts were obtained from MDOT's Transportation Data Management System (TDMS). Traffic volume counts were downloaded from the online portal for both mainline and entrance and exit ramps along the mainline. These data were downloaded in 24-hour counts in 15-minute intervals. Generally, these data were available for each year between 2021-2023. However, if recent years of data were not available, then MDOT approved growth factors were used to grow counts to estimated 2023 counts. The same online portal was also used to obtain vehicle classification data for the selected corridors. These data were downloaded for a 24-hour period where available in hourly intervals.

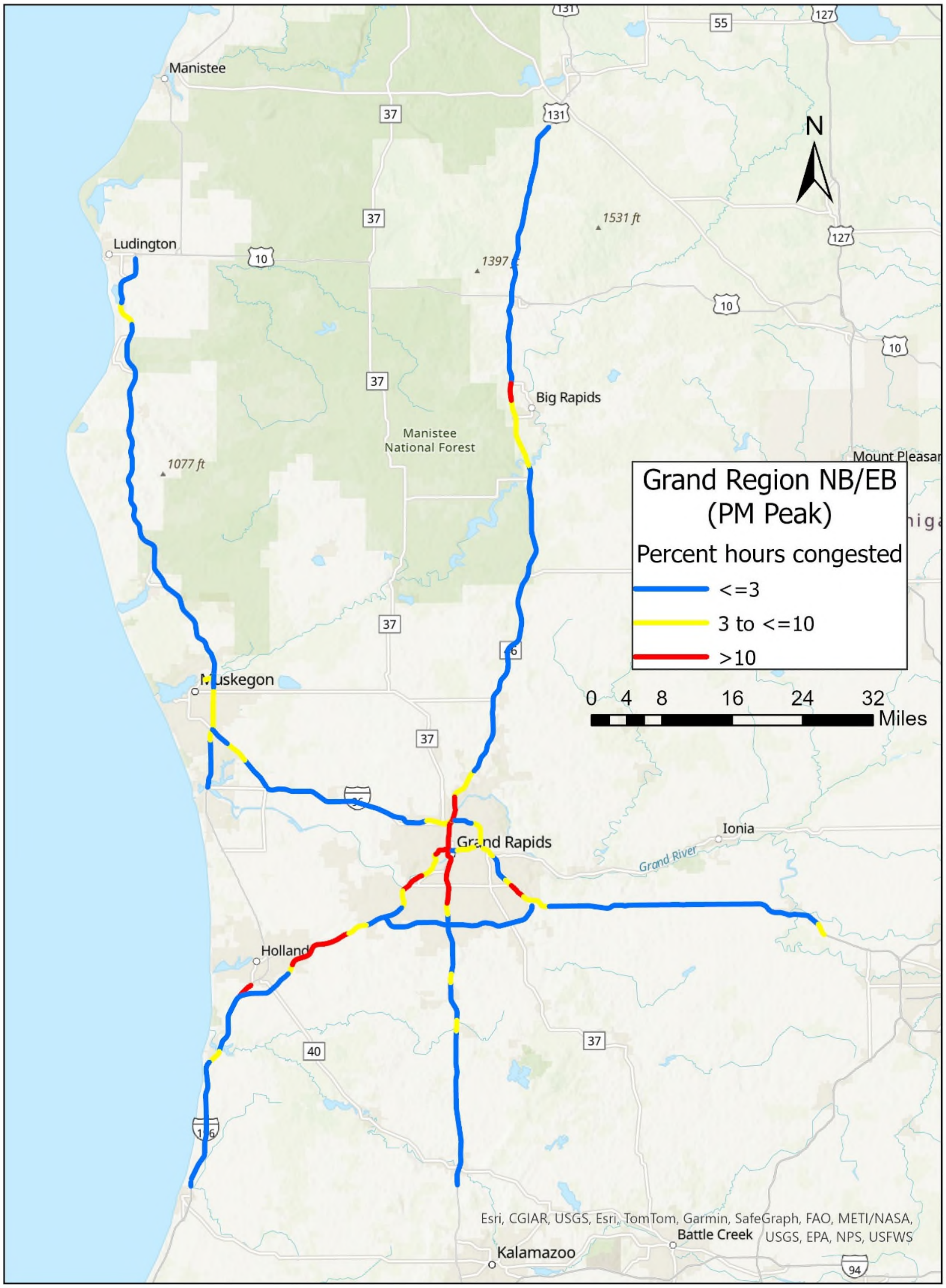


Figure 13 Congestion Trends based on Hourly Speed Data during PM Peak for Freeways in Grand Region

5 OPERATIONAL AND SAFETY ANALYSES

Detailed operational and safety analyses were conducted for the 16 potential corridors selected during the initial screening of the Michigan freeway network. This included analyzing speed and delay trends along the corridor based on time of day and subsequently conducting a more detailed comparison of the corridors using the HCS2024 Freeway Facility module. A comparison of crash rates across candidate corridors was also conducted. This chapter discusses the methodology and presents the results of these operational and safety analyses.

5.1 Speed and Delay Trends Along the Corridors

Speed and delay trends along each of the 16 corridors were investigated. Speed maps were prepared in a manner similar to discussed previously. This included developing maps that indicated the percent of hours the corridor segments were congested, separated by time period and direction of travel. Figure 14 shows the congestion maps for NB US-131 during AM and PM peak. The corridor is relatively more congested in NB during PM peak compared to AM peak.

Next, similar heat maps were also prepared for the delay experienced along the corridors. The methodology to calculate the delay on each segment was as follows:

1. Determine the free-flow speed (FFS) of each XD segment
    a. The speed data at 15-minute intervals for each XD segment of interest were obtained from RITIS.
    b. Speed data on weekdays (Monday through Friday) between 10 PM and 5 AM were filtered. These periods represent low traffic volume conditions used to calculate FFS.
    c. Remove periods when speed < 55 mph
    d. FFS on the XD segment is then calculated as the 85th percentile of 15-minute speeds.
2. For each XD segment, obtain the 15-minute traffic volume counts.
3. Calculate travel time (TT) and free-flow travel time for each XD segment:

a. $TT\ (min) = \frac{segment\ length\ (mi) \times 60}{speed\ (mph)}$

b. $Free - flow\ TT\ (min) = \frac{segment\ length\ (mi) \times 60}{FFS\ (mph)}$

4. Calculate the delay for each XD segment:

a. If travel speed is greater than FFS, delay = 0

b. If travel speed is less than FFS, then $Delay = \frac{Actual\ TT - Free\ Flow\ TT}{segment\ length}$, in minutes/mile/vehicle

c. $Total\ delay = Delay \times 15 - mnute\ volume$, in vehicle-minutes/mile in 15-minute period. Total delay was calculated for each 15-minute period for entire year (2022) using the corresponding 15-minute PTR traffic counts.

5. Total delay is then averaged over each PR segment for entire year separately by direction of travel and period.

Figure 15 shows delay trends along NB US-131 during AM and PM periods. Average total delay was categorized into three categories: ≤30, >30 and ≤60, >60, vehicle-minutes per mile in 15-minute period. Delay trends along other candidate corridors can be found in Appendix-C.

Table 11 and Table 12 present the summary of speed and delay metrics for each candidate corridors by direction for AM peak and PM peak, respectively. As mentioned previously, PTR volume counts were not available for two candidate corridors. Thus, delay was not estimated along these two corridors, namely, M-14 from US-23 to I-275, and US-131 from Center Ave. to US-131 BR Interchange. It should be noted that all routes have posted speed limit of 70 mph, except two, namely, US 10 in Bay City to I-75 which is posted at 75 mph, and M-39 from I-94 to John C Lodge Frwy which is posted at 55 mph.

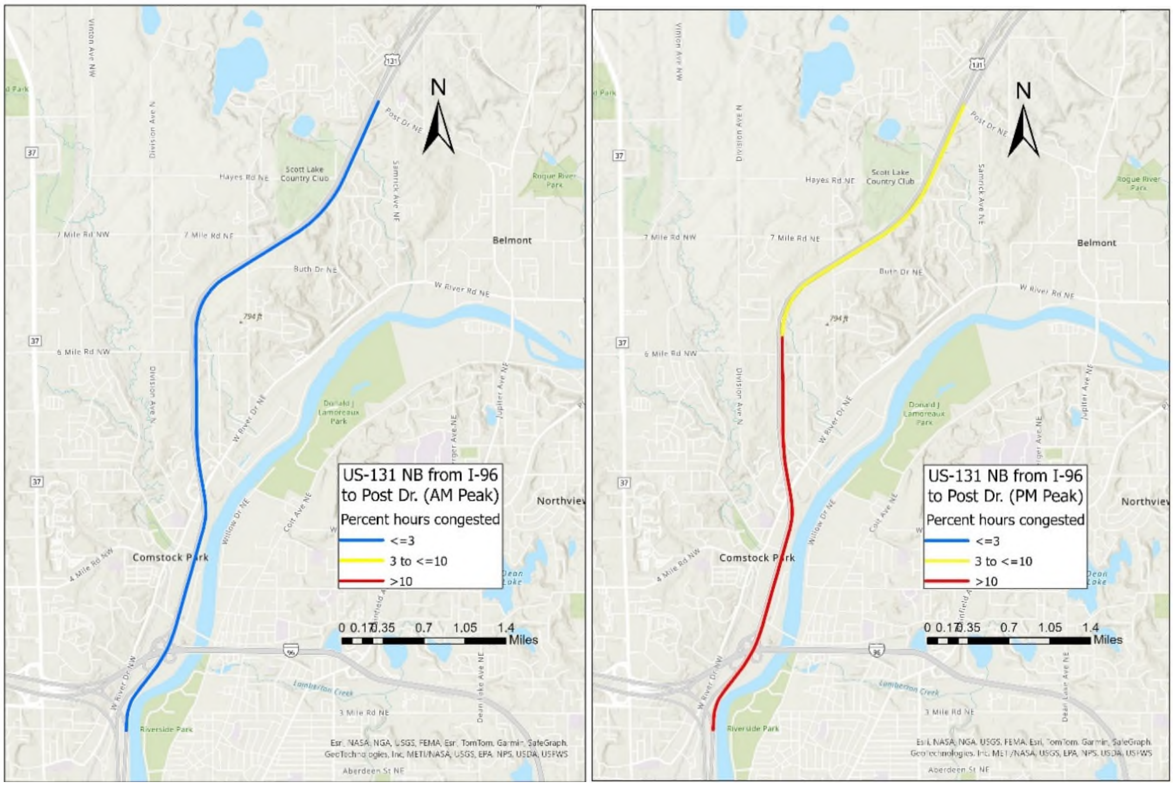


Figure 14 Congestion Levels along NB US-131 during AM and PM Peak

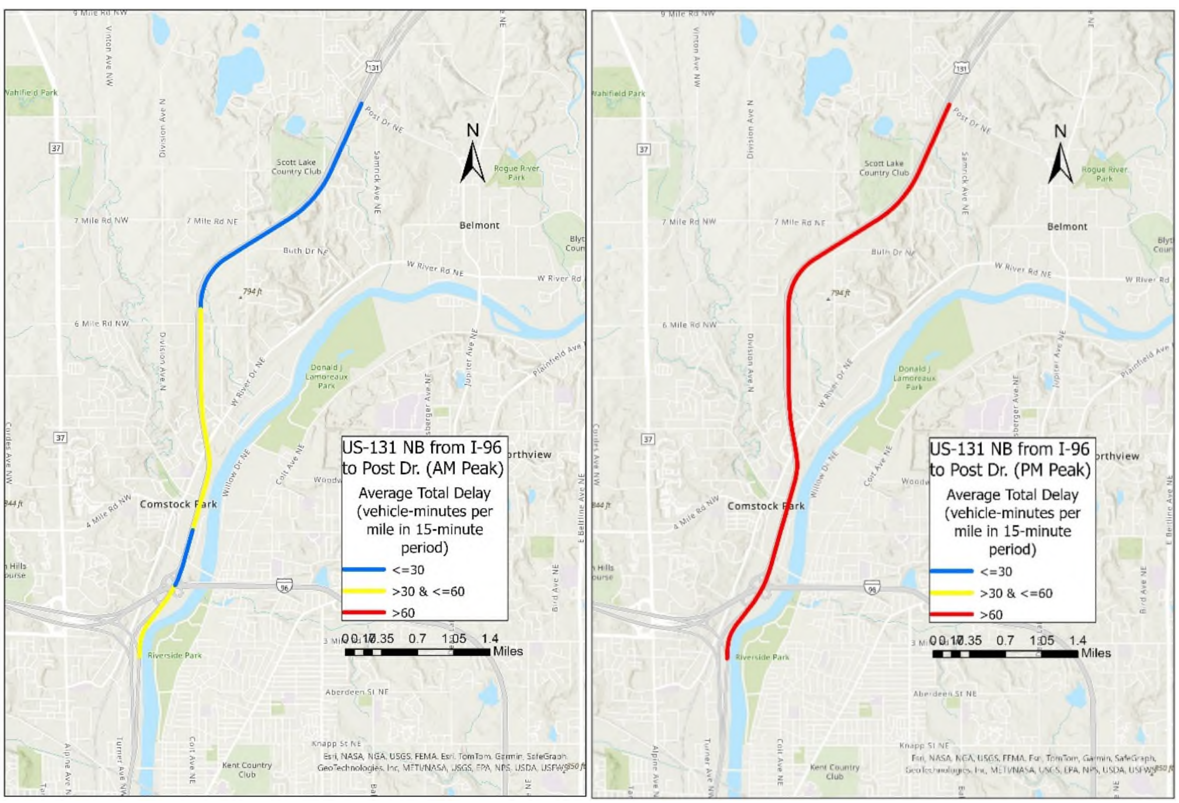


Figure 15 Delay Trends along NB US-131 during AM and PM Peak

Table 11 Summary of Speed and Delay Metrics on Candidate Corridors during AM Peak

Corridor	Direction	Average FFS (mph)	Average Percent Hours Congested	Average of Total Delay in Vehicle-Minutes per Mile
I-75 near Monroe between Luna Pier and Newport	NB	71.40	1.46	0.69
	SB	71.58	2.04	0.69
I-94 between Kalamazoo and Battle Creek	EB	71.13	2.86	37.14
	WB	71.05	2.35	11.76
I-94 from M-14 to US-12	EB	72.07	0.51	7.25
	WB	71.88	14.63	71.72
I-96 between M-44 and 28th St.	EB	71.86	4.56	43.26
	WB	72.21	2.94	14.02
I-96 from Kent Lake Rd. to US-23	EB	73.25	19.64	141.53
	WB	73.14	0.81	19.11
I-96 from Okemos to US-127	EB	72.60	0.94	6.74
	WB	72.30	1.28	9.02
M-14 from US-23 to I-275	EB	72.70	2.71	-
	WB	72.32	4.74	-
M-39 from I-94 to John C Lodge Frwy	NB	67.29	9.00	103.36
	SB	67.64	4.20	44.98
M-53 from 18 Mile to 27 Mile	NB	72.16	1.11	11.02
	SB	70.11	19.81	86.16
US-10 in Bay City to I-75	EB	71.40	1.76	6.24
	WB	71.63	1.33	4.22
US-131 from Center Ave. to US-131 BR Interchange	NB	69.95	2.40	-
	SB	70.42	2.79	-
US-131 from I-96 to Post Dr.	NB	71.99	1.24	27.24
	SB	72.54	10.15	167.18
US-131 from Post Dr to 10 Mile Rd	NB	72.69	0.71	27.24
	SB	73.24	4.36	167.18
US-23 in Genesee County to I-75 in Flint	NB	72.91	2.19	2.55
	SB	72.93	2.66	8.87
US-23 North Extension from Barker Rd. to I-96	NB	71.81	1.38	12.21
	SB	72.33	6.70	55.18
US-23 South Extension from M-14 to I-94	NB	71.47	2.92	14.89
	SB	71.85	3.01	72.95
Overall Average		71.35	4.38	40.10

Table 12 Summary of Speed and Delay Metrics on Candidate Corridors during PM Peak

Corridor	Direction	Average FFS (mph)	Average Percent Hours Congested	Average of Total Delay in Vehicle-Minutes per Mile
I-75 near Monroe between Luna Pier and Newport	NB	71.40	2.26	4.19
	SB	71.58	2.85	4.19
I-94 between Kalamazoo and Battle Creek	EB	71.13	3.92	53.55
	WB	71.05	4.65	59.88
I-94 from M-14 to US-12	EB	72.07	10.75	123.87
	WB	71.88	2.61	24.95
I-96 between M-44 and 28th St.	EB	71.86	7.99	41.29
	WB	72.21	13.88	164.70
I-96 from Kent Lake Rd. to US-23	EB	73.25	4.09	20.57
	WB	73.14	1.62	52.31
I-96 from Okemos to US-127	EB	72.60	0.74	6.16
	WB	72.30	0.99	10.03
M-14 from US-23 to I-275	EB	72.70	6.65	-
	WB	72.32	3.88	-
M-39 from I-94 to John C Lodge Frwy	NB	67.29	17.34	212.82
	SB	67.64	25.90	311.87
M-53 from 18 Mile to 27 Mile	NB	72.16	7.16	73.08
	SB	70.11	13.61	40.29
US-10 in Bay City to I-75	EB	71.40	1.05	3.61
	WB	71.63	1.50	5.96
US-131 from Center Ave. to US-131 BR Interchange	NB	69.95	2.98	-
	SB	70.42	2.16	-
US-131 from I-96 to Post Dr.	NB	71.99	17.61	240.52
	SB	72.54	3.17	51.48
US-131 from Post Dr to 10 Mile Rd	NB	72.69	5.29	17.61
	SB	73.24	2.02	5.61
US-23 in Genesee County to I-75 in Flint	NB	72.91	4.48	79.55
	SB	72.93	2.46	24.15
US-23 North Extension from Barker Rd. to I-96	NB	71.81	40.79	430.55
	SB	72.33	2.02	21.14
US-23 South Extension from M-14 to I-94	NB	71.47	12.72	160.91
	SB	71.85	39.33	378.72
Overall Average		71.35	7.94	105.44

Generally speaking, each corridor is congested and experiences more delays in either direction during each peak period. Some corridors of particular interest are I-96 from Kent Lake Rd. to US-23, M-53 from 18 Mile to 27 Mile, and US-131 from Post Dr to 10 Mile Rd, which experience severe delays during AM peak in at least one direction of travel. On the other hand, corridors such as I-94 from M-14 to US-12, I-96 between M-44 and M-6, US-131 from I-96 to Post Dr., US-23 North Extension from M-36 to I-96, and US-23 South Extension from M-14 to I-94 experience relatively severe delays during the PM period. M-39 from I-94 to the Lodge Freeway experiences severe delay during both AM and PM peak periods.

5.2 Macroscopic Corridor Comparison for Potential Flex Lane

A macroscopic analysis of the 16 candidate corridors was conducted to generate comparative metrics to help identify the best candidate corridors for flex lanes through a high-level planning analysis that is easily reproducible using already available data sources. This analysis was done using the HCS2024 Freeway Facility module. This software tool is used to analyze freeway operations. It can calculate capacity, assess efficiency, calculate the impact of adjacent segments of the corridor on each other, and evaluate the impact of design changes, providing straightforward metrics for relative comparison.

The objective of this analysis was to evaluate the impacts of implementing a PTSU along the corridors on various operational performance measures. Initial analysis considered a full 24-hour day representative of typical conditions along the corridor were analyzed in 15-minute intervals. This resulted in 96 analysis periods for a single day in the facility analysis. Three alternatives were analyzed for each corridor:

1. Analysis for existing conditions (no-build condition),
2. Flex Lane Build condition, and
3. Flex Lane Build with induced demand condition.

For the Flex Lane Build condition, an additional lane of capacity was provided to the existing conditions model to represent the additional capacity of a flex lane through the corridor. The Flex Lane Build with induced demand condition was considered to evaluate the Flex Lane Build condition with the added assumption that the demand would increase globally due to added capacity following the implementation of a flex lane. Additional analyses were also conducted for just AM peak period (6 AM to 9 AM) and PM peak (3 PM to 7 PM) period. The assumptions of these analyses are discussed in the following sub-section.

5.2.1 Analysis Assumptions

The following assumptions were made in the macroscopic analyses using HCS2024 Freeway Facility module.

- **Flex Lane capacity**: The Flex Lane capacity was assumed to be the same as a regular 12-ft travel lane on the freeway with a full shoulder. A cursory literature review did not reveal a significant body of data to indicate deviating from this assumption at this time.
- **Flex Lane hours**: Separate analyses were conducted for full 24-hours (daily level), and AM peak and PM peak periods. For the purpose of this high-level analysis, it was assumed the Flex Lane would be in place during the entire analysis period, though it is known that it would be constrained to just the hours of operation it is most needed in reality.
- **Freeway free flow speed (FFS):** Freeway free flow speed for each HCS segment of the corridor was obtained using speed data from probe vehicles and was calculated as discussed in Section 5.1, i.e., 85th percentile value of nighttime weekday speeds.
- **Global HCS values**: The following values entered in HCS were assumed globally:
    - Freeway terrain type = level
    - Driver population = all familiar
    - Ramp FFS = 35 mph (suggested HCM default)
    - Ramp terrain type = level
    - Ramp total truck percentage = 5 (suggested HCM default)
    - Weather type = non-severe weather
- **Peak hour factor (PHF)**: As each individual analysis period was 15 minutes, a PHF of 1.0 was assumed for all time periods. For locations where data was only available in hourly intervals, the volume allocation for each of the 15-minute intervals was based on a traffic

count that contained the 15-minute intervals somewhere else along the corridor so the proper volume peaking was accounted for. Where a separate 15-minute count was not available, the 15-minute time periods were uniformly distributed based on the hourly traffic, i.e. each 15-minute interval was assumed to be a quarter of the hourly volume.

- **Heavy vehicle percentage:** For the mainline truck percentage entries, it was assumed that the hourly classification data will be the same for each of the four 15-minute intervals composing that hour.
- **Induced demand**: The addition of a Flex Lane may induce additional demand on a corridor. Induced demand is very corridor specific and typically would require a regional travel demand forecasting analysis. To keep this analysis high-level, but still potentially account for induced demand, two volume scenarios were analyzed for the Flex Lane Build condition. The first was the same volume set as the No-Build (existing) condition and the second applied a ten percent (10%) growth to the mainline and ramp volumes via a global demand adjustment factor in HCS.
- **Emissions**: Emissions are often a metric calculated by various macroscopic and microscopic traffic analysis software. The HCS Freeway Facility module does not report this metric directly, and there is no widely accepted method for estimating corridor emissions from the HCS outputs. Due to this limitation, emission analysis for the candidate corridors was not conducted.

5.2.2 Measures of Effectiveness

The following measures of effectiveness (MOEs) were primarily used to evaluate the corridor performance:

- Average travel time (min): The average travel time in minutes to travel the corridor.
- Vehicle miles traveled (VMT): The total number of miles driven by all vehicles within the corridor over the course of one day (24 hours).
- Vehicle hours of delay (VHD): The total time spent by the vehicles in the corridor above the free-flow travel time in vehicle-hours.

- Total user delay cost ($): The monetized value of the VHD derived via a weighted average of the latest MDOT published user costs for cars and trucks based on total commercial vehicle percentage for the corridor (MDOT, 2025a).

5.2.3 Analysis Results

As mentioned previously, the analyses were conducted for three conditions, and for three time periods. The various MOE discussed above were calculated for each condition and compared. Figure 16, Figure 17, and Figure 18 present graphical comparison of average travel time for each of the candidate corridors under the three conditions during the full 24 hour day, AM peak, and PM peak period, respectively. Similar comparisons for total vehicular delay are presented in Figure 19, Figure 20, and Figure 21. A more detailed summary of the MOEs are presented in Table 13, Table 14, and Table 15, for no build (existing) conditions, flex lane build condition, and flex lane build with induced demand condition, respectively.

Generally speaking, the introduction of the flex lane along the corridor resulted in reduced travel time, greater space mean speed, reduced delay and associated costs compared to existing conditions. This improvement is expected, as the flex lane acts as an additional travel lane, enhancing capacity and reducing congestion. These improvements were generally higher during PM peak period compared to AM peak period.

Additionally, these benefits of added flex lane were largely retained even with 10% induced demand increase. When the demand was increased by 10% due to the improved conditions, travel time remained similar or only increased marginally. This indicates the candidate corridors with added flex lane can potentially handle the increased demand without major deterioration in operational performance. While travel time remained stable, vehicle delay and associated user costs increased under the 10% increased demand scenario. This is possibly due to increases in traffic density and associated reductions in travel speeds (space mean speeds).

One exception was SB M-39 corridor that experienced by far the greatest amount of delay compared to other corridors in the no-build condition. This was because of the presence of several bottlenecks along this corridor, which contribute to recurring congestion and increased vehicle-hours of delay. Additionally, the HCS analysis generated warnings indicating that certain performance metrics for this corridor may be less reliable. These warnings typically occur when a corridor is operating at or near capacity in multiple segments, which can lead to greater variability in estimated operational parameters. Given these factors, caution should be exercised when interpreting results for the SB M-39 corridor. While the general trends remain useful, the absolute values of key metrics such as delay, density, and delay costs may be influenced by modeling limitations under severe congestion conditions.

Another important consideration when interpreting the results is the time for which the flex lane would be operational. The daily level analysis period assumes that the flex lane would be operational for the entire 24-hour period which is similar to adding an additional travel lane and doesn't necessarily reflect the PTSU strategy. Thus, the analyses may likely be overestimating the operational benefits in terms of travel time savings and delay reduction, since these benefits would likely only be realized during peak periods in actual implementation. The separate analyses conducted for AM and PM peak periods showed a more appropriate representation of real-world implementation of the flex lane. In any case, this high-level analysis provides important insights into the impacts of adding a flex lane on various operational parameters that would subsequently help MDOT in determining priority corridors for PTSU implementation.

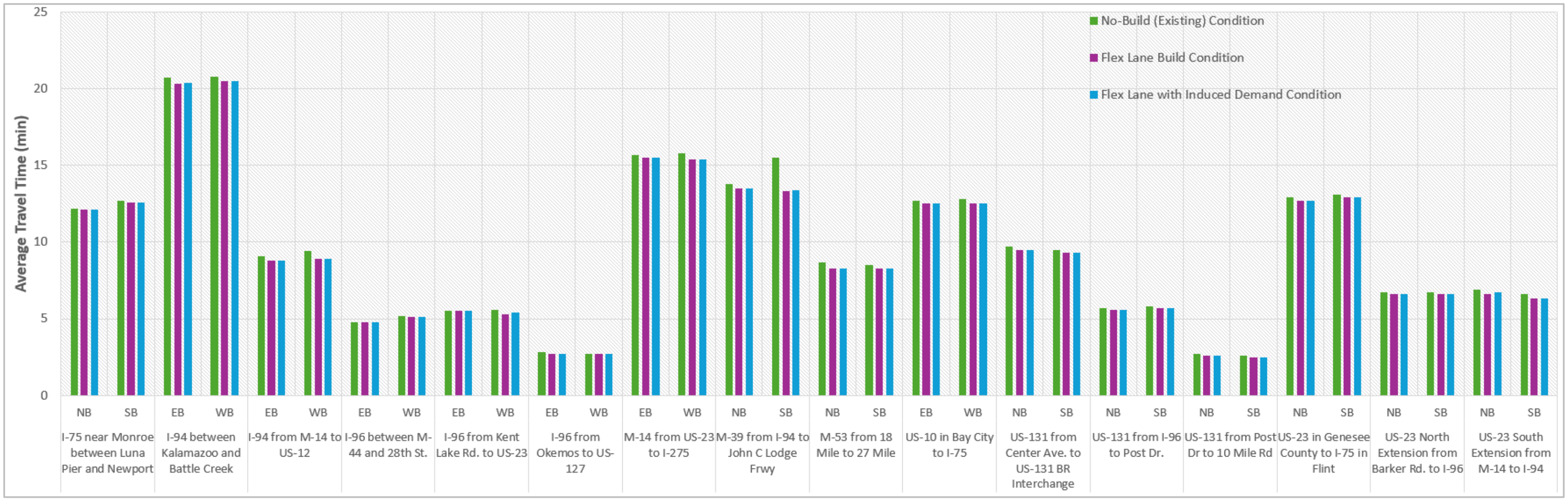


Figure 16 Comparison of Average Travel Time during Full 24-Hour Period Across Three Flex Lane Build Conditions

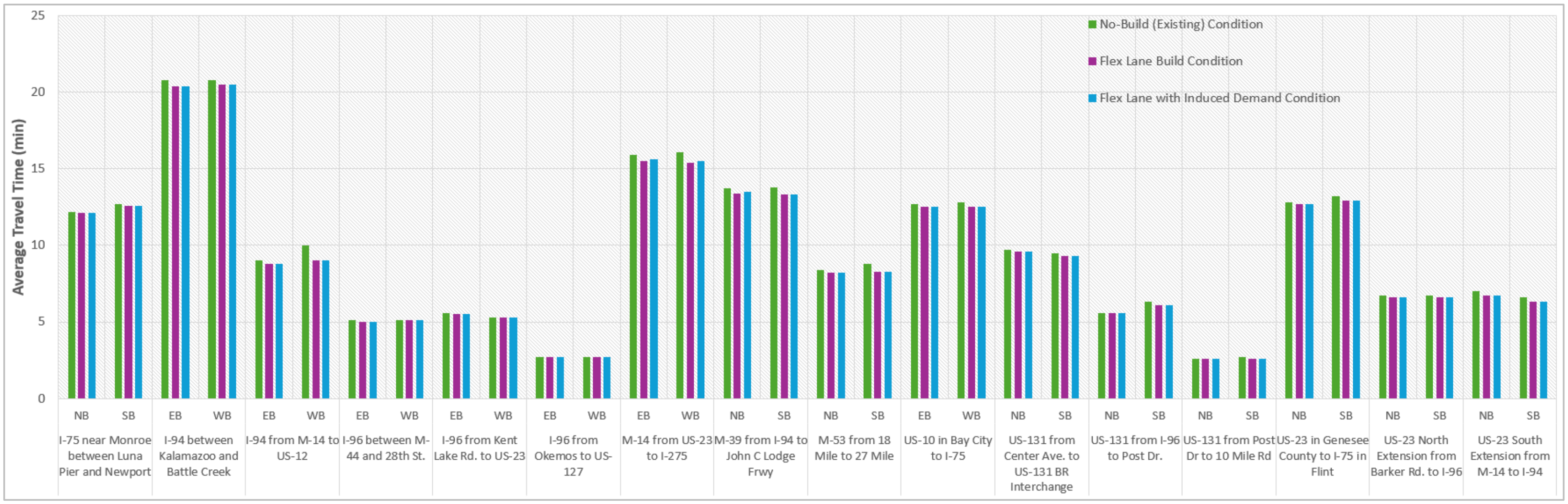


Figure 17 Comparison of Average Travel Time during AM Peak Period Across Three Flex Lane Build Conditions

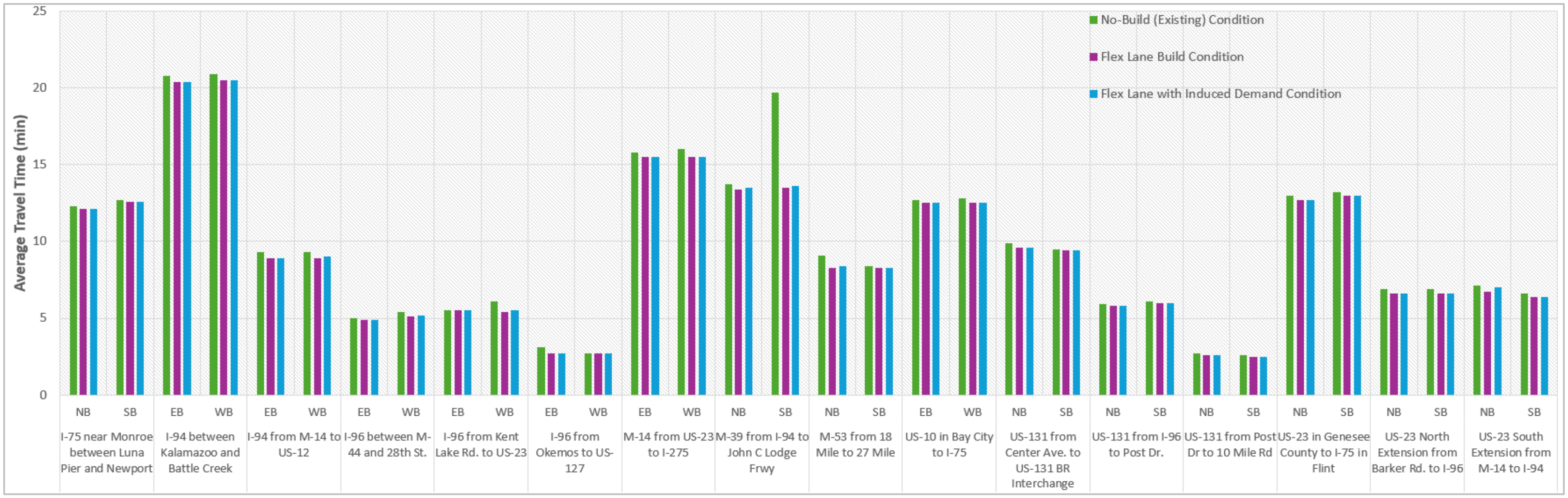


Figure 18 Comparison of Average Travel Time during PM Peak Period Across Three Flex Lane Build Conditions

