Evaluation of an Active Traffic Management System with Part-Time Use of the Inside Shoulder

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This study investigated the performance, safety, and public percerptions on US-23 Flex route. Overall, crashes were reduced by roughly 17 percent across the entire corridor in both directions. The improvements were significantly more pronounced in the SB direction, where crashes were reduced by 34 percent overall and more than 50 percent during the peak traffic periods. As with the operational issues, the crashes tended to increase predominantly in the bottleneck area where the lane drop is present. While crashes were generally reduced along the Flex route, some increases and decreases occurred on the adjacent upstream/downstream segments. In general, the SB direction outperformed the northbound direction with respect to most metrics as congestion was very limited in this direction once the Flex route went into operation. While the NB direction also showed better performance after the Flex lane opened in general, a downstream bottleneck was introduced at the NB lane drop and this section has experienced significant congestion. During the peak operational periods, reductions in crashes of approximately 50 percent were experienced in the SB direction. In contrast, total crashes were comparable in the NB direction and actually increased by approximately 24 percent during the peak traffic periods. However, much of this increase is attributable to the lane drop that occurs at the northern terminus of the Flex route. The planned extension to I-96 should remedy the existing performance and safety issues. Almost 70% of US-23 drivers were satisfied or very satisfied with the Flex route; to such an extent that there is significant support for both an expansion of the current Flex route and additional Flex routes throughout the state of Michigan. Moreover, drivers overwhelmingly desire the current Flex route be open for additional hours, especially on weekends.</td></tr>
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FINAL REPORT

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EXECUTIVE SUMMARY

In November of 2017, the Michigan Department of Transportation (MDOT) opened the first Flex route in Michigan on an 8.5-mile-long section of US-23. The Flex route is an attempt to mitigate peak-hour congestion, shorten incident response times, and improve safety. Overall, the Flex route has improved performance and safety of US-23 and drivers reported overwhelmingly satisfied with the US-23 Flex route.

Performance summary: Performance of US-23 has improved across several metrics including maximum throughput, travel time during peak periods, and level of travel time reliability. In general, the southbound direction outperformed the northbound direction with respect to most metrics as congestion was very limited in this direction once the Flex route went into operation. While the northbound direction also showed better performance after the Flex lane opened in general, a downstream bottleneck was introduced at the northbound lane drop and this section has experienced significant congestion. Fortunately, this problem is expected to be alleviated by the planned extension of the Flex lane to I-96 in 2024. The operational analyses also showed improved operations when special events occurred such as football games and holidays. Incident clearance times largely decreased after the Flex route was opened. Part-time shoulder running also provided an additional travel lane during peak periods, such as University of Michigan home football games, reducing such non-recurrent congestion.

Safety summary: Crash data were compared for a period of four years (i.e., 2012 to 2015) before the construction of the Flex route, and two years (i.e., 2018 and 2019) after its completion. After considering increases in traffic volume, crashes were reduced by 17 percent when considering all times of day, including 34 percent in the southbound direction. During the peak operational periods, reductions of approximately 50 percent were experienced in the southbound direction. In contrast, total crashes were comparable in the northbound direction and actually increased by approximately 24 percent during the peak traffic periods. However, much of this increase is attributable to the lane drop that occurs at the northern terminus of the Flex route. The planned extension to I-96 should remedy the existing safety issues.

Perceptions summary: Drivers were overwhelmingly satisfied with the performance and safety of the US-23 Flex route. Since the introduction of the Flex route, most drivers reported realizing tangible benefits including time savings and being more relaxed while driving on US-23. Drivers who reported the highest levels of satisfaction drive in the Flex lane regularly, compared to those who prefer to drive in the middle or right lanes. Drivers also reported that the Flex lanes create a safer driving experience when an incident occurs. Ultimately, support for additional Flex lanes throughout Michigan was high among drivers who currently use the US-23 Flex route. An analysis of the open-ended questions confirmed that drivers were satisfied with the Flex route and would like to see operating hours and the length of the Flex lane extended.

Positive social media commentary was twice as common as negative commentary. Positive comments included general praise and perceived benefits, such as time savings and reduced congestion. Notably, the Flex lane's cost-effectiveness was rarely mentioned on social media even though it was a significant reason for MDOT to choose the Flex route system over a traditional capacity solution. Negative comments more often reflected annoyances; some drivers demanded a permanent lane instead of a temporary lane.

Cost benefit analysis summary: The benefit-cost ratios of the Flex route ranged from 2.15 to 2.95 in the southbound direction, 2.25 to 3.09 in the northbound direction, and 2.20 to 3.01 in both directions. In general, the operational benefits were significantly greater in the southbound direction. This is due to the congestion that remains at the northern limits in the northbound direction. In contrast, the safety benefit was more pronounced in the northbound direction, due in large part to a decrease in fatalities that occurred between the before and after periods.

CHAPTER 1 INTRODUCTION AND OVERVIEW

Americans drive approximately 3 trillion miles on US roads annually (Bureau of Transportation Statistics, 2020). An average American drives more than 1,000 miles every month (Office of Highway Policy Information, 2018a). As Americans spend more time on the roads, transportation infrastructure faces increasing traffic congestion. The average one-way commuting time is 26.9 minutes across the United States (Census Bureau, 2019). For Michigan drivers, commutes fall just below the national average with a daily commute of 24.6 minutes each way (Census Bureau, 2019). Along with traffic congestion, more than 245,000 crashes occurred in the state of Michigan in 2020 (Michigan Office of Highway Safety Planning, 2021).

In an effort to better manage traffic congestion and improve road safety, many transportation agencies in the US deploy Active Traffic Management (ATM) systems. ATM is an approach to managing and controlling traffic demand that employs one or a combination of real-time and predictive operational strategies to increase effectiveness and efficiency (Brinckerhoff, 2010). Examples of ATM techniques include hard shoulder running, variable speed limits, queue warning systems, and lane use control systems (Chun & Fontaine, 2016; Guerrieri & Mauro, 2016; Mirshahi et al., 2007). ATM systems are tailored to the specific needs of the corridor to 1) increase average throughputs for congested periods of 3 to 7 percent, 2) increase overall capacity of 3 to 22 percent, 3) decrease primary incidents between 3 to 30 percent, 5) decrease secondary incidents between 40 to 50 percent, 6) decrease headways and more uniform driver behavior, and 7) increase trip reliability (Brinckerhoff, 2010).

In November 2017, the Michigan Department of Transportation (MDOT) opened its US-23 Flex route (Figure 1-1). To mitigate peak-hour congestion, shorten incident response times, and improve safety, the Flex route utilizes the corridor's 11- ft. wide inside shoulders as dynamic lanes (Figure 1-2). Along this 8.5-mi corridor, from M-14 to M-36 north of Ann Arbor, MDOT manages US-23's dynamic lanes through variable speed controls and queue warning systems. Variable speed limits and queue warning systems are strategies used often to prevent crashes from congestion (Mirshahi et al., 2007). The goal is to keep speeds along the US-23 dynamic stretch at 60 mph when the Flex route is in operation to accommodate 66,000 vehicles per day (MDOT, 2009).

Figure 1-1 US-23 Flex route in operation

Source: WHMI, 2018

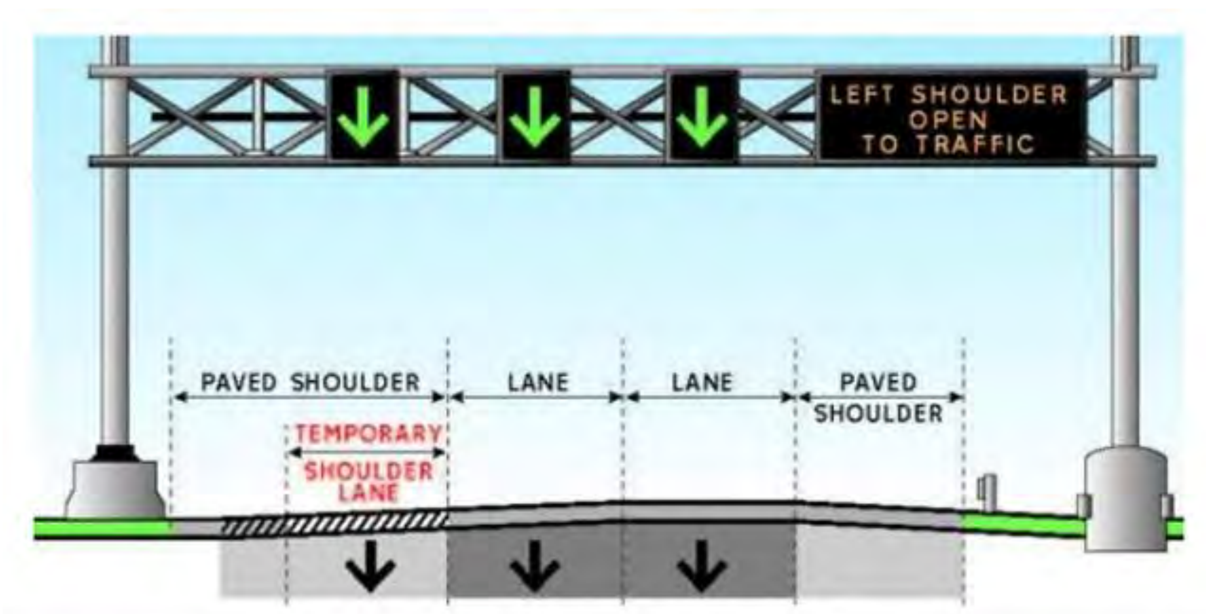


Figure 1-2 US-23 utilizes the inside shoulder as a dynamic lane

Only three states have implemented a similar collection of ATM techniques to the US-23 Flex route: Virginia, Minnesota, and Washington (Brinckerhoff, 2010; FHWA, 2020a). Virginia implements hard shoulder running on the right side with the left used as a high occupancy vehicle

(HOV) lane (Chun & Fontaine, 2016). Minnesota incorporates hard shoulder running on the same side as the US-23. Although the system in Minnesota uses hard shoulder running, it is considered a priced dynamic shoulder lane that can be used for a fee by drivers (FHWA, 2012a). The Minnesota Department of Transportation has also incorporated variable speed limits and other technological developments (Kary, 2016). The Washington State Department of Transportation implemented ATM strategies along I-5, including variable speed limits, signs with road conditions displayed every half-mile, and hard shoulder running on the left shoulder (Washington State Department of Transportation, 2009).

Temporary shoulders are a potential strategy to reduce congestion, improve safety, and increase performance. However, the functionality, as well as the impacts on road users, requires further study. Thus, research is needed to determine the performance, safety and perception of Michigan’s first Flex route, as well as potential impacts on upstream and downstream traffic. The findings and conclusion from the research will provide critical guidance and support for MDOT to effectively manage the US-23 Flex lane and to support the planning, design and operation of future flex lanes.

CHAPTER 2 LITERATURE REVIEW

For a couple of decades, transportation agencies have used temporary lanes to reduce traffic congestion. Temporary lanes, also called dynamic lanes or hard-shoulder running, allow traffic on shoulders or lanes during peak hours on either left or right of the main lanes. Previous studies suggest opening a dynamic lane during peak-hour traffic can increase throughput traffic, reduce traffic congestion, and increase trip reliability during peak-hour traffic. Many introductions of dynamic lanes have enjoyed public support due to expected benefits to drivers and surrounding communities. However, the safety impacts of using dynamic shoulders are often debatable. The long-term implications to safety along ATM corridors are uncertain due to the extent of possible deployment options. As a result, implementing dynamic shoulder and ATM techniques requires legal and regulatory involvement at the local, state, and federal level.

2.1 Brief History of Dynamic Shoulders

European countries like Great Britain, Germany, and the Netherlands have used dynamic lanes since the 1990's with speed harmonization, ramp metering, and dynamic signs, which (a) increases in average throughput for congested periods between 3 – 7%; (b) increases in overall capacity between 3 – 22%; (c) decreases in primary incidents between 3 – 30%; (d) decreases in secondary incidents between 40 – 50%; (e) decreases in headways; (f) increases in uniform driver behavior; (g) provides speed consistency during congestion; (h) increases in trip reliability; and (i) delays the onset of freeway breakdown (Geistefeldt, 2012). In Great Britain, the temporary hard shoulder is accompanied by emergency refuge pull-out areas every 500 meters, while the Germans use junction control methods, including ramp metering and lane control at entrance ramps or merge points to avoid bottlenecks. Spatiotemporal studies by Cassidy et al. (2015) show that access points along freeway traffic are prone to bottleneck conditions. This is due to limited space for vehicular maneuvers and can lead to driver refuge in the managed lane. In the Netherlands, both the right shoulder and left shoulder are used during peak traffic periods (FHWA, 2010).

Historically, the first US example of part-time shoulder use was on Seattle's SR 520, which allowed HOVs to form a queue approaching the city center. Since then, several states have implemented three 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) (FHWA, 2016b). A summary of the part-time shoulder use on U.S. freeways is listed in Table 2-1. The arterial applications are excluded from this table, which focuses only on freeway applications. The length of these corridors over which the shoulder is used as a travel lane is dependent on corridor specific needs, the investment capital for infrastructure, and the costs associated with right-of-way acquisition. The Federal Highway Administration (FHWA) (2010) reports a positive experience with ATM strategies in urban freeway networks.

Table 2-1 Part-time shoulder use on US freeways

Strategy	State	Corridor	Vehicle Type	Year
Bus on shoulder	Maryland	Multiple	Buses only	1991
	Florida	SR 826, 836, 874,878	Buses only	2005 - 2007
	Virginia	SR 267 EB	Buses only	
	Ohio	I-90/SR 2, I-71	Buses only	2006 - 2008
	Illinois	I-55	Buses only	2011
	North Carolina	I-40	Buses only	2012
	Kansas	I-35	Buses only	2012
Static	Georgia	GA 400	All	2005
	Massachusetts	I-93, I-95, SR 3	Passenger vehicles	1985
	Virginia	I-264, I-495	All	1992, 2015
	Washington	US 2	All	
	Colorado	I-70 EB	Passenger vehicles	2015
	Texas	SR 161	All	2016
Dynamic	Virginia	I-66	All	2015
	Minnesota	I-35 W	Dynamic priced	2009
	Michigan	US 23	Passenger vehicles	2017
	Pennsylvania	I-76 and I-476	All	2027

Source: FHWA, 2016b

2.2 Impacts on Safety

Opening a dynamic lane during peak-hour traffic reduces density and frequently increases average speed. However, the safety impacts of dynamic shoulders have been mixed.

The M42 corridor in Great Britain is equipped with a hard shoulder and variable speed limits. A crash analysis of this corridor indicated an overall reduction of between 1.83% and 5.08% crashes per month (MacDonald, 2008). Similarly, a 16% reduction in collisions, a 3% to 5% increase in throughput traffic, a 15% to 25% decrease in primary accidents, and a 40% to 50% decrease in secondary accidents with the use of speed harmonization has been reported (Taale, 2006). In the US, with lane control and variable speeds on the northbound portion of I-5 in Seattle, Washington reduced fatalities and injuries by 30% (Balogh, 2012). The National Cooperative Highway Research Program (NCHRP) reported 369 examined crash characteristics for ATM corridors in Washington, California, and Georgia and found that each state experienced a significant increase in crash frequency throughout the sections with combined use of shoulders and narrow lanes greater than 1 mile in length (FHWA, 2010). In addition, the FHWA (2014) found crash frequency slightly increased and the total annual crash rate increased 6.4% after using the shoulder as a travel lane on I-35 W in Minnesota. The increase in rear-end crashes was in part due to the altered traffic conditions along I-35 W with the installation of the priced dynamic shoulder lane. Shifting dense traffic conditions away from the recurring bottleneck and into the dynamic lane created an overall increase in crash frequency (Davis et al., 2018). Figure 2-1 shows the FHWA predicted changes in crash frequency for part-time shoulders with narrow lanes based upon two-way annual average daily traffic and number of lanes.