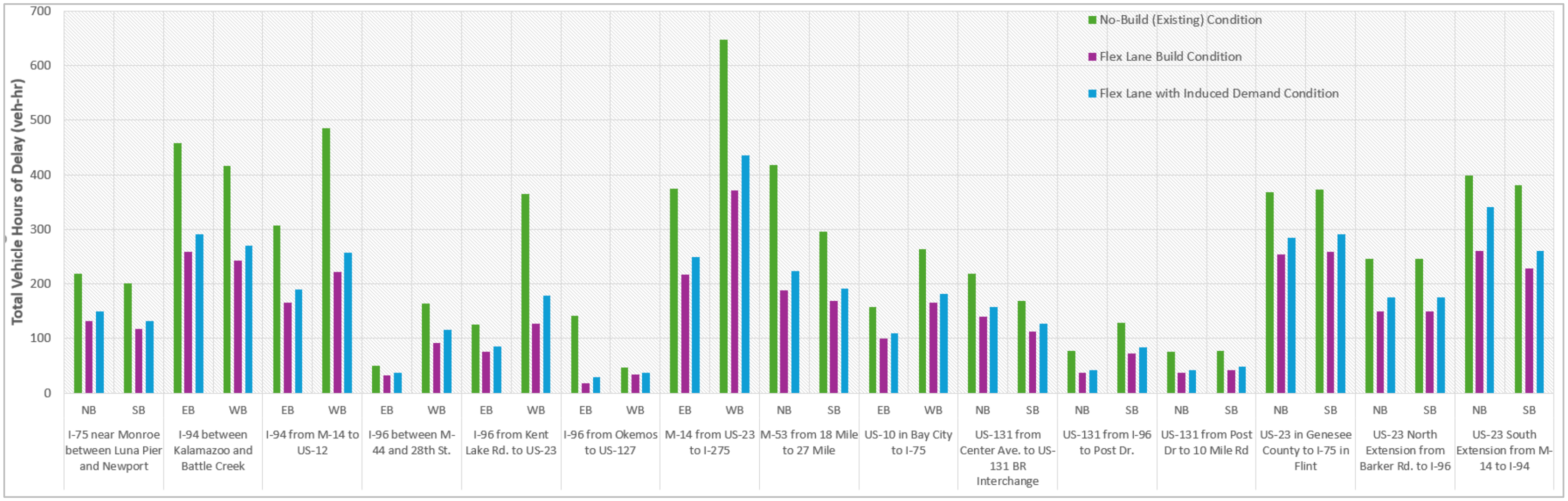


Figure 19 Comparison of Total Vehicle Delay during Full 24-Hour Period Across Three Flex Lane Build Conditions

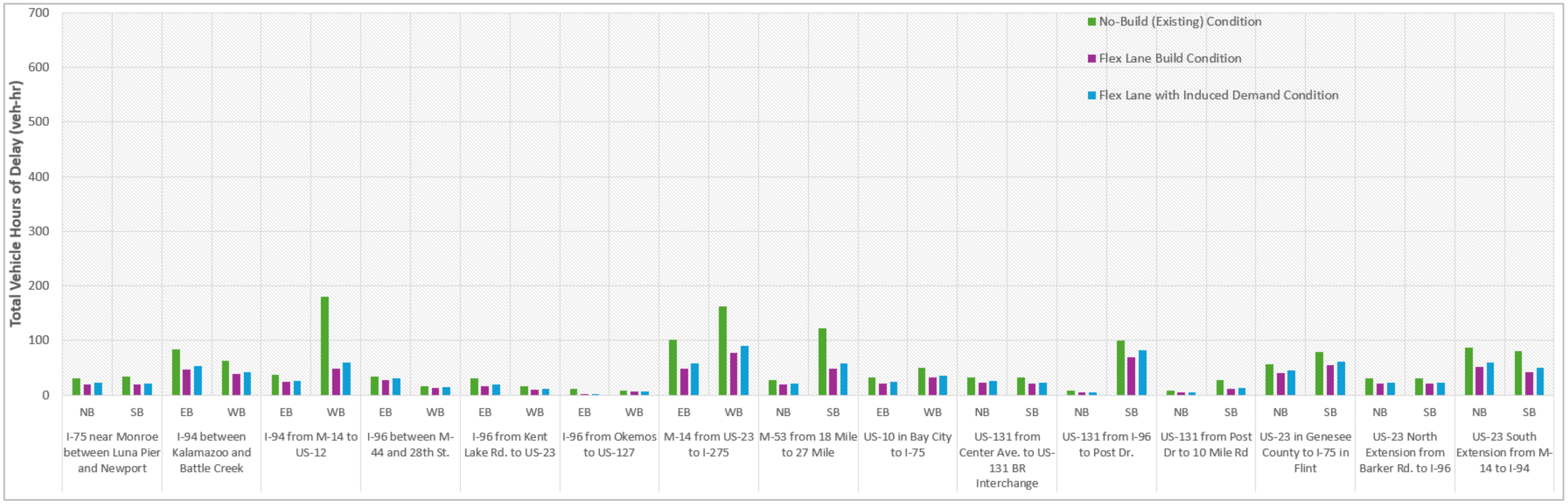


Figure 20 Comparison of Total Vehicle Delay during AM Peak Period Across Three Flex Lane Build Conditions

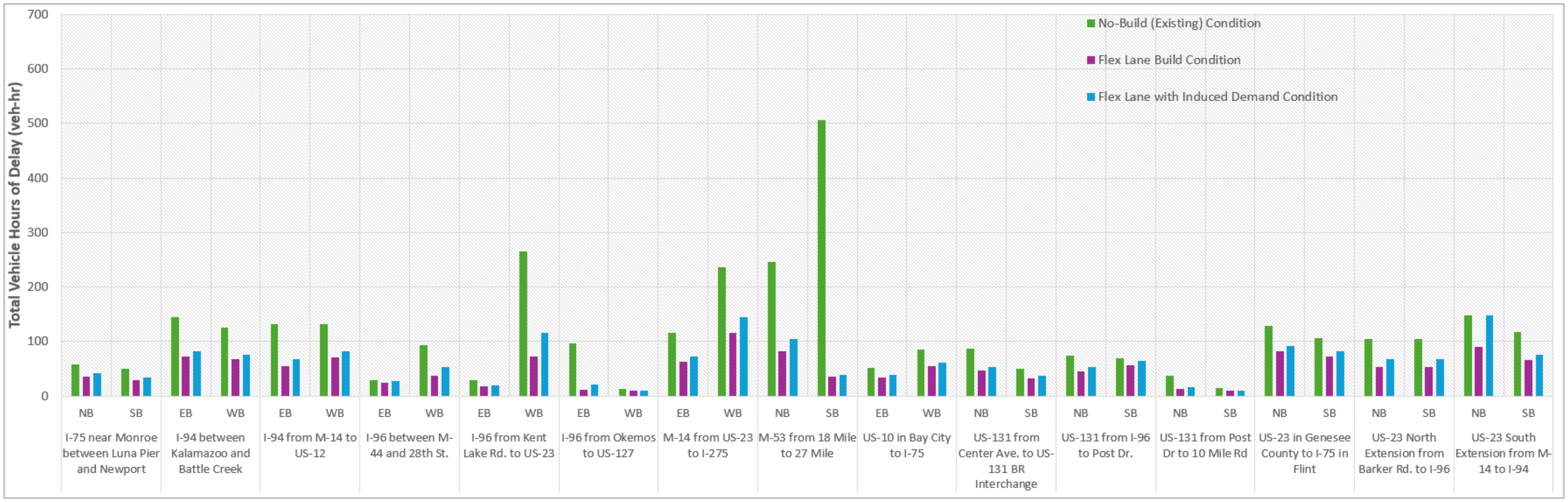


Figure 21 Comparison of Total Delay during PM Peak Period Across Three Flex Lane Build Conditions

Table 13 Summary of MOE for No-Build (Existing) Condition

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
Daily (24-hour) Period									
I-75 near Monroe between Luna Pier and Newport	NB	69.5	12.2	565045	29.15	7.6	10.2	218.07	6356.82
	SB	69.9	12.7	516947	28.98	6.7	8.9	201.66	5843.99
I-94 between Kalamazoo and Battle Creek	EB	68.3	20.7	839112	26.32	9.9	11.8	457.63	12044.69
	WB	67.8	20.8	761357	26.15	9.1	10.7	416.64	10895.01
I-94 from M-14 to US-12	EB	67.8	9.1	327863	25.44	9.3	10.4	307.14	7813.7
	WB	65.9	9.4	374874	24.56	10.7	11.5	485.48	11923.29
I-96 between M-44 and 28th St.	EB	69.5	7.7	193142	24.2	5.7	6.1	89.07	2155.61
	WB	68.2	8.4	310205	24.38	8.5	9.1	256.4	6251.07
I-96 from Kent Lake Rd. to US-23	EB	70.8	5.5	262293	26.15	8.3	9.8	125.84	3290.84
	WB	67.6	5.6	320870	27.03	10.8	13.2	364.86	9862.2
I-96 from Okemos to US-127	EB	67.5	2.8	136527	25.26	13.2	14.8	142.09	3589.28
	WB	70.1	2.7	93735	25.44	7.7	8.7	47.49	1208.12
M-14 from US-23 to I-275	EB	70	15.7	718460	24.73	9.5	10.3	374.28	9256.03
	WB	68.1	15.8	781620	24.56	11.1	12	647.21	15895.59
M-39 from I-94 to John C Lodge Frwy	NB	62.9	13.8	711160	24.02	10.8	11.3	770.78	18514.1
	SB	55.8	15.5	839341	24.02	14.6	15.3	2700.88	64875.07
M-53 from 18 Mile to 27 Mile	NB	65.7	8.7	302369	24.02	10.1	10.5	418.29	10047.36
	SB	67.4	8.5	318727	23.85	10.3	10.7	296.66	7075.27
	EB	69.5	12.7	263017	24.2	5.2	5.5	157.97	3822.94

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-10 in Bay City to I-75	WB	68.3	12.8	305140	24.2	6.3	6.7	263.23	6370.07
US-131 from Center Ave. to US-131 BR Interchange	NB	66.2	9.7	277057	24.73	8	8.7	219.19	5420.6
	SB	67.4	9.5	269080	25.09	7.7	8.5	169.1	4242.8
US-131 from I-96 to Post Dr.	NB	70.2	5.7	219205	24.38	8.4	9	76.93	1875.47
	SB	70.1	5.8	274159	24.56	10	10.9	128.22	3148.97
US-131 from Post Dr to 10 Mile Rd	NB	69.8	2.7	106975	24.38	10.3	11.1	75.46	1839.81
	SB	69.1	2.6	96760	24.56	9.7	10.5	77.63	1906.59
US-23 in Genesee County to I-75 in Flint	NB	69.3	12.9	451518	25.97	8.8	10.2	368.33	9565.49
	SB	69	13.1	475170	24.73	8.8	9.6	373.45	9235.52
US-23 North Extension from M-36 to Barker Rd.	NB	67.3	5.7	216017	25.44	9.9	11.2	210.91	5365.51
	SB	67.8	6.2	266904	25.44	10.7	12.1	258.78	6583.32
US-23 South Extension from M-14 to I-94	NB	64.9	6.9	273156	24.91	10.9	12	398.67	9930.95
	SB	65.3	6.6	271458	24.73	11.8	13	380.88	9419.13
AM Peak (6 AM-9 AM) Period									
I-75 near Monroe between Luna Pier and Newport	NB	69.5	12.2	80933	29.15	8.7	11.7	31.24	910.7
	SB	69.8	12.7	84096	28.98	8.7	11.2	33.32	965.7
	EB	68.1	20.8	142011	26.32	13.5	15.4	83.32	2192.85

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-94 between Kalamazoo and Battle Creek	WB	67.9	20.8	120095	26.15	11.5	13.4	63.34	1656.36
I-94 from M-14 to US-12	EB	68.6	9	48095	25.44	10.7	12.3	36.57	930.23
	WB	61.4	10	74685	24.56	18.2	19.8	180.14	4424.14
I-96 between M-44 and 28th St.	EB	67.3	5.1	34117	24.2	13.1	13.6	33.39	808.15
	WB	70.5	5.1	37440	24.38	12.2	13.2	15.65	381.6
I-96 from Kent Lake Rd. to US-23	EB	70.5	5.6	55500	26.15	14.2	16.2	30.51	797.84
	WB	71.1	5.3	41408	27.03	10.6	13.3	17.16	463.89
I-96 from Okemos to US-127	EB	69.9	2.7	22371	25.26	16.8	18.6	12	303.01
	WB	70	2.7	16880	25.44	11.1	12.5	9	229.03
M-14 from US-23 to I-275	EB	69.4	15.9	155141	24.73	16.5	17.9	101.4	2507.55
	WB	66.9	16.1	150346	24.56	17.3	18.7	162.81	3998.69
M-39 from I-94 to John C Lodge Frwy	NB	63	13.7	126974	24.02	15.4	16.3	130.5	3134.51
	SB	62.6	13.8	155022	24.02	19.2	20.2	200.45	4814.71
M-53 from 18 Mile to 27 Mile	NB	68.3	8.4	34661	24.02	8.9	9.3	27.47	659.85
	SB	65.2	8.8	86264	23.85	23.1	23.8	123.18	2937.89
US-10 in Bay City to I-75	EB	69.6	12.7	55472	24.2	8.8	9.2	32.93	796.9
	WB	68.2	12.8	56997	24.2	9.5	10.2	49.84	1206.01
US-131 from Center Ave. to US-131 BR Interchange	NB	66.5	9.7	45741	24.73	10.5	11.5	31.98	790.9
	SB	67.3	9.5	48501	25.09	11.1	12.3	32.04	803.96
	NB	70.7	5.6	30221	24.38	9.3	10.6	7.6	185.19

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-131 from I-96 to Post Dr.	SB	64.9	6.3	61700	24.56	20.7	21.6	99.77	2450.34
US-131 from Post Dr to 10 Mile Rd	NB	70.6	2.6	14632	24.38	11.1	12.6	7.82	190.58
	SB	67.6	2.7	24860	24.56	20.4	21.2	28.08	689.7
US-23 in Genesee County to I-75 in Flint	NB	69.6	12.8	79296	25.97	11.5	13.5	55.91	1452.05
	SB	68.9	13.2	96721	24.73	14.4	15.4	78.77	1948.07
US-23 North Extension from Barker Rd. to I-96	NB	68	6.7	37343	25.44	10.7	12.4	30.84	784.56
	SB	68	6.7	37343	25.44	10.7	12.4	30.84	784.56
US-23 South Extension from M-14 to I-94	NB	64	7	52744	24.91	17.1	18.6	87.41	2177.27
	SB	64.6	6.6	51229	24.73	18.1	19.9	80.42	1988.89
PM Peak (3 PM-7 PM) Period									
I-75 near Monroe between Luna Pier and Newport	NB	69.4	12.3	145575	29.15	11.7	14.7	58.97	1718.95
	SB	69.8	12.7	124228	28.98	9.6	12	49.8	1443.2
I-94 between Kalamazoo and Battle Creek	EB	67.9	20.8	224226	26.32	16.1	18.3	145.37	3826.2
	WB	67.5	20.9	208438	26.15	15.1	16.8	125.8	3289.7
I-94 from M-14 to US-12	EB	66.1	9.3	101096	25.44	17.6	19	132.46	3369.89
	WB	66.5	9.3	113122	24.56	19.1	20	132.36	3250.88
I-96 between M-44 and 28th St.	EB	68.4	5	39399	24.2	11.1	11.6	28.58	691.58
	WB	66.6	5.4	74928	24.38	19.4	20	93.46	2278.54

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-96 from Kent Lake Rd. to US-23	EB	70.9	5.5	61927	26.15	11.8	13.8	28.53	746.02
	WB	62.6	6.1	115070	27.03	25	30.6	266.12	7193.12
I-96 from Okemos to US-127	EB	62.2	3.1	41978	25.26	26.5	28.4	96.5	2437.59
	WB	69.9	2.7	24872	25.44	12.3	13.2	13.49	343.19
M-14 from US-23 to I-275	EB	69.7	15.8	199224	24.73	15.8	16.7	116.57	2882.73
	WB	67.1	16	230141	24.56	19.8	20.7	236.48	5807.94
M-39 from I-94 to John C Lodge Frwy	NB	63.1	13.7	186986	24.02	17.1	17.5	195.68	4700.22
	SB	43.8	19.7	255602	24.02	34	35.1	2072.36	49778.08
M-53 from 18 Mile to 27 Mile	NB	62.9	9.1	119534	24.02	25	25.7	246.72	5926.29
	SB	68.2	8.4	67622	23.85	13	13.4	507	1209.13
US-10 in Bay City to I-75	EB	69.2	12.7	79617	24.2	9.5	9.9	51.45	1245.1
	WB	68.1	12.8	93748	24.2	11.7	12.1	85.2	2061.8
US-131 from Center Ave. to US-131 BR Interchange	NB	65.3	9.9	85996	24.73	15.1	16	87.5	2163.99
	SB	67.1	9.5	73827	25.09	12.7	13.6	50.47	1266.33
US-131 from I-96 to Post Dr.	NB	67.2	5.9	76333	24.38	18.8	19.4	74.59	1818.46
	SB	67.1	6.1	63301	24.56	15.3	16.6	69.5	1706.98
US-131 from Post Dr to 10 Mile Rd	NB	68	2.7	34703	24.38	20.6	21.2	36.96	901.11
	SB	69.6	2.6	21044	24.56	12.6	13.7	14.84	364.38
US-23 in Genesee County to I-75 in Flint	NB	68.6	13	143575	25.97	15.8	17.8	129.48	3362.69
	SB	68.6	13.2	120998	24.73	13.6	14.3	105.98	2620.91
	NB	66.3	6.9	86177	25.44	19	20.3	105.12	2674.13

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-23 North Extension from Barker Rd. to I-96	SB	66.3	6.9	86177	25.44	19	20.3	105.12	2674.13
US-23 South Extension from M-14 to I-94	NB	63.2	7.1	78157	24.91	19.3	20.7	147.71	3679.55
	SB	64.5	6.6	73745	24.73	19.5	20.8	116.9	2890.93

Table 14 Summary of MOE for Flex Lane Build Condition

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
Daily (24-hour) Period									
I-75 near Monroe between Luna Pier and Newport	NB	70.3	12.1	565045	29.15	5.7	7.6	132	3847.89
	SB	70.7	12.6	516947	28.98	5.1	6.7	116.82	3385.44
I-94 between Kalamazoo and Battle Creek	EB	69.5	20.3	839112	26.32	6.7	7.9	259.33	6825.46
	WB	68.9	20.5	761357	26.15	6.2	7.2	243.34	6363.28
I-94 from M-14 to US-12	EB	69.8	8.8	327863	25.44	6.1	6.9	166.2	4228.13
	WB	69.1	8.9	372659	24.56	6.9	7.5	222.13	5455.6
I-96 between M-44 and 28th St.	EB	70	7.6	193142	24.2	3.9	4.2	69.07	1671.51
	WB	69.6	8.2	309911	24.38	5.8	6.2	161.5	3937.48
I-96 from Kent Lake Rd. to US-23	EB	71.8	5.5	262293	26.15	6.1	7.2	75.87	1984
	WB	71.1	5.3	320506	27.03	7.6	9.3	127.72	3452.21
I-96 from Okemos to US-127	EB	71.9	2.7	136794	25.26	8.3	9.3	18.16	458.67
	WB	70.8	2.7	93735	25.44	5.4	6.1	33.73	858.11
M-14 from US-23 to I-275	EB	71.1	15.5	718460	24.73	6.6	7.2	217.98	5390.74
	WB	69.7	15.4	781619	24.56	7.6	8.3	371.99	9136.11
M-39 from I-94 to John C Lodge Frwy	NB	64.3	13.5	711155	24.02	8	8.3	515.75	12388.21
	SB	64.9	13.3	841425	24.02	9.4	9.9	606.6	14570.43
M-53 from 18 Mile to 27 Mile	NB	69.1	8.3	300883	24.02	6.4	6.6	188.28	4522.49
	SB	69.2	8.3	318727	23.85	6.7	7	168.95	4029.37
	EB	70.6	12.5	263031	24.2	3.5	3.7	99.44	2406.36

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-10 in Bay City to I-75	WB	69.8	12.5	305153	24.2	4.2	4.4	165.34	4001.11
US-131 from Center Ave. to US-131 BR Interchange	NB	67.5	9.5	277057	24.73	5.3	5.7	139.95	3460.98
	SB	68.4	9.3	269080	25.09	5.1	5.6	113.17	2839.53
US-131 from I-96 to Post Dr.	NB	71.1	5.6	219205	24.38	5.7	6.2	36.81	897.38
	SB	71.1	5.7	274159	24.56	6.9	7.4	73.14	1796.34
US-131 from Post Dr to 10 Mile Rd	NB	71.5	2.6	106975	24.38	6.7	7.2	37.7	919.19
	SB	70.9	2.5	96760	24.56	6.3	6.8	42.93	1054.36
US-23 in Genesee County to I-75 in Flint	NB	70.4	12.7	481518	25.97	5.9	6.8	253.9	6593.69
	SB	70.2	12.9	475170	24.73	5.9	6.4	258.21	6385.44
US-23 North Extension from Barker Rd. to I-96	NB	69.4	5.5	216017	25.44	6.5	7.4	113.55	2888.82
	SB	70.2	6	266904	25.44	7.1	8	126.44	3216.7
US-23 South Extension from M-14 to I-94	NB	67.1	6.6	273156	24.91	7.2	7.9	260.95	6500.39
	SB	67.8	6.3	271466	24.73	7.7	8.4	229.19	5667.76
AM Peak (6 AM-9 AM) Period									
I-75 near Monroe between Luna Pier and Newport	NB	70.3	12.1	80933	29.15	6.5	8.8	19.5	568.29
	SB	70.6	12.6	84096	28.98	6.5	8.4	19.43	563.18
	EB	69.3	20.4	142011	26.32	9.1	10.4	46.5	1223.82

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-94 between Kalamazoo and Battle Creek	WB	68.9	20.5	120095	26.15	7.8	9.1	38.63	1010.28
I-94 from M-14 to US-12	EB	69.9	8.8	48095	25.44	7.2	8.2	23.78	605.05
	WB	68.8	9	73636	24.56	11	11.9	48.23	1184.48
I-96 between M-44 and 28th St.	EB	68.1	5	34117	24.2	9	9.3	27.06	654.8
	WB	70.9	5.1	37440	24.38	8.4	9.1	12.62	307.58
I-96 from Kent Lake Rd. to US-23	EB	71.7	5.5	55500	26.15	10.3	11.8	16.68	436.11
	WB	71.9	5.3	41408	27.03	7.8	9.8	10.62	287.01
I-96 from Okemos to US-127	EB	72.1	2.7	22371	25.26	10.8	12	1.79	45.23
	WB	70.8	2.7	16880	25.44	7.7	8.6	6.22	158.14
M-14 from US-23 to I-275	EB	71	15.5	155141	24.73	11.5	12.4	48.74	1205.4
	WB	69.6	15.4	150343	24.56	11.8	12.7	76.89	1888.51
M-39 from I-94 to John C Lodge Frwy	NB	64.4	13.4	126973	24.02	11.4	12	86.43	2076.09
	SB	65.2	13.3	155394	24.02	13.9	14.6	102.8	2469.24
M-53 from 18 Mile to 27 Mile	NB	69.4	8.2	34661	24.02	5.8	6.1	19.71	473.49
	SB	69.1	8.3	86264	23.85	14.5	15	48.13	1148
US-10 in Bay City to I-75	EB	70.6	12.5	55472	24.2	5.9	6.2	21.3	515.4
	WB	69.7	12.5	56997	24.2	6.2	6.7	32.22	779.65
US-131 from Center Ave. to US-131 BR Interchange	NB	67.4	9.6	45741	24.73	7	7.6	22.74	562.32
	SB	68.4	9.3	48501	25.09	7.3	8.1	20.45	513.17
	NB	71.1	5.6	30221	24.38	6.4	7.2	4.81	117.23

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-131 from I-96 to Post Dr.	SB	67	6.1	61700	24.56	13.9	14.4	69.1	1697.08
US-131 from Post Dr to 10 Mile Rd	NB	71.6	2.6	14632	24.38	7.3	8.3	5.04	122.76
	SB	70.8	2.6	24860	24.56	13	13.5	11.58	284.29
US-23 in Genesee County to I-75 in Flint	NB	70.5	12.7	79296	25.97	7.7	9.1	40.68	1056.4
	SB	70.1	12.9	96721	24.73	9.7	10.4	54.21	1340.72
US-23 North Extension from Barker Rd. to I-96	NB	69.3	6.6	37343	25.44	7.6	8.9	20.5	521.63
	SB	69.3	6.6	37343	25.44	7.6	8.9	20.5	521.63
US-23 South Extension from M-14 to I-94	NB	66.9	6.7	52744	24.91	11.2	12.1	51.81	1290.6
	SB	67.9	6.3	51230	24.73	11.5	12.7	42.63	1054.28
PM Peak (3 PM-7 PM) Period									
I-75 near Monroe between Luna Pier and Newport	NB	70.2	12.1	145575	29.15	8.8	11	36.12	1052.9
	SB	70.6	12.6	124228	28.98	7.2	9	30.01	869.81
I-94 between Kalamazoo and Battle Creek	EB	69.4	20.4	224226	26.32	10.8	12.3	72.59	1910.54
	WB	68.8	20.5	208438	26.15	10.1	11.3	67.58	1767.18
I-94 from M-14 to US-12	EB	69.6	8.9	101096	25.44	11.3	12.3	55.72	1417.56
	WB	69	8.9	113122	24.56	12.6	13.2	71.08	1745.74
I-96 between M-44 and 28th St.	EB	69	4.9	39399	24.2	7.7	8	23.72	574.07
	WB	70	5.1	74600	24.38	12.6	13	37.97	925.77

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-96 from Kent Lake Rd. to US-23	EB	71.8	5.5	61927	26.15	8.6	10.1	17.77	464.6
	WB	69.9	5.4	114773	27.03	16.5	20.2	73.44	1984.97
I-96 from Okemos to US-127	EB	71.2	2.7	42042	25.26	15.4	16.6	11.09	280.16
	WB	70.7	2.7	24872	25.44	8.4	9.1	9.35	237.9
M-14 from US-23 to I-275	EB	71	15.5	199224	24.73	11	11.7	62.67	1549.9
	WB	69.6	15.5	230135	24.56	13.5	14.1	116.1	2851.42
M-39 from I-94 to John C Lodge Frwy	NB	64.5	13.4	186986	24.02	12.5	12.8	130.8	3141.89
	SB	64.3	13.5	262318	24.02	17.8	18.4	222.73	5350
M-53 from 18 Mile to 27 Mile	NB	68.8	8.3	118685	24.02	15.1	15.6	81.57	1959.26
	SB	69.3	8.3	67622	23.85	8.5	8.8	35.49	846.45
US-10 in Bay City to I-75	EB	70.3	12.5	79617	24.2	6.4	6.7	33.41	808.48
	WB	69.6	12.5	93748	24.2	7.7	8	54.56	1320.39
US-131 from Center Ave. to US-131 BR Interchange	NB	67.4	9.6	85996	24.73	9.8	10.4	46.41	1147.69
	SB	68.2	9.4	73827	25.09	8.4	9	33.07	829.79
US-131 from I-96 to Post Dr.	NB	69	5.8	76333	24.38	12.6	13	45.26	1103.37
	SB	68.1	6	63301	24.56	10.4	11.4	56.33	1383.55
US-131 from Post Dr to 10 Mile Rd	NB	71.3	2.6	34703	24.38	13.1	13.5	13.52	329.51
	SB	70.9	2.5	21044	24.56	8.2	8.9	9.38	230.35
US-23 in Genesee County to I-75 in Flint	NB	70.2	12.7	143575	25.97	10.5	11.8	81.77	2123.46
	SB	69.9	13	120998	24.73	9.1	9.6	71.92	1778.54
	NB	69.1	6.6	86177	25.44	13.2	14.1	53.07	1350.02

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-23 North Extension from Barker Rd. to I-96	SB	69.1	6.6	86177	25.44	13.2	14.1	53.07	1350.02
US-23 South Extension from M-14 to I-94	NB	66.3	6.7	78157	24.91	12.6	13.4	90.08	2243.93
	SB	67.5	6.4	73752	24.73	12.5	13.3	66.3	1639.62

Table 15 Summary of MOE for Flex Lane Build with Induced Demand Condition

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
Daily (24-hour) Period									
I-75 near Monroe between Luna Pier and Newport	NB	70.2	12.1	621410	29.15	6.2	8.3	150.14	4376.69
	SB	70.6	12.6	568495	28.98	5.6	7.4	131.45	3809.52
I-94 between Kalamazoo and Battle Creek	EB	69.4	20.4	922810	26.32	7.4	8.7	291.4	7669.64
	WB	68.8	20.5	837411	26.15	6.8	8	269.98	7059.87
I-94 from M-14 to US-12	EB	69.7	8.8	360835	25.44	6.7	7.6	190.47	4845.46
	WB	69	8.9	409267	24.56	7.6	8.2	257.67	6328.48
I-96 between M-44 and 28th St.	EB	70	7.6	210238	24.2	4.3	4.6	75.97	1838.56
	WB	69.5	8.2	340275	24.38	6.3	6.8	187.01	4559.25
	EB	71.7	5.5	288769	26.15	6.7	7.9	86.1	2251.61

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-96 from Kent Lake Rd. to US-23	WB	70.6	5.4	352553	27.03	8.4	10.3	179.3	4846.51
I-96 from Okemos to US-127	EB	71.6	2.7	150473	25.26	9.2	10.3	29.44	743.75
	WB	70.8	2.7	103107	25.44	6	6.8	37.52	954.58
M-14 from US-23 to I-275	EB	71	15.5	792911	24.73	7.3	8	249.91	6180.36
	WB	69.6	15.4	858859	24.56	8.4	9.1	434.92	10681.68
M-39 from I-94 to John C Lodge Frwy	NB	64.2	13.5	781647	24.02	8.8	9.2	589.41	14157.64
	SB	64.7	13.4	923204	24.02	10.4	10.9	714.49	17162.16
M-53 from 18 Mile to 27 Mile	NB	68.8	8.3	330973	24.02	7	7.3	224.35	5388.86
	SB	69.2	8.3	350592	23.85	7.4	7.7	192.26	4585.45
US-10 in Bay City to I-75	EB	70.5	12.5	289162	24.2	3.9	4.1	110.13	2665.22
	WB	69.8	12.5	335146	24.2	4.6	4.9	182.22	4409.65
US-131 from Center Ave. to US-131 BR Interchange	NB	67.5	9.5	304548	24.73	5.8	6.3	157.42	3893.02
	SB	68.3	9.3	295741	25.09	5.6	6.2	126.68	3178.36
US-131 from I-96 to Post Dr.	NB	71.1	5.6	238302	24.38	6.3	6.8	41.61	1014.33
	SB	71	5.7	298484	24.56	7.5	8.2	84.6	2077.82
US-131 from Post Dr to 10 Mile Rd	NB	71.4	2.6	117673	24.38	7.4	7.9	42.91	1046.07
	SB	70.8	2.5	106435	24.56	6.9	7.5	48.23	1184.58
US-23 in Genesee County to I-75 in Flint	NB	70.4	12.7	529328	25.97	6.5	7.5	285	7401.36
	SB	70.1	12.9	522058	24.73	6.5	7.1	290.89	7196.71
	NB	69.2	5.5	238175	25.44	7.2	8.2	135.24	3440.49

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-23 North Extension from Barker Rd. to I-96	SB	70.1	6	292841	25.44	7.8	8.8	145.46	3700.48
US-23 South Extension from M-14 to I-94	NB	66.3	6.7	297533	24.91	8	8.8	340.29	8476.64
	SB	67.6	6.3	298300	24.73	8.4	9.2	261.31	6462.11
AM Peak (6 AM-9 AM) Period									
I-75 near Monroe between Luna Pier and Newport	NB	70.2	12.1	89002	29.15	7.1	9.6	22.11	644.37
	SB	70.6	12.6	92469	28.98	7.2	9.3	21.92	635.17
I-94 between Kalamazoo and Battle Creek	EB	69.3	20.4	156157	26.32	10	11.5	52.74	1388.06
	WB	68.9	20.5	132092	26.15	8.6	10	42.79	1118.96
I-94 from M-14 to US-12	EB	69.8	8.8	52936	25.44	7.9	9	26.47	673.39
	WB	68.5	9	80890	24.56	12.1	13.2	59.46	1460.36
I-96 between M-44 and 28th St.	EB	67.9	5	37204	24.2	9.9	10.3	31.17	754.26
	WB	70.9	5.1	44042	24.38	9.9	10.7	14.98	365.18
I-96 from Kent Lake Rd. to US-23	EB	71.6	5.5	61291	26.15	11.4	13	19.78	517.22
	WB	71.8	5.3	45548	27.03	8.5	10.7	12.12	327.63
I-96 from Okemos to US-127	EB	72	2.7	24607	25.26	11.9	13.3	2.55	64.47
	WB	70.8	2.7	18568	25.44	8.4	9.4	6.93	176.24
M-14 from US-23 to I-275	EB	70.9	15.6	171344	24.73	12.7	13.7	58.76	1453.02
	WB	69.4	15.5	165141	24.56	13	14	90.21	2215.57
	NB	64.3	13.5	139527	24.02	12.5	13.2	99.42	2388.09