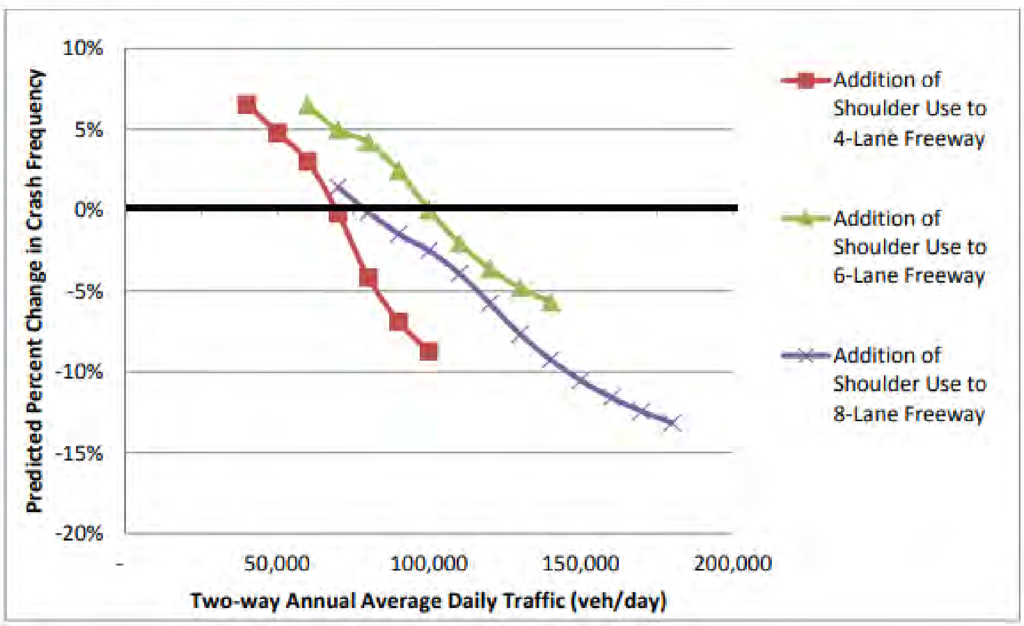


Figure 2-1 Crash frequency for part-time shoulder ATM with narrow lanes

Source: FHWA, 2016b

Aron et al. (2013) measured an increase in crashes downstream from France's dynamic lane along the A4-A86. Even though the dynamic lane section shows a reduction of 8% in the number of crashes annually, the entire system including the weave lane, upstream and downstream operation shows evidence of "crash migration" downstream as the number of crashes increased 5%. In addition, Germany reported no difference in crash rates on the stretches with dynamic shoulders while crashes slightly decreased upstream (Geistefeldt, 2012). These findings are consistent with other highways in Germany (BMVI, 2011), which indicate part-time shoulder use has no effect on roadway safety. Similarly, the Italian motorway A22 reported an increase of 35% in capacity due to hard shoulder running without a significant variation to safety conditions given the present crash modification factors which include lane and hard shoulder widths, safety barrier presence and location, and curve segment) (Guerrieri & Mauro, 2016). Research conducted by Coffey and Park (2018) showed that ATM strategies should be based on safety effects and structurally sound road operations. These factors should be carefully assessed prior to expanding the roadway.

Some states reported that hard shoulder running has no significant impact on safety. After implementation of an inside lane for HOVs and part-time right shoulder on I-66 in Virginia, no significant differences showed in crash frequency (Lee et al., 2007). FHWA (2016b) reported that driver confusion and aggressive lane change behavior were potential negative influences. The behavioral adaption to changes in roadway systems can often times be misinterpreted between engineering estimates and the perceived or actual outcomes since it is difficult to determine individual driver characteristics and acceptable risk. Rudin-Brown and Noy (2002) used qualitative methods to determine the degree of behavioral adaptation to changes in roadway systems and found that and ability to trust system automation is an influencing factor. Therefore, successful ATM systems should be reliable and accurate to generate positive driver behavior.

The safety concerns for ATM has led to state police agencies and transportation departments developing regional response protocols for shoulder use fatalities. To offset the loss of shoulder use as a refuge or emergency response in non-ATM corridors, Ma et al. (2016) suggested utilizing dynamic lanes for incident management to redirect traffic and allow for better incident recovery. In addition, their research showed that the overall effectiveness of a dynamic shoulder could vary greatly since impacts rely specifically on the roadway geometry, the occurrence of traffic incidents, and other scenarios. An empirical explanation offered by Kononov et al. (2012) distinguishes the relationship of flow, density, and speed to freeway crash rates. As flow increases, the crash rate remains constant; however, once the speed and density thresholds are exceeded, the crash rates will increase rapidly. The only way to offset this relationship is substantial reduction in speed to compensate for driver error.

The long-term implications to safety along ATM corridors are uncertain due to the extent of possible deployment options. As a result, the FHWA and agencies employing ATM strategies will need to cohesively address safety within the design exceptions that are required for traffic on shoulders.

NCHRP Project 17-89 examined the safety performance of part-time shoulder use on various freeways across the United States (Jenior et al., 2021). The project involved the development of safety performance functions for fatal-and injury (FI) crashes and property-damage-only (PDO) crashes for freeway segments, ramp entrance speed-change lane sites, and ramp exit speed-change lane sites. The study also resulted in a series of severity distribution functions that can be used to predict the distribution of crashes at various injury severity levels. The analysis included traffic and geometric characteristics, as well as details of the features of associated transition zones (i.e., locations upstream, downstream, or between portions of a freeway with a PTSU typical section) and turnouts (i.e., paved areas adjacent to a shoulder used for PTSU that function as refuge areas for disabled vehicles).

The results showed that higher FI crashes were observed on urban freeway segments with PTSU operations, especially on those segments where PTSU was in operation for longer periods of the day. Segments with turnouts or lane widths of 12 feet tended to experience fewer FI crashes. Interestingly, the results showed that the total number of crashes was 137 percent higher during times when the shoulder was open for use versus when it was closed. The report noted that no significant difference was observed in crash risks between right- and left-shoulder PTSU, which is due in part to the fact that there were limited numbers of cases where left-side shoulders were used by state DOTs. Total crashes were 7.3 percent lower at facilities that had converted from static PTSU to dynamic PTSU (e.g., activation based on volumes rather than fixed time periods).

2.3 Impacts on Congestion

Congestion has increased in urban areas in the US and Europe. As peak hour traffic conditions worsen, productivity decreases while crash rates and fuel consumption increase (FHWA, 2010). Dynamic lanes can be used to manage recurrent and non-recurrent congestion. A breakdown of the contributing factors of recurrent and non-recurrent congestion frequency in the US is shown in Figure 2-2.

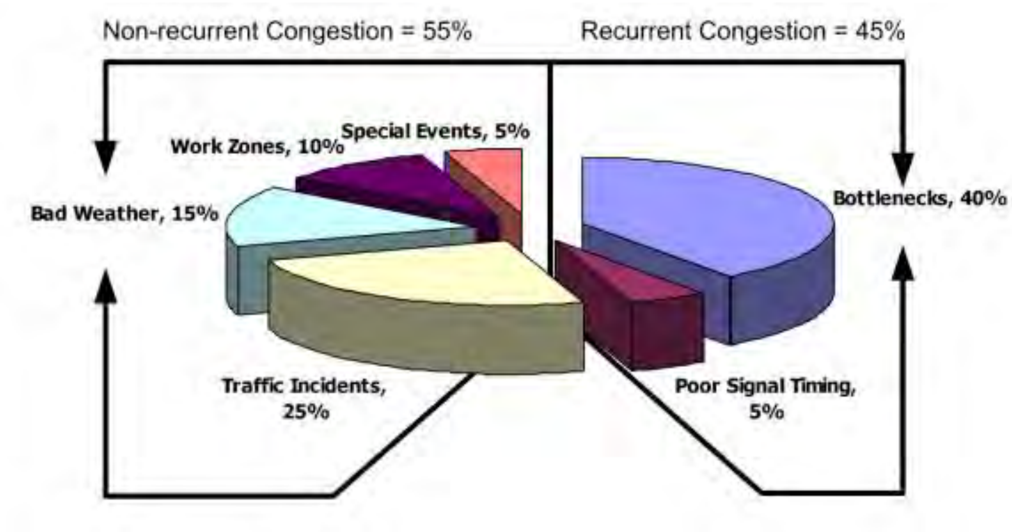


Figure 2-2 Congestion in the US

Source: FHWA, 2010

Similarly, European countries document that dynamic shoulders increase throughput traffic, reduce traffic congestion, and increase trip reliability during peak hour traffic (Fuhs & Brinckerhoff, 2010; Mirshahi et al., 2007). The UK reported smooth and consistent traffic conditions along M42 with an increase in capacity of weekday traffic from 7% to 9% when the hard shoulder is open. Speed harmonization has decreased peak hour travel times by 24% in the northbound and 9% in the southbound portion of M42. This reduction in travel time is consistent during winter and summer months despite the fluctuation of traffic demands. Since there is high consistency among all travel lanes of M42, the UK reported no adverse effect to the traffic in the surrounding areas due to ATM implementation (FHWA, 2010).

Another example of successful part-time shoulder use is along Munich area freeways in Germany, which has resulted in a 20% increase in capacity during rush hour (Fuhs & Brinckerhoff, 2010). Similarly, in Hessen, the capacity of a three-lane highway increased by 20% to 25% and the duration of congestion decreased by up to 90% (Geistefeldt, 2012). In the Netherlands, the Dutch employed a narrow median dynamic lane, similar to the US-23 Flex route. This lane was constructed in addition to the outside hard shoulder and is used when there is an increase in traffic volume. However, the temporary shoulders are only used in conjunction with variable speeds to minimize congestion and increase capacity by 7% to 22% (FHWA, 2010).

The Netherlands has provided sufficient data on variable speed management techniques since this ATM strategy was first implemented in 1981. By 2007, a total of 620 miles of roadway was reportedly equipped with variable speed technology. The standard operating speed along this Netherlands corridor is 75 mph and can be reduced to 31 mph to manage high traffic volume or incidents. The Dutch monitors speeds of the entire ATM corridor so that inconsistencies can be measured and displayed to drivers approaching congested areas. The queue warning displays offer driver awareness for sudden speed reductions to increase safety and improve traffic flow during congestion (FHWA, 2010).

In the US, part-time shoulder use on I-5 in Washington has increased throughput and reduced travel times by 8 to 10 minutes (FHWA, 2010). Similarly, Dutta et al. (2019) found a significant improvement in operational performance on I-66 in Virginia, and I-35W in Minnesota, which reported a 17% decrease in congestion with the dynamic shoulder (Neudorff & McCabe, 2015). Studies that evaluated ATM performance through numerical experiments of dynamic lane strategies found that ATM increases traffic capacity and decreases delays for the weaving and upstream segments (Wang et al., 2015).

There is a consensus among European countries and the US that dynamic lanes can reduce traffic congestion and increase traffic flow efficiency. Additional traffic benefits resulted directly from congestion reduction include trip reliability and freeway operational improvements.

2.4 Impacts on Drivers and Adjacent Communities

Many introductions of dynamic lanes have received public support due to expected operational benefits realized by drivers and communities (International Bridge, Tunnel and Turnpike Association, 2016). Ultimately, transportation agencies must deliver reliable traffic information, and the community must be able to effectively interpret and respond to the information displayed on ATM signs and signals for dynamic lanes to be optimally successful. To this end, driver understanding of the traffic control devices associated with dynamic shoulder use is critical. For example, a survey of drivers using the hard-running shoulder on M-42 in Birmingham, England, during peak traffic periods reported 90% awareness of ATM signs. But, only 25% of local users changed lanes when the "lane ahead closed" sign was displayed (Brinckerhoff, 2010). The Netherlands reported 95% of trips were completed on time through the effective use of speed harmonization, high-level customer service, and transportation reliability (FHWA, 2010). Likewise, Minnesota received support from I-35W MnPASS users and commuters for its I-35W corridor as it is an effective way to reduce congestion (FHWA, 2016b). The positive feedback comes in response to Minnesota Department of Transportation's outreach and education efforts to incorporate the public with design alternative discussions since acceptance is generally higher if there are clear and understandable benefits (Munnich et al., 2015). In contrast, research on the deployment of a dynamic lane along I-66 in Virginia shows significant increase in motorists' aggressiveness when changing lanes at the merge and diverge areas. In those areas, the crashes increased by 38% (Lee et al., 2007).

In an effort to avoid negative impacts to drivers and adjacent communities along the US-23 Flex route in Michigan, a total of 75 public, local and stakeholder meetings were held. The locals' primary concerns were secondary traffic impacts such as bottlenecks (Johnson, 2018). MDOT conducted an environmental assessment (EA) to mitigate controversy and address concerns presented at the public meetings. The EA reviewed multiple design alternatives including no build, Transportation System Management and Operation (TSMO), ramp metering, ATM with dynamic shoulder and lane use, and ATM with dynamic shoulder and lane use for HOVs (Johnson, 2018). The ATM with dynamic shoulder and lane use was selected based on MDOT's EA and the overall effort to minimize impacts on drivers. Additionally, MDOT displayed graphics on the queue warning system to avoid driver confusion during the final system testing phase.

2.5 Enforcement and Compliance

The level of driver awareness is directly related to compliance of ATM operations (Levecq et al., 2011; Neudorff & McCabe, 2015). Implementing dynamic shoulder and ATM techniques require legal and regulatory involvement at the local, state and federal level. Automated systems and external agencies that enforce compliance with dynamic lane operations should follow local, state, and federal laws and regulations.

The UK Highway Agency tracks the license plates of drivers on M42 using digital cameras. The Association of Chief Police Officers recorded high compliance of posted speed limits: 97% of drivers adhered to the 50mph speed limit; 93% of drivers adhered to the 40 mph (Brinckerhoff, 2010). Neudorff and McCabe (2015) reported that drivers' perception of enforcement directly relates to positive driving habits, and ATM corridors with dynamic lanes and variable speeds would not provide peak traffic performance without adequate enforcement.

Both Great Britain and the Netherlands have deployed the use of dynamic lanes that operate automatically during programmed peak hours or in the event of congestion and/or incidents (FHWA, 2010). The Dutch ATM system gathers data over 3 km sections of the highway corridor to effectively manage and control traffic. The National Traffic Control Center (NTCC) acts as the enforcement agency and records traffic patterns from five regional centers that operate 24 hours a day, 7 days a week in major cities. The NTCC develops national transportation guidelines to manage traffic emergencies across Europe through agreements with regional governments (FHWA, 2010).

It is uncommon for automated speeds to be posted outside of school or work zones in the U.S. since some states have legal restrictions on automated enforcement (FHWA, 2010, 2016b). Similar to US-23, Minnesota currently displays variable speeds on I-35 that are non-enforceable because dynamic speed limits are not permitted in the state. However, MnDOT contracts the Minnesota State Patrol to enforce the use of dynamic shoulder during peak traffic periods (Mirshahi et al., 2007). Johnson (2018) reported Michigan State Police issuing 22 citations for "improper lane use" along US-23 in Michigan during the first 3 weeks of operation. The Virginia State Police have noted difficulty employing enforcement along I-66 during off-peak periods due to narrow lane widths and tight spacing with short distances between interchanges. State police in Massachusetts and Washington reported minimal violations along ATM corridors with shoulder use (FHWA, 2010).

Introducing new enforcement mechanisms and rules is challenging, and concurrent literature suggests that compliance is higher if the public has direct input into decision-making over rules and regulations. The enforcement strategies outlined by Neudorff and McCabe (2015) include defining the legal support (regulatory or advisory), the station points for enforcement vehicles, and supporting technologies that notify enforcement for speed changes from the ATM operations.

2.6 Costs of Dynamic Shoulders

The life cycle costs of the ATM systems include initial construction and infrastructure upgrades, intelligent transportation systems (ITS) replacements or installations, maintenance, and enforcement. Determining a cost effective and appropriate strategy is specific to geometric clearance, visibly and the impact to safety (FHWA, 2010).

When considering the economic viability of a dynamic shoulder, the infrastructure and capital costs (initial pavement application, ITS design, environmental assessment, construction), operations and maintenance (continued compliance, driver training and awareness), and replacement costs (periodic replacements) must be included (FHWA, 2016b). The UK Highway Agency has developed a tool called "Managed Motorways Toolkit" to compare cost-benefit scenarios of ATM systems. The US FHWA developed a similar tool: Tool for Operations Benefit Cost Analysis (TOPS-BC). This tool can be used to estimate costs associated with ATM operations and evaluate deployment strategies, operational costs and maintenance prior to deployment. To account for inflation, a 10 to 20-year analysis should be used to monetize the cost-benefit of an ATM project. This analysis period will address the life cycle costs of the ATM system outlined in Table 2-2 for selected corridors. Maintenance of ATM is an ongoing cost that involves repairs, electricity costs and oversight of communication networks. The enforcement costs are region specific and may involve police and IT support staff.

Table 2-2 Life cycle costs for ATM systems

Corridor	Length	Infrastructure	ITS	Maintenance	Enforcement
M42 England	11 mi	$15 million per route mile; equates to $7.5 million per directional mile	$26.5 million for smart motorway features	N/A, extensive ATM routes with maintenance costs combined	$125K annually, includes staff and IT support services
I-35 W Minnesota	2.5 mi	$21.5 million for 10-mile stretch; $1.1 million per directional mile; $4 million per mile for dynamic shoulder	$1.2 million per mile for ITS signs + communications for the 2.5 mile ATM	$300k annual operation costs, $60k utility costs	$180k annually

I-5 Washington	1.5 mi	$23.8 million for preliminary engineering and construction costs for a 7-mile section; $11 million for ATM construction costs	$13 million cost for ITS and tolling on the express lanes	$1.2 million for operations and maintenance	$315k annually for entire ATM corridor
I-66 Virginia	12.4 mi	$14.6 million for infrastructure upgrades	$24 million for gantries, sensors, and traffic control devices	$3.7 million annually for operations costs	N/A, police cannot enforce variable speeds
US-23 Michigan	10 mi	$60 million in ATM costs, $40 million in additional construction costs	$17 million in ITS costs	$500k/year for operations and maintenance of field devices, $250k for additional staffing at the Transportation Operations Center	N/A, agency partners and emergency responders to provide feedback

Source: Buckeye, 2012; Chun and Fontaine, 2016; Johnson, 2018; McCourt, 2015; Neudorff and McCabe, 2015; Walker, 2014; Washington State Department of Transportation, 2011

It is evident that cost per mile for ATM systems can vary greatly based on the specific ATM strategies implemented. The potential for significant cost savings by combining ATM installations with a freeway construction project was reported by Minnesota during I-35 W development (Neudorff and McCabe, 2015). FHWA (2016b) reported that a temporary shoulder is considerably less expensive in comparison to the construction of a new freeway lane. However, the cost for ITS components such as queue warning and speed harmonization should be accounted for in a cost-benefit analysis for a specific corridor. It is necessary to identify the economic benefit of the entire system as well as its individual components for a proper evaluation of the ATM benefits and costs (Hadi et al., 2008).

2.7 FHWA Guidance on Dynamic Shoulders

The FHWA's Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD) establishes a national standard for traffic control devices used on all public highways. The

MUTCD provides guidance for transportation agencies as to the design and operation of part-time shoulder use. The latest draft edition published in 2020 incorporates recent technological advances and innovations, which aims to improve and promote the safe and efficient utilization of public roads (FHWA, 2020b).

The regulatory signage for part-time shoulder use is detailed under Section 2G.21. 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 signs and PART-TIME TRAVEL ON SHOULDER VARIABLE OPERATION signs to give road users with particular signage that distinguishes between fixed period and variable operation, as well as beacons to signal when shoulder use is permitted for variable operation. 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. FHWA proposes similarly proposes a sequence of signs, including TRAVEL ON SHOULDER ENDS, END TRAVEL ON SHOULDER, and DO NOT DRIVE ON SHOULDER, to ensure consistency in signage and to promote safety at all places that allow part-time shoulder travel by establishing a common understanding of when and where shoulder travel is permitted. 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 stopping 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.

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

Furthermore, FHWA proposes an option that would allow the installation of 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. FHWA suggests the overhead lane-use control signals should be installed and 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.” During the period when the temporary shoulder is open, a yellow X should be displayed about 1/2 mile in advance of the location where part-time shoulder ends. At the location where part-time shoulder use ends, a red X should be displayed at all times. To allow for additional flexibility if more advance warning of a lane closure is necessary, FHWA offers an option to allow a steady yellow X signal indication to 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 part-time shoulder ends). FHWA suggests lane-use control signals to 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 proposes an option that would allow the use of TRAVEL ON SHOULDER ALLOWED WHEN FLASHING signs and TRAVEL ON SHOULDER ON GREEN ARROW ONLY signs. However, MUTCD states that the combining of lane-use signals with overhead signs should be minimized to reduce the informational load on drivers and avoid miscommunicated messaging.

Ultimately, this research will supplement this guidance from the FHWA with empirical data as to the efficacy of using temporary lanes. This includes measures from ongoing performance and operations of US-23 as well as feedback from drivers and focus groups as to the utility of the US-23 Flex lane, the signage, as well as data detailing the degree to which the temporary lane shows tangible impacts on driver behavior and traffic safety upstream and downstream.

CHAPTER 3 OPERATIONAL PERFORMANCE

This chapter details a series of analyses focused on assessing the operational performance of the US-23 Flex route. A before-after comparison is conducted to quantify changes in speeds and travel times along the corridor after the median shoulder was converted to a temporary travel lane. This includes an evaluation of changes in average speeds/travel times, as well as various travel time reliability measures. Additional investigations were conducted to examine Flex route performance on the dates of special events (i.e., University of Michigan home football games and holidays), incident clearance times, and driver response to gantry messages.

3.1 Data

Several data sources were utilized to assess the operational performance of the Flex route. This includes probe vehicle data, microwave vehicle detection systems (MVDS) reports, permanent traffic recorder (PTR) data, ATM reports, and incident clearance data. The following sections provide an overview of each data source and describe how and where these data were used for analysis purposes.

3.1.1 Probe Vehicle Data

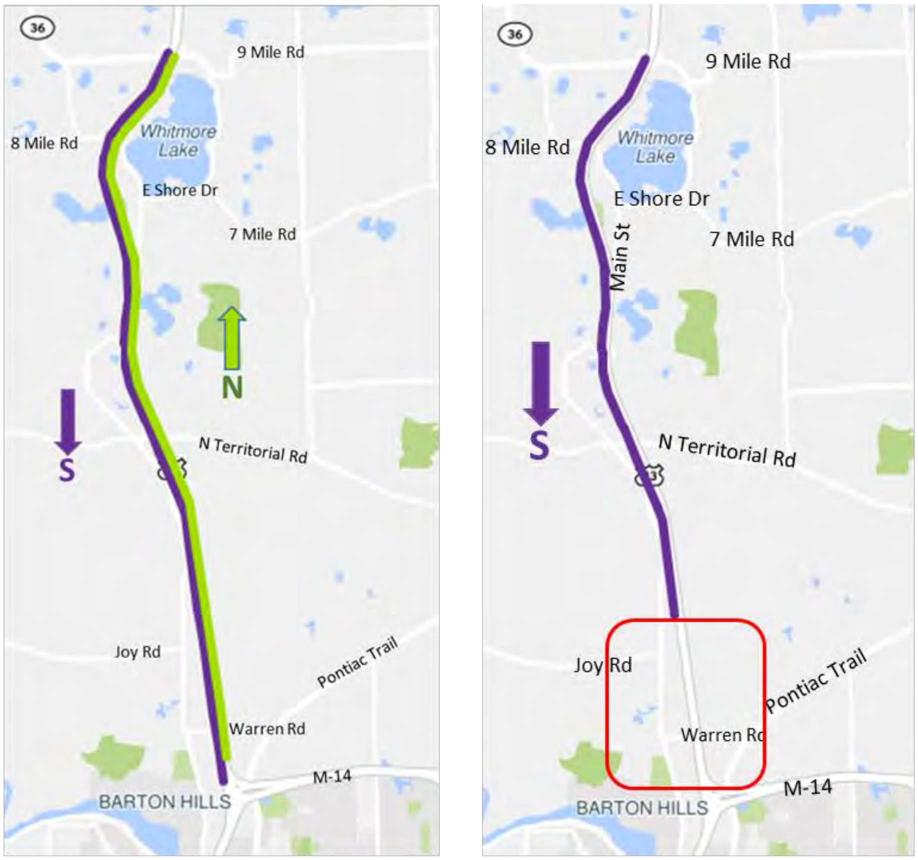
Probe vehicle data are collected from global positioning system (GPS) equipment that is installed in a wide variety of vehicles and devices, including commercial vehicle fleets, connected passenger vehicles, and cell phones. The GPS devices send and receive signals from earth-orbiting satellites. A control center converts information from the GPS signal to display real-time position and speed data for the probe vehicles. The corresponding travel time can be determined from the travel speed and distance (Barichello & Knickerbocker, n.d.; Turner et al., 1998).

In Michigan, probe vehicle data from INRIX is available through the Regional Integrated Transportation Information System (RITIS). RITIS is a secure data platform that integrates existing operational data from transportation agencies. It has a variety of uses for transportation officials, first responders, planners, and researchers to assess operational performances of roadways, evaluate active operations, perform long-range planning and capital programming, conduct research, improve executive leadership, and obtain traveler information (CATT Lab, 2021).

The Michigan INRIX data is available dating back to January 1, 2016 and includes real-time travel time information for each eXtreme Definition (XD) segment along the Flex route at various time intervals (1-minute, 5-minute, 10-minute, 15-minute, and 1-hour). Data are also available at the Traffic Message Channel (TMC) level. In comparison to a typical TMC segment, the XD segments generally have more granularity and allow for more detailed investigations as to how travel times/speeds vary over the road network (INTRIX, 2021). For the purposes of the Flex route evaluation, this is the only data source that provides travel speed and time information during the periods both before (i.e., 2016) and after (2018 onward) the route went into operation.

Ultimately, the data used as a part of this evaluation covered 8.76 miles of the US-23 corridor in the southbound direction and 8.49 miles in the northbound direction (based upon XD segmentation). Figure 3-1a shows the target area of INRIX probe vehicle data on the Flex route. A detailed quality assurance/quality control (QA/QC) review was conducted on these data at the onset of the analysis. This review of data available through RITIS showed that 1.75 miles of data were missing in the southbound direction from 12:00 am, January 1, 2016, to 2:00 pm, October 8, 2019. This area is highlighted in Figure 3-1b. In addition, there were also a few other minor issues with the data, including a few instances of missing or duplicate data. Ultimately, the data from the missing 1.75 miles were obtained directly from INRIX. Duplicate data were removed and there were a small number of cases where gaps existed in the final dataset, though these did not have a substantive impact on the analysis.

Initially, the operational evaluation was intended to compare changes in speed/travel time data between 2016 and 2018-2020. However, two issues created challenes in analyzing data from the latter time period. A significant inflection point was observed from speed profiles as shown in Figure 3-2 for both the southbound (Figure 3-2a) and northbound (Figure 3-2b) directions. In both instances, all speeds increased significantly in early June of 2019. This was due to changes in the fleet data that are used to provide the travel time estimates. From this point forward, there was a large increase in the relative proportion of passenger vehicle data (as compared to large trucks). This resulted in increases of 5 mph or more in travel speeds. In addition, it is also important to note that data from March 2020 onward were not directly comparable to the pre-Flex route data as substantive changes in travel patterns occurred due to travel restrictions imposed by the coronavirus disease 2019 (COVID-19) pandemic. The impacts of the pandemic are discussed further in latter sections of the report.

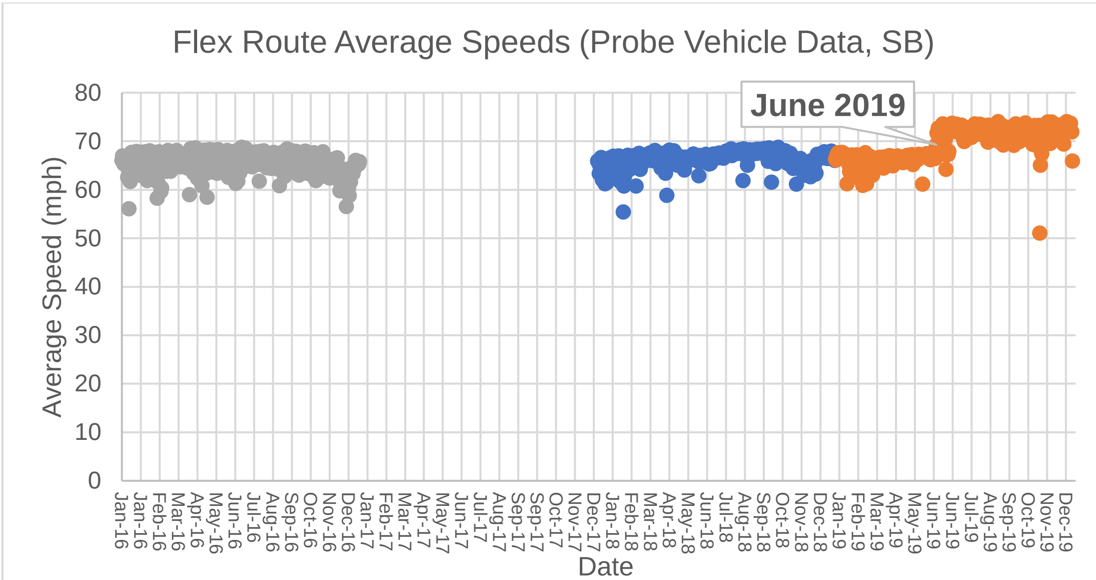


a. Target Area of Probe Vehicle Data

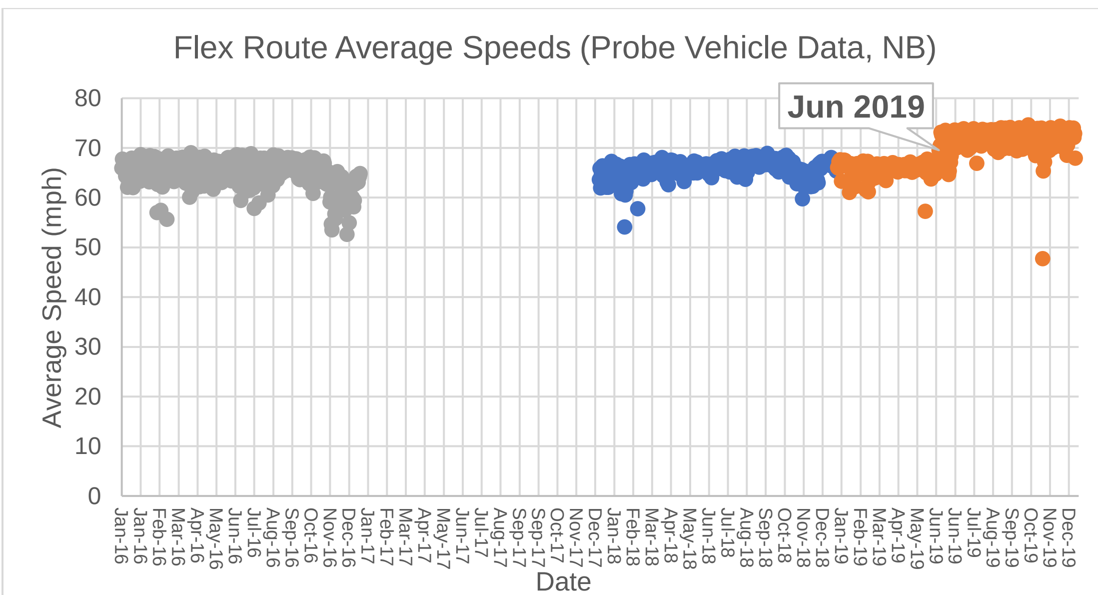
b. Missing Portion of RITIS

Figure 3-1 Coverage of INRIX probe vehicle data from RITIS

Consequently, to allow for a more appropriate comparison between the pre- and post-implementation periods, data from 2019 onward were removed from the analysis. As such, the before-after operational analyses focused exclusively on data from calendar years 2016 and 2018.



a. Southbound



b. Northbound

Figure 3-2 Yearly speed profile of INRIX probe vehicle data

3.1.2 Microwave Vehicle Detection System (MVDS) Reports

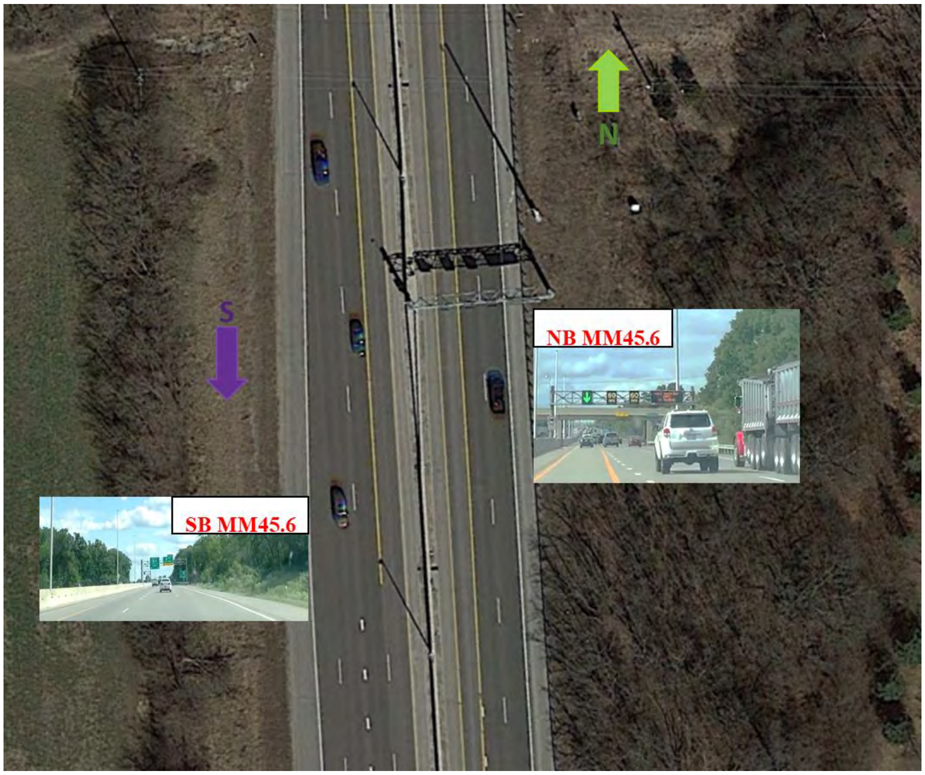
Microwave vehicle detection systems (MVDS) are a noninvasive means of collecting data from above ground sidefire microwave sensors. The data collection equipment consists of a radar detection unit pole-mount assembly, mounting hardware, Underwriters Laboratories (UL) approved power supply, lightning and surge protection, cables, and communications patch rods (MDOT, 2017). The system transmits microwave energy toward vehicles and the reflected signal can be used to determine vehicle volume counts and speeds in each travel lane based on the waveform that is transmitted by the radar sensor (Gordon & Tighe, 2005).

For the purposes of this study, two years of MVDS reports for the Flex route were provided by MDOT. These reports included directional speed and volume data for each lane at every mile marker (MM) along the Flex route at one-minute intervals. Unfortunately, these data are only available from January 1, 2018 onward. Since no data were available prior to when the Flex route went into operation, the MVDS reports were used for a series of analyses that focused on the in-service performance after the hard shoulder running was introduced in November 2017.