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
M-39 from I-94 to John C Lodge Frwy	SB	64.9	13.3	170694	24.02	15.3	16.1	123.12	2957.36
M-53 from 18 Mile to 27 Mile	NB	69.4	8.2	38127	24.02	6.4	6.7	21.79	523.29
	SB	68.9	8.3	94892	23.85	16	16.5	57.73	1376.81
US-10 in Bay City to I-75	EB	70.5	12.5	60982	24.2	6.5	6.8	23.87	577.74
	WB	69.6	12.5	62611	24.2	6.9	7.4	36.29	878.3
US-131 from Center Ave. to US-131 BR Interchange	NB	67.4	9.6	50278	24.73	7.7	8.3	25.29	625.47
	SB	68.4	9.3	53310	25.09	8.1	8.9	22.93	575.23
US-131 from I-96 to Post Dr.	NB	71.1	5.6	32868	24.38	7	8	5.32	129.7
	SB	66.6	6.1	67126	24.56	15.4	16	81.68	2006.06
US-131 from Post Dr to 10 Mile Rd	NB	71.5	2.6	16096	24.38	8.1	9.1	5.58	136.16
	SB	70.6	2.6	27347	24.56	14.3	14.9	13.54	332.63
US-23 in Genesee County to I-75 in Flint	NB	70.4	12.7	87186	25.97	8.5	10	45.52	1182.07
	SB	70	12.9	106263	24.73	10.6	11.4	61.24	1514.58
US-23 North Extension from Barker Rd. to I-96	NB	69.3	6.6	41079	25.44	8.4	9.8	22.67	576.62
	SB	69.3	6.6	41079	25.44	8.4	9.8	22.67	576.62
US-23 South Extension from M-14 to I-94	NB	66.7	6.7	57465	24.91	12.3	13.3	59.24	1475.58
	SB	67.7	6.3	56305	24.73	12.7	14	49.55	1225.35
PM Peak (3 PM-7 PM) Period									
	NB	70.1	12.1	160098	29.15	9.6	12.1	41.52	1210.34

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
I-75 near Monroe between Luna Pier and Newport	SB	70.6	12.6	136623	28.98	7.9	9.9	33.78	978.88
I-94 between Kalamazoo and Battle Creek	EB	69.4	20.4	246588	26.32	11.9	13.5	82.54	2172.42
	WB	68.8	20.5	229253	26.15	11.1	12.4	75.36	1970.77
I-94 from M-14 to US-12	EB	69.4	8.9	111351	25.44	12.5	13.6	67.56	1718.64
	WB	68.8	9	124247	24.56	13.9	14.5	82.61	2028.88
I-96 between M-44 and 28th St.	EB	68.9	4.9	43037	24.2	8.4	8.8	26.96	652.46
	WB	69.5	5.2	86353	24.38	14.6	15.1	52.89	1289.43
I-96 from Kent Lake Rd. to US-23	EB	71.7	5.5	68121	26.15	9.5	11.1	20.05	524.4
	WB	68.6	5.5	126251	27.03	18.5	22.6	115.41	3119.44
I-96 from Okemos to US-127	EB	70.3	2.7	46246	25.26	17.2	18.5	20.63	521.16
	WB	70.7	2.7	27359	25.44	9.3	10	10.44	265.56
M-14 from US-23 to I-275	EB	71	15.5	221072	24.73	12.3	12.9	72.44	1791.37
	WB	69.2	15.5	253262	24.56	15	15.7	144.34	3544.98
M-39 from I-94 to John C Lodge Frwy	NB	64.3	13.5	207526	24.02	13.9	14.3	153.1	3677.47
	SB	63.9	13.6	286831	24.02	19.7	20.4	272.22	6538.81
M-53 from 18 Mile to 27 Mile	NB	68.3	8.4	130553	24.02	16.7	17.2	104.15	2501.67
	SB	69.3	8.3	74386	23.85	9.4	9.7	39.52	942.6
US-10 in Bay City to I-75	EB	70.2	12.5	87528	24.2	7	7.3	38.39	928.95
	WB	69.5	12.5	102975	24.2	8.5	8.8	61.54	1489.25
	NB	67.3	9.6	94525	24.73	10.8	11.4	53.49	1322.69

Corridor	Direction	Space Mean Speed, mi/h	Average Travel Time, min	Total VMT, veh-mi/AP	Vehicle Value of Time (VOT), $/h	Average Density, veh/mi/ln	Average Density, pc/mi/ln	Total VHD, veh-h	Total Delay Cost, $
US-131 from Center Ave. to US-131 BR Interchange	SB	68.2	9.4	81136	25.09	9.2	9.9	37.2	933.3
US-131 from I-96 to Post Dr.	NB	68.8	5.8	83003	24.38	14	14.4	53.36	1300.94
	SB	67.8	6	68899	24.56	11.5	12.6	65	1596.48
US-131 from Post Dr to 10 Mile Rd	NB	71.1	2.6	38175	24.38	14.4	14.9	16.12	392.95
	SB	70.9	2.5	23149	24.56	9.1	9.8	10.37	254.8
US-23 in Genesee County to I-75 in Flint	NB	70.1	12.7	157812	25.97	11.6	13	92.69	2407.12
	SB	69.8	13	132936	24.73	10	10.6	81.49	2015.23
US-23 North Extension from Barker Rd. to I-96	NB	68.6	6.6	95531	25.44	14.7	15.7	67.55	1718.57
	SB	68.6	6.6	95531	25.44	14.7	15.7	67.55	1718.57
US-23 South Extension from M-14 to I-94	NB	63.8	7	85151	24.91	14.4	15.3	148.12	3689.66
	SB	67.3	6.4	81048	24.73	13.8	14.7	76.55	1893.1

5.3 Safety Analysis

High-level safety analyses were conducted for the selected 16 candidate corridors to identify corridors experiencing more than average crashes at different times of day. To that end, segment-level data were prepared for three years from 2021 to 2023. Data were prepared for three periods for each segment. This included AM peak from 6 AM to 9 AM, PM peak from 3 PM to 7 PM, and the remaining hours of the day were coded as off peak. The number of crashes occurring during each of these periods during weekdays only were counted for each segment and integrated. Traffic volume counts during each of the three periods were obtained from MDOT's Transportation Data Management System (TDMS) as described earlier.

Figure 19 shows the average crash rate for total crashes for each of the corridors and for each of the three time periods. Crash counts were also segregated based on crash type. The predominant crash types were single vehicle, rear-end and same direction sideswipe crashes. The crash rates for each of these three crash types are presented in Figure 20, Figure 21, and Figure 22, respectively. As expected, peak periods (AM and PM peak) generally experienced higher crash rates than the off-peak period. The off-peak period experienced a higher rate of single vehicle crashes which is due to relatively lower volumes leading to fewer vehicle to vehicle interactions. The rate of sideswipe crashes was the highest during periods of high volume while rear-end crashes were relatively uniformly distributed across all the three time periods.

To identify those corridors experiencing higher than average crash rates while accounting for differences in traffic volume and other pertinent factors, a series of statistical models were developed. Since crash counts are discrete non-negative integers, negative binomial regression models were estimated for each of the three time periods separately. In a negative binomial model, the average number of crashes on a segment i is given as shown in equation 1.

$$\lambda_i = EXP(\beta X_i + \varepsilon_i) \quad \text{Eq. 1}$$

The term $EXP(\varepsilon_i)$ is gamma distributed with mean and variance equal to 1 and α, respectively, where α is the overdispersion parameter. X is a vector of parameters and β is a vector of estimable parameters. Due to repeated nature of observations in the data, a random effects modeling framework was adopted to account for any correlation among crash count observations across different years. The random-effects model allows the constant term to vary across segments as shown in Equation 2.

$$\beta_{0i} = \beta_0 + \omega_i \qquad \text{Eq. 2}$$

Where, ω_i is a randomly distributed random effect for segment i and all other variables are as defined previously. The natural logarithm of the segment length was taken as the offset variable which means that the coefficient of log of segment length was fixed at unity.

Table 16 presents the analysis results for total weekday crashes modeled separately for each of the three time periods. Parameter estimates that are statistically significant at 95% confidence level are marked with an asterisk sign. Indicator variables were included for each of the 16 corridors by direction. A positive sign for these indicator variables indicates that the corridor experiences more than average crash rate relative to other corridors. For example, US-131 as well as the north and south extension of US-23 exhibited higher crash frequencies across all three time periods. Similarly, M-53 in both NB and SB directions experienced more than average crashes. The results also showed that the crash rates vary by direction of travel and by peak period across the analyzed corridors. More specifically, each corridor generally exhibited higher crash rates in one direction of travel during a particular peak period (AM or PM). Conversely, the opposite direction tended to experience higher crash rates during the other peak period. Off-peak crash rates were generally lower but varied depending on corridor characteristics and traffic demand patterns.

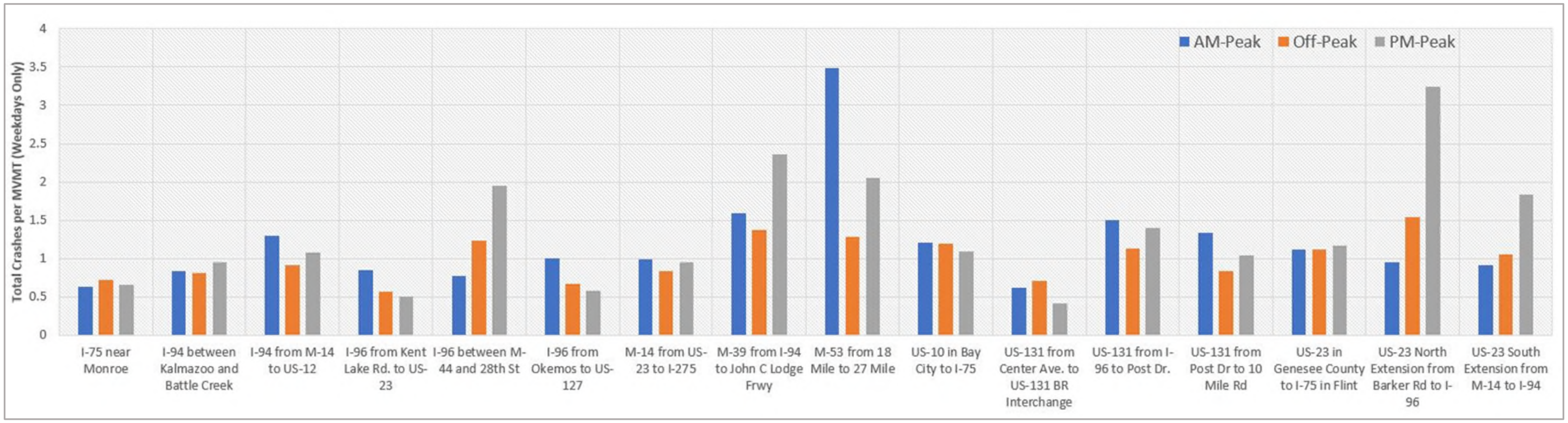


Figure 22 Average Crash Rate by Corridor and Time of Day

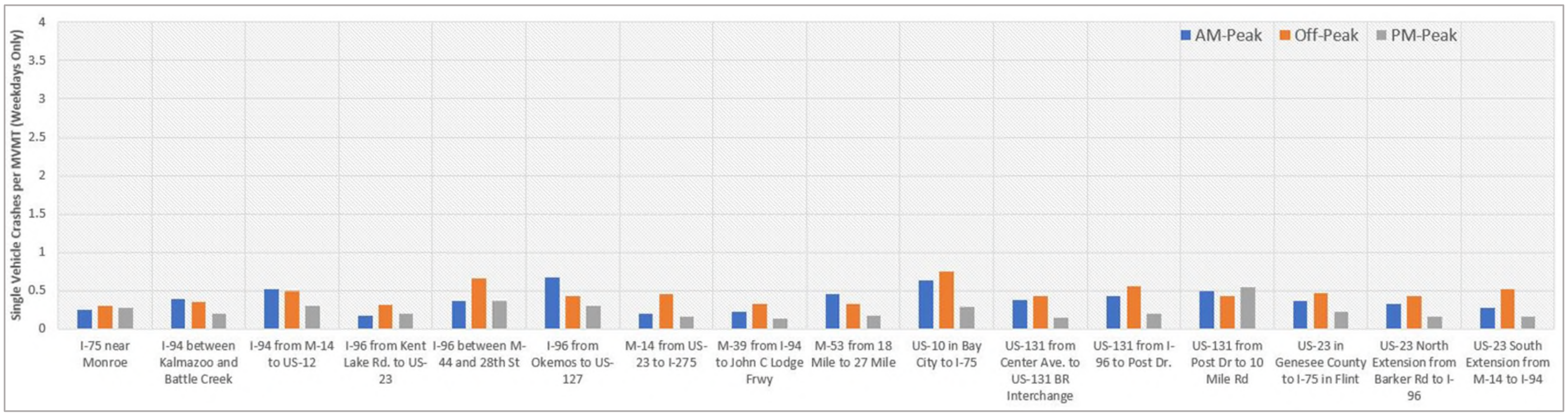


Figure 23 Average Single Vehicle Crash Rate by Corridor and Time of Day

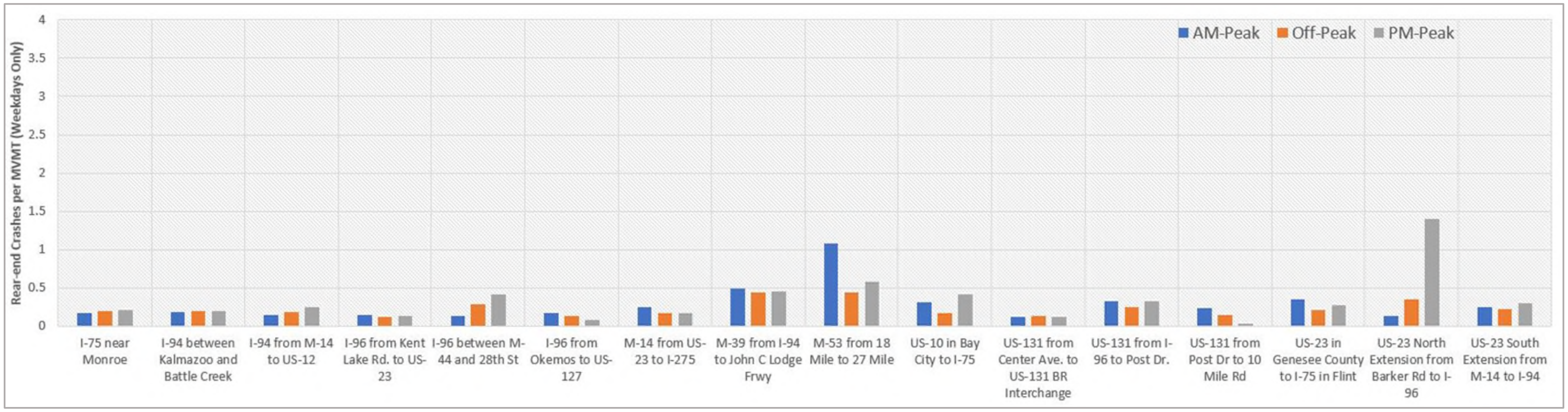


Figure 24 Average Rear-end Crash Rate by Corridor and Time of Day

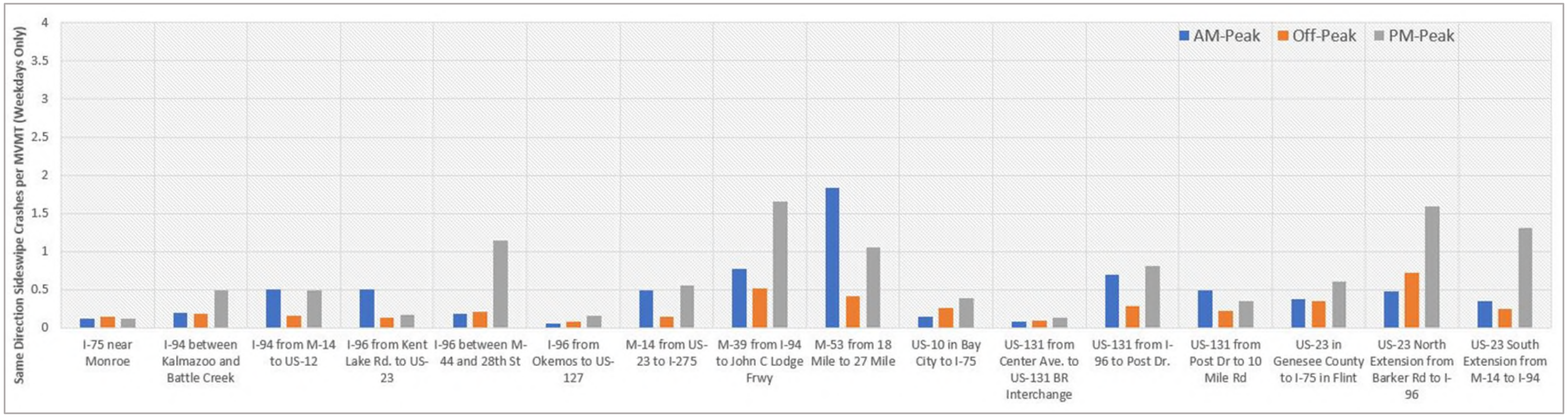


Figure 25 Average Sideswipe (Same Direction) Crash Rate by Corridor and Time of Day

Table 16 Negative Binomial Regression Analysis Results for Total Weekday Crashes

Parameter	AM-Peak		PM-Peak		Off-Peak	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	-2.255*	1.077	-7.396*	1.768	-10.149*	1.386
Ln(Volume)	0.299*	0.122	0.880*	0.192	1.163*	0.139
Median width (ft)	-0.010*	0.003	-0.008*	0.003	-0.007*	0.002
SB US-23 in Genesee County to I-75 in Flint	0.809*	0.307	0.265	0.322	0.531*	0.204
NB US-23 in Genesee County to I-75 in Flint	0.356	0.318	0.938*	0.312	0.759*	0.205
SB US-23 South Extension from M-14 to I-94	0.715	0.409	1.492*	0.402	0.781*	0.264
NB US-23 South Extension from M-14 to I-94	1.032*	0.397	1.231*	0.406	0.761*	0.264
SB US-23 North Extension from Barker Rd to I-96	0.883*	0.360	0.228	0.389	0.623*	0.245
NB US-23 North Extension from Barker Rd to I-96	0.080	0.404	2.281*	0.345	1.217*	0.234
SB US-131 from Post Dr to 10 Mile Rd	1.554*	0.522	0.903	0.571	0.691	0.372
NB US-131 from Post Dr to 10 Mile Rd	1.173*	0.551	1.230*	0.541	0.786*	0.369
SB US-131 from I-96 to Post Dr.	1.874*	0.371	0.833*	0.396	0.872*	0.253
NB US-131 from I-96 to Post Dr.	0.595	0.425	1.555*	0.389	1.001*	0.257
SB US-131 from Center Ave. to US-131 BR Interchange	0.235	0.429	0.004	0.443	0.633*	0.276
NB US-131 from Center Ave. to US-131 BR Interchange	0.476	0.406	0.163	0.417	0.665*	0.269
WB US-10 in Bay City to I-75	0.128	0.339	0.231	0.353	0.598*	0.250
EB US-10 in Bay City to I-75	-0.142	0.350	0.324	0.355	0.941*	0.242
SB M-53 from 18 Mile to 27 Mile	1.402*	0.343	0.920*	0.371	0.945*	0.238
NB M-53 from 18 Mile to 27 Mile	0.553	0.398	1.245*	0.369	0.853*	0.250
SB M-39 from I-94 to John C Lodge Frwy	0.458	0.295	1.207*	0.302	0.546*	0.196
NB M-39 from I-94 to John C Lodge Frwy	1.161*	0.287	1.141*	0.299	0.655*	0.194
WB M-14 from US-23 to I-275	0.830*	0.325	0.588	0.332	0.359	0.214
EB M-14 from US-23 to I-275	0.397	0.334	0.627	0.332	0.626*	0.216
WB I-96 from Okemos to US-127	0.508	0.499	0.302	0.513	0.411	0.330
EB I-96 from Okemos to US-127	0.773	0.480	0.265	0.515	0.273	0.343
WB I-96 from Kent Lake Rd. to US-23	-0.002	0.403	-0.195	0.403	0.030	0.249
EB I-96 from Kent Lake Rd. to US-23	1.108*	0.356	0.001	0.388	-0.171	0.254
WB I-96 between M-44 and 27th St.	0.234	0.411	1.551*	0.356	0.879*	0.239
EB I-96 between M-44 and 28th St.	0.756	0.395	0.731	0.391	0.783*	0.252
WB I-94 from M-14 to US-12	0.991*	0.331	0.174	0.358	0.243	0.235

Parameter	AM-Peak		PM-Peak		Off-Peak	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
EB I-94 from M-14 to US-12	-0.086	0.356	0.662	0.340	0.415	0.228
WB I-94 between Kalamazoo and Battle Creek	0.202	0.292	0.350	0.290	0.327	0.190
EB I-94 between Kalamazoo and Battle Creek	0.261	0.290	0.535	0.288	0.344	0.190
SB I-75 near Monroe	-0.309	0.343	0.030	0.335	0.241	0.212
NB I-75 near Monroe	Baseline		Baseline		Baseline	

Note: *represents parameter estimate statistically significant at 95% confidence interval

5.4 Summary

Operational and safety analyses were conducted for 16 candidate corridors to investigate speed, delay, and crash trends. Subsequently, macroscopic comparison of corridors was conducted using the HCS2024 Freeway Facility module to investigate the operational impacts of implementing a 24-hour PTSU strategy along each of these corridors. Several operational measures of effectiveness were extracted for three scenarios- 1) existing conditions, 2) added flex lane condition, and 3) added flex lane with 10% induced demand condition. Separate analyses were conducted for full 24-hour day, AM peak and PM peak periods. The results showed that the addition of the flex lane resulted in reduced travel time, greater space mean speed, reduced delay and associated costs compared to existing conditions, in both off peak and peak periods. The safety analyses showed trends in crashes by crash type based on time of day. Subsequent regression modeling helped in identifying corridors that are experiencing higher than average crash rates compared to other corridors. Overall, the results from these analyses would ultimately assist towards developing and ranking the corridors based on the priority to implement PTSU in the future.

6 CORRIDOR RANKING SCHEME

In order to identify and rank the candidate corridors based on priority for implementation of PTSU strategy in the future, a ranking scheme was developed. This chapter discusses the methodology for ranking the corridors and the results of this exercise.

6.1 Parameters

For ranking and prioritization, a summary dataset of each of the 16 candidate corridors was prepared. This dataset included a summary of various operational, safety, and geometric parameters for each corridor by direction of travel (i.e., northbound vs. southbound, eastbound vs. westbound). This resulted in a final dataset that included 32 total directional corridors. The operational and safety parameters were obtained through the analyses conducted during the project as summarized in the previous chapter. In addition to this analysis output, the number of interchanges, bridges, and rest areas were also included in this list of parameters as these factors would affect the feasibility and costs associated with the implementation of the PTSU strategy. Ultimately, for each candidate corridor, the following parameters were summarized by direction:

A. Operational Parameters

   1. Free-flow speed, mph
   2. Space-mean speed, mph
   3. Average travel time, min
   4. Total vehicle miles traveled
   5. Vehicle value of time (VOT), $/h
   6. Average density, veh/mi/lane, passenger car/mi/lane
   7. Total vehicle delay, veh-h
   8. Total delay cost, $

B. Safety Parameters

   1. AM-peak crash rate

2. PM-peak crash rate
3. Off-peak crash rate
4. Weighted total crash rate

C. Geometric and Traffic Parameters

1. Annual average daily traffic, veh/day
2. Proportion of trucks
3. Maximum hourly volume, veh/h
4. Average and minimum median width, ft
5. Average and minimum right shoulder width, ft
6. Average and minimum left shoulder width, ft
7. Number of raised freeway interchanges
8. Number of depressed freeway interchanges
9. Number of bridges (separate counts of on-grade and overhead bridges)
10. Number of rest areas
11. Number of on/off ramps on the left
12. Indicator whether the corridor transitions to a surface street
13. Total length of corridor

6.2 Normalization and Weighting

Initially, all 16 corridors were included in this exercise. However, as also discussed previously, corridor M-39 from I-94 to John C Lodge Frwy experienced significant congestion and delay and exhibited significantly higher values of operational parameters. Thus, this corridor was considered as an outlier and was not included in the ranking process for PTSU implementation. Once the summary data were prepared for the remaining 15 corridors (or 30 unidirectional corridors), normalized scores were calculated for each metric to ensure that the metrics are on a comparable scale. To that end, min-max normalization was used to scale each factor between 0 and 1, using the following formula:

$$Normalized\ score = \frac{X - min(X)}{max(X) - min(X)} \qquad \text{Eq. 3}$$

Normalization is necessary since each metric is measured in a different unit. This normalization ensures that the corridor with the highest value for a given factor gets 1, and the corridor with the lowest value gets 0, while other corridors fall proportionally in between.

In this method of normalization, higher scores indicate higher feasibility for PTSU implementation. However, there are some factors in the list that behave differently. For example, higher values of factors such as total delay and delay cost indicate higher need for implementation of PTSU. However, higher values of factors such as number of bridges, indicate lower need for implementation since more bridges along the corridor would increase implementation cost. Thus, the following factors were reverse scaled by subtracting the normalized score calculated using equation 3 from 1.

1. Truck proportion
2. Count of depressed freeway interchanges, and raised freeway interchanges,
3. Count of overhead and on-grade bridges, ramps on the left, and rest area

Next, weights were assigned for select parameters that were ultimately considered to be included in the ranking scheme. Table 17 presents the list of parameters and their corresponding assigned weights that were included in ranking the candidate corridors.

Table 17 Final List of Parameters and their Weights Considered in Ranking Scheme

Parameter	**Weight (%)**
Maximum density	10
Maximum total vehicle hour delay	30
Ratio of off-peak to peak period delay	10
Maximum of level of travel time reliability	10
Weighted total crash rate	30
Maximum hourly volume	10

Parameter	Weight (%)
Minimum median width	5
Minimum right shoulder width	10
On-grade bridge count	5
Overhead bridge count	5

6.3 Ranking Results

Once the weights were assigned to desired parameters of interest, the normalized score was calculated by adding the products of normalized metric and its corresponding weight. The corridors were then ranked based on this normalized score. It should be noted that the weights of each metric can be changed depending upon the priority of MDOT. An excel sheet was developed and shared with MDOT for this purpose that would allow MDOT to change weights of the listed metrics and obtain a modified ranking of the candidate corridors. Table 18 presents the top 5 ranked corridors based on the above-mentioned weighting scheme.

Table 18 Corridors Ranked based on Priority of PTSU Implementation

Route	Direction	Rank
M-53 from 18 Mile to 27 Mile	SB	1
US-23 North Extension from M-36 to I-96	NB	2
US-23 South Extension from M-14 to I-94	SB	3
M-53 from 18 Mile to 27 Mile	NB	4
I-96 between M-44 and M-6	WB	5

7 CONCLUSIONS AND FUTURE WORK

State DOTs are increasingly adopting ATM strategies as a more cost-effective means to manage congestion and reduce travel time and delay. Given the potential that has been demonstrated for part-time shoulder use on the MDOT US-23 corridor, this study provides important insights that will aid in identifying and prioritizing prospective corridors for the implementation of PTSU of other managed lane strategies. This chapter summarizes the study findings and recommendations for future research.

7.1 Operational and Safety Trends on Candidate Corridors

Sixteen potential candidates for implementation of PTSU strategy were identified during the early stages of the project in consultation with MDOT region staff, RAP members, and based on an aggregate-level review of travel time/speed trends on the Michigan freeway network. Subsequent detailed analyses of these 16 candidate corridors were conducted. This included: (1) estimation of delay by direction and time of day using probe vehicle data from RITIS; (2) calculation of crash frequencies and rates along these corridors, as well as regression analyses; and (3) a macroscopic comparison of corridors under various scenarios. The latter comparison was conducted using the HCS2024 freeway module to contrast existing conditions with 24-hour PTSU operations (both with and without a 10% induced demand assumption). Separate comparisons were also made for AM and PM peak periods.

Overall, each of the 16 corridors exhibited significant delays during peak periods with certain directions experiencing higher delays in either the AM or PM peak period. Safety analyses also showed similar directional trends where each corridor exhibited directional and time-period variations in crash rates. Even after controlling for traffic volume and other differences, each corridor experienced higher than average crash rates in one direction of travel during either the AM peak or the PM peak period. This is generally reflective of broader congestion patterns along these corridors, where crash risks were generally elevated during the peak traffic periods.

Subsequent operational analyses of the candidate corridors showed significant reduction in delay and travel time along the corridor due to the implementation of a flex lane or PTSU. Even if the demand was assumed to increase by 10% due to PTSU, travel times remained stable compared to the case without induced demand, but total vehicle delay and associated user costs increased, suggesting that additional demand could partially offset the benefits of PTSU. Similar trends were obtained when analysis period was restricted to just peak periods. The M-39 corridor exhibited significantly higher delays in the no-build (existing) condition due to multiple bottlenecks.

7.2 Ranking Scheme

A straight-forward ranking scheme was adopted to rank the candidate corridors based on their feasibility to implement PTSU strategy. Several operational, geometric, and safety related measures of effectiveness were summarized for the candidate corridors by direction. The metrics were normalized using min-max scaling and the corridors were ranked by direction based on a weighted scoring system. The assigned weights are flexible and can be adopted depending upon the needs and priorities of MDOT. The final ranking provided a data-driven prioritization of corridors where PTSU would be most beneficial, balancing operational improvements with safety and feasibility concerns.

7.3 Conclusions and Recommendations

This study provides a data-driven framework for prioritizing PTSU implementation on Michigan freeways. The findings demonstrate that PTSU has the potential to significantly reduce congestion and improve mobility, but safety considerations and corridor-specific constraints must be carefully evaluated before implementation. The ranking system developed in this study serves as a useful decision-support tool for MDOT to guide future PTSU planning and investment. Some specific recommendations are as follows:

- Corridors with higher scores should be prioritized for further feasibility assessment, including detailed engineering evaluations and cost-benefit analysis.
- Corridors with safety concerns may require additional countermeasures (e.g., dynamic lane control, signage, enforcement strategies) to mitigate potential risks associated with PTSU.
- Induced demand effects should be considered when planning PTSU, as additional travel demand may reduce some of the congestion relief benefits.

- The M-39 corridor should not be considered for PTSU implementation at this stage, particularly in the Southbound direction due to unique congestion challenges. Although the corridor experiences significant delays, the results for this particular corridor may be unrealistic given that the corridor operates at or near capacity due to several bottlenecks. Rather than considering PTSU implementation in its current state, it is recommended that the existing bottlenecks along the corridor should be addressed first to alleviate congestion. Once these issues are mitigated, a reevaluation of PTSU feasibility may be warranted.

7.4 Limitations and Future Work

There are some important limitations in this research that provide venues for future research:

- Microsimulation analysis tools, such as VISSIM, can simulate near real-world scenarios of PTSU implementation and could provide more detailed insights as to the potential impacts of PTSU on the candidate corridors.

- The safety analysis was based on historical traffic crash and volume data. However, the introduction of PTSU may alter traffic patterns in ways not captured by these historical trends. Microsimulation-based safety assessments could provide additional insights in this regard, as well.

- Additional analyses that consider environmental impacts, noise effects, and other secondary impacts of PTSU implementation can also be conducted in the future. A more extensive cost-benefit analysis should be conducted on a case-by-case basis to consider the full economic impacts of implementing PTSU.

APPENDIX-A

This appendix presents the state DOT survey that was distributed to all 50 state DOTs and District DOT to document current state of practice related to identifying locations for implementation of PTSU and other ATM strategies, and their design practices.

Introduction:

In 2017, the Michigan Department of Transportation (MDOT) opened a "flex route" on US-23, which includes part-time shoulder use (PTSU) (also known as hard shoulder running (HSR) by some agencies) and an Active Traffic Management (ATM) system to address congestion. MDOT is currently constructing its second such route and has plans to implement similar initiatives on other congested corridors throughout the state.

In support of this program, Michigan State University has been contracted to assist MDOT in assessing the national state-of-the-art and state-of-the-practice regarding PTSU and other related strategies. This includes documenting various use cases by state DOTs, as well as available documentation and guidance as to when such strategies are appropriate.

This questionnaire survey has been developed for those purposes and is being sent to state DOTs nationwide. We realize that you receive many inquiries like this and that they take up a lot of your time, but the success of this project depends on your input. Therefore, we sincerely appreciate your efforts in sharing your experience with others who can benefit from it. Your response to this survey by Friday, September 15, 2023, would be very much appreciated. The survey should take only 15 to 20 minutes of your time.