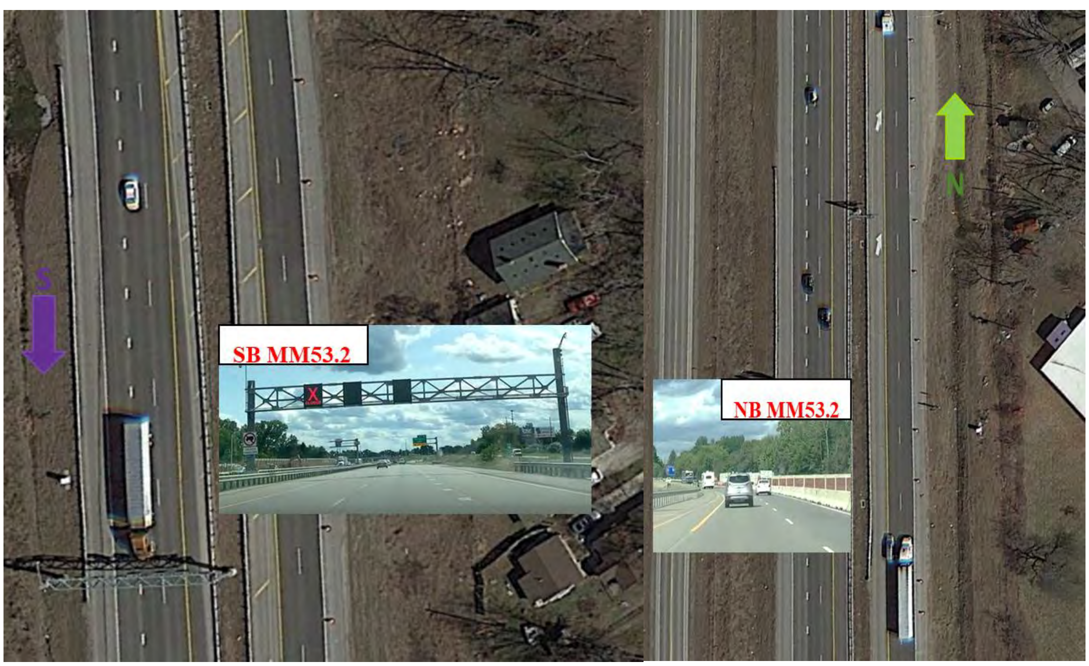
The Flex route is located between MM 45.6 and MM 53.2 as shown in Figure 3-3. In the southbound direction, the route starts at MM 53.2 and ends at MM 45.6 prior to the M-14 interchange (Figure 3-3a). The Flex lane is introduced near an auxiliary lane in this direction and the temporary travel lane terminates directly at the M-14 interchange without a lane drop (the shoulder lane converts to a general purpose lane just north of the M-14 interchange in the vicinity of Warren Road)

In the northbound direction, the Flex route starts at MM 45.6, where a third travel lane is introduced. One important difference as compared to the southbound direction is that a lane drop from three to two lanes occurs at the termination of the northbound Flex Lane near MM 53.2. This introduces a bottleneck as vehicles from the leftmost (shoulder) lane attempt to merge into the subsequent two-lane section (Figure 3-3b).

In addition to the data along the extents of the Flex route, the MVDS reports also contain partial upstream and downstream data at MM 43.4, MM54.0, and MM 55.6. These data are available from August 28, 2018 to December 31, 2019 and provide additional information that allows for an in-depth investigation of impacts immediately upstream and downstream of the Flex route, including the northbound bottleneck. Figure 3-4 displays a coverage map of where the MVDS sensors are installed.



a. MM 45.6



b. MM 53.2

Figure 3-3 Starting and ending mile markers of the US-23 Flex route

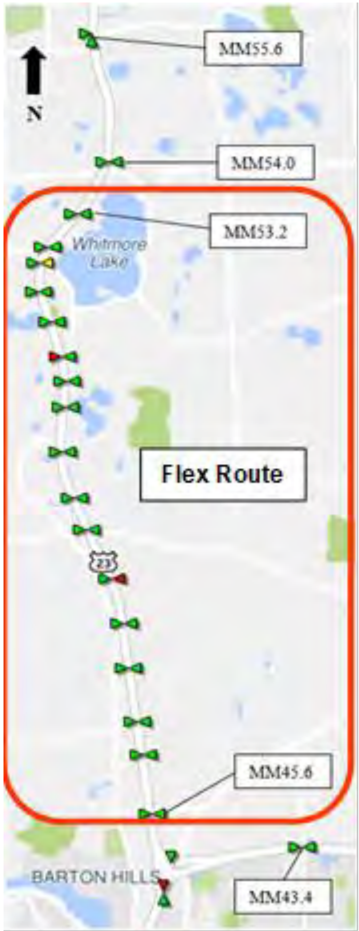
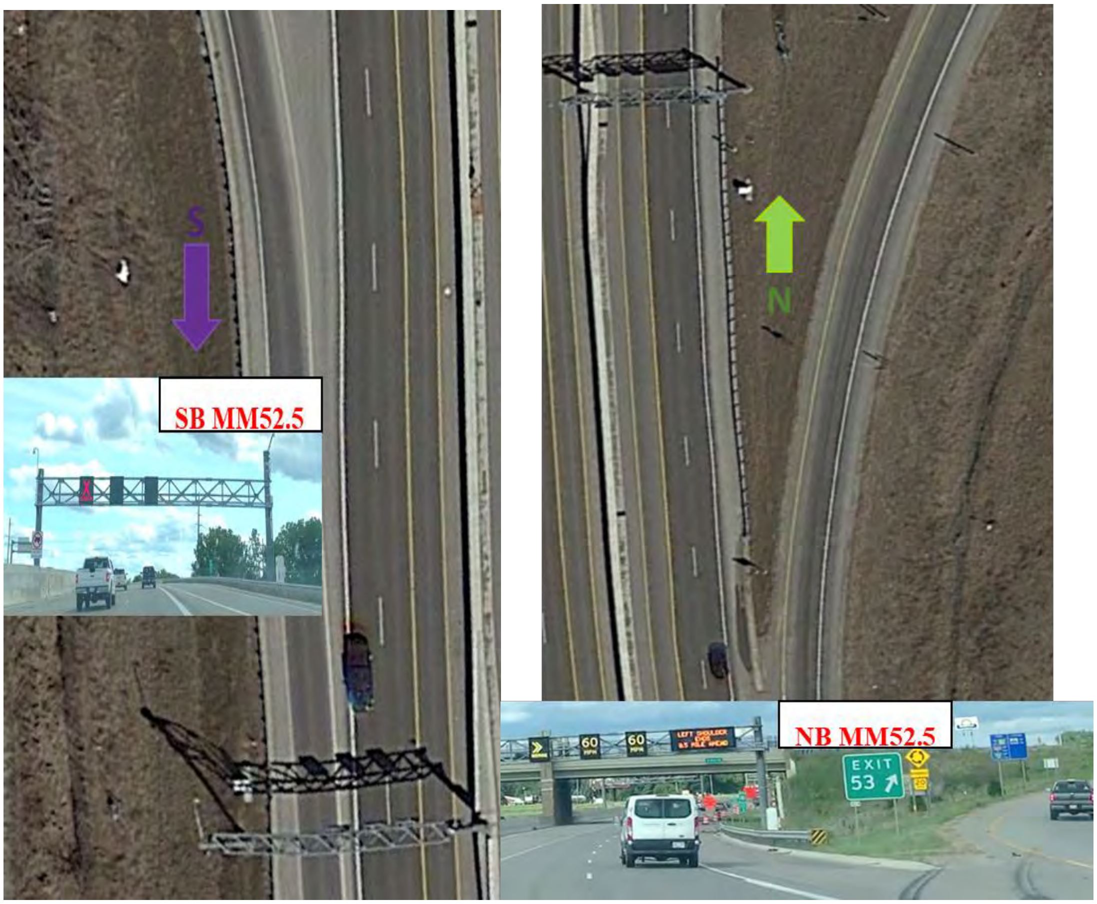


Figure 3-4 Map of MVDS sensor locations

As with the probe vehicle data, QA/QC reviews were conducted before analyzing the data. Several points should be noted regarding a few issues that were identified as a part of these reviews. In general, data are provided for three lanes in each direction along the Flex route. This includes the left shoulder, left lane, and right lane. However, additional data were available for the auxiliary lane at MM 52.5 in both directions. A deceleration lane is also located in the southbound direction at MM 52.5. Consequently, four lanes of data were anticipated at this location. However, data for only three lanes were provided in the MVDS reports. An investigation suggests that data from the inside shoulder (Flex lane) were missing at this location. Figure 3-5 shows pictures of the gantries at each of these locations, which illustrate the presence of additional acceleration/deceleration lanes at MM 52.5, as well as a deceleration lane at MM 53.2.



a. MM 52.5

b. SB MM 53.2

Figure 3-5 Pictures of mile markers 52.5 and 53.2 on US-23 Flex route

3.1.3 Permanent Traffic Recorder (PTR) Data

As noted above, the only operational data available prior to January 1, 2018 were from RITIS/INRIX. While this information includes travel time and speed information, there were no volume data available. The only source of detailed volume data is from the MVDS.

Consequently, estimates of the hourly traffic volume for the period prior to Flex route implementation were obtained from permanent traffic recorder (PTR) stations. PTR stations are installed throughout Michigan as a part of the MDOT traffic monitoring program. Permanent electronic sensors are installed in the pavement and continuously record the passage of vehicles over a specific portion of roadway over time. The resultant reports provide hourly data for each day of the month, in addition to summary average daily traffic (ADT) counts for every Saturday, Sunday, weekday, and month (MDOT, n.d.-b).

MDOT provided PTR reports for the period from 2014 through 2020. The PTR data for the Flex route were specifically obtained for PTR Station 8239, which is located 0.5 miles south of Barker Road. These data include hourly volume count and travel speeds from 2014 through 2017. The volume and speed data are available at 15-minute intervals after 2017. However, data inspection showed a number of time gaps, including the periods from January to February 2016 and January 2017 to June 2018. Consequently, 2015 and 2019 PTR data were utilized in the study as these were the years for which full data were available as near to the implementation date of the Flex route as possible. A summary of the PTR data is shown in Table 3-1 and details of changes in hourly volumes between 2015 and 2019 are included in Figure 3-6. The results showed that the maximum throughput in the northbound direction increased by 11.0 percent and in the southbound direction by 35.4 percent.

Table 3-1 Descriptive statistics of PTR hourly volume data

Direction	Period	Year	Min.	Max.	Mean	Std. Dev.
NB (veh/hr)	Before	2015	149.7	3141.62	1372.87	943.23
	After	2019	154.6	3486.16	1482.23	1050.21
SB (veh/hr)	Before	2015	112.29	2502.29	1371.89	838.32
	After	2019	122.14	3388.63	1524.99	995.58

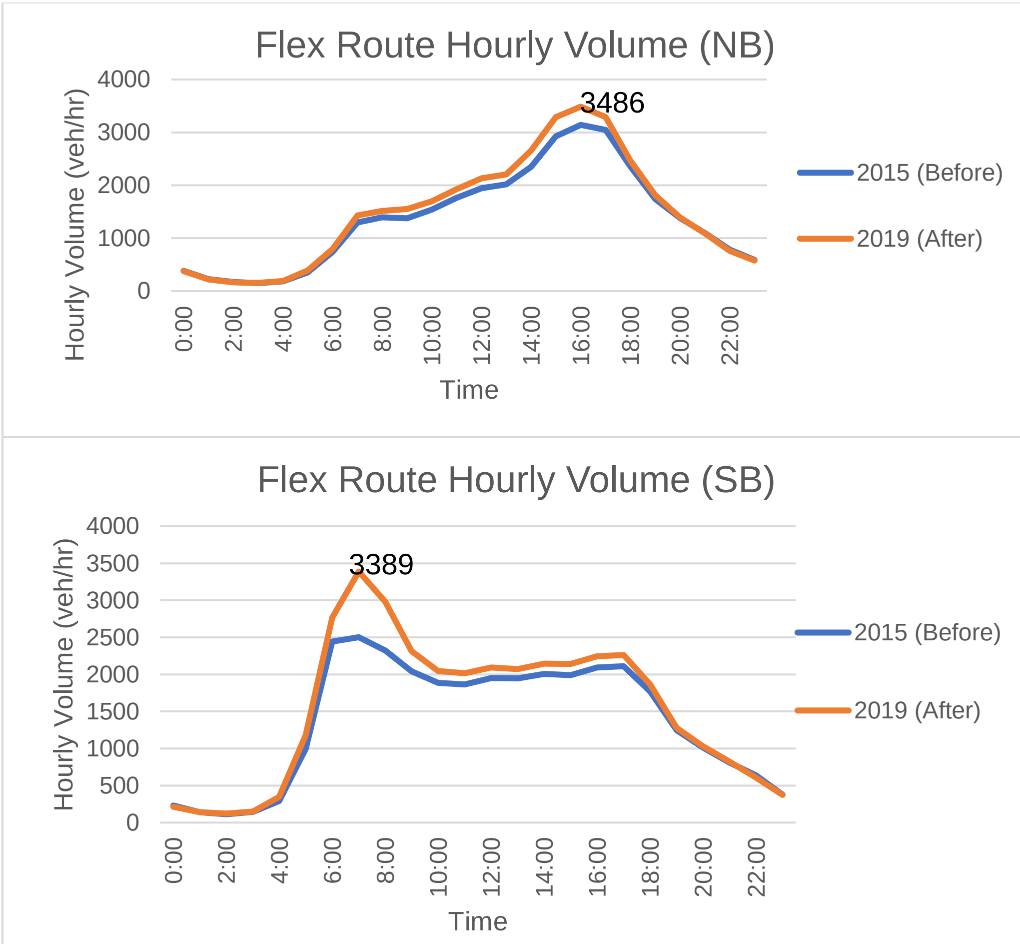


Figure 3-6 Hourly volume of US-23 Flex route

3.1.4 Active Traffic Management (ATM) Reports

As a part of the active traffic management (ATM) system, a series of dynamic message signs (DMS) are installed on the overhead gantries at each mile marker which are spaced at approximately every 0.5 miles along the Flex route. These signs display different messages, such as whether the shoulder or a specific travel lane is opened or closed, as well as variable advisory speeds, queue warnings, overheight vehicle warnings, etc. An example photo of a gantry with four DMS from the Flex route is shown in Figure 3-7. There are 16 and 18 gantries installed in the southbound and northbound directions, respectively, of the US-23 Flex route. Among these, five gantries in the southbound and four gantries in the northbound direction include a sequence of four DMS as shown in Figure 3-7. The other gantries include three DMS, exclusive of the large text-based sign that appears over the right shoulder.

The ATM reports provided by MDOT included timestamps (to the nearest second) and corresponding messages whenever a gantry message changes. Similar to the MVDS reports, the ATM reports were available from January 1, 2018 onward. As with the previously described datasets, the analyses in this project were from January 1, 2018 to December 30, 2019.

The typical messages shown on each of the four DMS are summarized below:

- **DMS 1:**
    - Red X, Green Arrow, Merge Right
- **DMS 2 and DMS 3:**
    - Various advisory speeds (e.g., 60/50/40/30 mph)
    - Red X, Green Arrow, Merge Right or Merge Left
- **DMS 4:**
    - Detailed messages to guide drivers: slow traffic warning, lane closure, crash warning, left shoulder is open/closed etc.

Figure 3-7 An example of gantry messages on the US-23 Flex route (NB MM46.8)

3.1.5 Incident Clearance Data

Unexpected and non-recurring incidents (e.g., crashes, debris, disabled vehicles) generally cause frustration for motorists, introduce considerable delay, and create additional adverse impacts such as wasted fuel. In response to these issues, MDOT established a Freeway Courtesy Patrol (FCP) in 1994 to assist motorists who encountered such issues on select freeways in Southeast Michigan, including the US-23 corridor. The FCP operates 24 hours per day, seven days a week. The primary goals of the FCP are to reduce the delay caused by these types of incidents and improve the operations of the freeway system. The FCP services include (MDOT, n.d.-a):

- servicing disabled vehicles by providing fuel, oil, and other system fluids;
- clearing stranded vehicles and debris from driving lanes;
- changing or inflating tires;
- making minor mechanical repairs;
- securing the area around your vehicle;
- transporting motorists to a safe location;
- providing cell phone assistance;
- transporting stranded motorists; and,
- providing directions.

For the purposes of this study, data from the FCP data was obtained in order to better understand the impacts of the Flex route on the operational and safety performance of the corridor. To this end, incident clearance data from the FCP was obtained for periods before (January 2015-December 2016) and after (January 2018 – March 2019) implementation of the US-23 Flex route. After March 2019, the vendor of this data changed from the MDOT FCP to a third-party contractor. Thus, additional data for the rest of 2019's months were obtained from this contractor. The data involved traffic management information such as locations of events, types of events and services, FCP arrival time, and the incident clearance time, etc. The incident clearance time is defined as the time when the traffic fully recovers after incidents.

3.1.6 Data Integration

The datasets described previously were integrated for analysis purposes. As a part of the operational analyses, three primary datasets were utilized: microwave vehicle detection system (MVDS) reports; permanent traffic recorder (PTR) data; and INRIX probe vehicle data.

Data at the highest level of fidelity were obtained from the MVDS reports, which provide traffic volume and average speed information at each mile marker in one-minute intervals. These data became available once the ITS infrastructure was installed and, consequently, these data are only available for the period after the Flex route went into operation. Before period Flex Route volumes were assumed to be proportional (across XD segments) to the after period volumes. Consequently, the 2016 traffic volumes were estimated using the ratio of annual average daily traffic (AADT) between the before and after periods. Data for the 2016 and 2018 AADT were collected from MDOT's Traffic Data Management System (TDMS). The TDMS provides continuous count data from PTR stations. The segment-specific 2016 volumes were estimated by multiplying the 2018 MVDS volume data by the ratio of 2016 AADT to 2018 AADT. To be consistent with the INRIX probe vehicle data, all MVDS traffic volumes were aggregated into 15-minute intervals.

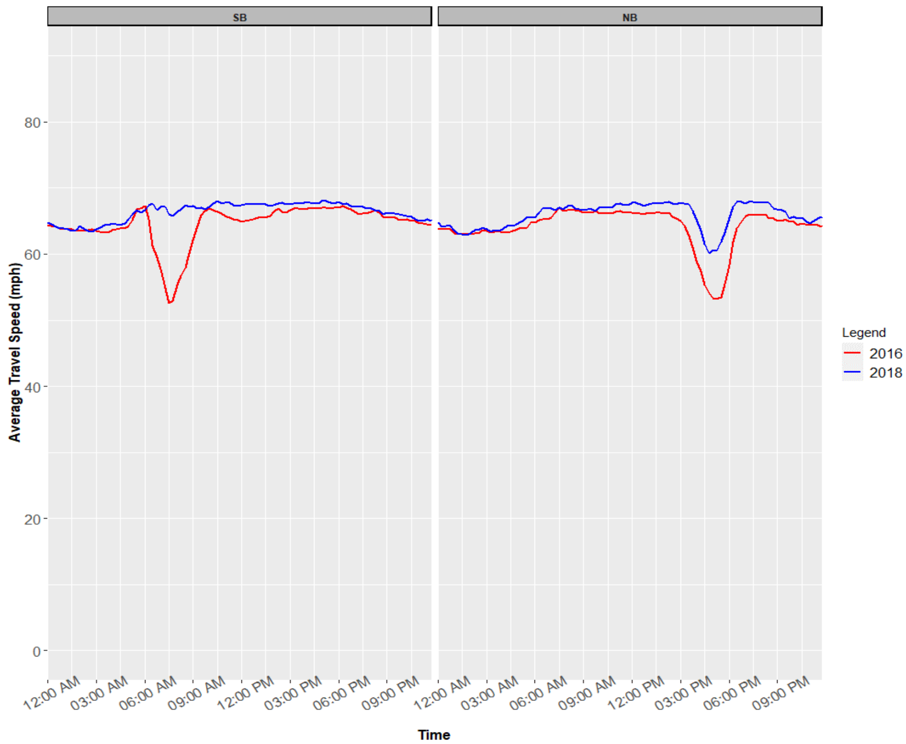
As noted previously, the travel times for each XD segment before (2016) and after (2018) construction of the Flex route were available from INRIX probe vehicle data. The travel time was calculated based on the average vehicle speed and length of each XD segment (i.e., segment length divided by average speed). The INRIX travel time data are available at the segment level, but the MVDS traffic volume data are available at the point level. To join the two datasets, the shapefiles for the Michigan INRIX XD segments, 2015 sufficiency file, and Michigan mile marker database were obtained from MDOT. The XD segment shapefiles include the coordinates of the starting points and ending points for each segment's hours. The sufficiency file provides the physical road (PR) number, as well as the beginning mile points (BMP) and ending mile points (EMP) for each Michigan trunkline segment. It also serves as the base map for the Michigan government. The mile marker shapefile indicates the locations of specific mile markers along the US-23 corridor, along with the corresponding physical road (PR) number and mile points. The following steps outline the integration procedures for these databases:

1. The Flex route segments, as well as the upstream and downstream segments, were aggregated such that they were approximately one mile in length based on PR numbers, as well as BMPs and EMPs from the sufficiency file. This resulted in a total of nine segments in the southbound direction and eight segments in the northbound direction.
2. A linear referencing tool was used in ArcMap to locate the starting and ending points of XD segments along the Flex route. These points were matched with the sufficiency file to determine the corresponding PR numbers and mile points.

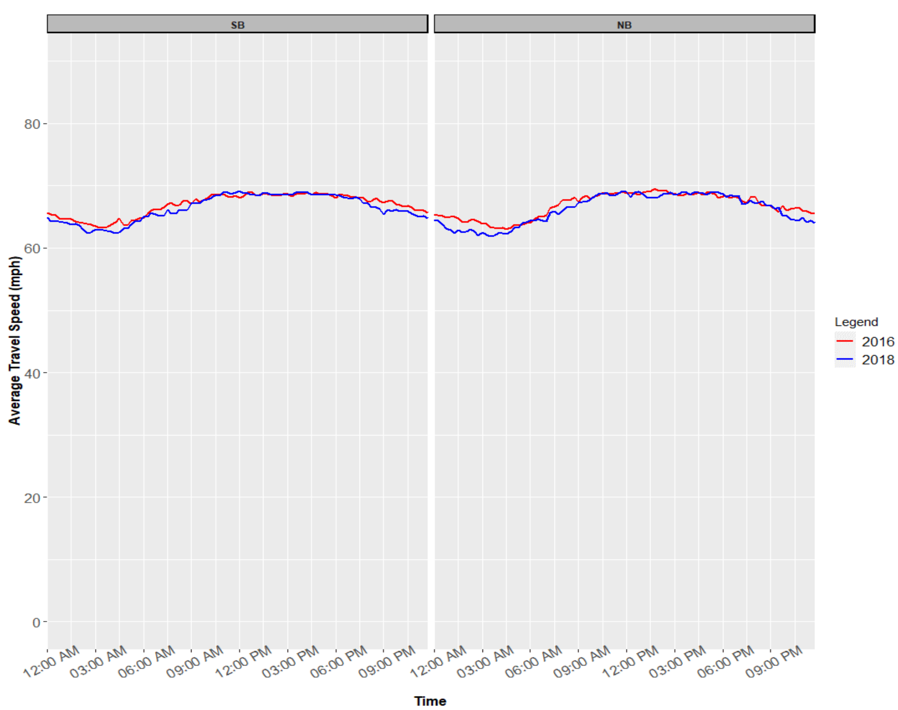
3. The XD segments were aggregated into approximately one-mile lengths based on PR numbers, BMPs, and EMPs as detailed in Step 1. Travel times were calculated for these segments from the INRIX probe vehicle data.
4. The traffic volume was calculated at the segment level using the PR numbers and mile points from the mile marker shapefile.
5. Vehicle miles traveled (VMT) were calculated by multiplying these volumes by the adjusted segment lengths.
6. VMT-weighted travel times were then calculated for each segment.

3.2 Impacts on Travel Time and Reliability

The INRIX probe vehicle data were used to examine changes in travel time and speed data before and after implementation of the Flex route. Figure 3-8 shows trends in average travel speeds between the before and after periods. Average travel speeds increased significantly during weekdays, especially during peak hours. In contrast, no significant difference was found during the weekends. In addition, Figure 3-9 presents changes in the average speeds moving in each direction along the Flex route. These data generally show increasing speeds in both the southbound and northbound directions, except for the northernmost extent in the northbound direction at the lane drop.



a. Weekdays



b. Weekends

Figure 3-8 US-23 Flex route average travel speed over time

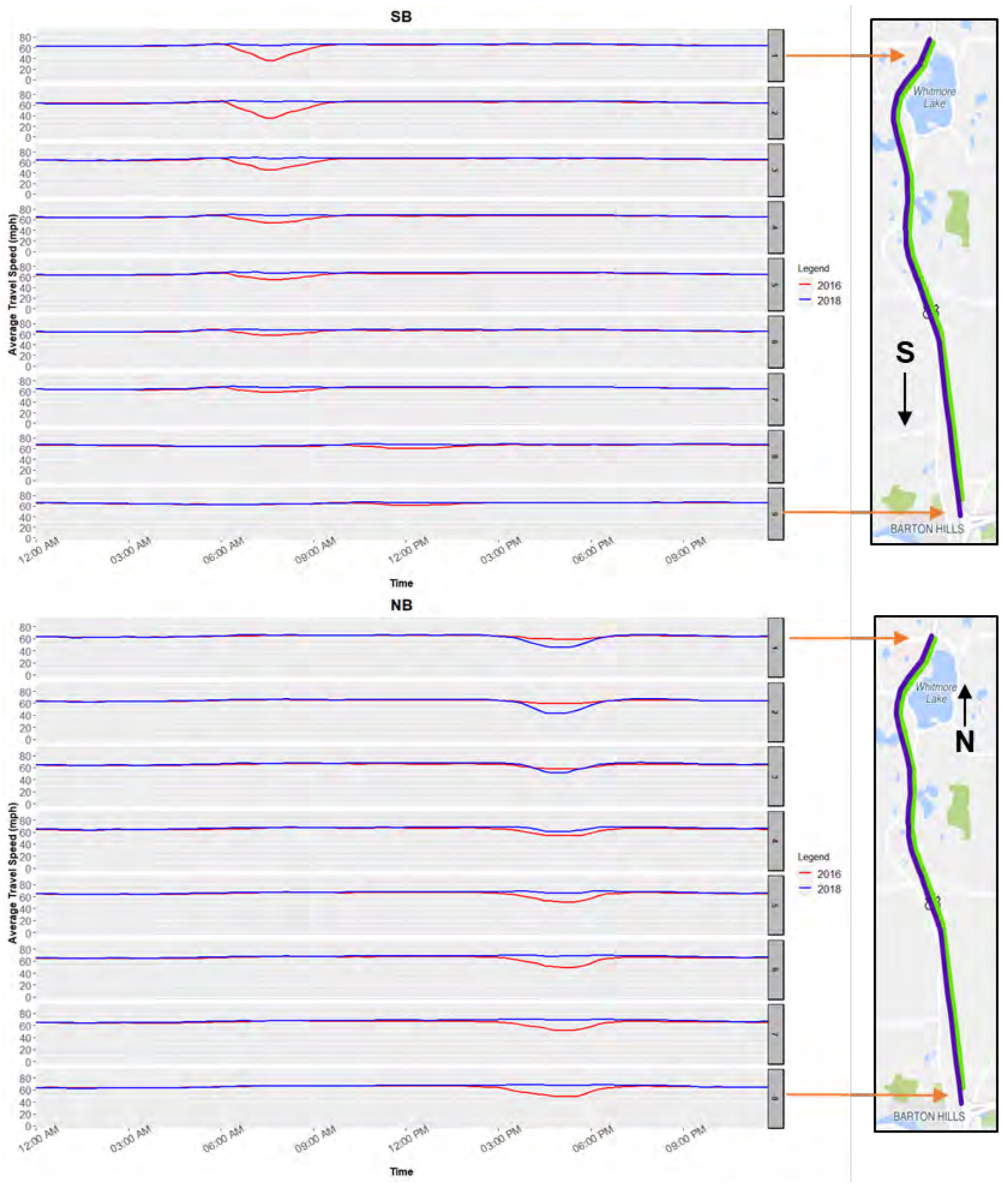


Figure 3-9 US-23 average travel speed over time at segment-level

3.2.1 Travel Time Reliability Definitions

Travel time reliability is one of the key factors to evaluate the operational performance of a transportation system. According to the FHWA, travel time reliability is “the consistency or dependability in travel times, as measured from day-to-day and/or across different times of times of the day” (Office of Operations, 2005). Reliability is crucial to both motorists and freight carriers.

Consistent, reliable travel times allow travelers to assess their time and make better use of it. Similarly, freight carriers rely on predictable travel times to stay competitive in the market. Travel time reliability has also become a widely used measure for evaluating the effectiveness of countermeasures, such as hard shoulder running (Office of Operations, 2005). Therefore, to understand the effectiveness of the US-23 Flex route, various travel time reliability measures were calculated for the periods before and after implementation. This section introduces several of these measures and details the methodology used to calculate each using the data described previously.

According to the FHWA, reliability can be quantified in the following ways (Office of Operations, 2005):

- Free-flow travel time: The free-flow travel time was calculated as the 85th percentile travel time during the off-peak period (Office of Operations, 2015). For the purposes of the Flex route, this period is defined as Monday through Friday, from 9 am to 4 pm and 7 pm to 10 pm, as well as Saturday and Sunday from 6 am to 10 pm.
- Travel time index: The travel time index is the ratio of the average travel time required as compared to the free-flow travel time and is calculated as shown in Equation 1.

$$\textbf{Travel Time Index} = \frac{\textbf{Average Travel Time}}{\textbf{Free Flow Travel Time}}$$ **Equation 1**

- Planning time (or 95th percentile travel time): The planning time provides an upper bound, or near worst-case scenario, for the travel time. This is calculated as the 95th percentile travel time.
- Planning time index: The planning time index represents how much larger the 95th percentile travel time is as compared to the ideal or free-flow travel time. Equation 2 shows the calculation of the planning time index.

$$\textbf{Planning Time Index} = \frac{\textbf{95th Percentile Travel Time}}{\textbf{Free Flow Travel Time}}$$ **Equation 2**

- Buffer time: The buffer time denotes the extra time (beyond the average travel time) required by drivers in order to traverse a segment in no greater than the 95th percentile travel time. Equation 3 shows the calculation of buffer time.

$$\textbf{Buffer Time} = \textbf{95th Percentile Travel time} - \textbf{Average Travel Time}$$ **Equation 3**

- Buffer time index: The buffer time index expresses the buffer time as a proportion of the average travel time as shown in Equation 4.

$$\textit{Buffer Time Index} = \frac{\textit{Buffer Time}}{\textit{Average Travel Time}} \qquad \textbf{Equation 4}$$

3.2.2 Travel Time Reliability Results

Summary data for each of the travel time reliability measures were calculated over the Flex route limits and are included in Table 3-2, Table 3-3, and Table 3-4. First, Table 3-2 presents reliability measures on a daily basis for weekdays. Separate estimates are provided for the periods before and after the Flex route went into operation. Table 3-3 presents these same quantities for weekends.

Table 3-2 Results of travel time reliability during weekdays (24 hours)

Direction	Period	Year	Free Flow Travel Time (mins)	Average Travel Time (mins)	95th percentile Travel Time (mins)	Buffer Index	Planning Time Index	Travel Time Index
Southbound	Before	2016	8.2	8.4	11.0	0.3	1.3	1.0
	After	2018	8.2	8.0	8.6	0.1	1.1	1.0
Northbound	Before	2016	8.0	8.3	11.4	0.4	1.4	1.0
	After	2018	8.0	7.9	9.0	0.1	1.1	1.0

Collectively, these data show that the average travel times on the Flex route were reduced from 8.4 to 8.0 minutes in both directions when considering the entire 24-hour period on weekdays. The 95th percentile travel times were reduced by 2.4 minutes (21.5 percent) regardless of direction. The corresponding indices all generally improved as well. In contrast, the free-flow and average travel times on the Flex route ranged from 7.8 to 8.0 minutes during weekends when considering the entire 24-hour period. These travel times (and the associated speeds) were virtually unchanged between the before and after periods. Similarly, the other metrics tended to be quite similar when averaging over weekend days.

Table 3-3 Results of travel time reliability during weekends

Direction	Period	Year	Free Flow Travel	Average Travel Time (mins)	95th percentile Travel	Buffer Index	Planning Time Index	Travel Time Index

			Time (mins)		Time (mins)			
Southbound	Before	2016	8.2	8.0	8.6	0.1	1.0	1.0
	After	2018	8.2	8.0	8.8	0.1	1.1	1.0
Northbound	Before	2016	8.0	7.7	8.4	0.1	1.0	1.0
	After	2018	8.0	7.8	8.7	0.1	1.1	1.0

These same quantities were calculated separately for the peak and off-peak hours on weekdays and are detailed in Table 3-4. Table 3-4 is of particular interest as this illustrates the changes that occurred during the peak traffic periods when the Flex route is in operation. After the Flex route went into operation, average travel times during the peak periods were reduced by 16.5 percent and 11.2 percent in the southbound and northbound directions, respectively. Similarly, reductions of 37.3 percent and 20.8 percent in the 95th percentile travel times were observed southbound and northbound, respectively. These reductions led to improvements in the corresponding trip planning time and buffer time metrics, as well. Furthermore, drivers were able to save additional time during the off-peak hours, though these savings were relatively small.