Please feel free to contact me directly if you have any questions or comments. We would also appreciate it if you could share any state-specific design guidance your agency may have as it relates to PTSU.

Sincerely,

Peter T. Savolainen, Ph.D., P.E., F.ITE (he/him/his)
Chair of ITE Transportation Education Council
Director of NSF REU Site: Sociomobility
MSU Foundation Professor and Interim Chair
Department of Civil and Environmental Engineering
Michigan State University
428 S Shaw Ln, Room 3559
East Lansing, MI 48824
Phone: (517) 432-1825
Email: pete@msu.edu

<u>Questionnaire:</u>
Contact Information

1. Name:
2. Agency/Department:
3. Job Title:
4. Phone Number:
5. Email Address:

6. Which of the following ATM strategies has your agency implemented to address congestion? (Select all that apply.)
   - Part-time shoulder use (PTSU)
   - High-Occupancy Vehicle (HOV) lanes
   - High-Occupancy Toll (HOT) lanes
   - Express lanes
   - Reversible lanes
   - Ramp metering
   - Variable speed limits
   - Variable advisory speeds
   - Congestion pricing
   - Bus Rapid Transit (BRT) or preferential (e.g., "transit-only") lanes
   - Others (Please list.) ________________________________

If the Part-time shoulder use (PTSU) option is checked, the survey will proceed to question 7; otherwise, the survey will proceed to question 6a.

6a. You indicated that your agency has NOT implemented part-time shoulder use (PTSU) as a strategy to address congestion. While your agency has not implemented PTSU, has it considered this strategy for implementation?

- Yes
- No

If "Yes" is selected for question 6a, the survey will proceed to question 6b and end; otherwise, the survey will end after 6a.

6b. Why did your agency ultimately decide to NOT implement PTSU in these instances?

____

7. In which of the following forms has your agency implemented part-time shoulder use (PTSU) (Check all that apply.)
   - Static (time-of-day) PTSU
   - Dynamic (traffic-responsive) PTSU
   - Bus-on-Shoulder PTSU
   - Other ________________

8. Please list the corridors where PTSU has been implemented in your state and indicate whether this corridor utilizes the left shoulder, the right shoulder, or both shoulders (e.g., US-23 from M14 to M-36, left shoulder). ________________________________

9. Please indicate whether it was intended to be a permanent or temporary solution to meet the corridor needs (e.g., US-23 from M14 to M-36, permanent).

10. Have any PTSU sites been removed after being in operation by your agency?
    - Yes
    - No

10a. If yes, what reasons led to their removal?
- A permanent lane was added
- Other ATM or TSM&O strategies were implemented
- No substantial improvement in traffic operation
- Adverse impacts on safety
- Negative public feedback
- An alternate route was provided
- Other ________________________

11. Does your agency have any formal policies or guidance as to conditions (e.g., traffic volume ranges, available right-of-way, geometric conditions) under which PTSU may be considered?
    - Yes
    - No

11a. If yes, is your agency willing to provide access to these policies or guidance documents?
- Yes
- No

12. Does your agency have any formal policies or guidance on the design of PTSU projects?
    - Yes
    - No

12a. If yes, is your agency willing to provide access to these policies or guidance documents?
- Yes
- No

13. Does your agency utilize modeling or simulation techniques to evaluate potential PTSU locations?
    - Yes
    - No

13a. Which microsimulation software do you use to evaluate PTSU? (Check all that apply.)
- AIMSUM

- Freeval
- SUMO
- VISSIM
- Other (Please list.) _______________

13b. What performance measures are used to evaluate new PTSU locations? (Check all that apply.)

- Total delay
- Vehicle-miles Traveled (VMT)
- Travel time index (TTI)
- Planning time index (PTI)
- Congestion duration and delay
- Level-of-Service (LOS)
- Level of travel time reliability (LOTTR)
- Other (Please list.) ________________

14. Does your agency have data as to the capacity of the shoulder when PTSU is active?
- Yes
- No

14a. If yes, what is the approximate capacity of the shoulder? ___________________

15. If applicable, what minimum shoulder width does your agency consider for PTSU? _____________

16. Has shoulder hardening, such as pavement designs or modifications similar to a travel lane, been required for your PTSU installations?
- Yes, for all PTSU sites
- Yes, for some PTSU sites
- No

17. Does your agency have guidance for minimum or maximum lengths for PTSU implementation? (Check all that apply.)
- Minimum length
- Maximum length
- No

17a. Please specify this length: ____
- Minimum length ____________________
- Maximum length ___________________

18. Were any of the following required as a part of your PTSU installations:

	Yes, for all PTSU sites	Yes, for some PTSU sites	No
1. Cross-slope modification			
2. Additional inlets or drainage modification?			
3. Noise mitigation?			

19. How does your agency **initiate** part-time shoulder use (PTSU)? (Check all that apply.)
    - PTSU is initiated along basic freeway segments through the strategic placement of visible signage and clear pavement markings
    - PTSU begins by adding a "lane" from an on-ramp
    - PTSU starts as an auxiliary lane created between adjacent interchanges, serving to mitigate the effects of closely-spaced entrance and exit ramps
    - PTSU commences at high-volume ramp locations where the merging of on-ramp traffic onto the freeway creates bottlenecks
    - PTSU starts between interchanges to effectively create part-time auxiliary lanes
    - Other_______________________________________

20. How does your agency **terminate** part-time shoulder use (PTSU)? (Check all that apply.)
    - PTSU is ended along basic freeway segments through the strategic placement of visible signage and clear pavement markings
    - PTSU is ended on exit ramps to avoid unexpected lane changes
    - PTSU is ended at exit ramps, where a significant portion of traffic is exiting (e.g., exit ramp for system interchanges)
    - PTSU ends at the nearest downstream interchange to effectively create part-time auxiliary lanes
    - PTSU is carried onto one of the forks at major forks on the freeway
    - Other____

21. What type(s) of traffic control device(s) does your agency utilize to alert road users that they are **transitioning into** the PTSU segments? (Check all that apply.)
    - Regulatory signs (e.g., "Shoulder open for travel in 1/2 miles", "Part-Time Shoulder use begins ahead")
    - Pavement markings (e.g., transition skip lines, arrows, and other markings) indicating PTSU is about to start
    - Warning signs (e.g., "Traffic using shoulder ahead")
    - Other (Please list.) ____________________________

22. What type(s) of traffic control device(s) does your agency utilize to notify road users **at the start** of the PTSU segments? (Check all that apply.)
    - Regulatory signs (e.g., "Shoulder now open to travel", "Do not drive on shoulder", "Shoulder use permitted on green arrow")

- Pavement markings (e.g., "Bus only" markings, skip lines, or other markings) at the start of PTSU segments
- Warning signs (e.g., "Traffic using shoulder")
- Lane-use control signals (e.g., red X display, green arrow display)
- Other (Please list.) __________________

23. What type(s) of traffic control device(s) does your agency utilize to alert road users that they are **transitioning out of** the PTSU segments? (Check all that apply.)
    - Regulatory signs (e.g., "End travel on shoulder in 1/2 mile", "Travel on shoulder ends in 1/2 mile")
    - Pavement markings (e.g., transition skip lines, arrows, or other markings) indicating PTSU is about to end
    - Warning signs (e.g., "Watch out for traffic exiting shoulder")
    - Lane-use control signals (e.g., yellow X display)
    - Other (Please list.) ________________________

24. What type(s) of traffic control device(s) does your agency utilize to notify drivers **at the end** of the PTSU segment? (Check all that apply.)
    - Regulatory signs (e.g., "End travel on shoulder", "Do not drive on shoulder")
    - Pavement markings (e.g., transition skip lines, arrows, or other markings) at the end of the PTSU segment
    - Lane-use control signals (e.g., red X display)
    - Other (Please list.) ________________________

25. Does your agency consider emergency services, such as state or local police or fire or emergency services, when selecting new PTSU locations?
    - Yes
    - No

26. Is real-time monitoring and incident response in place for your PTSU installations?
    - Yes, for all PTSU sites
    - Yes, for some PTSU sites
    - No

27. How are traffic incidents on the shoulder handled during PTSU operation? (Check all that apply.)
    - PTSU is closed during traffic incidents
    - Emergency turnouts are provided
    - A dedicated fleet of highway patrol, emergency patrol, or incident response vehicles is provided for prompt resolution of incidents
    - Incidents are handled by law enforcement and emergency medical services (EMS)
    - CCTV cameras, communication equipment, or other ITS devices, such as automatic incident detection, are installed along the corridor to monitor for traffic incidents in real-time

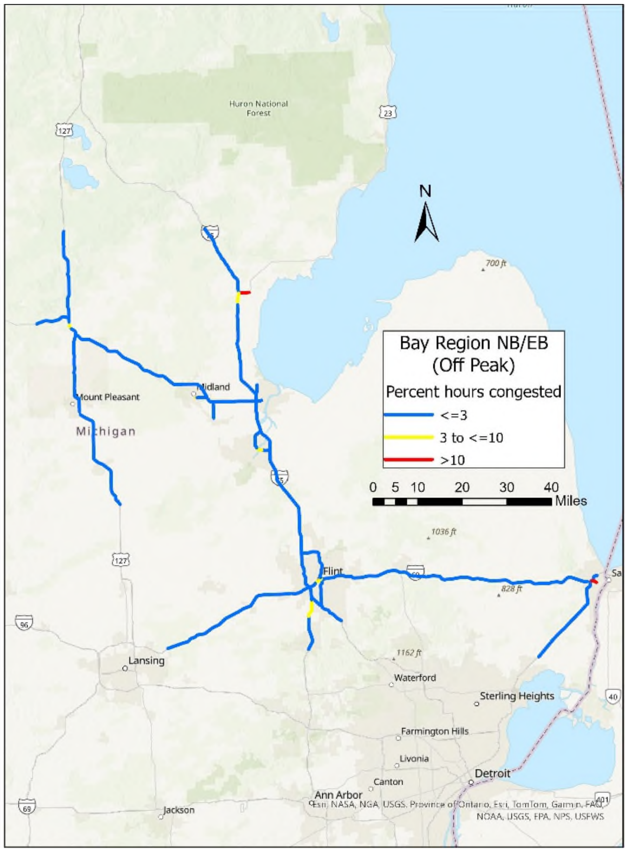
- Additional static warning signage is provided at locations that experience a high number of traffic incidents
- Additional dynamic warning signage is provided at locations that experience a high number of traffic incidents
- Other ____________________

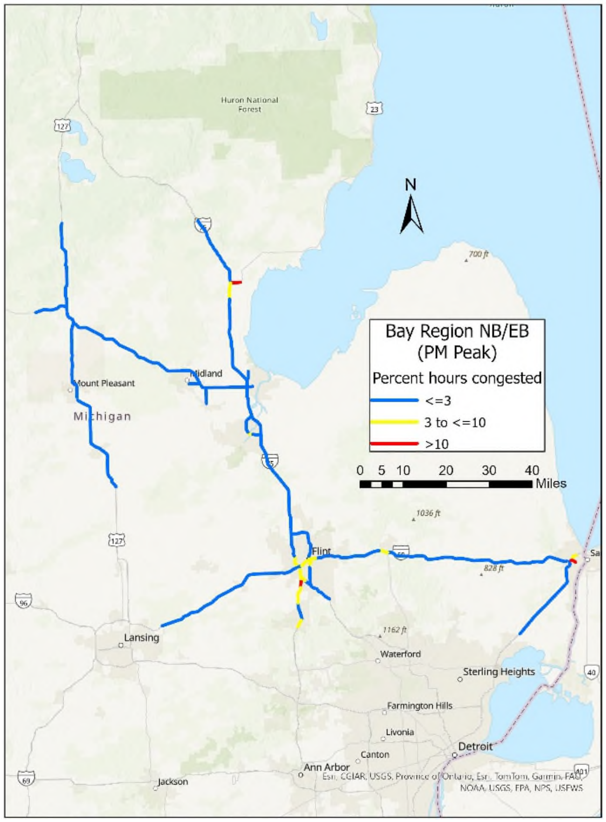
28. How does your agency consider inclement weather as it relates to PTSU? (Check all that apply.)
    - PTSU is closed during bad weather
    - The shoulder is plowed during winter weather
    - Areas with a history of crashes during weather incidents are avoided for PTSU locations
    - Road weather information sensors are used to determine the condition of the pavement before opening the PTSU
    - Additional static warning signage is provided at locations that are prone to weather-related traffic incidents
    - Additional dynamic warning signage is provided at locations that are prone to weather-related traffic incidents
    - Weather is only considered for PTSU monitoring and operations
    - Other ________________

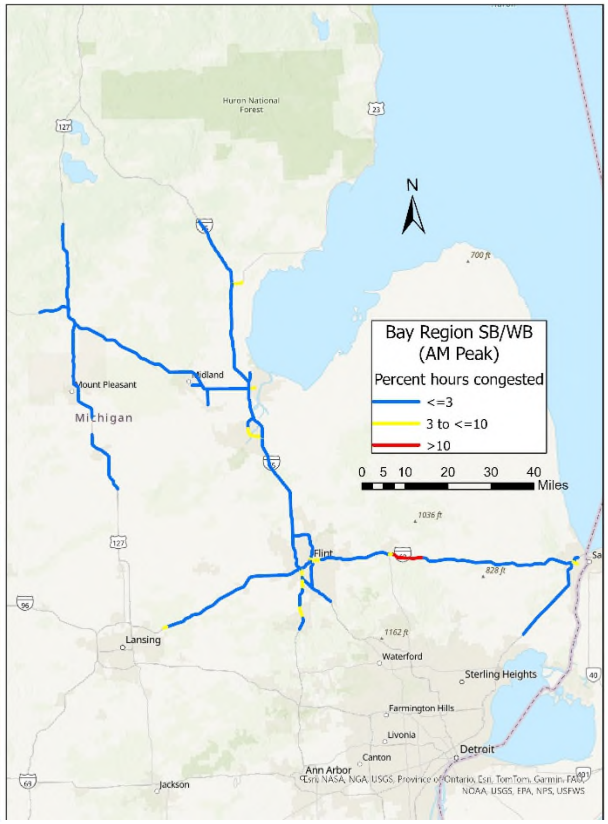
End of Survey

APPENDIX-B

This appendix presents the speed trends for all freeways in the state of Michigan by MDOT Region and time of day. The maps are presented for 5 MDOT regions, namely, Bay, Grand, Metro, Southwest, and University.

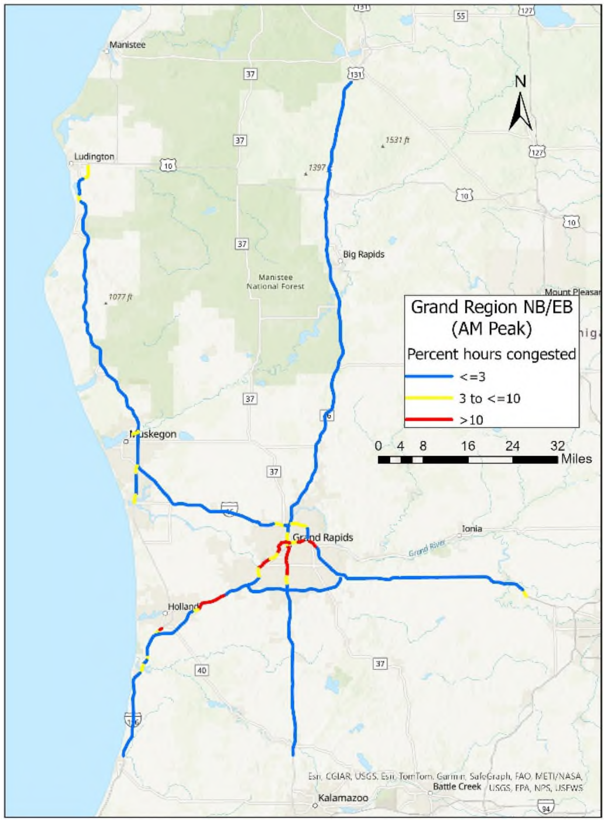


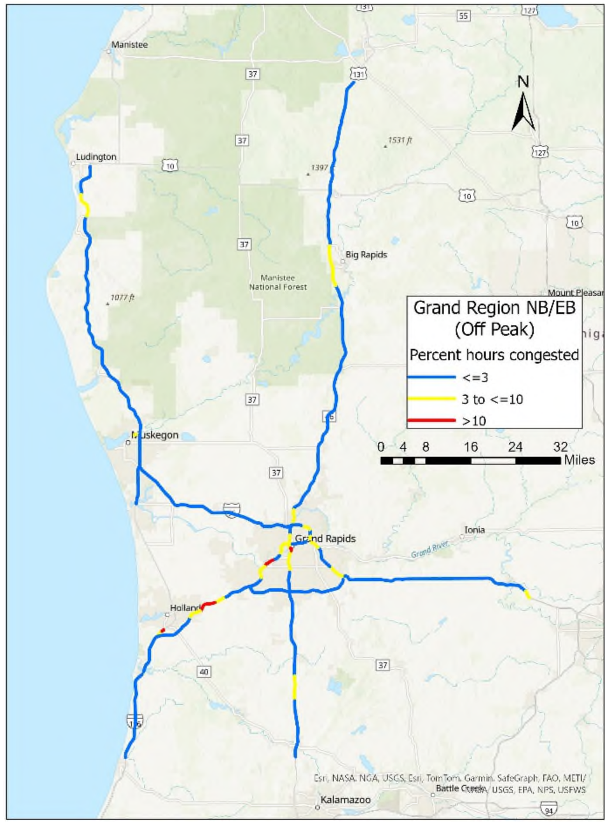

Bay Region NB/EB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 5 10 20 30 40
Miles
N
Huron National Forest
Midland
Mount Pleasant
Michigan
Flint
Lansing
Waterford
Sterling Heights
Farmington Hills
Livonia
Detroit
Canton
Ann Arbor
Jackson
Esri, CGIAR, USGS, Province of Ontario, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, NPS, USFWS

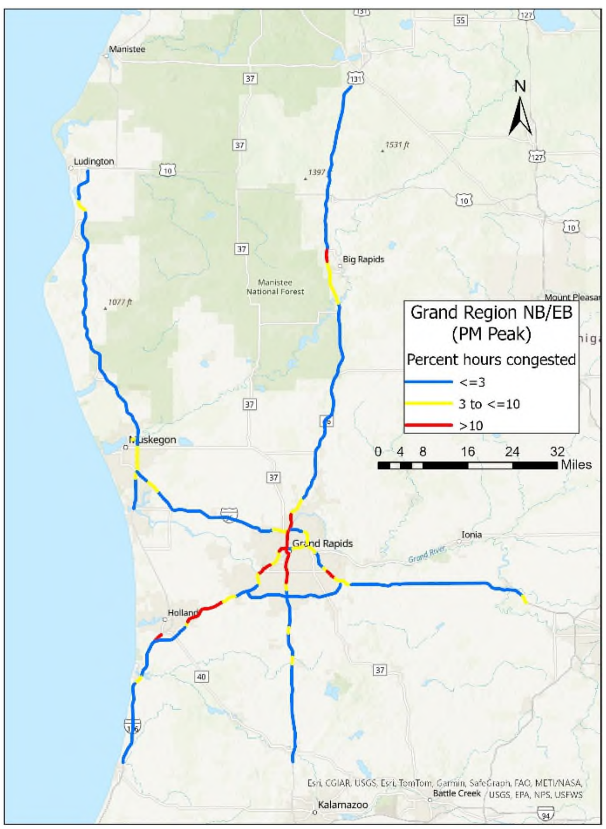

Bay Region SB/WB
(AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 5 10 20 30 40
Miles
N
Huron National Forest
Midland
Mount Pleasant
Michigan
Flint
Lansing
Waterford
Sterling Heights
Farmington Hills
Livonia
Detroit
Canton
Ann Arbor
Jackson
Esri, NASA, NGA, USGS, Province of Ontario, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, NPS, USFWS

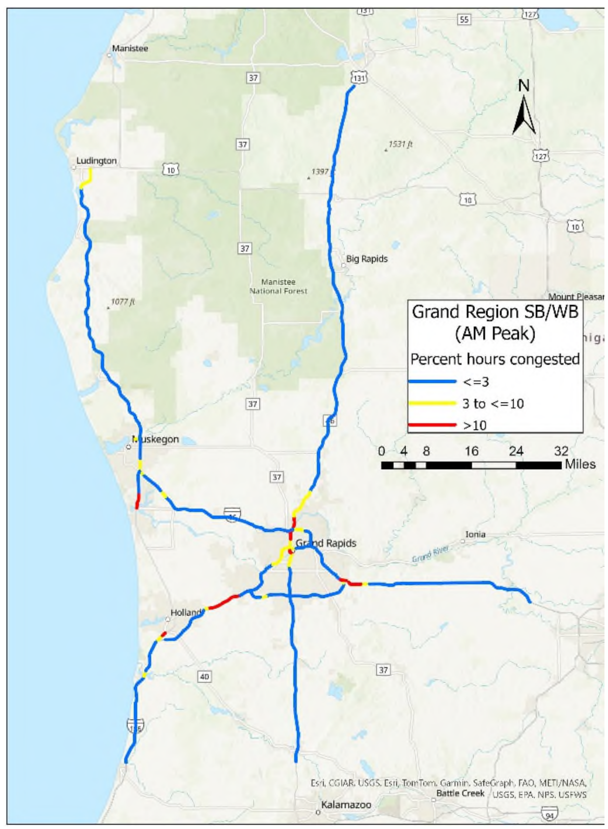

Bay Region SB/WB
(Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 5 10 20 30 40
Miles
N
Huron National Forest
Midland
Mount Pleasant
Michigan
Flint
Lansing
Waterford
Sterling Heights
Farmington Hills
Livonia
Detroit
Canton
Ann Arbor
Jackson
Esri, NASA, NGA, USGS, Province of Ontario, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, NPS, USFWS

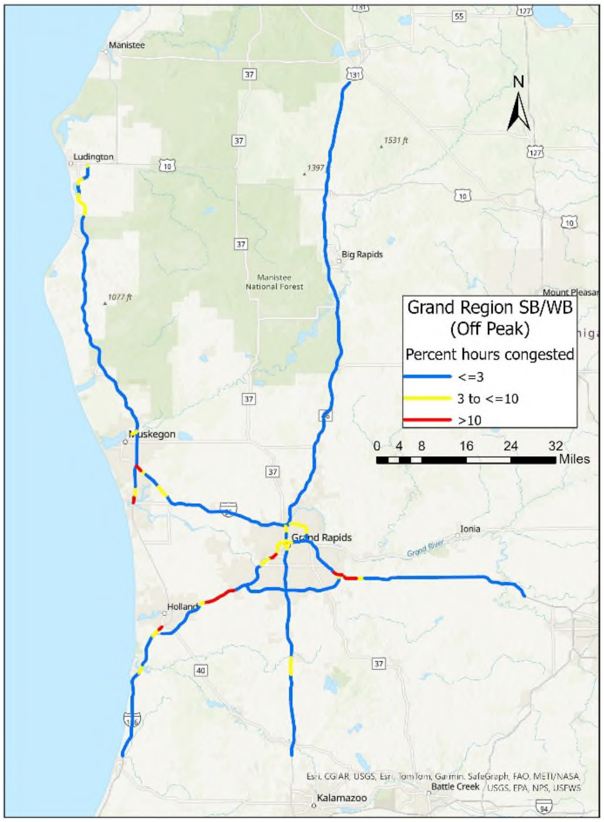

Bay Region SB/WB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 5 10 20 30 40
Miles
N
Huron National Forest
Midland
Mount Pleasant
Michigan
Flint
Lansing
Waterford
Sterling Heights
Farmington Hills
Livonia
Detroit
Canton
Ann Arbor
Jackson
Esri, CGIAR, USGS, Province of Ontario, Esri, TomTom, Garmin, FAO, NOAA, USGS, EPA, NPS, USFWS

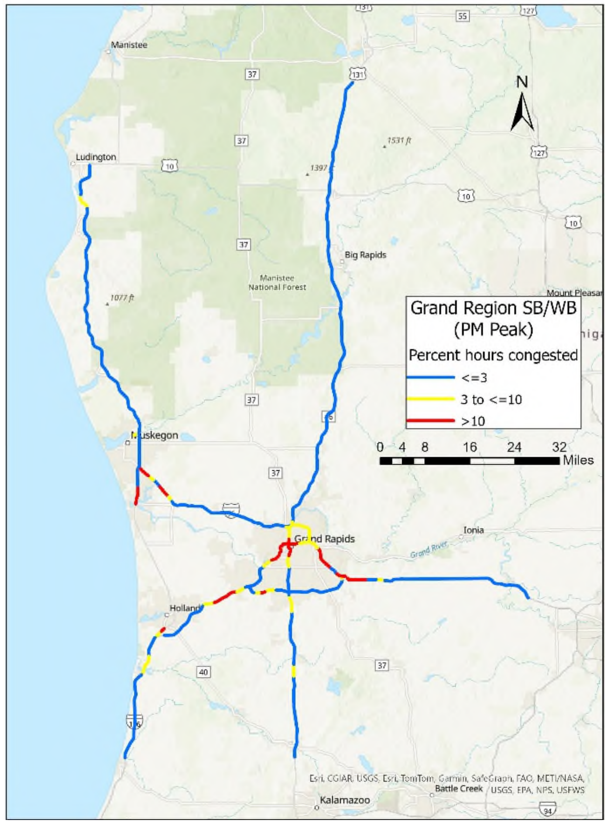

Grand Region NB/EB
(AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32 Miles
Manistee
Ludington
Big Rapids
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Manistee National Forest
Mount Pleasant
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

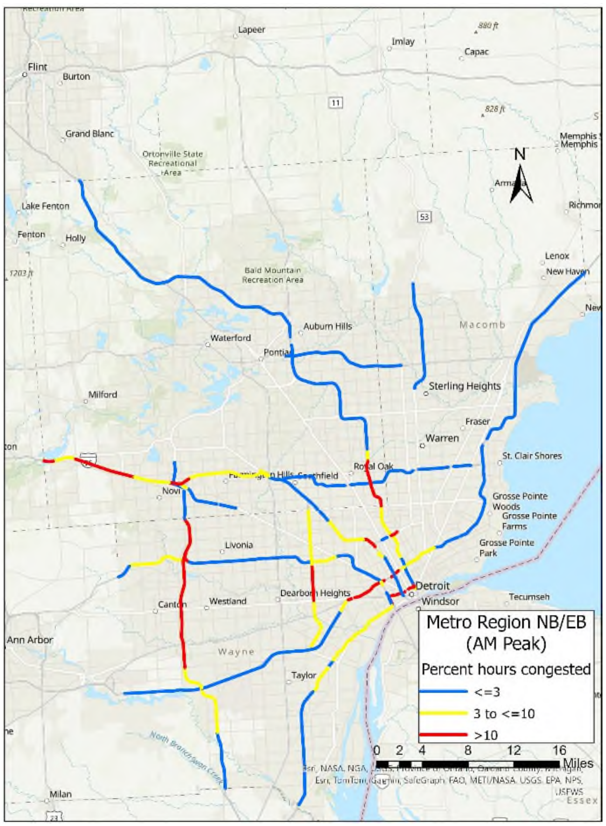

Grand Region NB/EB
(Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32 Miles
Manistee
Ludington
Big Rapids
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Manistee National Forest
Mount Pleasant
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

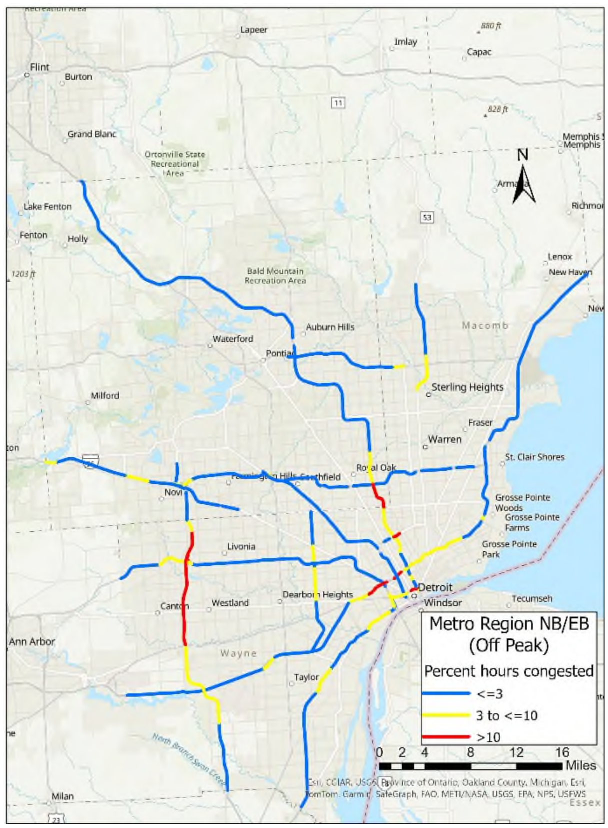

Grand Region NB/EB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32 Miles
Manistee
Ludington
Big Rapids
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Manistee National Forest
Mount Pleasant
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

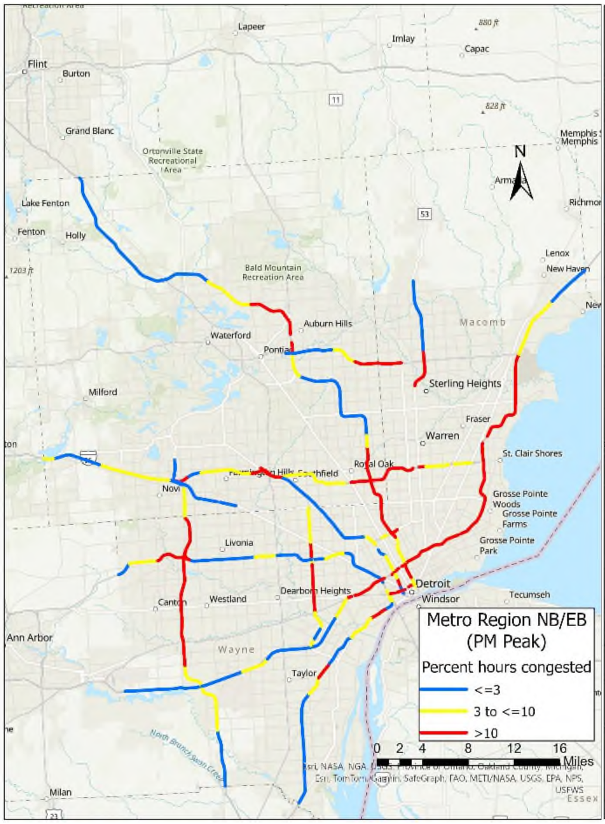

Grand Region SB/WB
(AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32 Miles
Manistee
Ludington
Big Rapids
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Manistee National Forest
Mount Pleasant
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

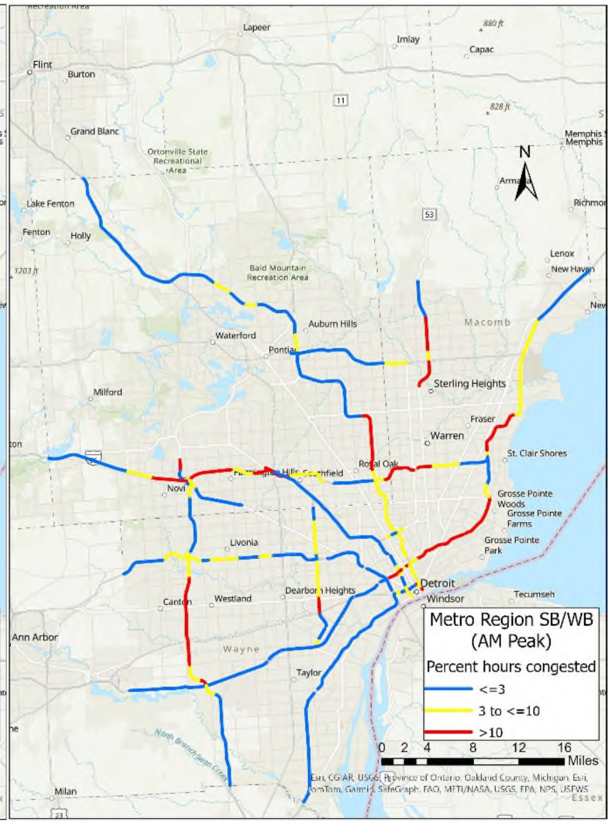

Grand Region SB/WB
(Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32
Miles
N
Manistee
Ludington
Big Rapids
Manistee National Forest
Mount Pleasant
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS


Grand Region SB/WB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4 8 16 24 32
Miles
N
Manistee
Ludington
Big Rapids
Manistee National Forest
Mount Pleasant
Muskegon
Grand Rapids
Ionia
Holland
Kalamazoo
Battle Creek
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