Table 3-4 Results of travel time reliability during weekdays (peak vs. off-peak hours)

Direction	Period	Year	Free Flow Travel Time (mins)	Average Travel Time (mins)	95th percentile Travel Time (mins)	Buffer Index	Planning Time Index	Travel Time Index
Peak Hour								
Southbound 6:00–9:30 am	Before	2016	8.2	9.7	14.2	0.5	1.7	1.2
	After	2018	8.2	8.1	8.9	0.1	1.1	1.0
Northbound 3:00–7:00 pm	Before	2016	8.0	9.8	17.3	0.8	2.2	1.2
	After	2018	8.0	8.7	13.7	0.6	1.7	1.1
Off-Peak Hour								
Southbound	Before	2016	8.2	8.2	8.7	0.1	1.1	1.0
	After	2018	8.2	8.0	8.6	0.1	1.1	1.0
Northbound	Before	2016	8.0	8.0	8.6	0.1	1.1	1.0
	After	2018	8.0	7.8	8.5	0.1	1.1	1.0

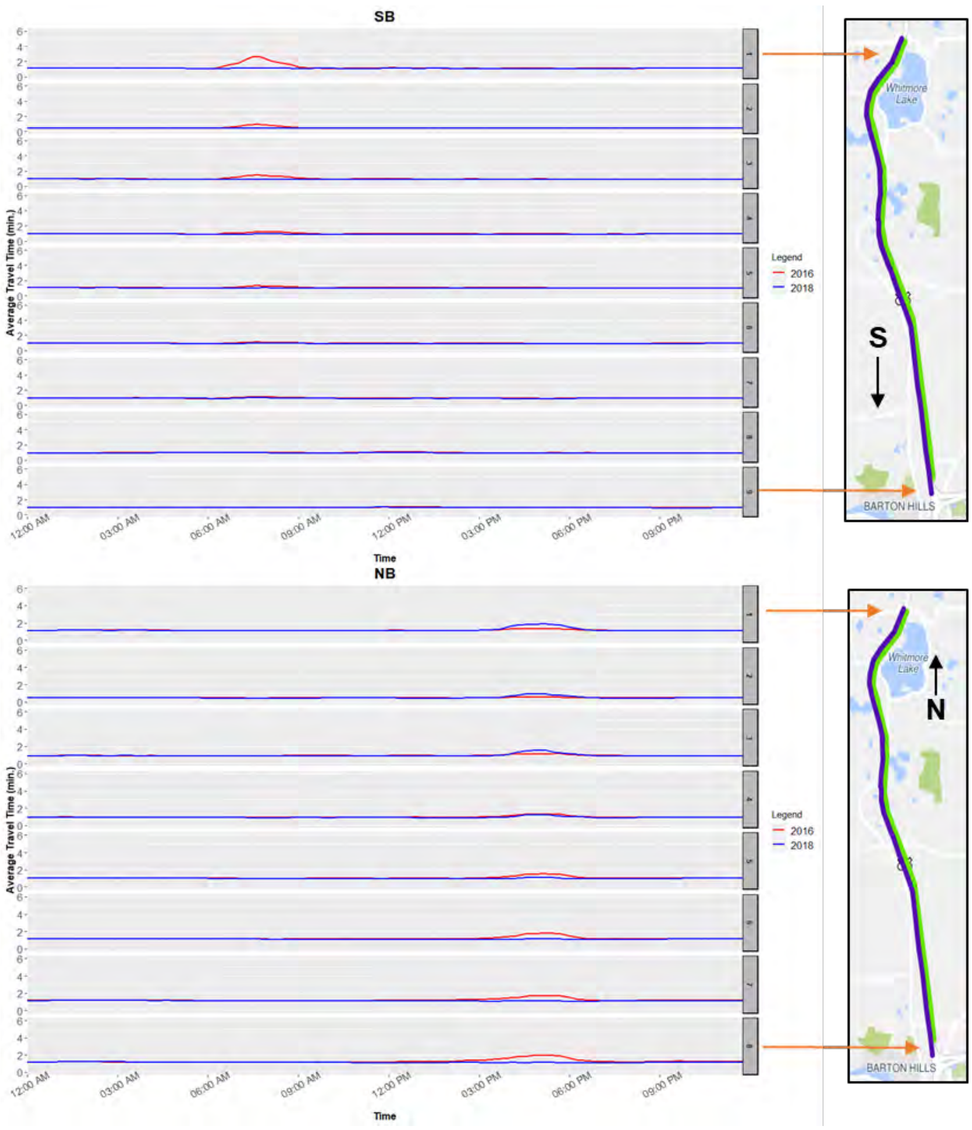
In general, motorists in the southbound direction tended to save more time than in the northbound direction. This is largely due to a bottleneck that is present at the northbound terminus of the Flex route where the left (inside shoulder) lane terminates in a lane drop condition.

In addition to the overall performance, travel time reliability was also examined at the individual segment level. As discussed previously, the southbound and northbound directions were comprised of nine segments and eight segments, respectively. The average and 95th percentile travel time, buffer time index, planning time index, and travel time index were calculated for each segment during weekdays and weekends.

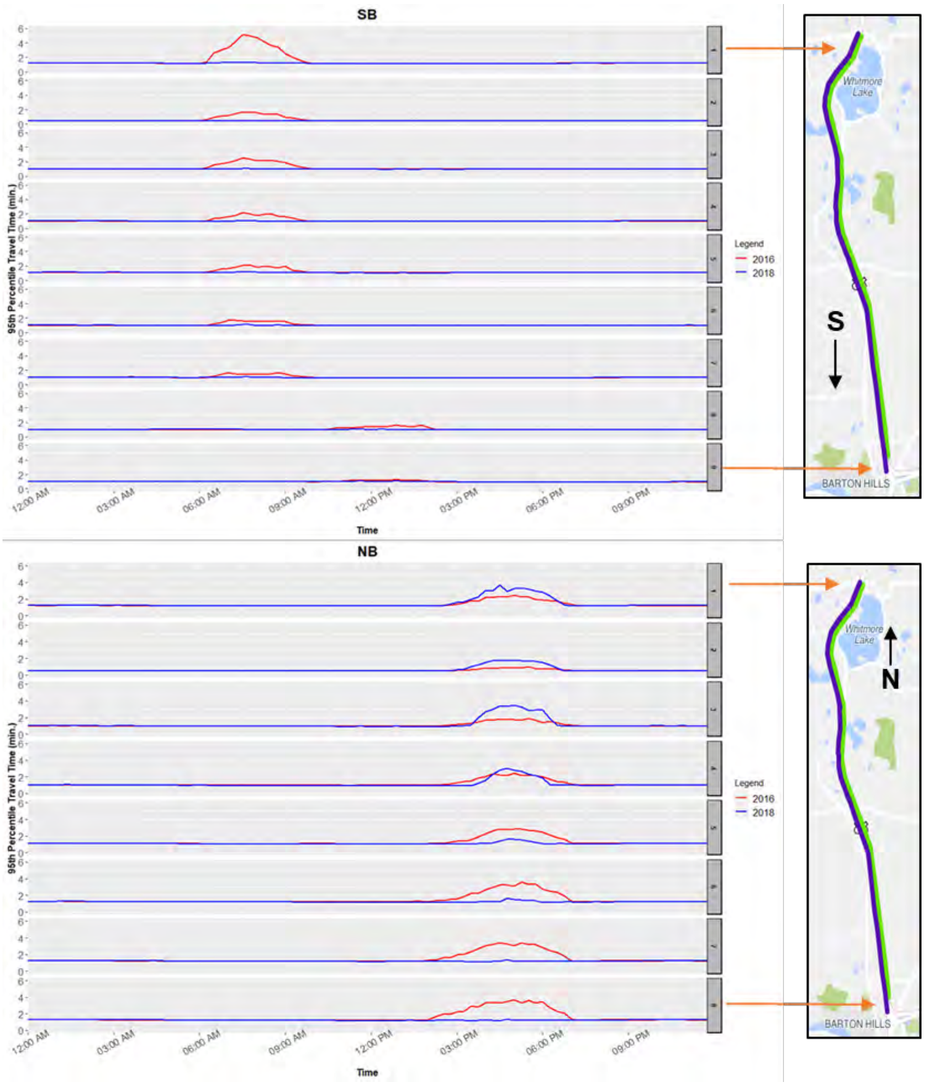
To allow for a visual assessment of changes in travel times over time and space, the target variables were plotted for each segment by time of day and are shown in Figure 3-10 and Figure 3-11. Since the trends of planning time and travel time index were similar to the trends of average and 95th percentile travel time, the plots of planning time and travel time index can be found in APPENDIX A.

Figure 3-10 shows gradual, but persistent, improvement in average annual travel times during weekday peak hours in both directions. These benefits were more pronounced in the southbound direction. In contrast, travel times actually increased downstream near the Flex route terminus in the northbound direction. This was again due to the bottleneck that occurs at the lane merge at the Flex Route termination point. The planned extension of the Flex route to I-96 should address this issue and result in improvements that are consistent across the corridor.

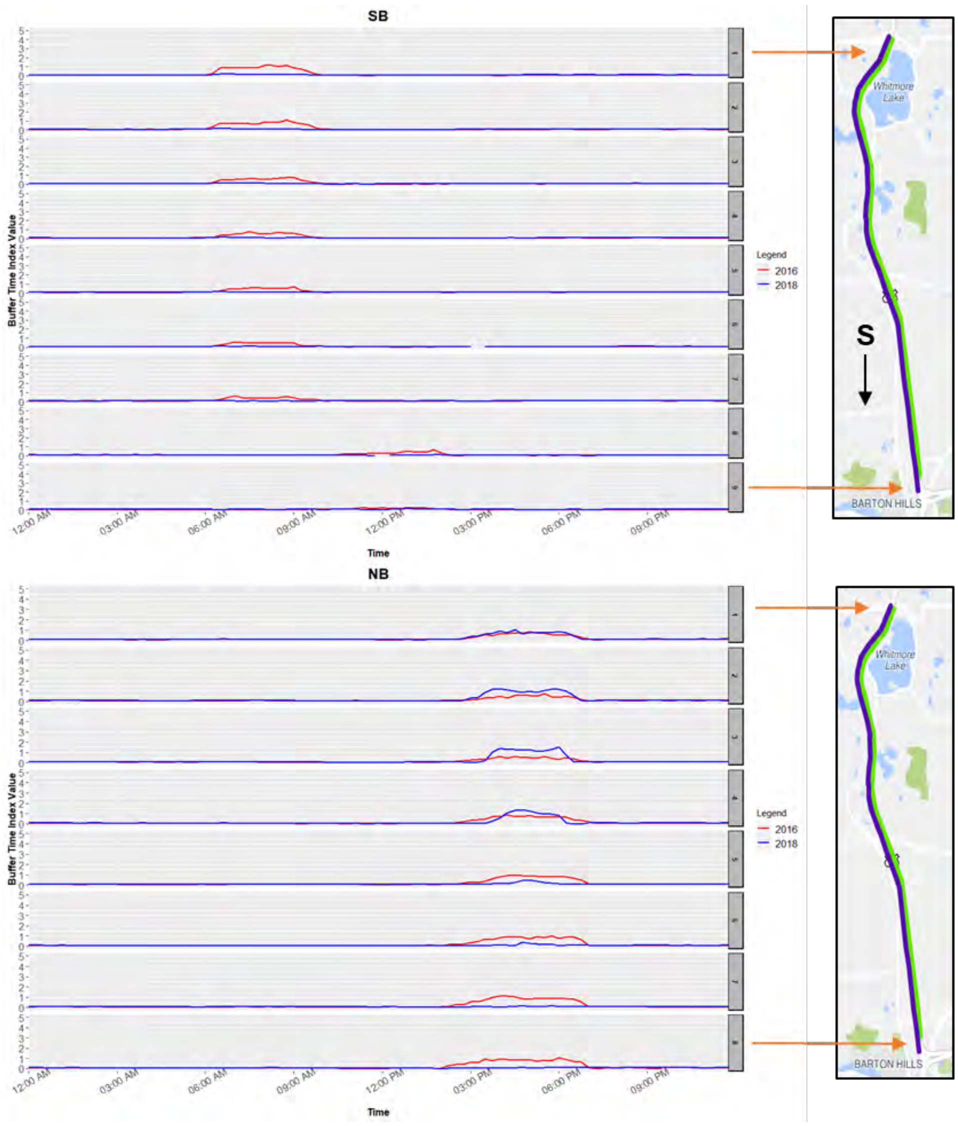
Figure 3-11 provides a similar graphical summary for changes in average annual travel times during weekends. These results show that travel times remained quite stable during weekends after Flex route implementation. This is reflective of the lower traffic volumes that are generally experienced during the weekends and the fact that the Flex route is generally not in operation at these times. The one exception would be for special events, such as home football games at the University of Michigan. This special case is covered subsequently in this chapter of the report. Beyond average travel times, 95th percentile travel time, buffer time index, planning time index, and travel time index all showed similar trends and the associated plots can be found in APPENDIX A.



a. Plot of average travel time during weekdays



b. Plot of 95th travel time during weekdays



c. Plot of buffer time index during weekdays

Figure 3-10 Plots of travel time reliability over time at segment-level during weekdays

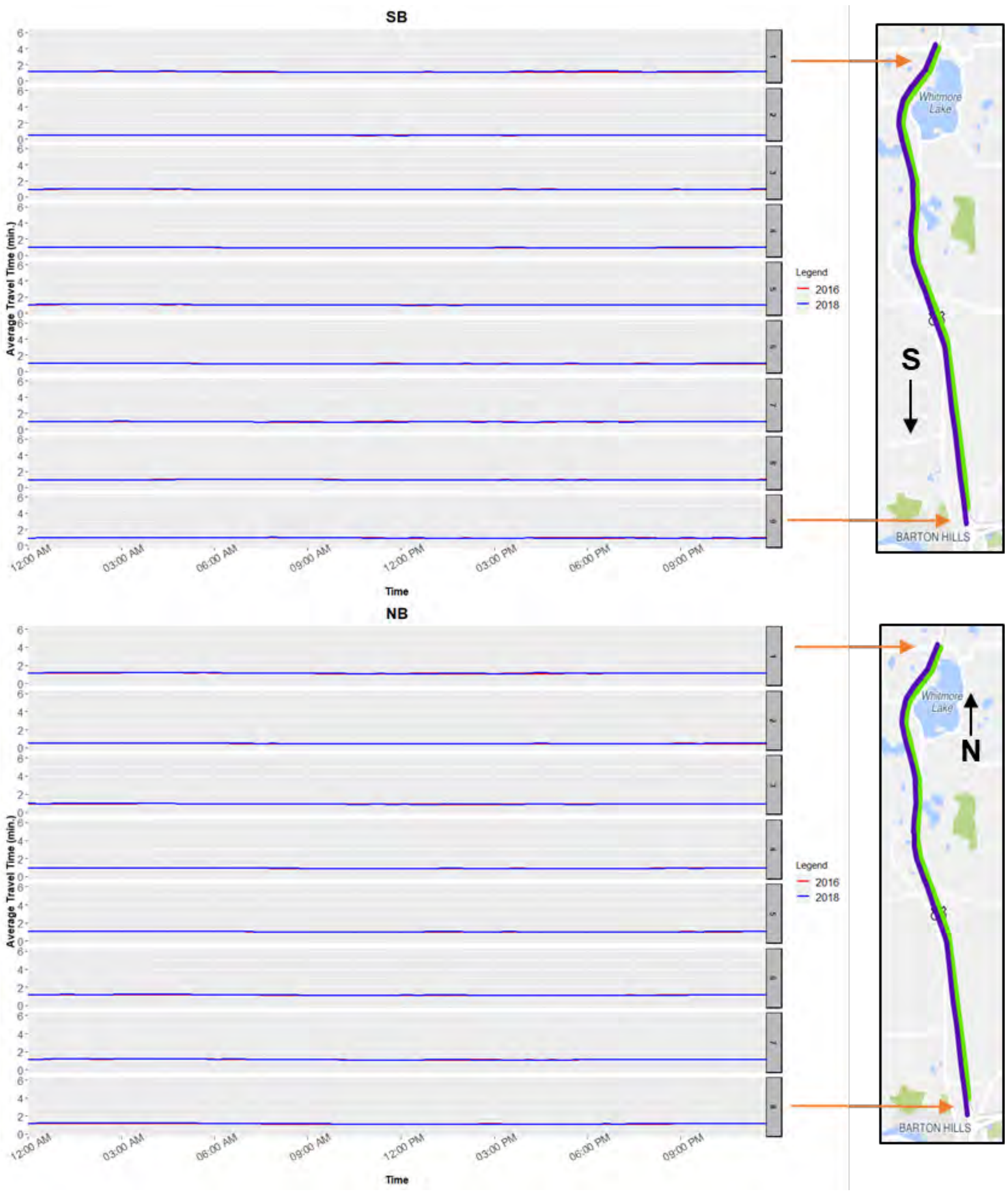


Figure 3-11 Plot of average travel time at segment-level during weekends

3.2.3 Level of Travel Time Reliability (LOTTR)

As part of the Moving Ahead for Progress in the 21st Century (MAP-21), the level of travel time reliability (LOTTR) was introduced as a preferred service measure by the FHWA. The LOTTR is defined as "the ratio of the 80th percentile travel to the normal travel time (i.e., the 50th percentile occurring throughout a full calendar year)" (Culotta et al., 2019). The LOTTR is required to be estimated for four different time periods based on the Highway Performance Monitory System (HPMS) Field Manual Supplemental Guidance (i.e., am peak, pm peak, midday, and weekend)

(Office of Highway Policy Information, 2018b). The default time periods from the FHWA were adjusted for this study based on the operational periods of the Flex route. The four-time periods of interest for this study are:

(1) AM peak hours in weekdays (6:00 – 9:30 AM);
(2) midday in weekdays (9:30 AM– 3:00 PM);
(3) PM peak hours in weekdays (3:00 – 7:00 PM); and
(4) weekend (6:00 AM – 7:00 PM).

Table 3-5 displays summary results of LOTTR for these time periods, for the periods before (2016) and after (2018) the Flex route went into operation, including separate estimates for each of the aforementioned periods.

Research generally suggests that values of LOTTR less than 1.50 can be considered to be reliable (Boston Region Metropolitan Planning Organization, 2018; Taylor & Change, 2017). Overall, the US-23 Flex route met this reliability threshold during both the pre- and post-implementation periods. However, it should be noted that the LOTTR values were close to the 1.50 threshold prior to implementation in both the northbound (LOTTR=1.42) and southbound (LOTTR=1.36) peak periods. In addition to the entire corridor, LOTTR values were also calculated at the segment level and are presented in Figure 3-12. Consistent with the metrics detailed previously, LOTTR was also found to generally improve from the upstream to downstream Flex route segments in both the northbound and southbound directions. The exception was again the northernmost sections in the northbound direction, which was unreliable as per the 1.50 threshold after the Flex route went into operation.

Table 3-5 Results of LOTTR

Direction	Year	Time Period	80th Percentile Travel Time (min.)	50th Percentile Travel Time (min.)	LOTTR
Southbound	2016	AM Peak	11.40	8.40	1.36
Southbound	2016	Midday	8.20	7.90	1.04
Southbound	2016	PM Peak	8.10	7.80	1.03
Southbound	2016	Weekend	8.00	7.70	1.05
Southbound	2018	AM Peak	8.10	7.80	1.04
Southbound	2018	Midday	8.00	7.80	1.03
Southbound	2018	PM Peak	8.00	7.80	1.03

Southbound	2018	Weekend	8.10	7.70	1.05
Northbound	2016	AM Peak	8.00	7.70	1.04
Northbound	2016	Midday	7.90	7.60	1.04
Northbound	2016	PM Peak	11.40	8.00	1.42
Northbound	2016	Weekend	7.80	7.40	1.05
Northbound	2018	AM Peak	7.90	7.70	1.03
Northbound	2018	Midday	7.80	7.60	1.03
Northbound	2018	PM Peak	9.10	7.70	1.19
Northbound	2018	Weekend	7.90	7.50	1.05

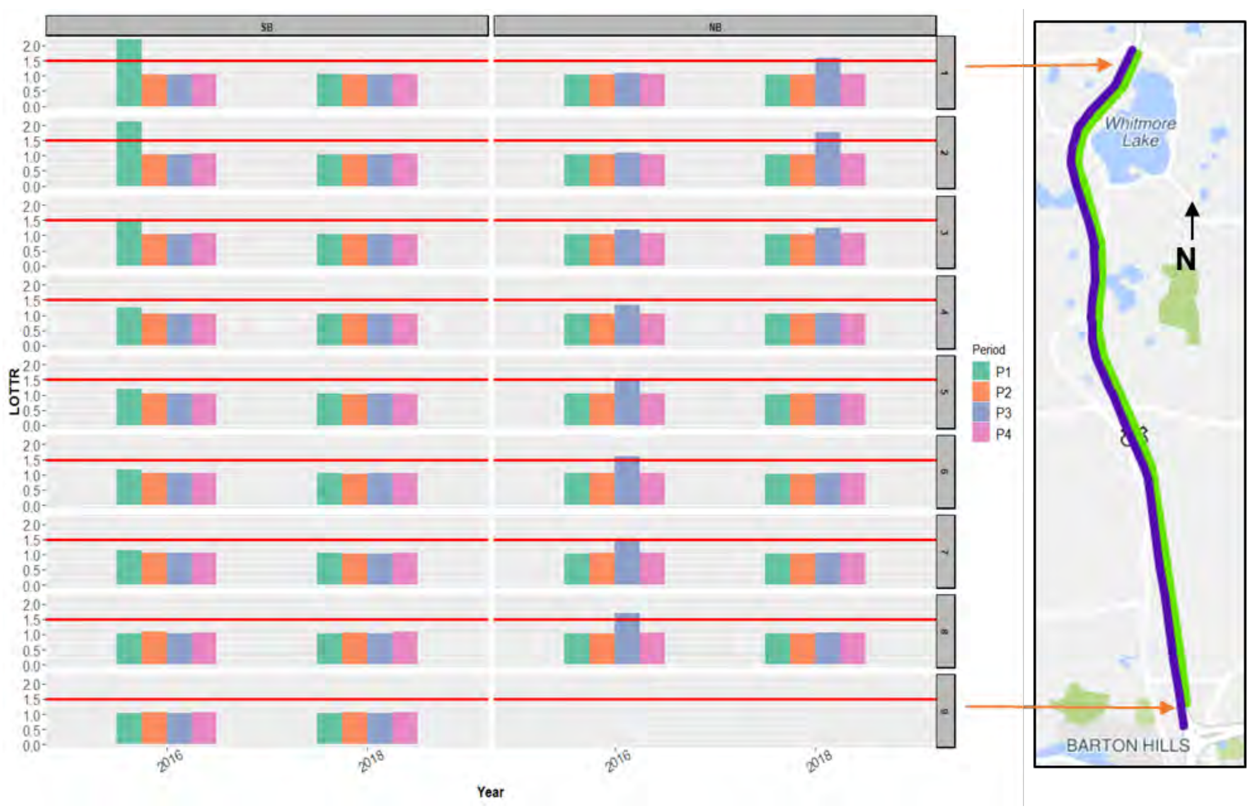


Figure 3-12 Results of LOTTR at segment-Level

3.2.4 Worst Hour Performance

In addition to the travel time reliability measures detailed previously, this study also involved an investigation of the worst-case scenarios from an operational perspective. To that end, a one-hour sliding window method was utilized to identify the one-hour periods over the course of the calendar year that showed the highest travel times (and lowest speeds). The results are shown in Figure 3-13. Looking at the data from this perspective shows particular improvements in the southbound direction, where the longest travel time was observed from 7:15 am to 8:15 am during the periods before and after the Flex route went into operation. During the post-installation period, the average travel time decreased 27.3 percent from 11.36 minutes to 8.26 minutes on average. In the northbound direction, travel times were reduced by 10 percent under these worst-case scenarios. Interestingly, there were also shifts in the period during which these worst-case scenarios occurred after the introduction of the Flex route. During 2016, the worst hour occurred between 4:45 PM and 5:45 PM. Afterward, this shifted up to 4:30 PM to 5:30 PM.

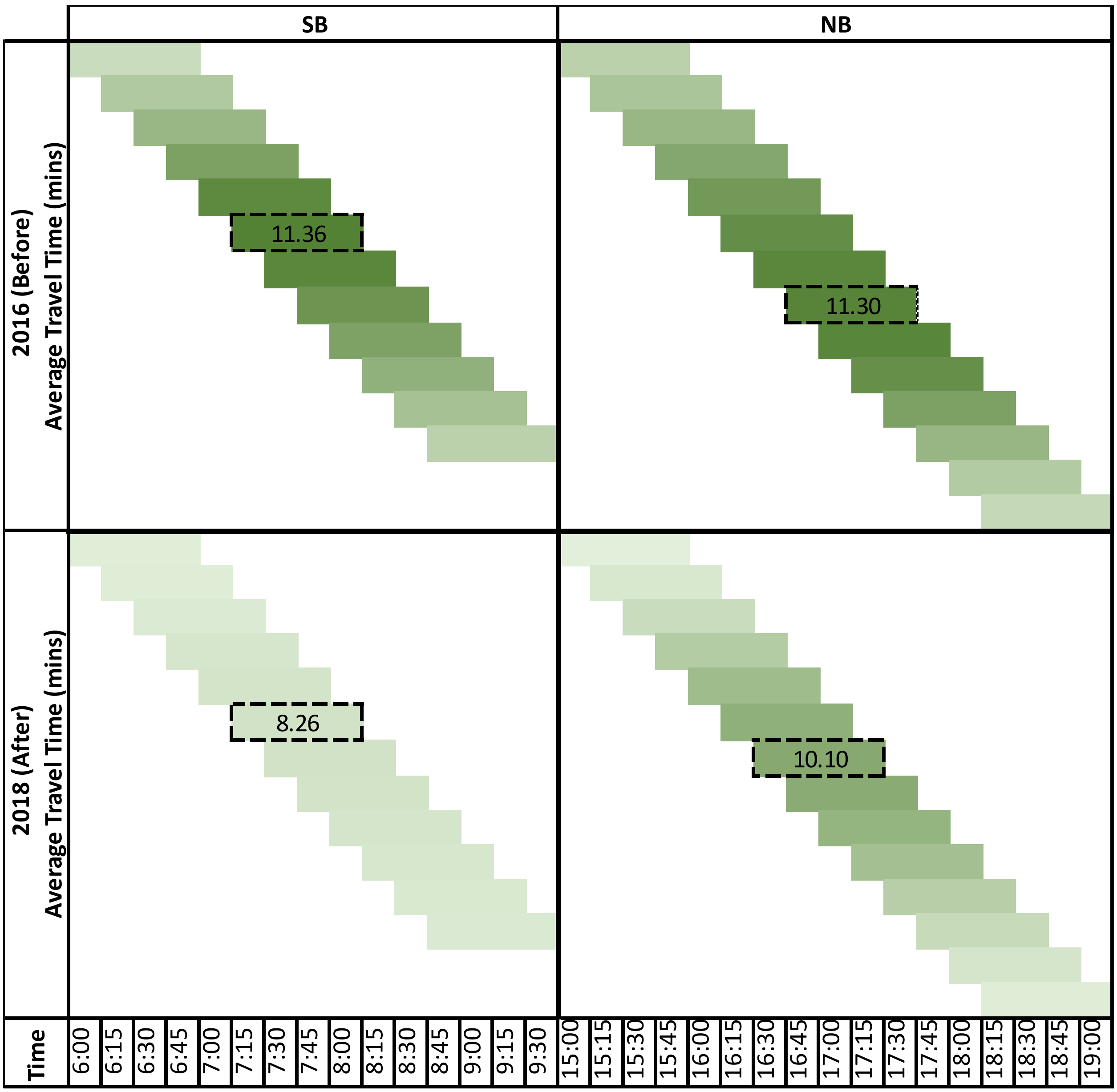


Figure 3-13 Peak hours performance

3.3 Speed-Volume Relationships for Flex Route

3.3.1 Evaluation of Annual Operational Data

The MVDS reports include both speed and traffic volume information on a lane-by-lane basis. These data allow for an evaluation of the speed-flow relationships, as well as the potential estimation of capacity on a directional and/or lane-by-lane basis.

To better understand the nature of driver behavior along the Flex route, the speed and flow relationships along the Flex route are detailed in this section of the report. While MVDS reports were reviewed for both 2018 and 2019, the discussion focuses on the 2019 data as the results are very similar between the two years. The results from 2018 are included in APPENDIX B.

A summary of the speed and volume data during weekdays and weekends from 2019 for the entire Flex route is shown in Table 3-6. In addition, a similar table was developed for peak hour and off-peak hour, as well (Table 3-7). These results show that average travel speeds on the Flex route were approximately 70 mph regardless of the time-of-day and day-of-week. The northbound direction showed lower travel speeds and higher variability as compared to the southbound direction, which is again attributable largely to the bottleneck in the northbound direction.

Table 3-6 Descriptive statistics for speed and volume over 24-hour period by day-of-week and direction

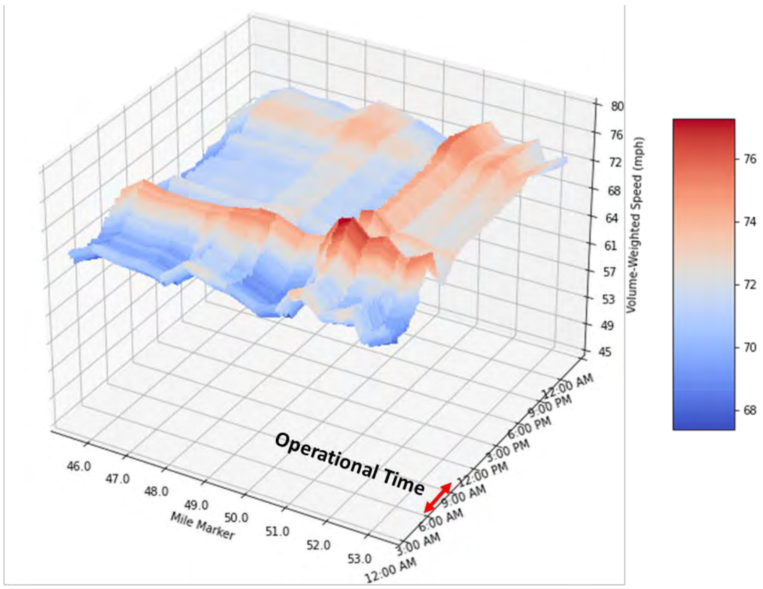
Day	Direction	Variable	Min	Max	Mean	Std. Dev.
Weekdays	Southbound	Volume-Weight Speed (mph)	50.97	77.73	71.61	2.18
		Flow Rate (veh/h)	89.61	5054.18	1669.74	1202.84
	Northbound	Volume-Weight Speed (mph)	41.03	75.88	70.56	4.05
		Flow Rate (veh/h)	109.87	4900.95	1602.84	1145.67
Weekends	Southbound	Volume-Weight Speed (mph)	65.36	78.59	73.05	1.67
		Flow Rate (veh/h)	74.83	3677.60	1296.96	857.43
	Northbound	Volume-Weight Speed (mph)	65.77	76.97	72.62	1.99
		Flow Rate (veh/h)	97.58	3564.80	1260.23	836.02

Table 3-7 Descriptive statistics for speed and volume during peak and off-peak periods by direction

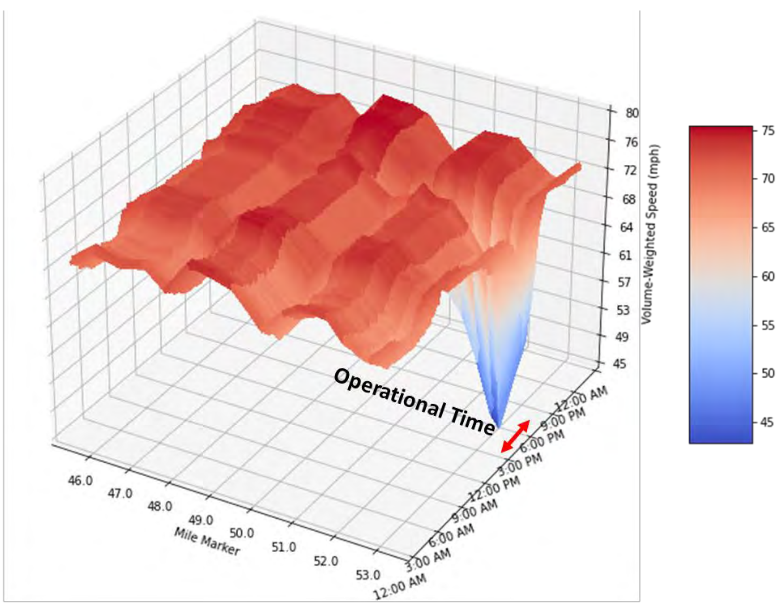
Time Period	Direction	Variable	Min	Max	Mean	Std. Dev.
Peak Period	Southbound (6:00 AM - 9:30 AM)	Volume-Weight Speed (mph)	50.97	77.59	71.21	3.77
		Flow Rate (veh/h)	1862.04	5054.18	3687.10	722.50
	Northbound (3:00 PM - 7:00 PM)	Volume-Weight Speed (mph)	41.03	75.88	67.25	7.91
		Flow Rate (veh/h)	1800.79	4900.95	3453.80	591.96
Off-Peak Period	Southbound (6:00 AM - 9:30 AM)	Volume-Weight Speed (mph)	65.79	77.73	71.67	1.76
		Flow Rate (veh/h)	89.61	3945.56	1323.39	887.09
	Northbound (3:00 PM - 7:00 PM)	Volume-Weight Speed (mph)	63.49	75.86	71.22	2.12
		Flow Rate (veh/h)	109.87	3944.38	1230.80	823.95

A series of speed profiles were developed to provide a graphical overview of how travel times/speeds varied, both overall and within specific travel lanes. These profiles provide insights as to where and when congestion was most pronounced and when speed reductions occurred. Figure 3-14 and Figure 3-15 provide these speed profile plots in both directions for weekdays and weekends, respectively. Travel speeds tended to be fairly consistent in the southbound direction during weekdays, generally operating at or near free-flow conditions. The northbound direction also generally showed consistently high travel speeds, with the exception of the northernmost sections leading up to the lane drop as illustrated by the sharp drop during the PM peak period between milemarkers 51 and 53 specifically.

Speeds during weekends were also relatively stable regardless of the direction. There were some minor drops in speeds in the northbound direction. Once again, these occurred leading into the terminus of the Flex lane where the number of lanes is reduced from three to two. The planned extension of Flex route to I-96 is expected to largely mitigate the speed reductions during all operational periods.