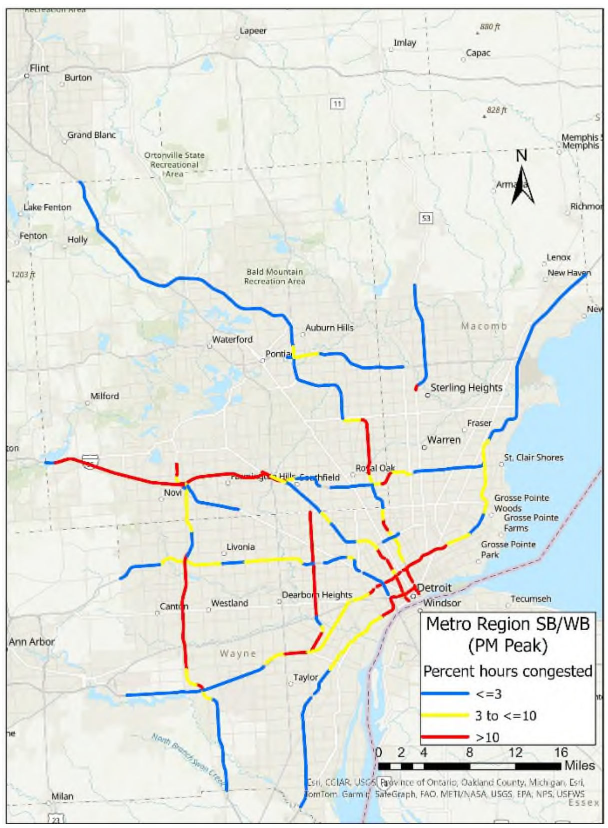

Metro Region NB/EB
(AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles
N
Lapeer
Imlay
Capac
Flint
Burton
Grand Blanc
Ortonville State Recreational Area
Memphis
Lake Fenton
Fenton
Holly
Lenox
New Haven
Bald Mountain Recreation Area
Auburn Hills
Macomb
Waterford
Pontiac
Sterling Heights
Milford
Fraser
Warren
St. Clair Shores
Royal Oak
Novi
Grosse Pointe Woods
Grosse Pointe Farms
Grosse Pointe Park
Livonia
Detroit
Windsor
Dearborn Heights
Tecumseh
Canton
Westland
Ann Arbor
Wayne
Taylor
Milan
Essex

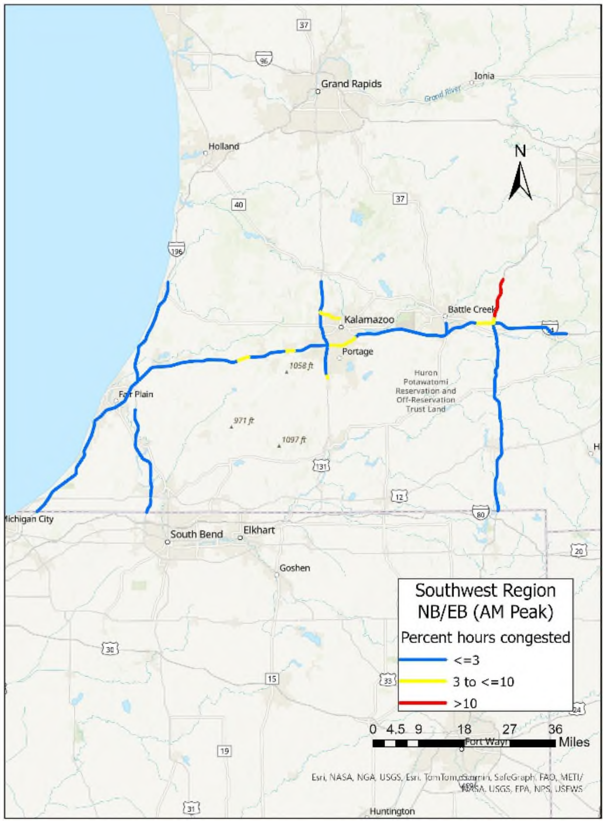

Metro Region NB/EB
(Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles
N
Lapeer
Imlay
Capac
Flint
Burton
Grand Blanc
Ortonville State Recreational Area
Memphis
Lake Fenton
Fenton
Holly
Lenox
New Haven
Bald Mountain Recreation Area
Auburn Hills
Macomb
Waterford
Pontiac
Sterling Heights
Milford
Fraser
Warren
St. Clair Shores
Royal Oak
Novi
Grosse Pointe Woods
Grosse Pointe Farms
Grosse Pointe Park
Livonia
Detroit
Windsor
Dearborn Heights
Tecumseh
Canton
Westland
Ann Arbor
Wayne
Taylor
Milan
Essex
Esri, CGIAR, USGS, Province of Ontario, Oakland County, Michigan, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

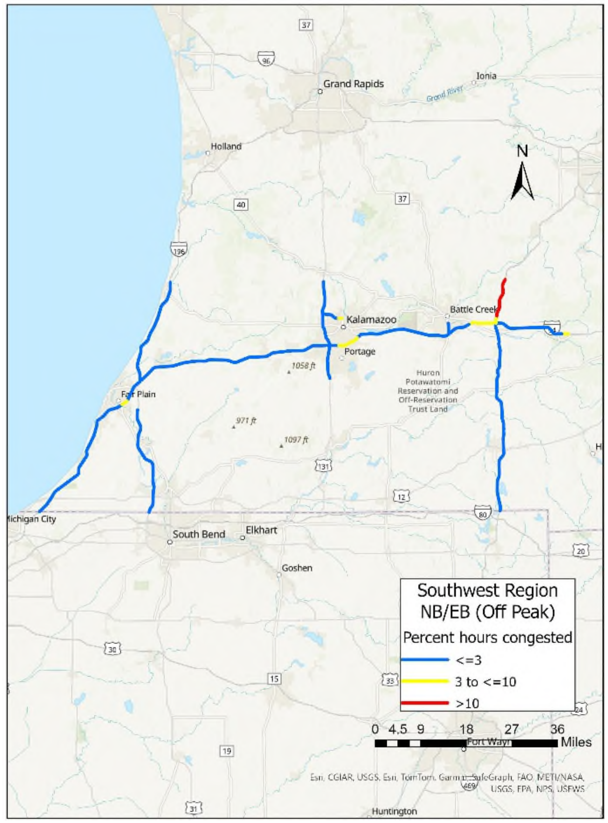

Metro Region NB/EB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles

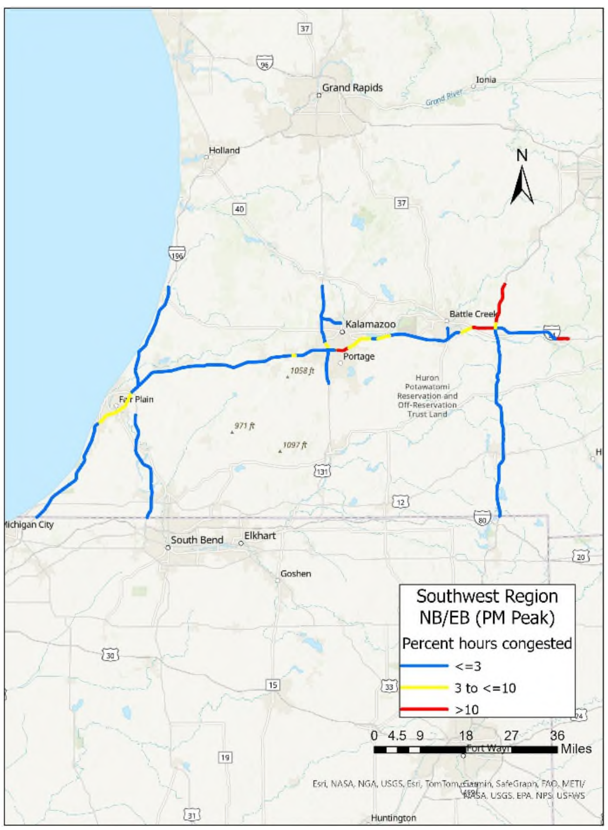

Metro Region SB/WB
(AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles

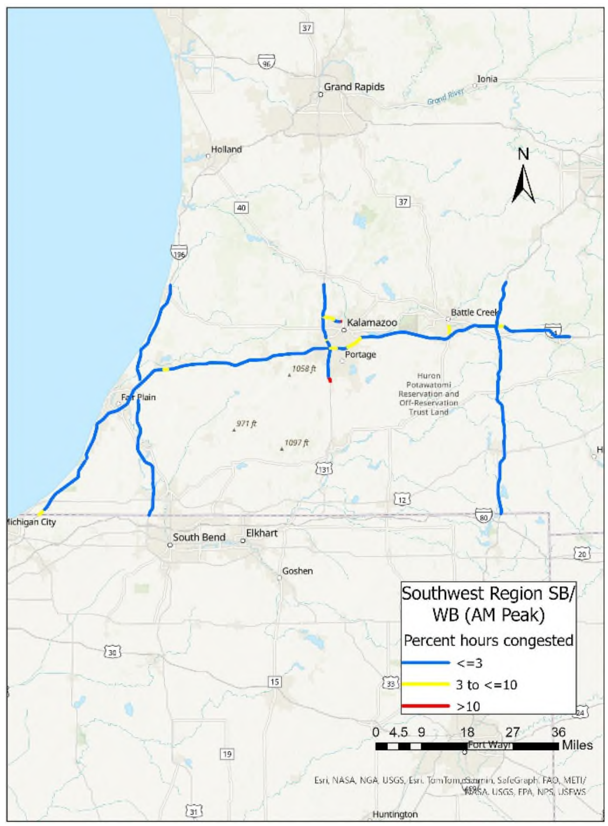

Metro Region SB/WB
(Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles

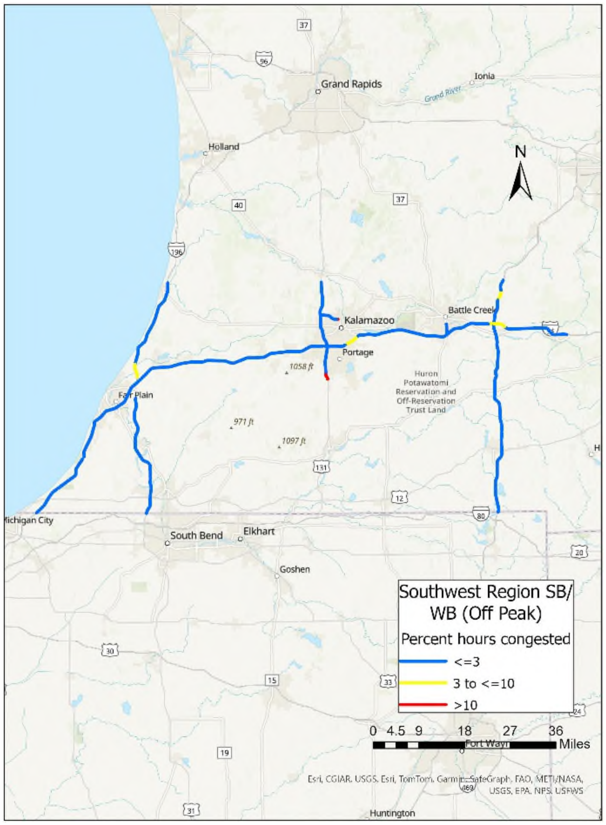

Metro Region SB/WB
(PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 2 4 8 12 16
Miles

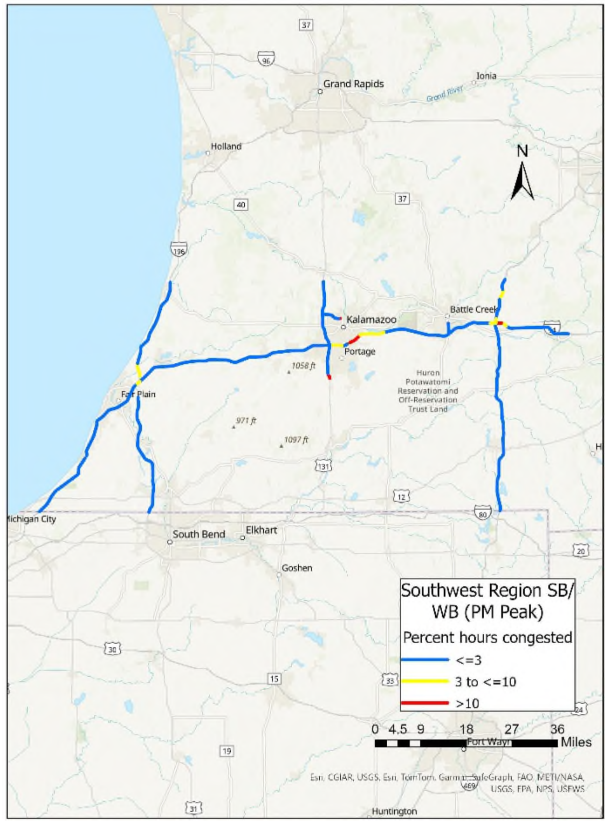

Southwest Region NB/EB (AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Holland
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart
Goshen
Huntington
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

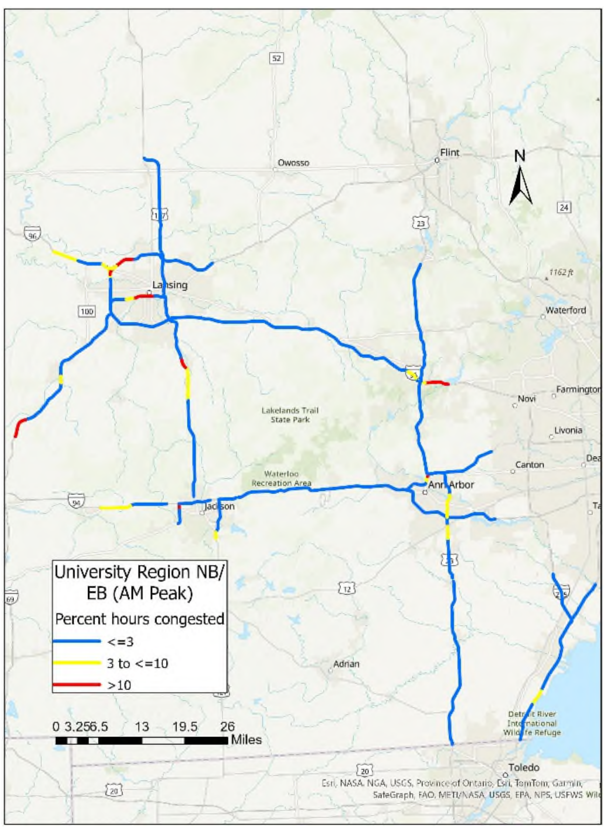

Southwest Region NB/EB (Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Holland
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart
Goshen
Huntington
Esri, CGIAR, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

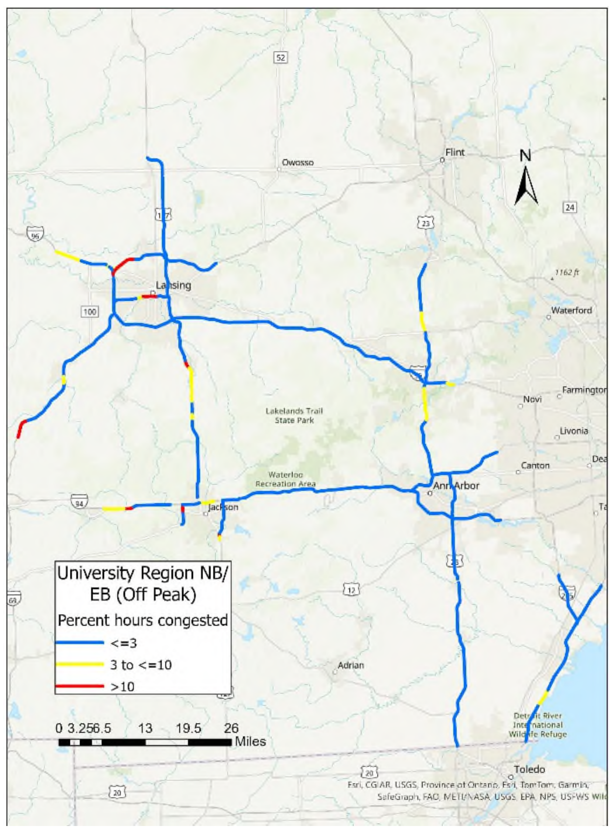

Southwest Region NB/EB (PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Holland
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart
Goshen
Huntington
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

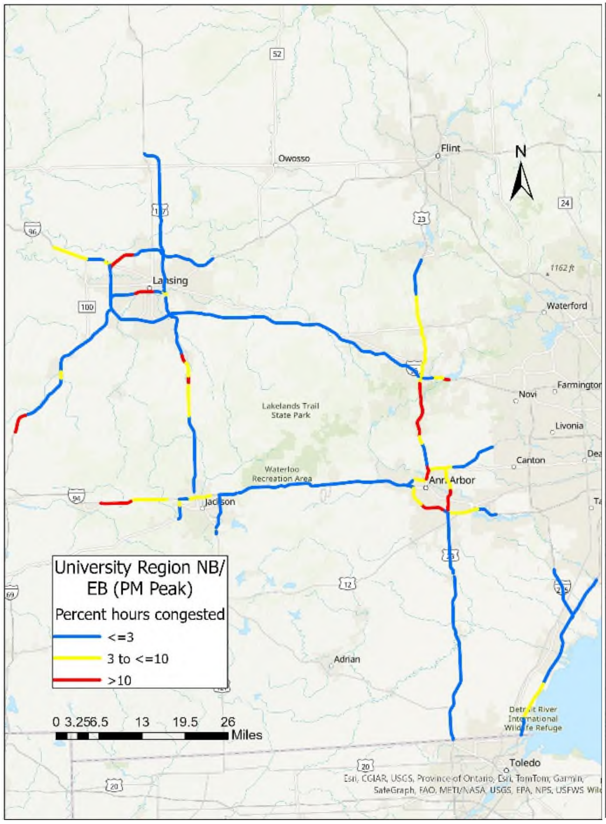

Southwest Region SB/WB (AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Holland
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart
Goshen
Huntington
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

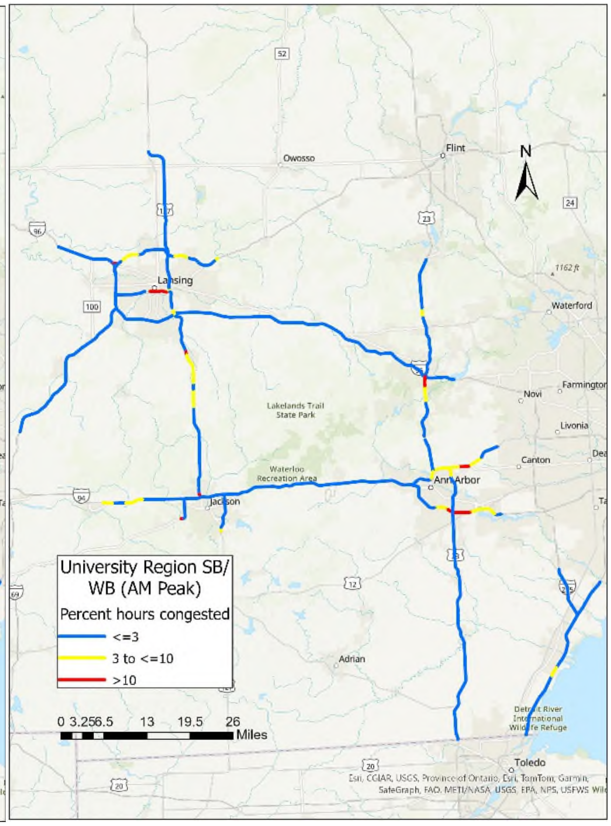

Southwest Region SB/ WB (Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart

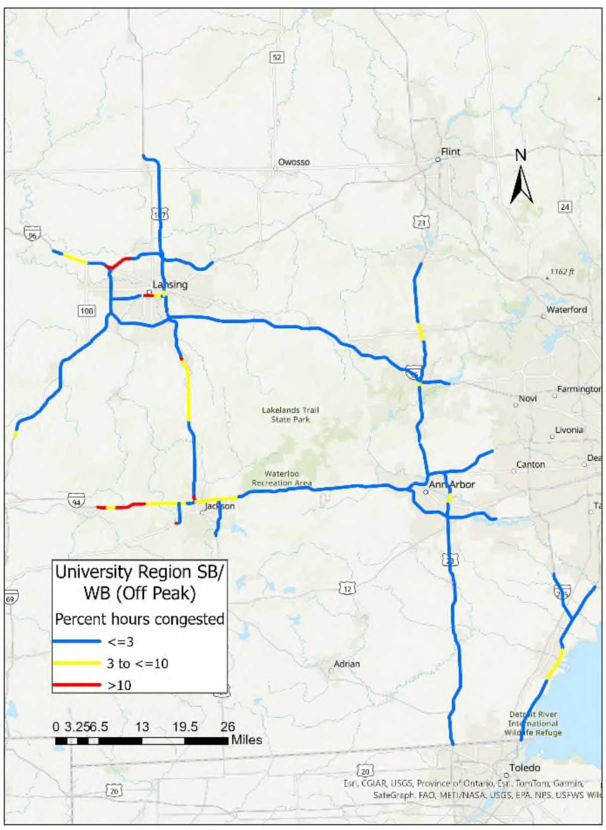

Southwest Region SB/ WB (PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 4.5 9 18 27 36 Miles
Grand Rapids
Kalamazoo
Battle Creek
Portage
South Bend
Elkhart

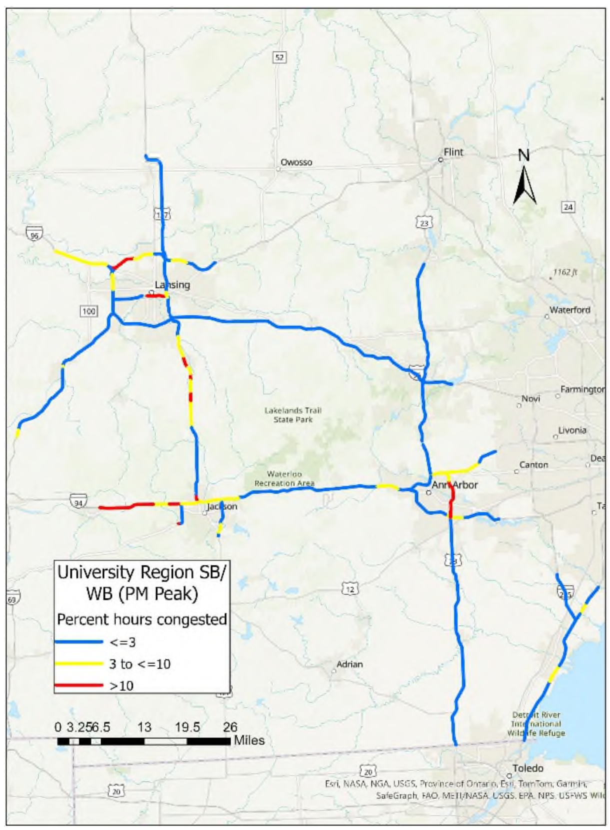

University Region NB/ EB (AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Flint
Lansing
Ann Arbor
Jackson
Toledo


University Region NB/ EB (Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Flint
Lansing
Ann Arbor
Jackson
Toledo


University Region NB/ EB (PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Owosso
Flint
Lansing
Waterford
Novi
Farmington
Livonia
Canton
Ann Arbor
Jackson
Lakelands Trail State Park
Waterloo Recreation Area
Adrian
Toledo
Detroit River International Wildlife Refuge
Esri, CGIAR, USGS, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

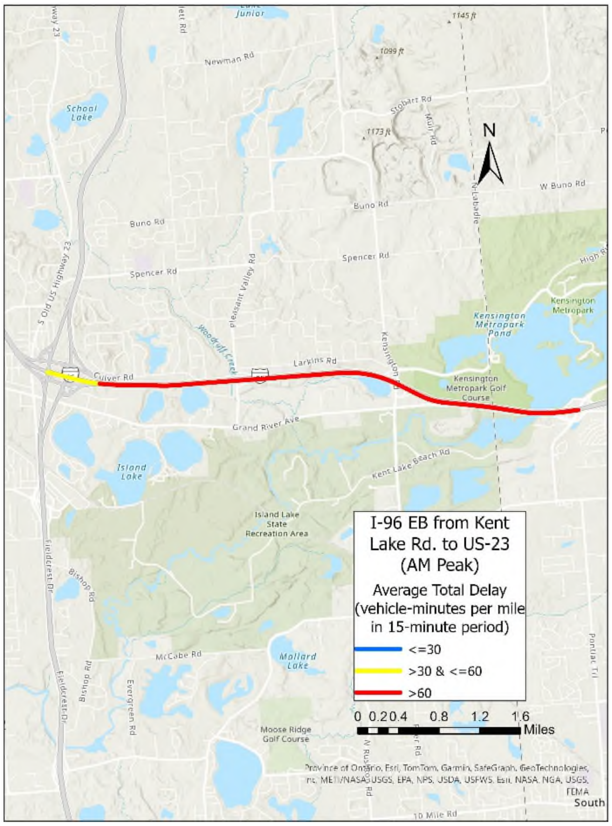

University Region SB/ WB (AM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Owosso
Flint
Lansing
Waterford
Novi
Farmington
Livonia
Canton
Ann Arbor
Jackson
Lakelands Trail State Park
Waterloo Recreation Area
Adrian
Toledo
Detroit River International Wildlife Refuge
Esri, CGIAR, USGS, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

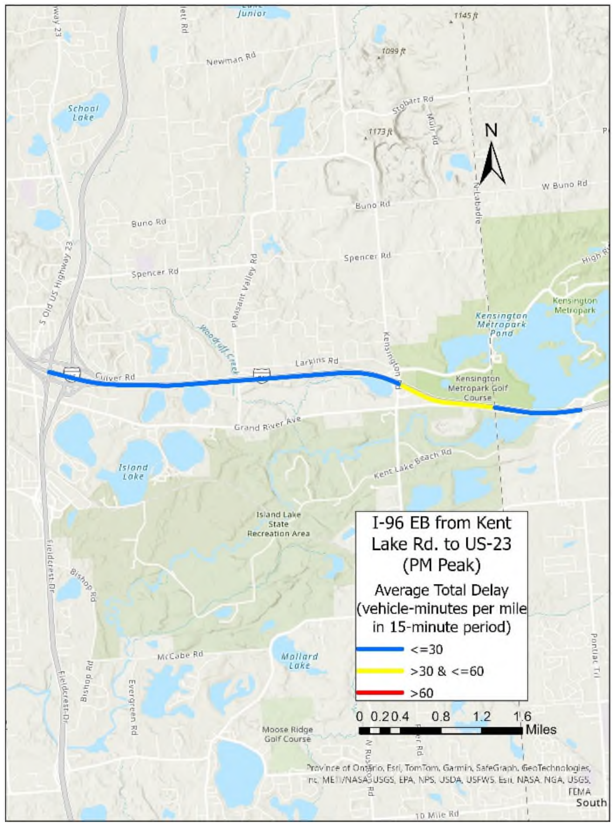

University Region SB/ WB (Off Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Owosso
Flint
Lansing
Waterford
Novi
Farmington
Livonia
Canton
Ann Arbor
Jackson
Lakelands Trail State Park
Waterloo Recreation Area
Adrian
Toledo
Detroit River International Wildlife Refuge
Esri, CGIAR, USGS, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

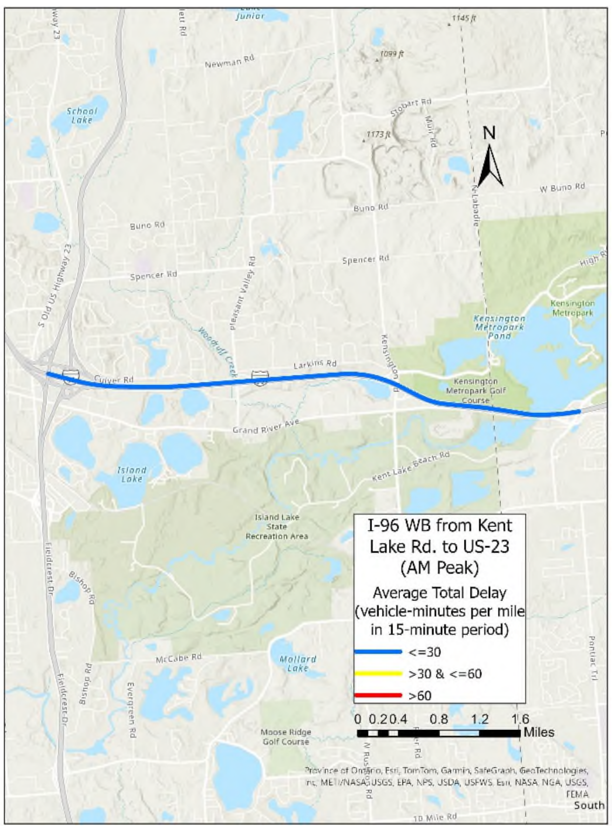

University Region SB/ WB (PM Peak)
Percent hours congested
<=3
3 to <=10
>10
0 3.25 6.5 13 19.5 26 Miles
Owosso
Flint
Lansing
Waterford
Novi
Farmington
Livonia
Canton
Ann Arbor
Jackson
Lakelands Trail State Park
Waterloo Recreation Area
Adrian
Toledo
Detroit River International Wildlife Refuge
Esri, NASA, NGA, USGS, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

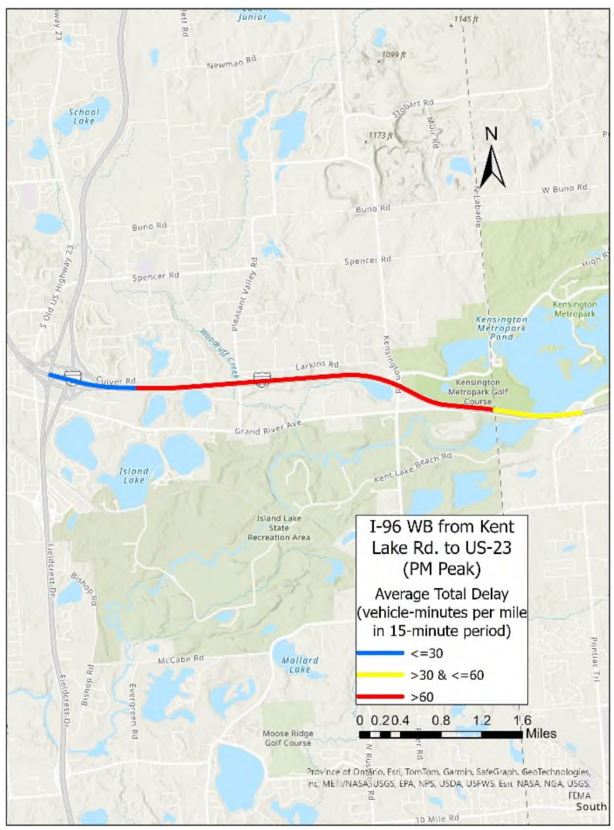
APPENDIX-C

This appendix presents the delay trends for the candidate corridors by direction of travel and peak period.

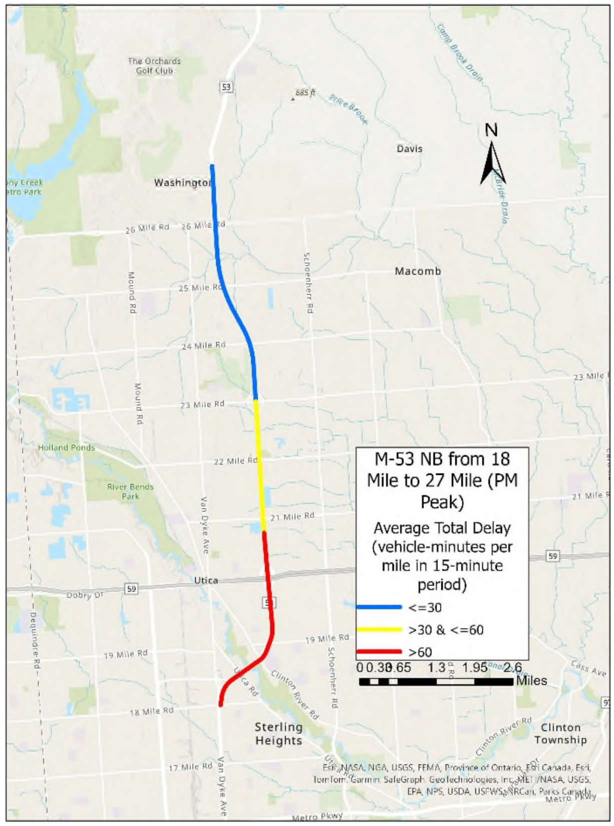

I-96 EB from Kent Lake Rd. to US-23 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6 Miles

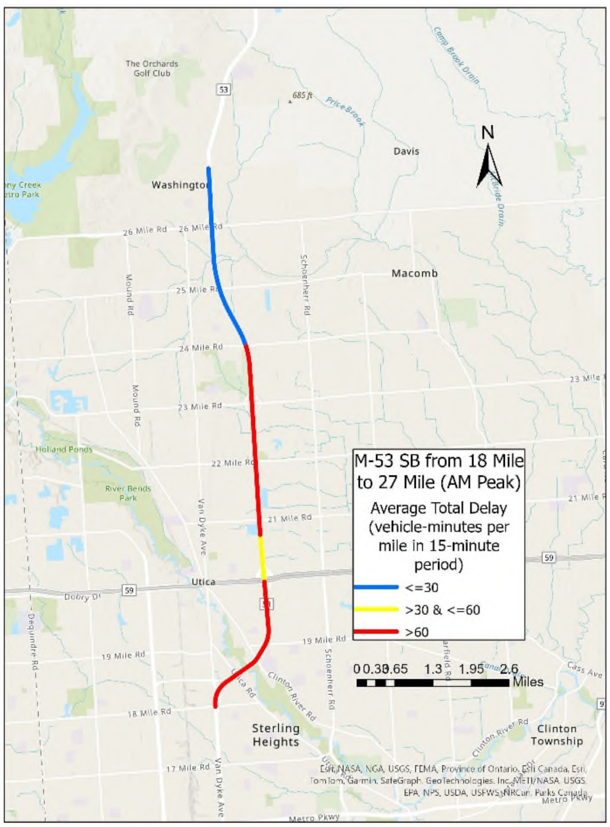

I-96 EB from Kent Lake Rd. to US-23 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6 Miles

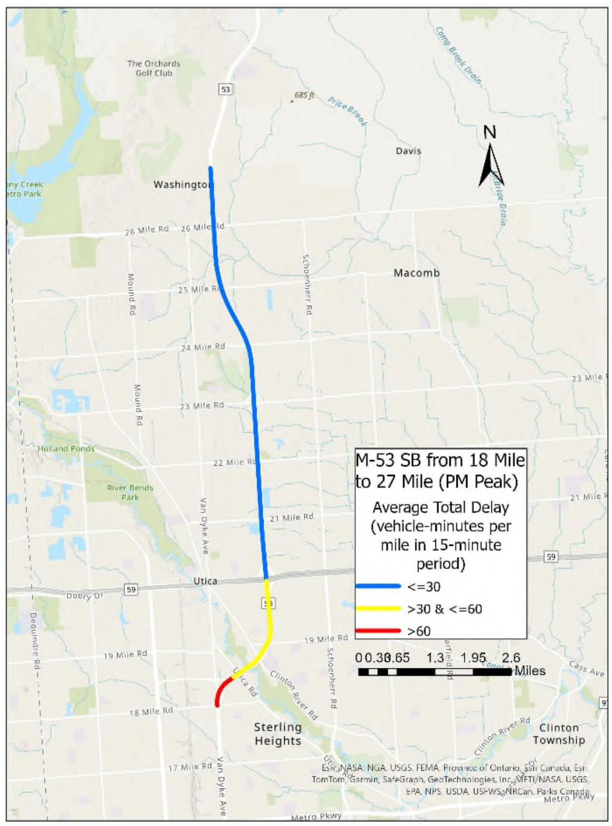

I-96 WB from Kent Lake Rd. to US-23 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6 Miles

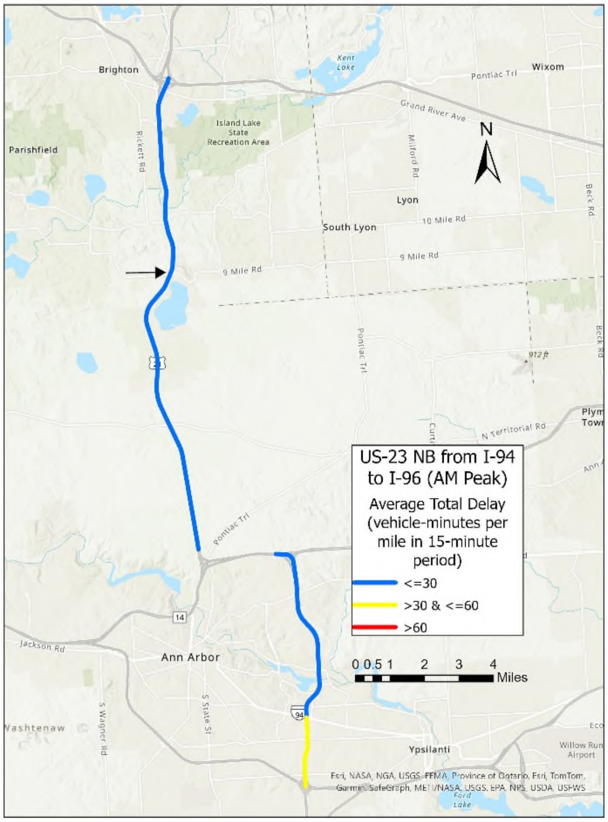

I-96 WB from Kent Lake Rd. to US-23 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6 Miles

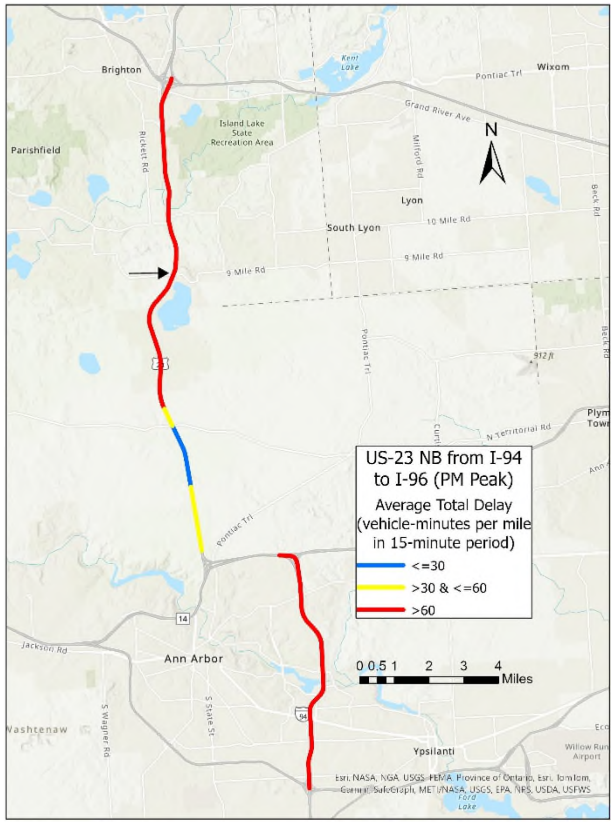

M-53 NB from 18 Mile to 27 Mile (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.33 0.65 1.3 1.95 2.6
Miles
N
Washington
Davis
Macomb
Utica
Sterling Heights
Clinton Township
26 Mile Rd
25 Mile Rd
24 Mile Rd
23 Mile Rd
22 Mile Rd
21 Mile Rd
19 Mile Rd
18 Mile Rd
17 Mile Rd
Van Dyke Ave
Mound Rd
Schoenherr Rd
Metro Pkwy

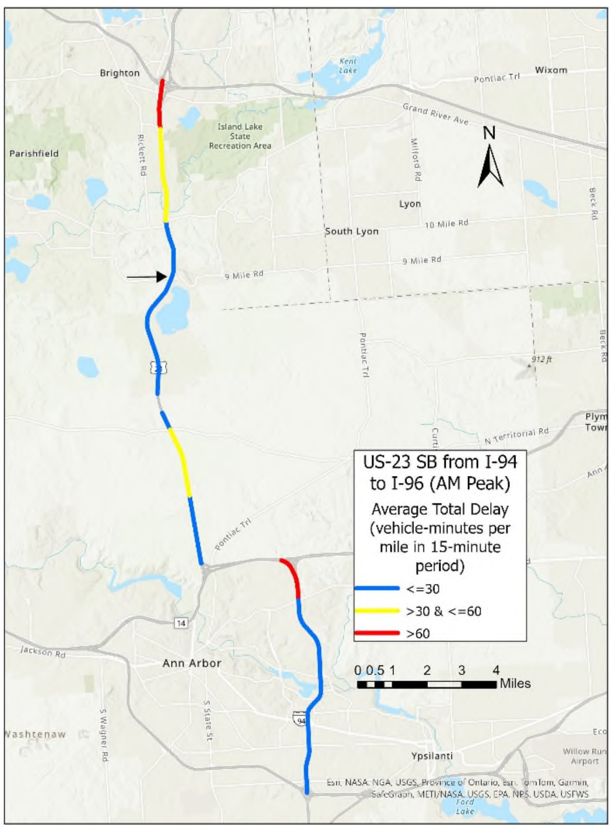

M-53 NB from 18 Mile to 27 Mile (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.33 0.65 1.3 1.95 2.6
Miles
N
Washington
Davis
Macomb
Utica
Sterling Heights
Clinton Township

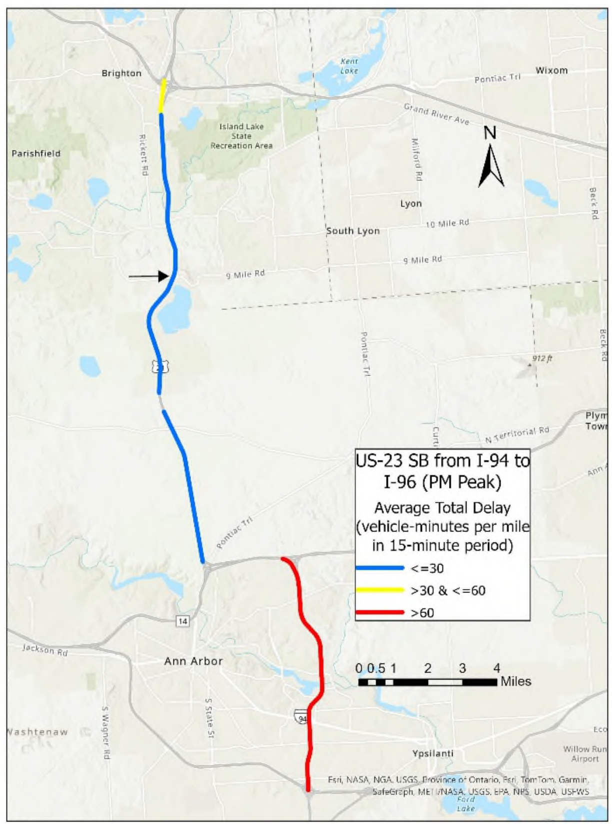

M-53 SB from 18 Mile to 27 Mile (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.33 0.65 1.3 1.95 2.6
Miles
N
Washington
Davis
Macomb
Utica
Sterling Heights
Clinton Township

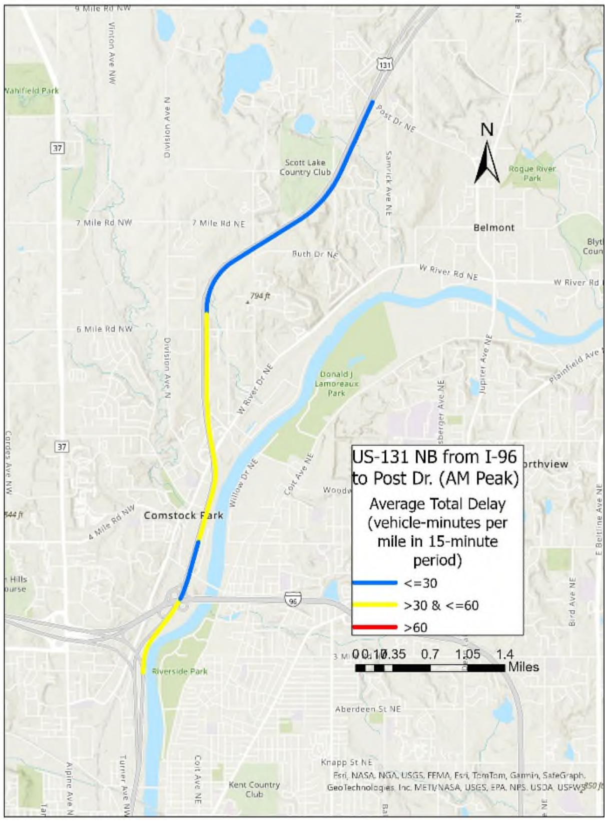

M-53 SB from 18 Mile to 27 Mile (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.33 0.65 1.3 1.95 2.6
Miles
N
Washington
Davis
Macomb
Utica
Sterling Heights
Clinton Township

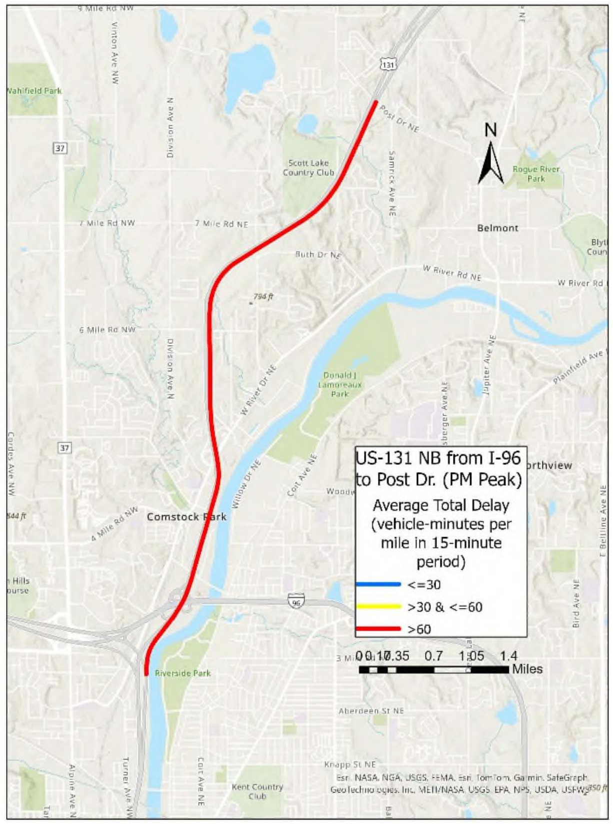

US-23 NB from I-94 to I-96 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Brighton
Parishfield
Ann Arbor
South Lyon
Lyon
Wixom
Ypsilanti

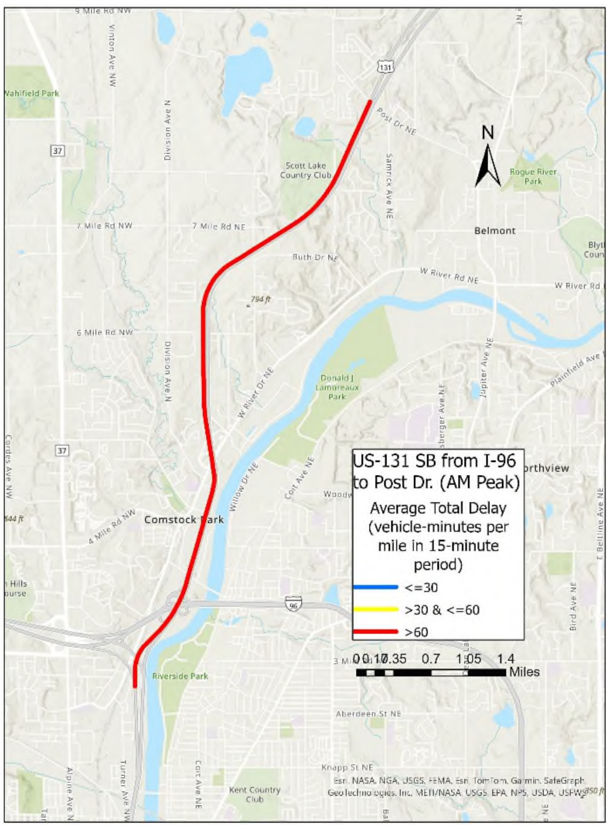

US-23 NB from I-94 to I-96 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Brighton
Parishfield
Ann Arbor
South Lyon
Lyon
Wixom
Ypsilanti

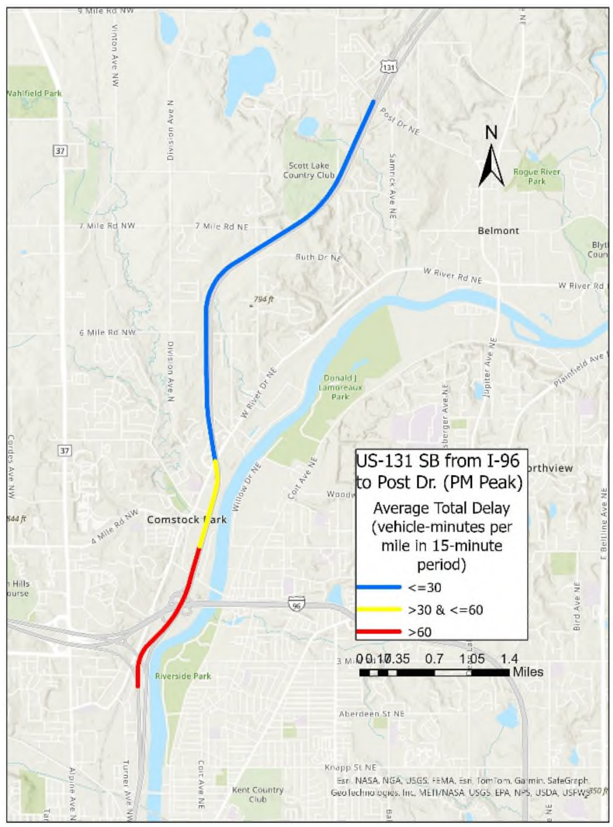

US-23 SB from I-94 to I-96 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Brighton
Parishfield
Ann Arbor
South Lyon
Lyon
Wixom
Ypsilanti

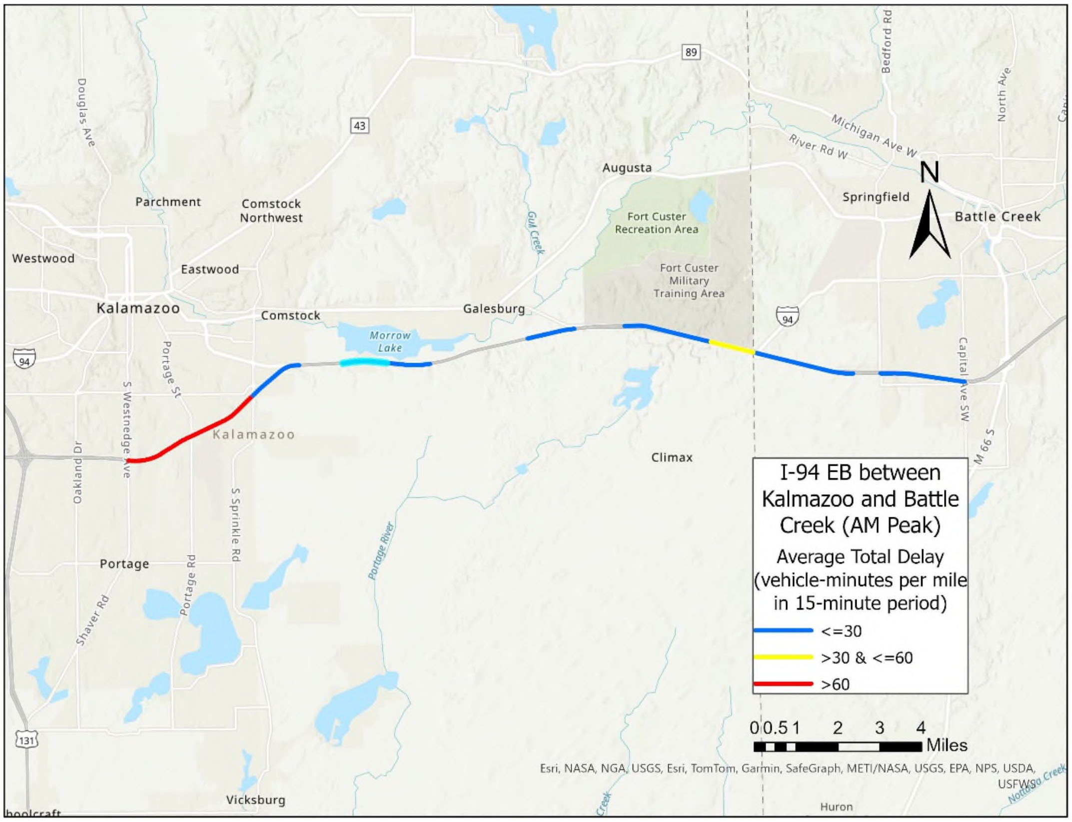

US-23 SB from I-94 to I-96 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Brighton
Parishfield
Ann Arbor
South Lyon
Lyon
Wixom
Ypsilanti

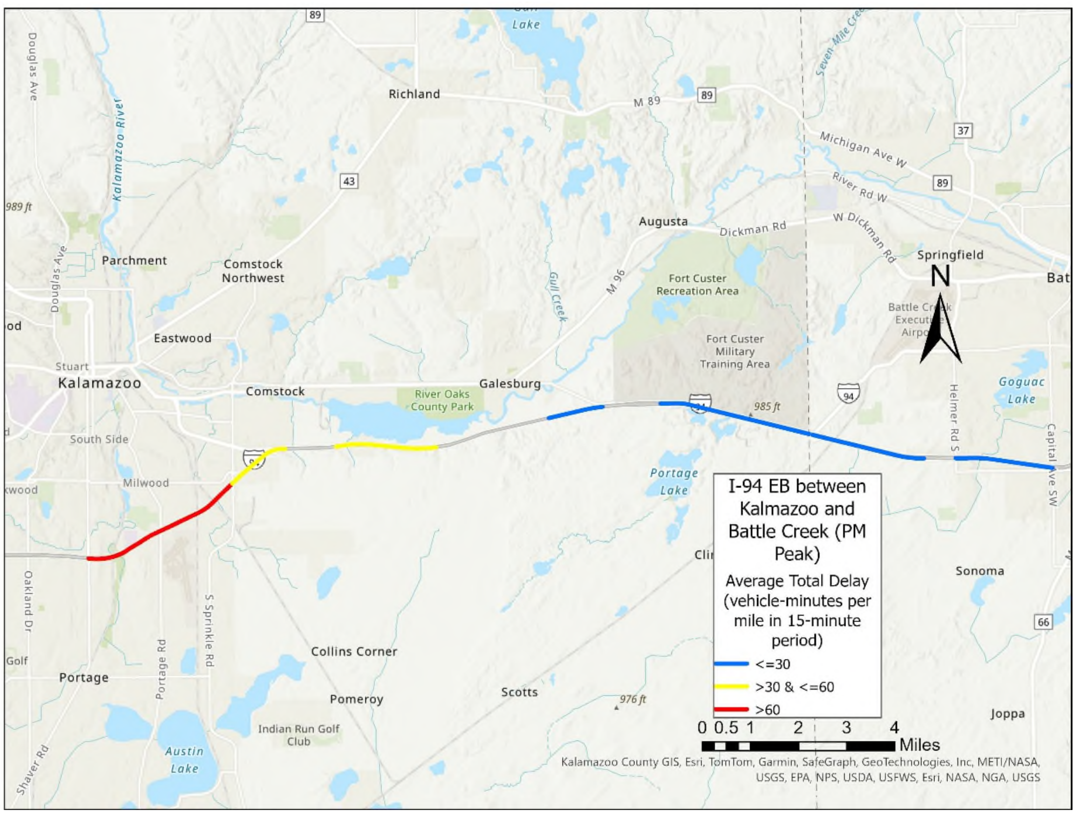

US-131 NB from I-96 to Post Dr. (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
Miles
N
Comstock Park
Belmont
Riverside Park
Scott Lake Country Club
Rogue River Park
Donald J Lamoreaux Park
Kent Country Club
Post Dr NE
7 Mile Rd NW
7 Mile Rd NE
6 Mile Rd NW
W River Rd NE
Aberdeen St NE
Knapp St NE

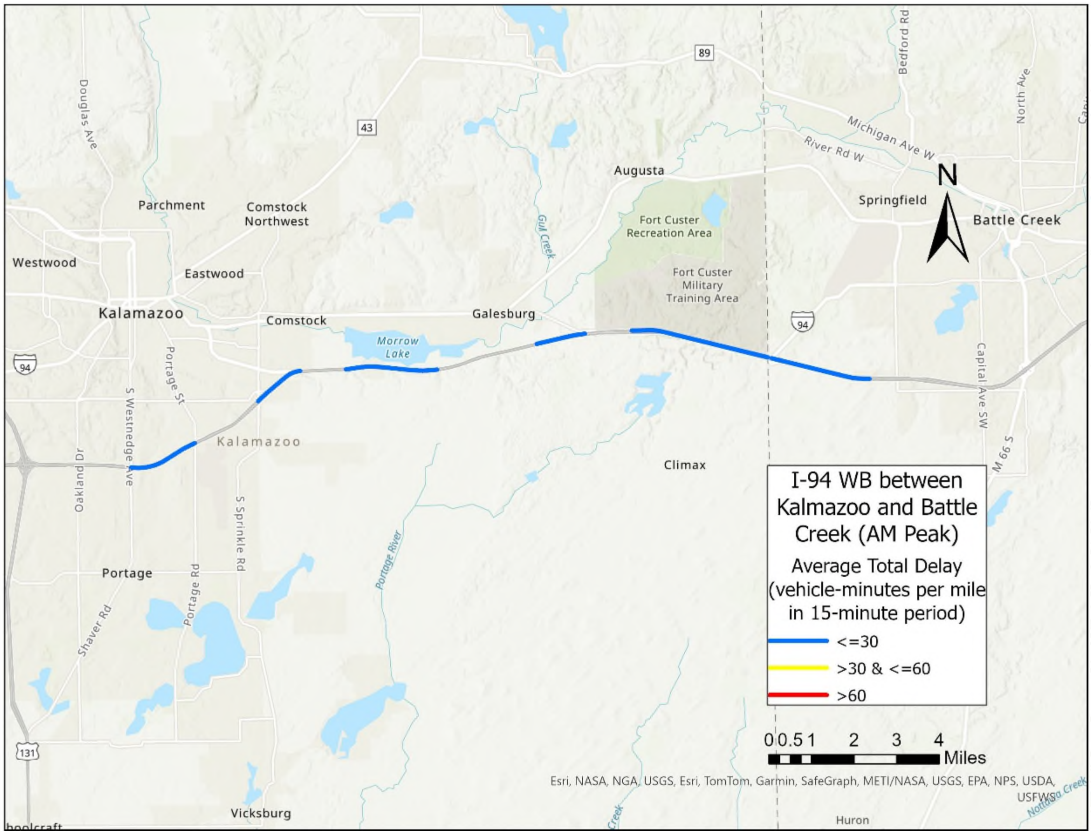

US-131 NB from I-96 to Post Dr. (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
Miles
N
Comstock Park
Belmont
Riverside Park
Scott Lake Country Club
Rogue River Park
Donald J Lamoreaux Park
Kent Country Club

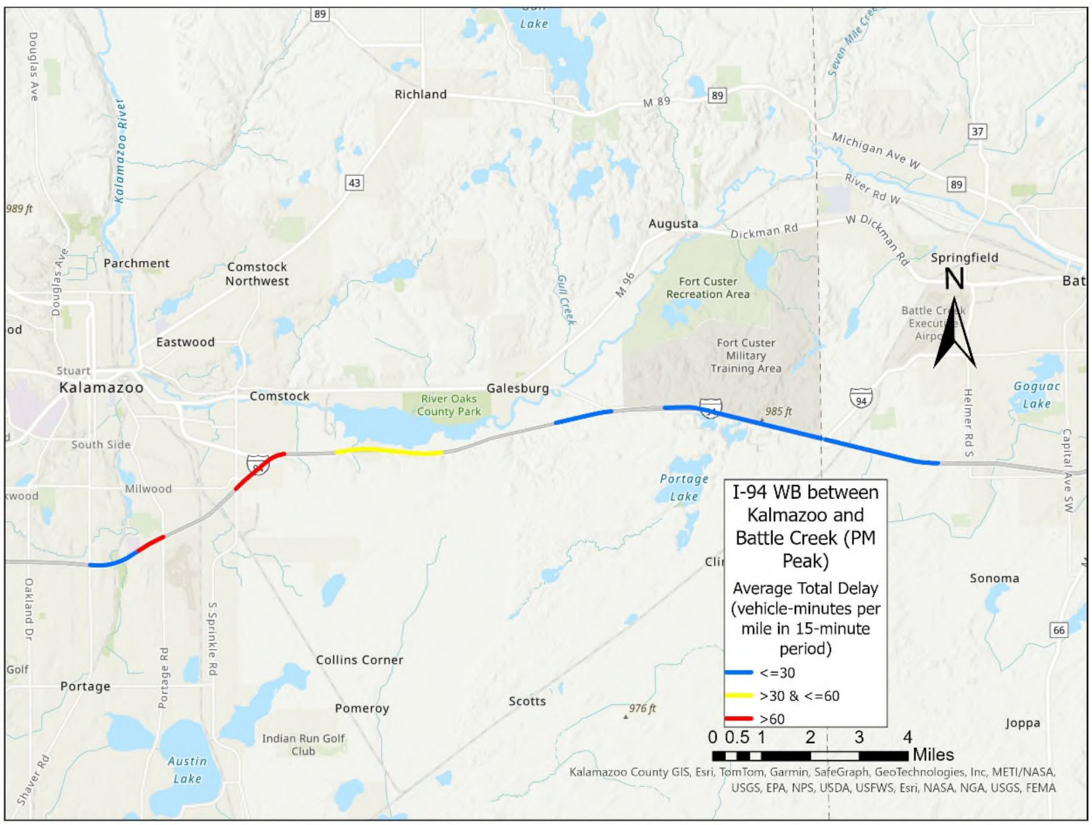

US-131 SB from I-96 to Post Dr. (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
Miles
N
Comstock Park
Belmont
Riverside Park
Scott Lake Country Club
Rogue River Park
Donald J Lamoreaux Park
Kent Country Club


US-131 SB from I-96 to Post Dr. (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
Miles
N
Belmont
Riverside Park
Scott Lake Country Club
Rogue River Park
Donald J Lamoreaux Park
Kent Country Club

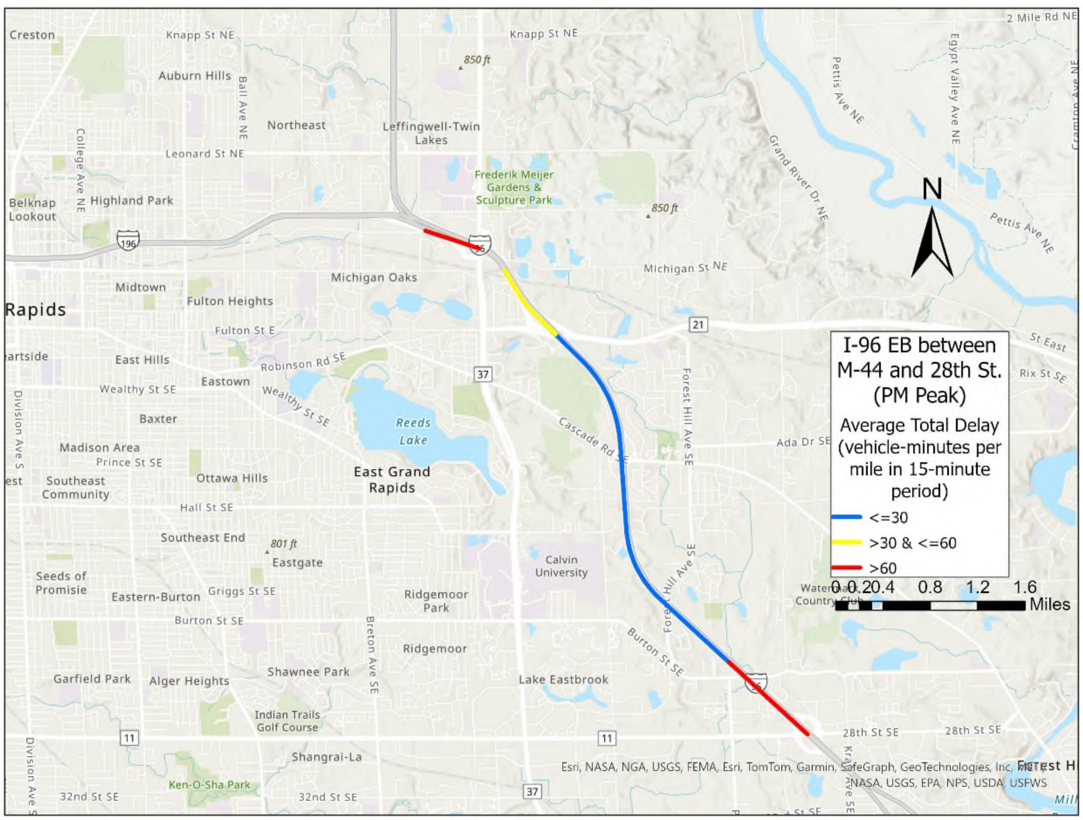

I-94 EB between Kalmazoo and Battle Creek (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4
Miles
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA, USFWS
Kalamazoo
Parchment
Comstock Northwest
Westwood
Eastwood
Comstock
Galesburg
Augusta
Fort Custer Recreation Area
Fort Custer Military Training Area
Springfield
Battle Creek
Climax
Portage
Vicksburg
Huron
Morrow Lake
N


I-94 EB between Kalmazoo and Battle Creek (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4
Miles
Kalamazoo County GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS
Richland
Augusta
Parchment
Comstock Northwest
Eastwood
Kalamazoo
Comstock
River Oaks County Park
Galesburg
Fort Custer Recreation Area
Fort Custer Military Training Area
Springfield
Portage Lake
Sonoma
Collins Corner
Pomeroy
Scotts
Portage
Joppa
N

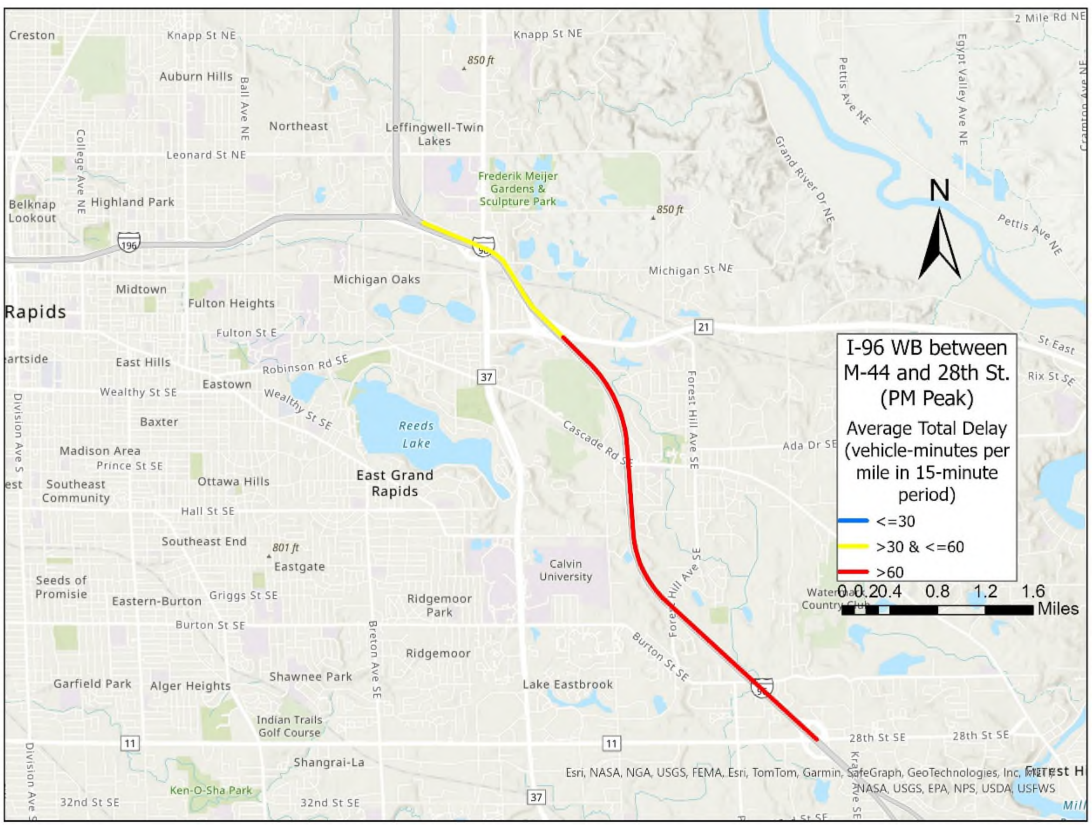

I-94 WB between Kalmazoo and Battle Creek (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Esri, NASA, NGA, USGS, Esri, TomTom, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA, USFWS

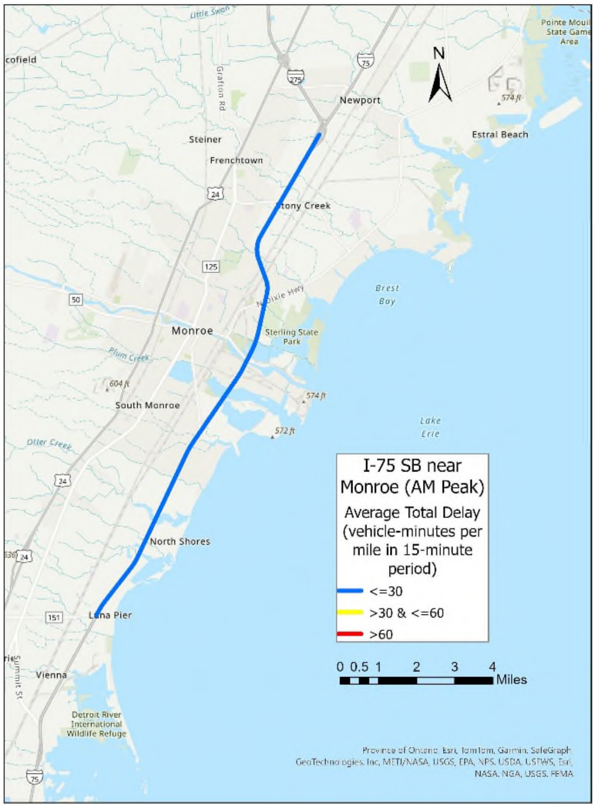

I-94 WB between Kalmazoo and Battle Creek (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Kalamazoo County GIS, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

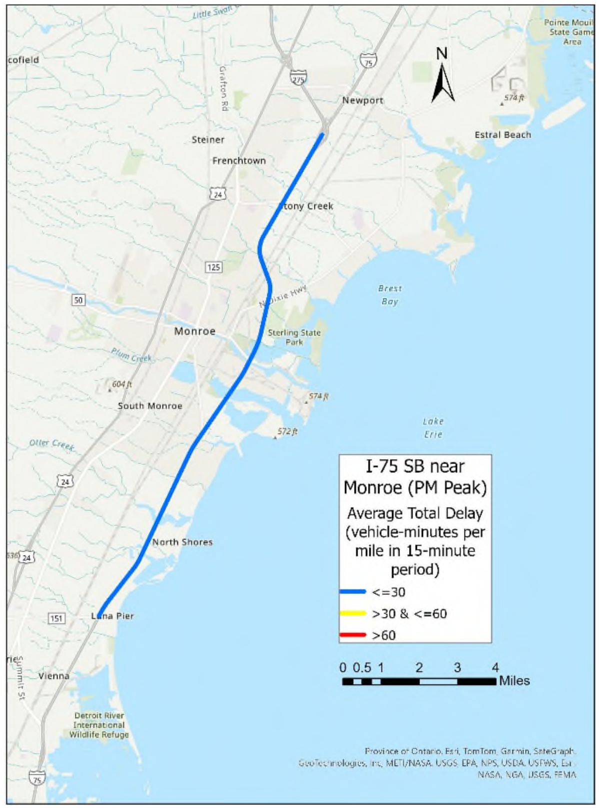

I-96 EB between M-44 and 28th St. (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.20.4 0.8 1.2 1.6 Miles
N
Esri, NASA, NGA, USGS, FEMA, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

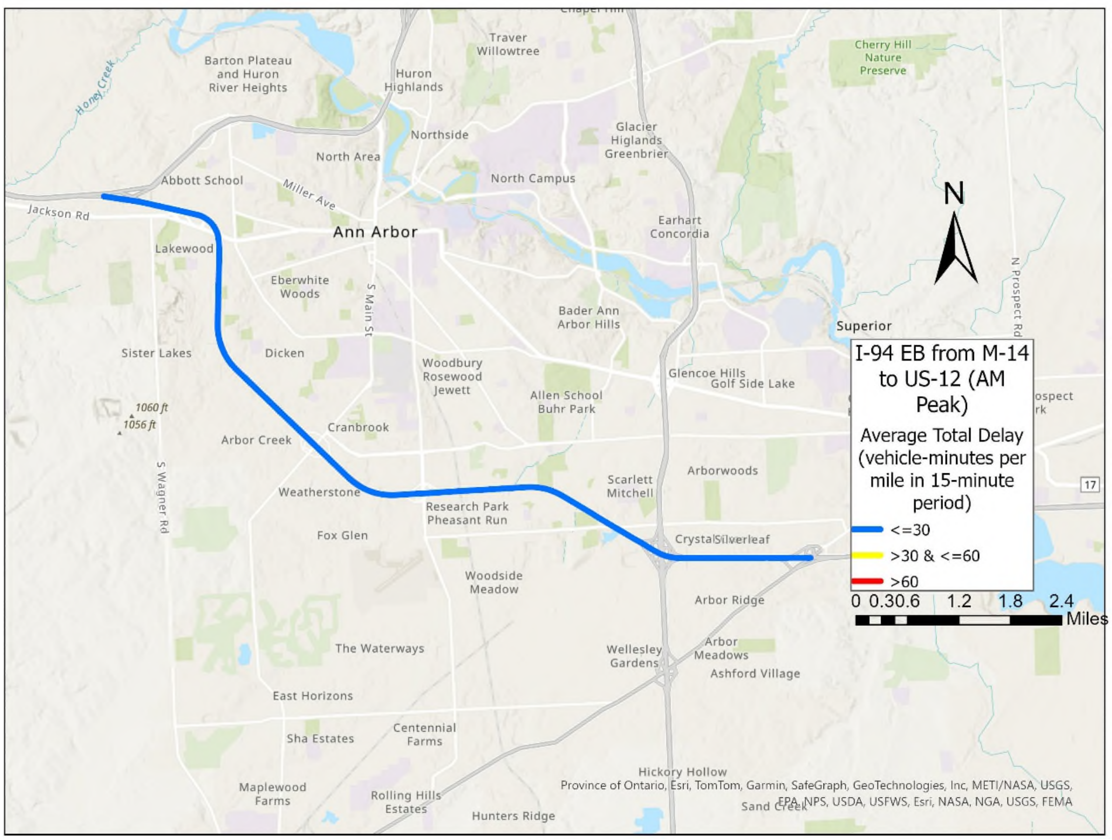

I-96 EB between M-44 and 28th St. (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.20.4 0.8 1.2 1.6 Miles
N
Esri, NASA, NGA, USGS, FEMA, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

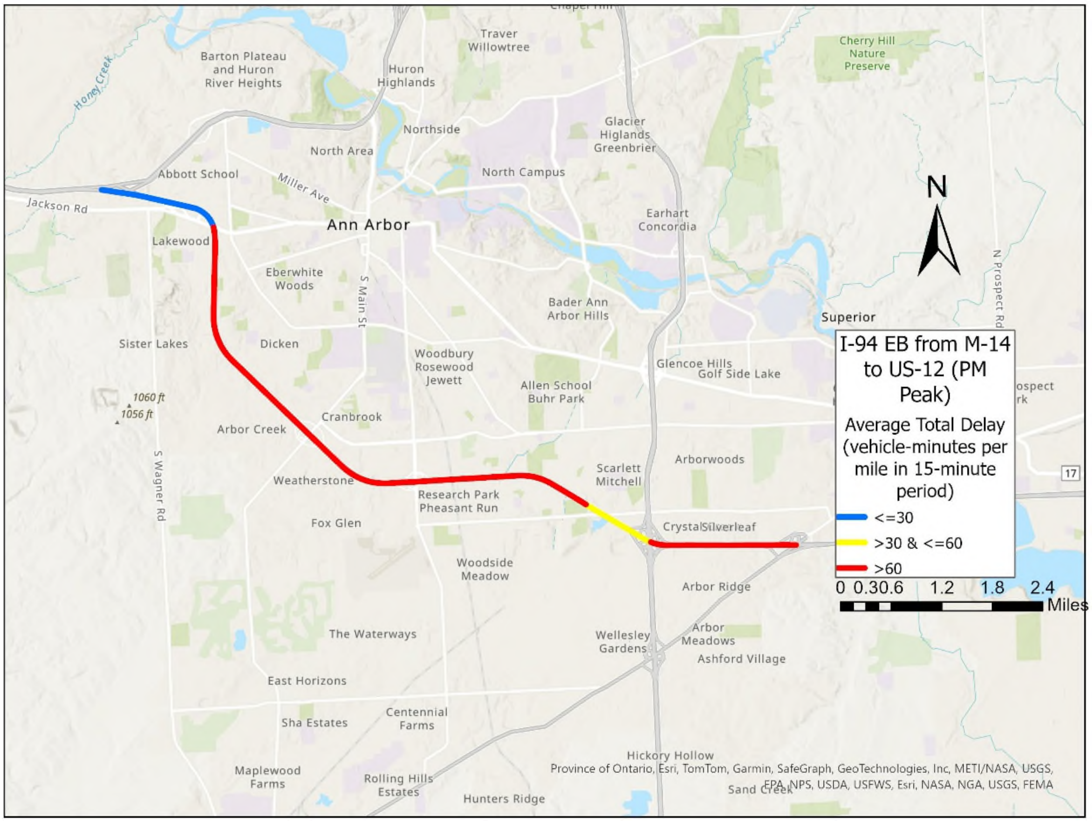

I-96 WB between M-44 and 28th St. (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6
Miles
N
Esri, NASA, NGA, USGS, FEMA, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

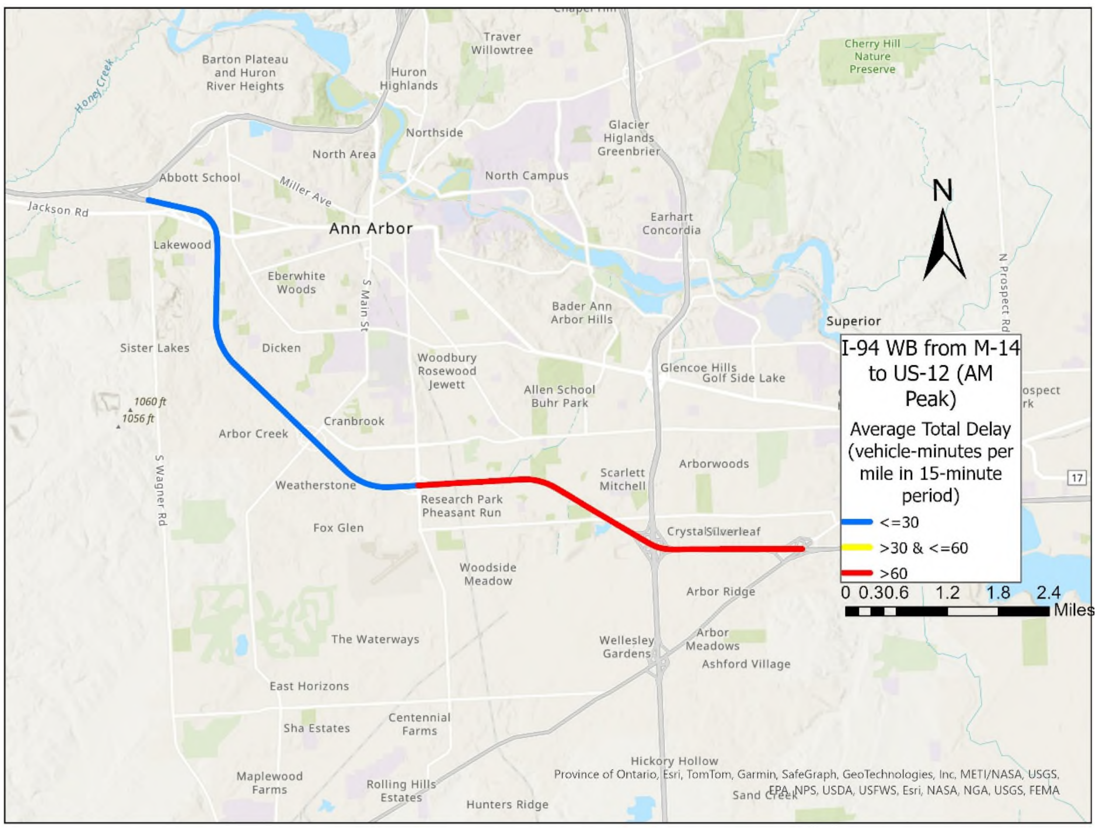

I-96 WB between M-44 and 28th St. (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6
Miles
N
Esri, NASA, NGA, USGS, FEMA, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

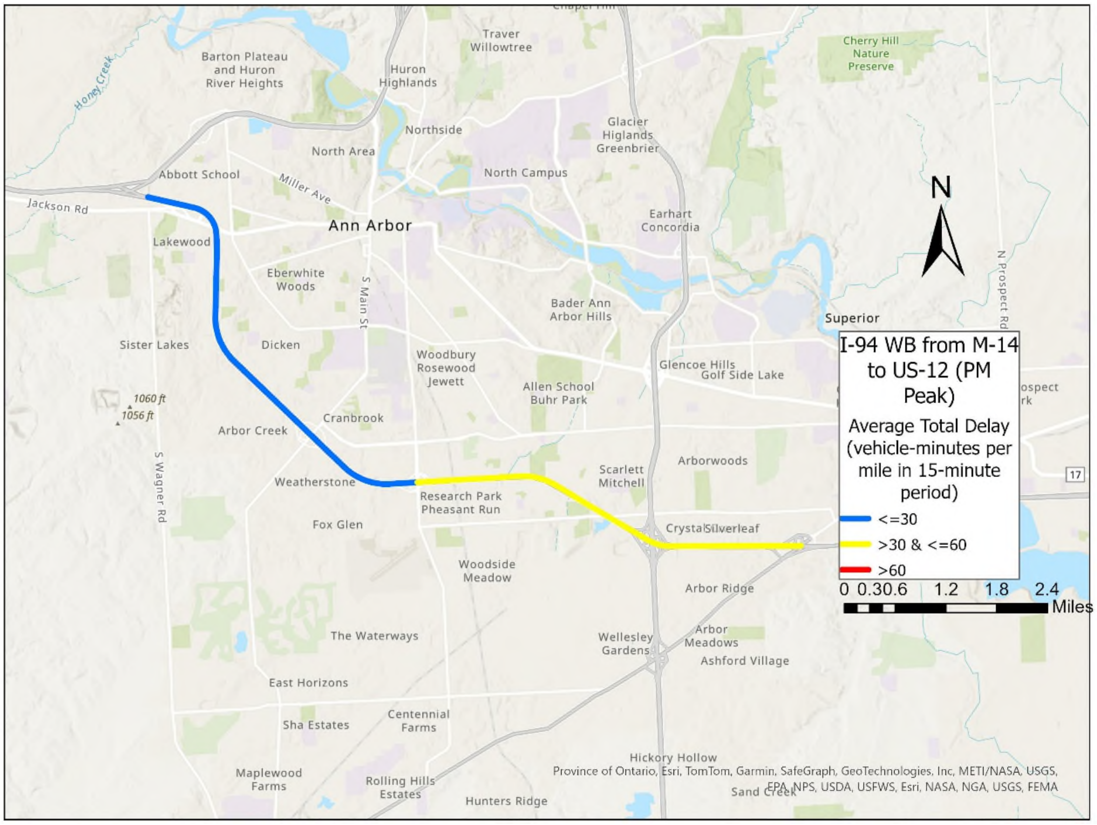

I-75 SB near Monroe (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N
Newport
Estral Beach
Steiner
Frenchtown
Monroe
South Monroe
North Shores
Luna Pier
Vienna
Sterling State Park
Brest Bay
Lake Erie
Detroit River International Wildlife Refuge

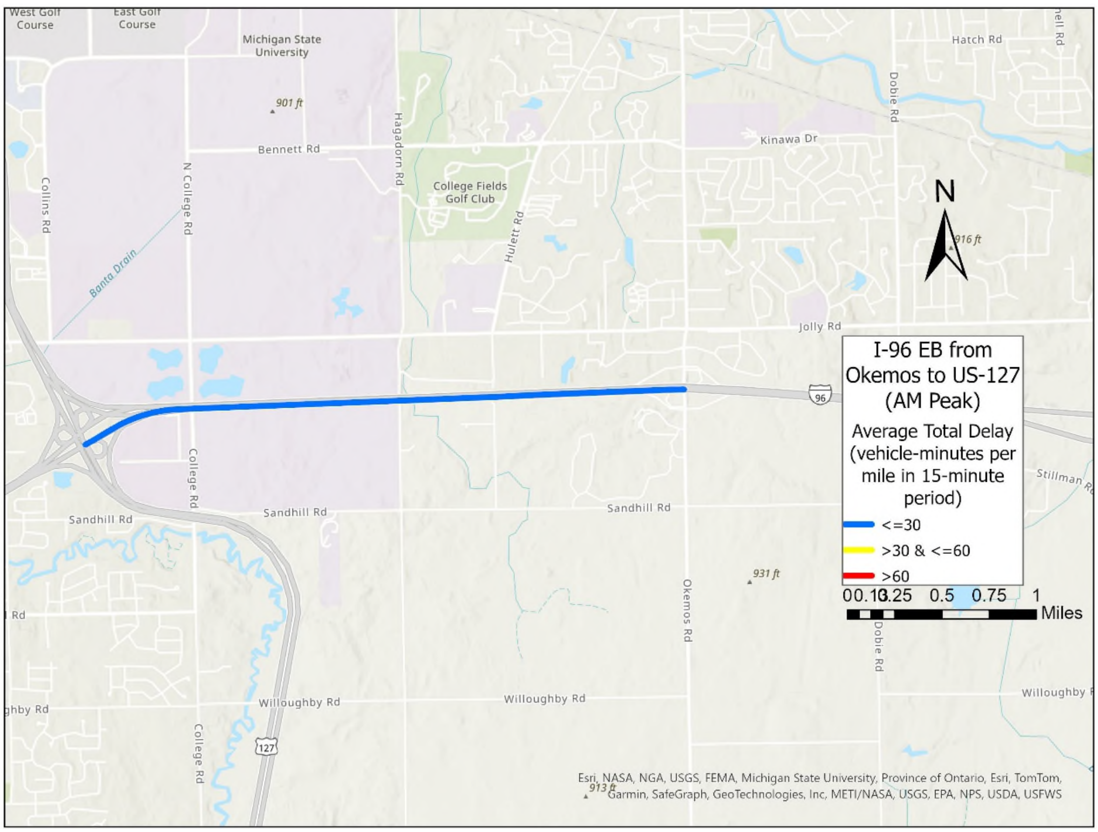

I-75 SB near Monroe (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N
Newport
Estral Beach
Steiner
Frenchtown
Monroe
South Monroe
North Shores
Luna Pier
Vienna
Sterling State Park
Brest Bay
Lake Erie
Detroit River International Wildlife Refuge

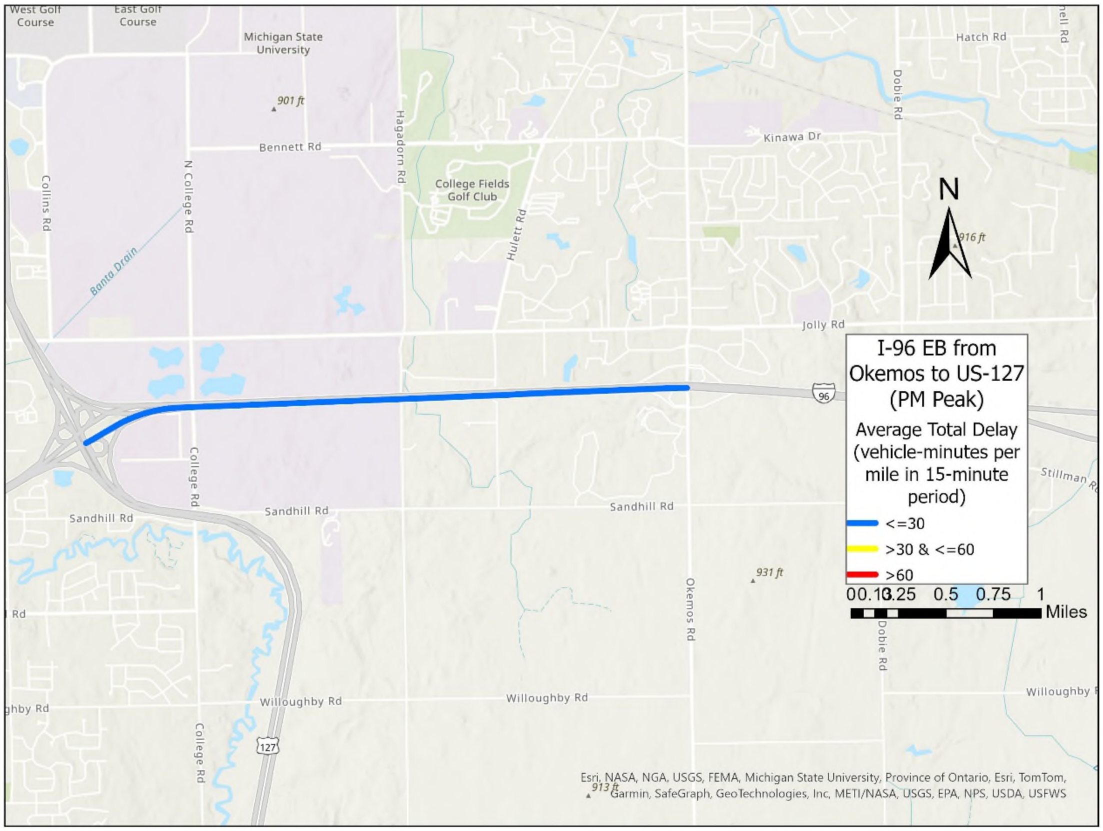

I-94 EB from M-14 to US-12 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.30.6 1.2 1.8 2.4 Miles
N
Ann Arbor
Barton Plateau and Huron River Heights
Huron Highlands
Traver Willowtree
Northside
North Area
North Campus
Abbott School
Jackson Rd
Lakewood
Eberwhite Woods
Sister Lakes
Dicken
Arbor Creek
Cranbrook
Weatherstone
Fox Glen
Research Park Pheasant Run
Woodside Meadow
The Waterways
East Horizons
Sha Estates
Centennial Farms
Maplewood Farms
Rolling Hills Estates
Hunters Ridge
Superior
Glencoe Hills
Golf Side Lake
Arborwoods
Scarlett Mitchell
Arbor Ridge
Wellesley Gardens
Arbor Meadows
Ashford Village
Hickory Hollow
Cherry Hill Nature Preserve
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

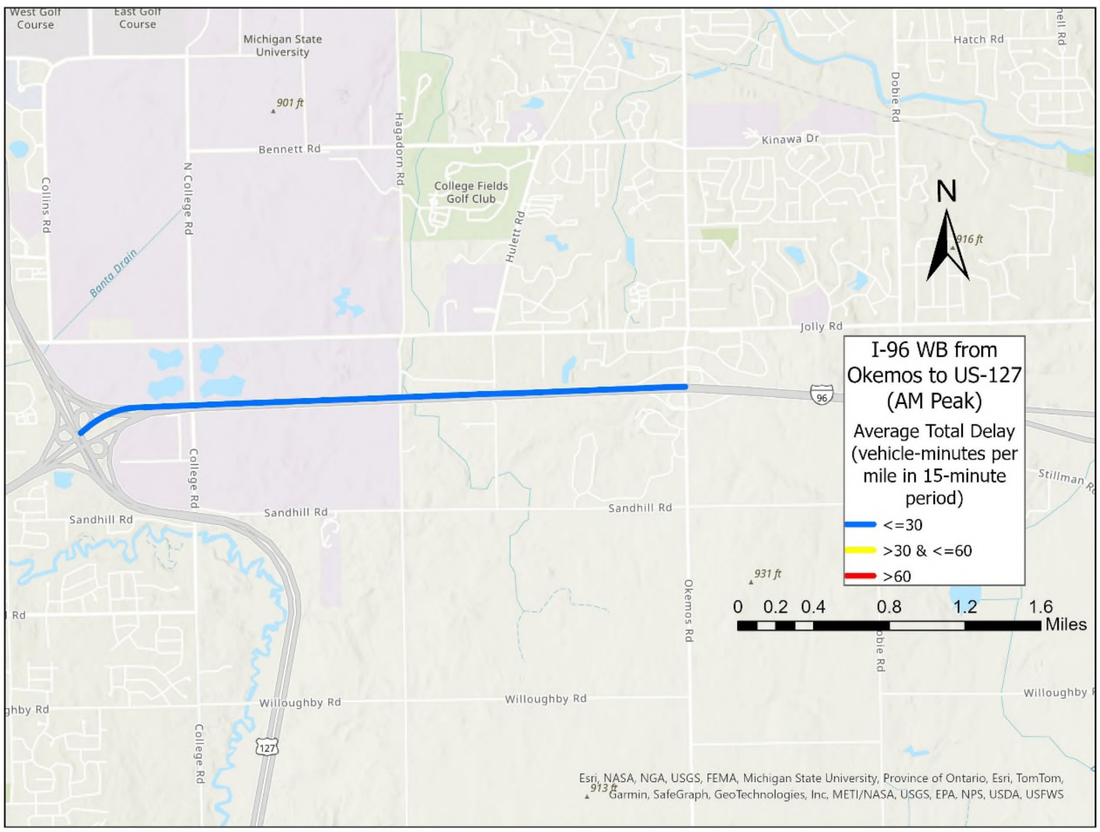

I-94 EB from M-14 to US-12 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.3 0.6 1.2 1.8 2.4
Miles
N
Traver Willowtree
Barton Plateau and Huron River Heights
Huron Highlands
Cherry Hill Nature Preserve
Northside
Glacier Higlands Greenbrier
North Area
Abbott School
Miller Ave
North Campus
Jackson Rd
Ann Arbor
Earhart Concordia
Lakewood
Eberwhite Woods
S Main St
Bader Ann Arbor Hills
Superior
Sister Lakes
Dicken
Woodbury Rosewood Jewett
Glencoe Hills
Golf Side Lake
Allen School Buhr Park
1060 ft
1056 ft
Cranbrook
Arbor Creek
S Wagner Rd
Arborwoods
Scarlett Mitchell
Weatherstone
Research Park Pheasant Run
Fox Glen
Crystal
Silverleaf
Woodside Meadow
Arbor Ridge
The Waterways
Wellesley Gardens
Arbor Meadows
Ashford Village
East Horizons
Sha Estates
Centennial Farms
Hickory Hollow
Maplewood Farms
Rolling Hills Estates
Hunters Ridge
Sand Creek
N Prospect Rd
17
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

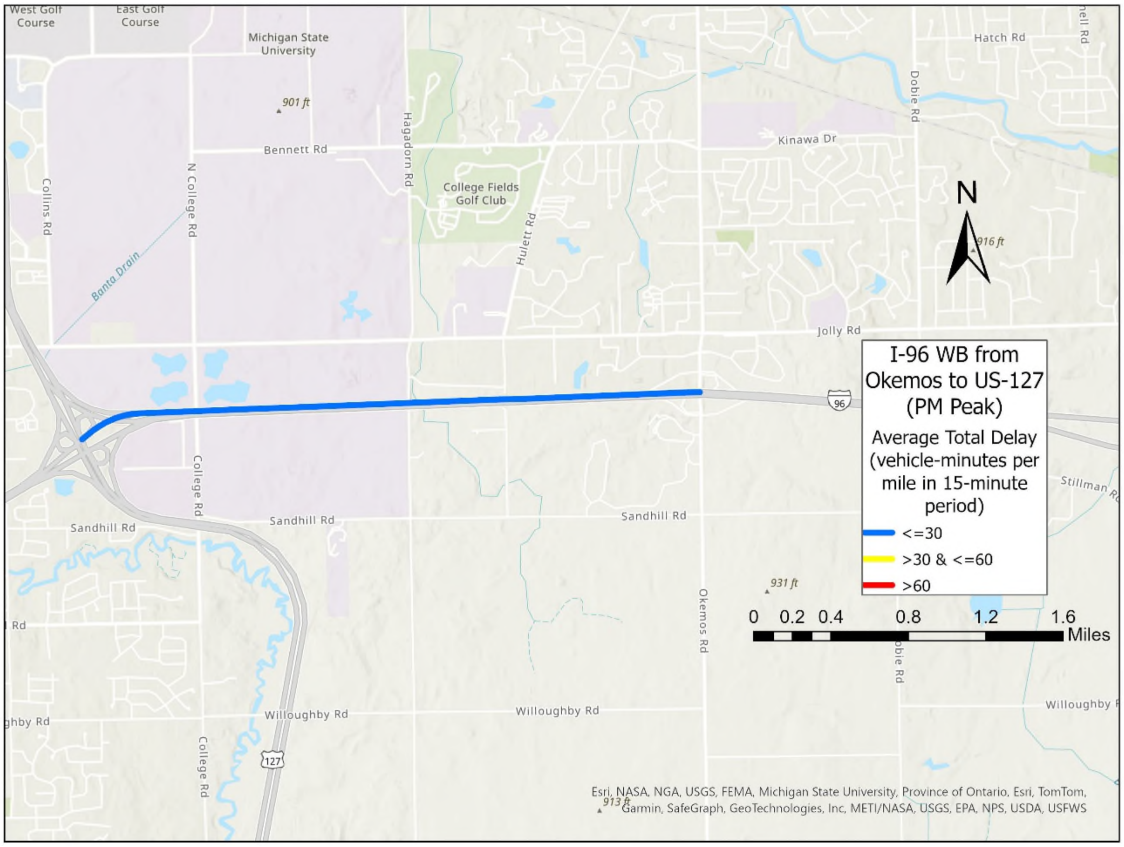

I-94 WB from M-14 to US-12 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.3 0.6 1.2 1.8 2.4
Miles
N
Traver Willowtree
Barton Plateau and Huron River Heights
Huron Highlands
Cherry Hill Nature Preserve
Northside
Glacier Higlands Greenbrier
North Area
Abbott School
Miller Ave
North Campus
Jackson Rd
Ann Arbor
Earhart Concordia
Lakewood
Eberwhite Woods
S Main St
Bader Ann Arbor Hills
Superior
Sister Lakes
Dicken
Woodbury Rosewood Jewett
Glencoe Hills
Golf Side Lake
Allen School Buhr Park
1060 ft
1056 ft
Cranbrook
Arbor Creek
S Wagner Rd
Arborwoods
Scarlett Mitchell
Weatherstone
Research Park Pheasant Run
Fox Glen
Crystal
Silverleaf
Woodside Meadow
Arbor Ridge
The Waterways
Wellesley Gardens
Arbor Meadows
Ashford Village
East Horizons
Sha Estates
Centennial Farms
Hickory Hollow
Maplewood Farms
Rolling Hills Estates
Hunters Ridge
Sand Creek
N Prospect Rd
17
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

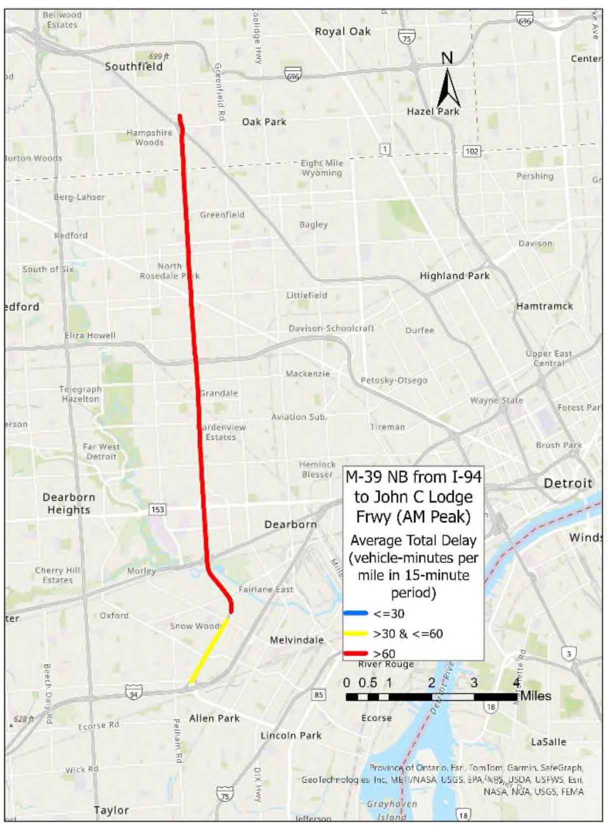

I-94 WB from M-14 to US-12 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.30.6 1.2 1.8 2.4
Miles
N
Ann Arbor
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

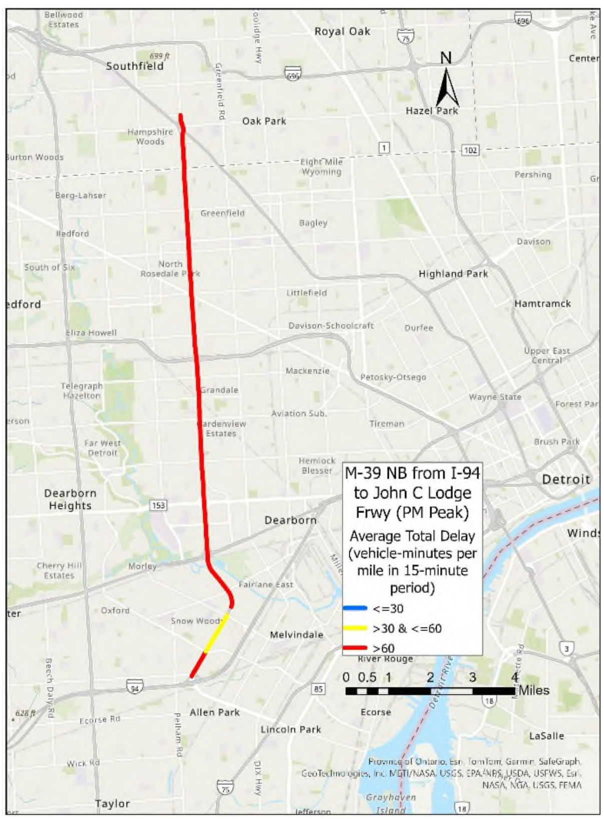

I-96 EB from Okemos to US-127 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
00.10.25 0.5 0.75 1
Miles
N
Michigan State University
Esri, NASA, NGA, USGS, FEMA, Michigan State University, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS


I-96 EB from Okemos to US-127 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.125 0.25 0.5 0.75 1
Miles
N
Michigan State University
West Golf Course
East Golf Course
College Fields Golf Club
Hatch Rd
Kinawa Dr
Bennett Rd
Jolly Rd
Sandhill Rd
Willoughby Rd
Stillman Rd
Collins Rd
N College Rd
College Rd
Hagadorn Rd
Hulett Rd
Okemos Rd
Dobie Rd
Esri, NASA, NGA, USGS, FEMA, Michigan State University, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

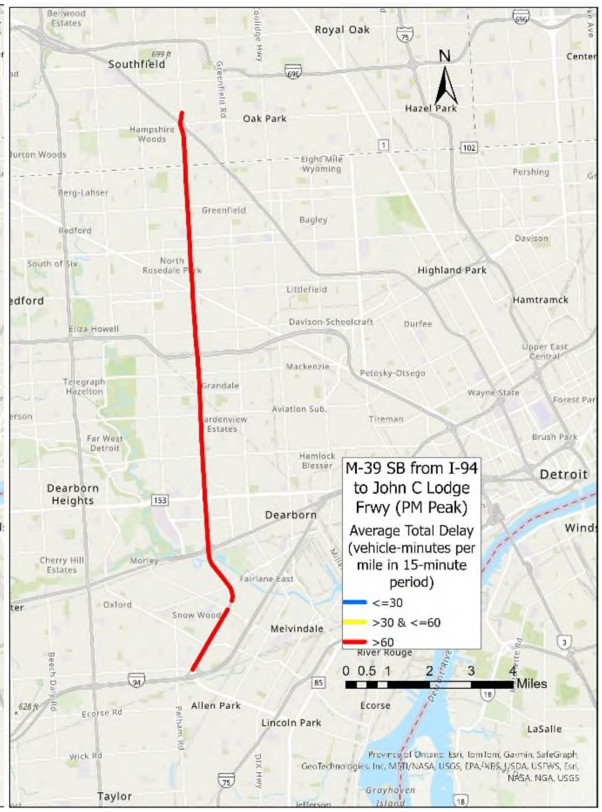

I-96 WB from Okemos to US-127 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6
Miles
N
Michigan State University
West Golf Course
East Golf Course
College Fields Golf Club
Hatch Rd
Kinawa Dr
Bennett Rd
Jolly Rd
Sandhill Rd
Willoughby Rd
Stillman Rd
Collins Rd
N College Rd
College Rd
Hagadorn Rd
Hulett Rd
Okemos Rd
Dobie Rd
Esri, NASA, NGA, USGS, FEMA, Michigan State University, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

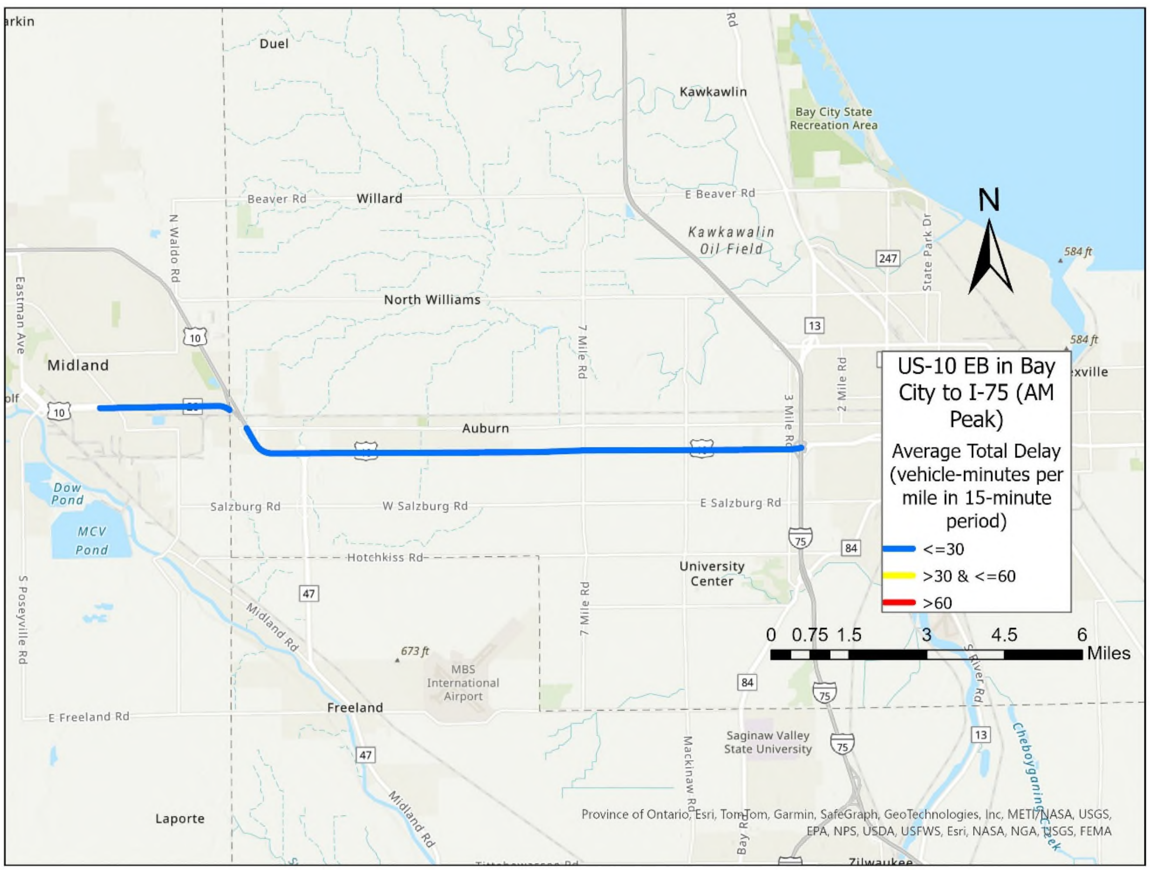

I-96 WB from Okemos to US-127 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.2 0.4 0.8 1.2 1.6 Miles
N
Esri, NASA, NGA, USGS, FEMA, Michigan State University, Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

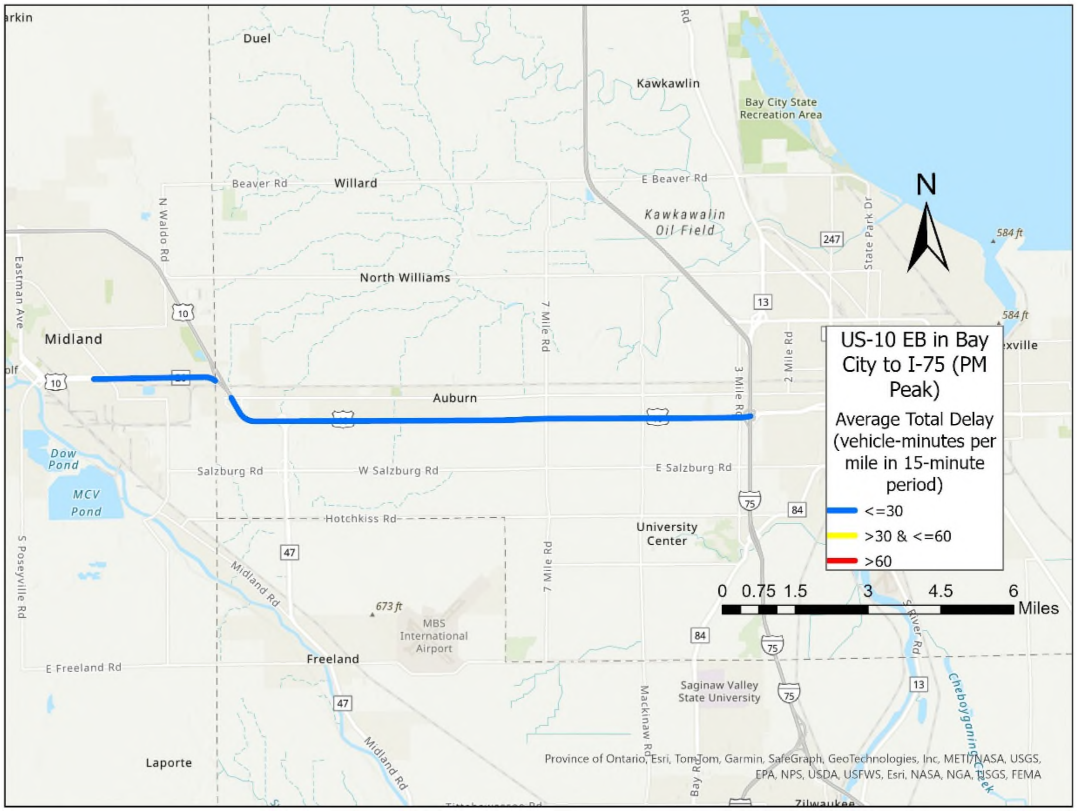

M-39 NB from I-94 to John C Lodge Frwy (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N

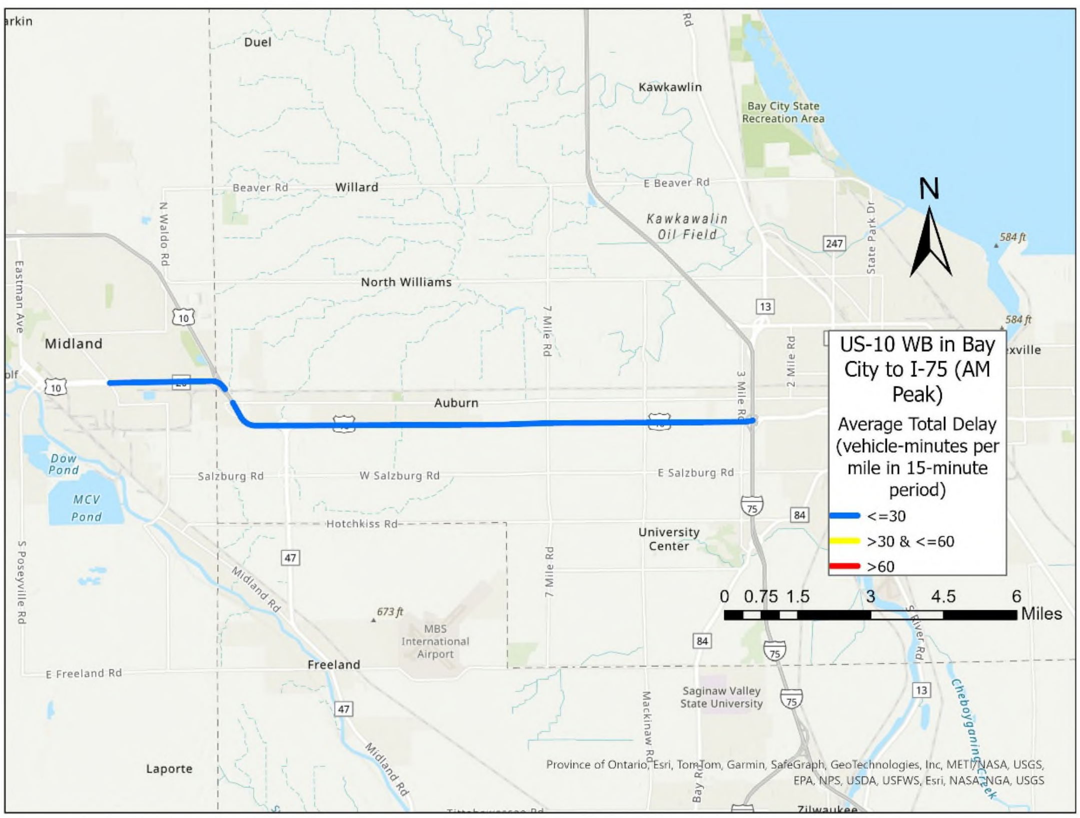

M-39 NB from I-94 to John C Lodge Frwy (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N

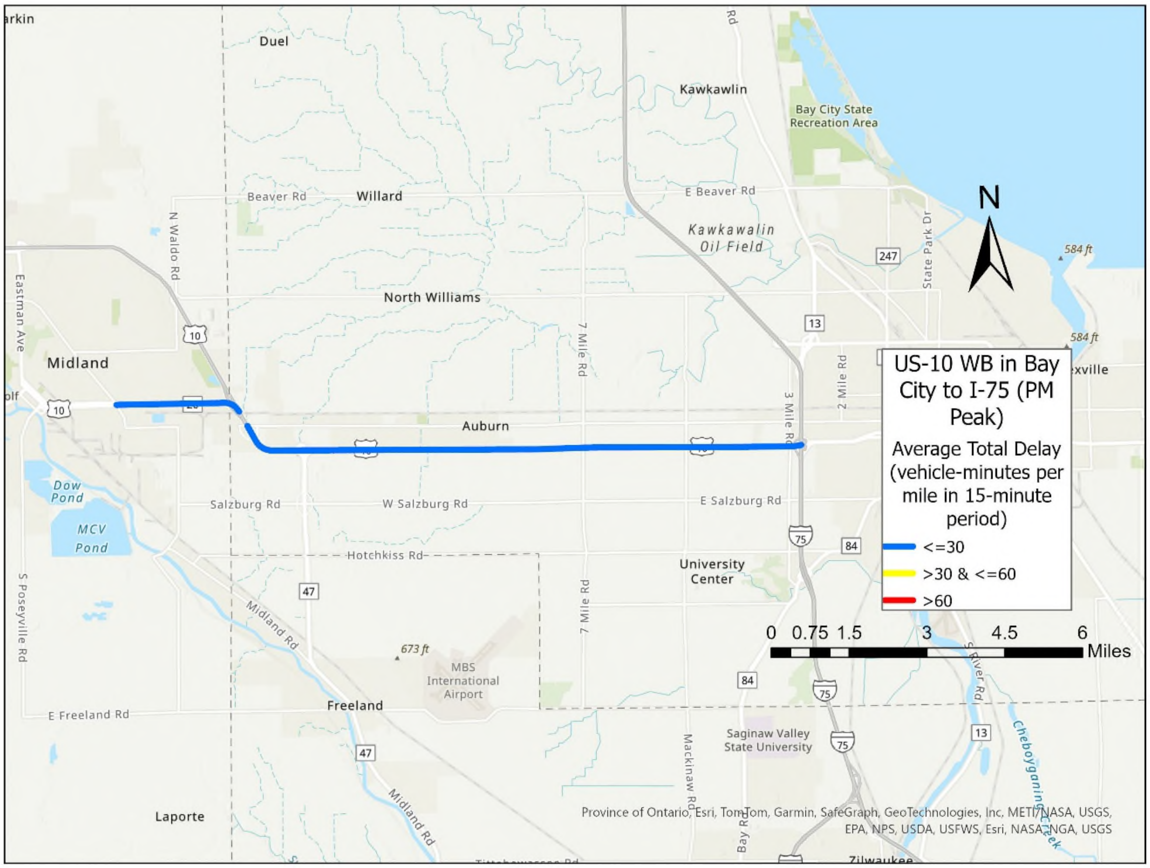

M-39 SB from I-94 to John C Lodge Frwy (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4
Miles
N

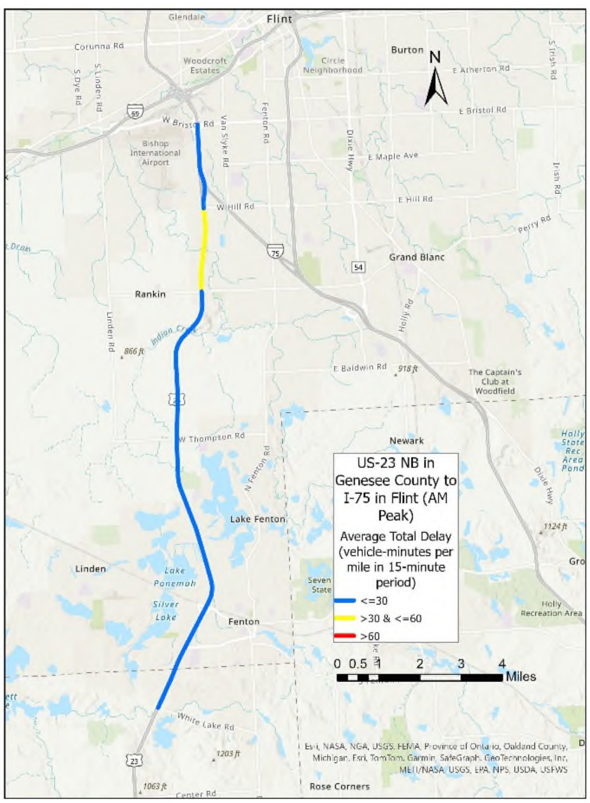

M-39 SB from I-94 to John C Lodge Frwy (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4
Miles
N

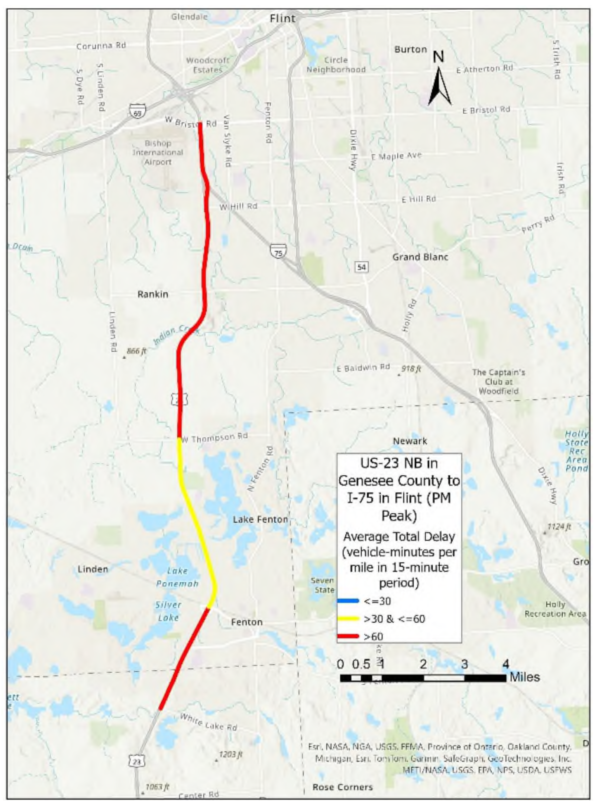

US-10 EB in Bay City to I-75 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.75 1.5 3 4.5 6
Miles
N
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

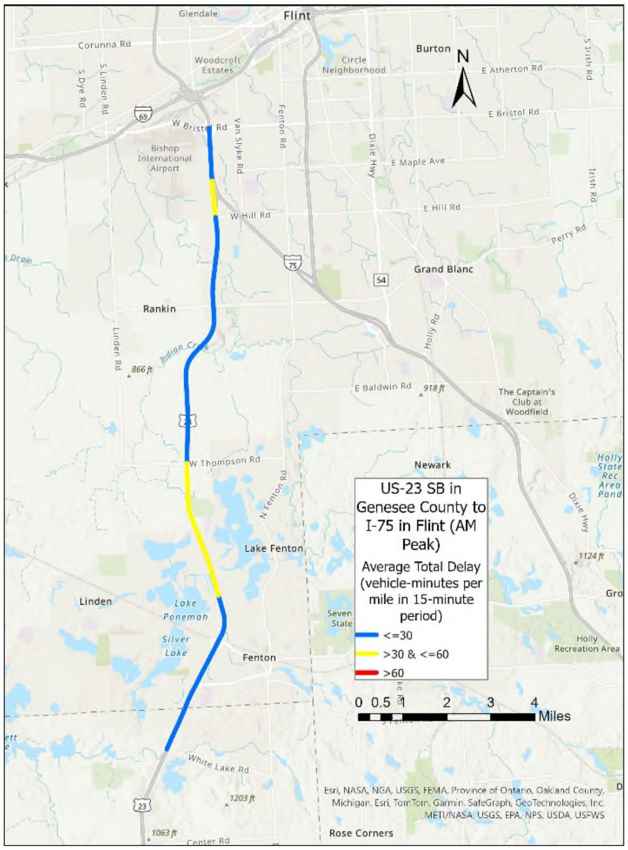

US-10 EB in Bay City to I-75 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.75 1.5 3 4.5 6
Miles
N
Midland
Auburn
Kawkawlin
Willard
North Williams
Freeland
Laporte
University Center
Duel
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS, FEMA

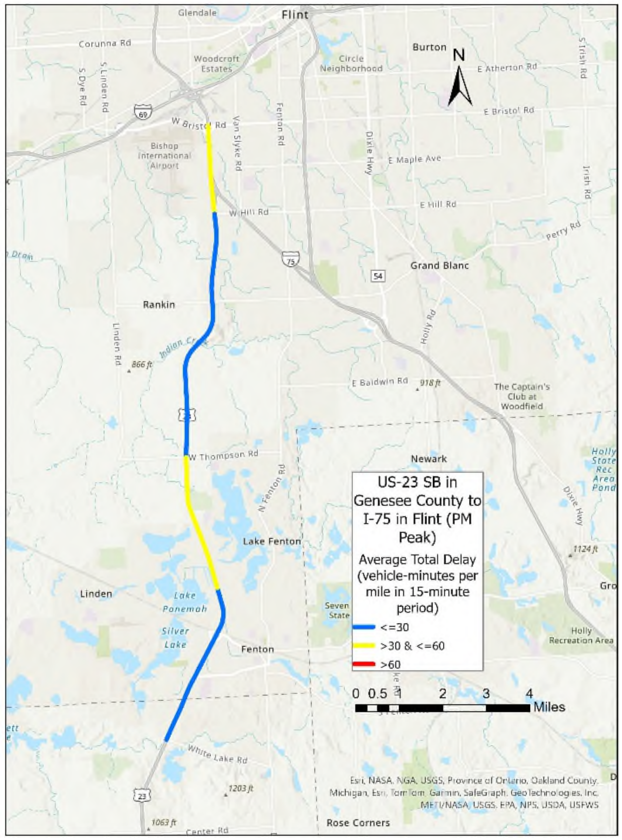

US-10 WB in Bay City to I-75 (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.75 1.5 3 4.5 6
Miles
N
Midland
Auburn
Kawkawlin
Willard
North Williams
Freeland
Laporte
University Center
Duel
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS

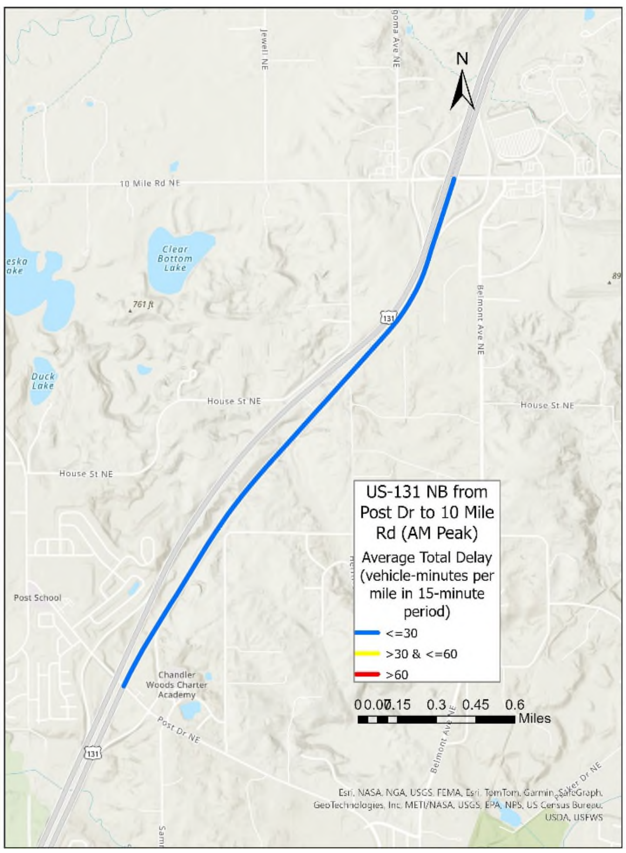

US-10 WB in Bay City to I-75 (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.75 1.5 3 4.5 6 Miles
N
Midland
Auburn
Duel
Willard
North Williams
Kawkawlin
Bay City State Recreation Area
Kawkawalin Oil Field
University Center
Freeland
Laporte
MBS International Airport
Saginaw Valley State University
Dow Pond
MCV Pond
Beaver Rd
E Beaver Rd
Salzburg Rd
W Salzburg Rd
E Salzburg Rd
Hotchkiss Rd
Midland Rd
E Freeland Rd
N Waldo Rd
Eastman Ave
S Poseyville Rd
7 Mile Rd
3 Mile Rd
2 Mile Rd
State Park Dr
Mackinaw Rd
Province of Ontario, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS, Esri, NASA, NGA, USGS

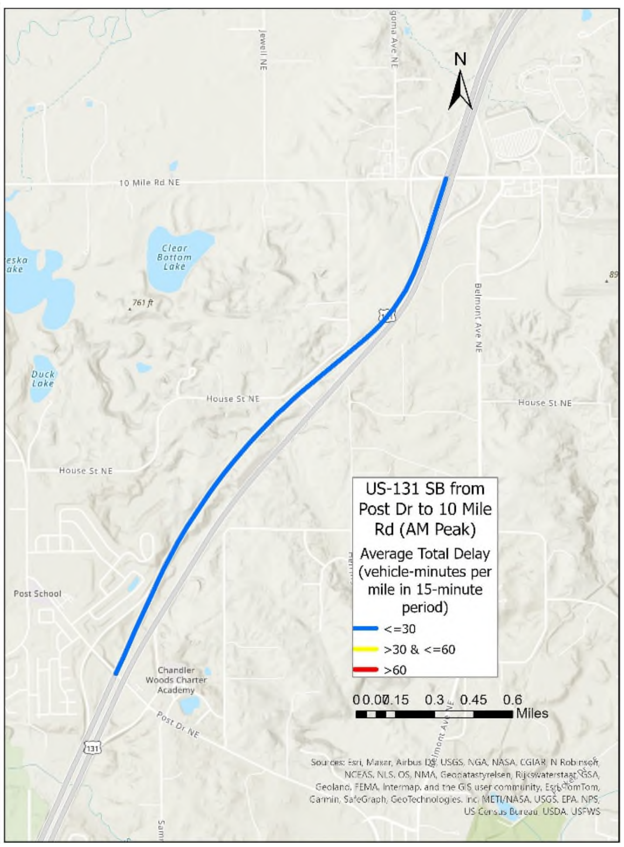

US-23 NB in Genesee County to I-75 in Flint (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N
Flint
Burton
Grand Blanc
Rankin
Newark
Lake Fenton
Linden
Fenton
Rose Corners
Esri, NASA, NGA, USGS, FEMA, Province of Ontario, Oakland County, Michigan, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS

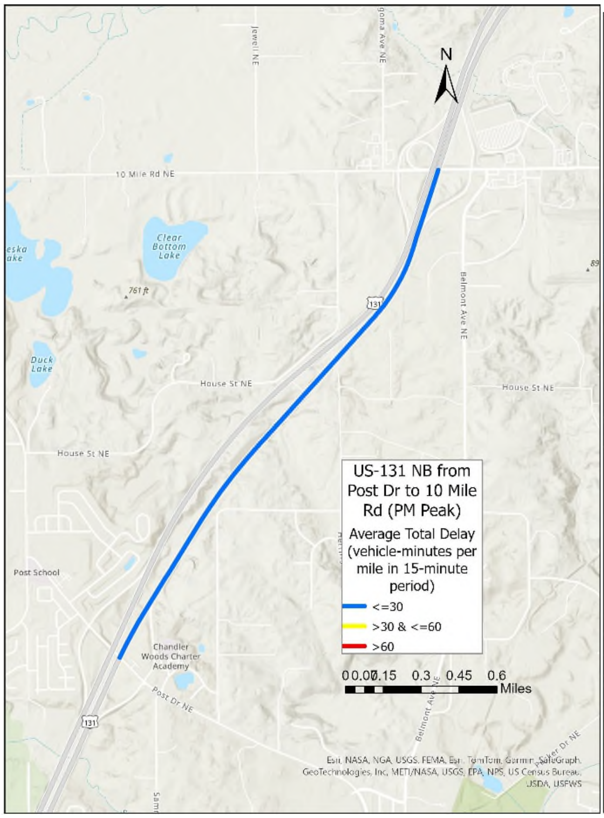

US-23 NB in Genesee County to I-75 in Flint (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
N
Flint
Burton
Grand Blanc
Rankin
Newark
Lake Fenton
Linden
Fenton
Rose Corners
Esri, NASA, NGA, USGS, FEMA, Province of Ontario, Oakland County, Michigan, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS


US-23 SB in Genesee County to I-75 in Flint (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles
Esri, NASA, NGA, USGS, FEMA, Province of Ontario, Oakland County, Michigan, Esri, TomTom, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, USDA, USFWS


US-23 SB in Genesee County to I-75 in Flint (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.5 1 2 3 4 Miles


US-131 NB from Post Dr to 10 Mile Rd (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.07 0.15 0.3 0.45 0.6 Miles


US-131 SB from Post Dr to 10 Mile Rd (AM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.07 0.15 0.3 0.45 0.6 Miles


US-131 NB from Post Dr to 10 Mile Rd (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.075 0.15 0.3 0.45 0.6
Miles
10 Mile Rd NE
House St NE
Post School
Post Dr NE
Belmont Ave NE


US-131 SB from Post Dr to 10 Mile Rd (PM Peak)
Average Total Delay (vehicle-minutes per mile in 15-minute period)
<=30
>30 & <=60
>60
0 0.075 0.15 0.3 0.45 0.6
Miles
10 Mile Rd NE
House St NE
Post School
Post Dr NE
Belmont Ave NE