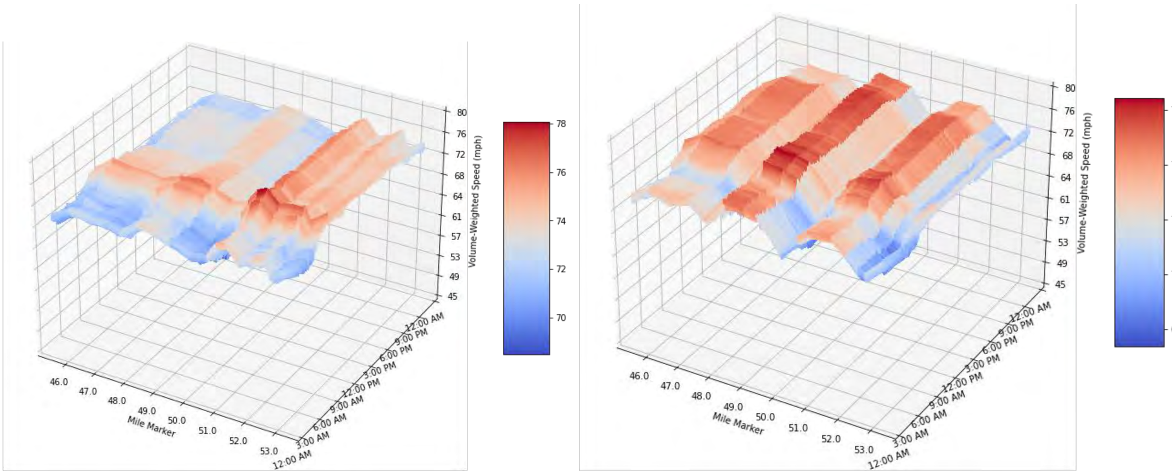


a. Southbound



b. Northbound

Figure 3-14 Average travel speed over time and mile marker for US-23 Flex route (weekdays)



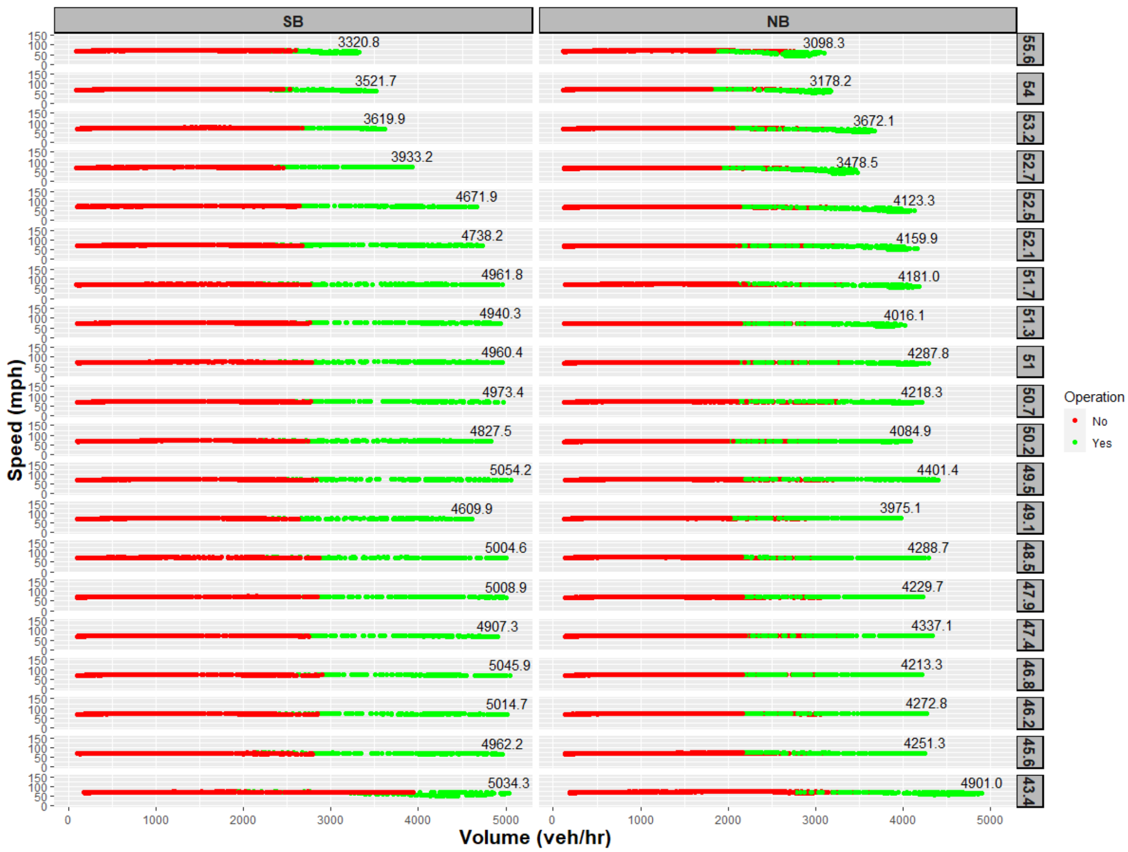
a. Southbound

b. Northbound

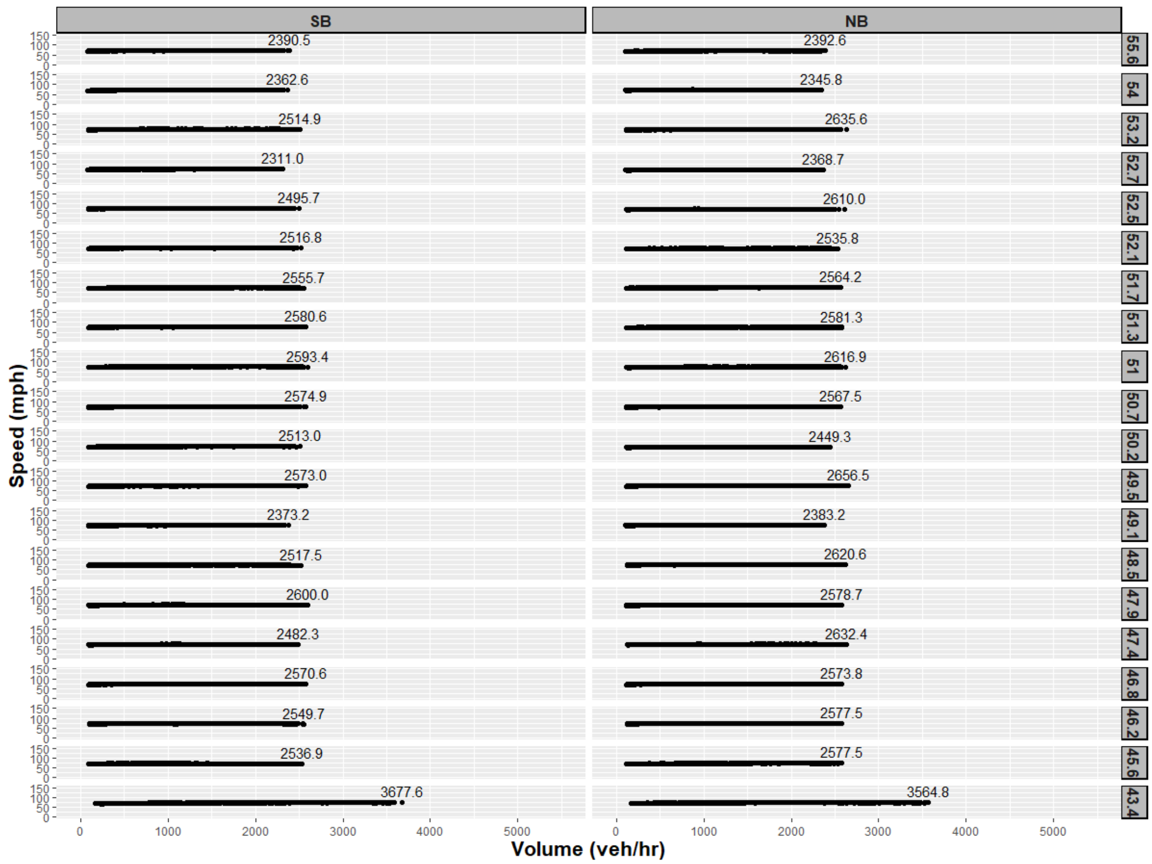
Figure 3-15 Average travel speed over time and mile marker for US-23 Flex route (weekends)

The speed and flow relationships during weekdays for the entire corridor (averaged across all travel lanes) are plotted in Figure 3-16a. The speed and volume data were differentiated by the fixed operational time of the Flex route. The green color is reflective of speeds and volumes while the Flex lane is in operation (i.e., southbound from 6:00 AM - 9:30 AM; northbound from 3:00 PM - 7:00 PM). The red color indicates periods when the Flex lane was not in operation. As the figure shows, speeds were largely consistent across most flow rates. Generally speaking, the corridor operated at traffic volumes that were significantly less than capacity.

The exception is the northernmost section of northbound US-23, where speeds begin to decline as congestion begins to occur, particularly near MM 52.7 and MM 53.2, leading up to the lane drop. In general, the southbound direction experienced very limited congestion once the Flex route went into operation. Speed-flow curves were also developed for weekends (Figure 3-16b) and the trends were consistent in both directions and throughout the course of the day.


SB
NB
Speed (mph)
Volume (veh/hr)
Operation
No
Yes
55.6
54
53.2
52.7
52.5
52.1
51.7
51.3
51
50.7
50.2
49.5
49.1
48.5
47.9
47.4
46.8
46.2
45.6
43.4
3320.8
3521.7
3619.9
3933.2
4671.9
4738.2
4961.8
4940.3
4960.4
4973.4
4827.5
5054.2
4609.9
5004.6
5008.9
4907.3
5045.9
5014.7
4962.2
5034.3
3098.3
3178.2
3672.1
3478.5
4123.3
4159.9
4181.0
4016.1
4287.8
4218.3
4084.9
4401.4
3975.1
4288.7
4229.7
4337.1
4213.3
4272.8
4251.3
4901.0

a. Weekdays



b. Weekends

Figure 3-16 Speed-flow curve during weekdays and weekends (oneyear) for US-23 Flex route

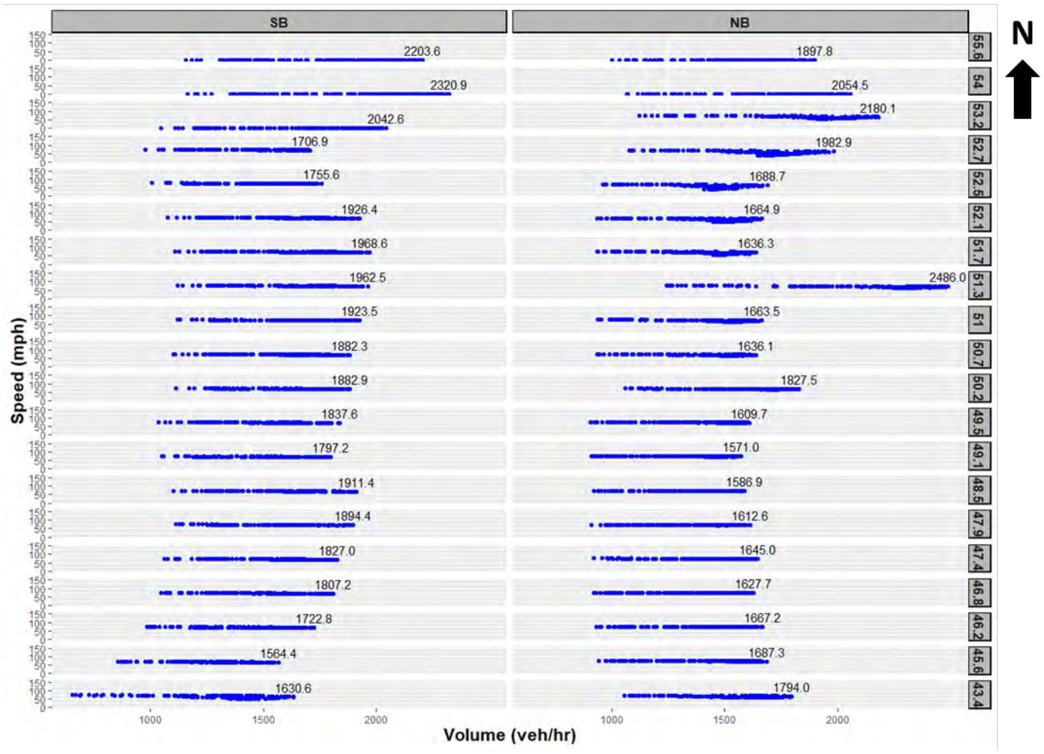
In addition to the preceding plots that detail total volumes and average speeds in each direction, speed-flow curves were also generated on a lane-by-lane basis. Figure 3-17 provide sa summary of these data for calendar year 2019 for the left shoulder, left lane, and right lane during the periods when the Flex lane was open for motorists. APPENDIX B includes similar plots for 2018 as the data were again very consistent between the two years.

These plots are largely consistent with the total directional data detailed previously. Speeds and flow rates were largely consistent, with the exception of the northernmost extents in the northbound direction. Comparing the lane-by-lane data, volumes tended to be highest in the middle (i.e., left) lane as compared to the right lane. Volumes also tended to be higher in the southbound direction as compared to northbound. The Flex route ends near MM 53.2 northbound and this is where the lowest speeds and flow rates are found on the left shoulder.

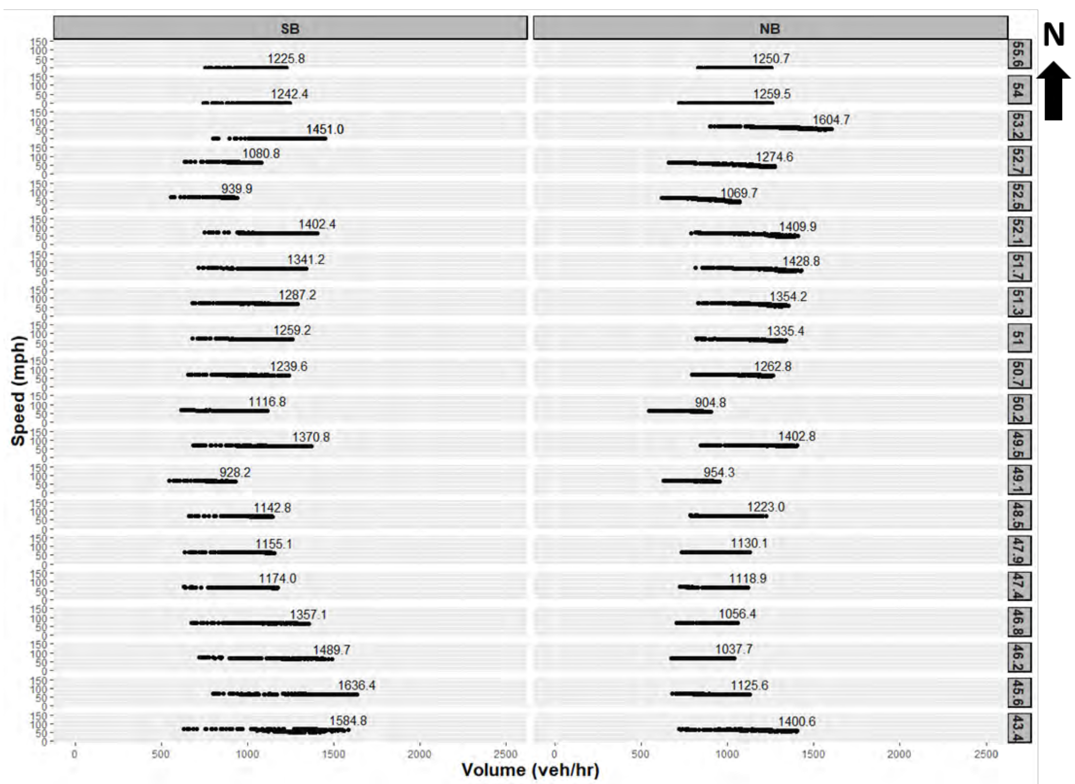
Some issues were observed in the data, including an unusual trend at MM 51.3 northbound, where significantly lower flow rates and speeds were recorded on the left shoulder, while higher flow rates and speeds occurred on the middle (left) lane. As Figure 5a shows, this section is generally similar to the other three-lanes sections. It appears there are sensor alignment and/or classification issues here.

a. i) Left shoulder (Flex lane)

a. ii) Gantry at MM 51.3 northbound



b. Left lane



c. Right lane

Figure 3-17 Speed-flow curves for US-23 Flex route during peak hours on lane-by-lane basis

3.3.2 Evaluation of Sample Data from Normal Week

This section provides a more detailed assessment of speed-flow relationships using sample data for a one-week period during which there were no crashes or other sources of non-recurrent congestion based upon a review of available ATM, speed, crash, and incident data.

3.3.2.1 Data Integration

As a part of this investigation, the gantry messages that were displayed were identified from the ATM report. Travel speed and volume data were drawn from the MVDS reports and were integrated with the ATM information based on the associated timestamps and milemarkers to determine specific times when the Flex route was open. As the milemarkers for the gantry messages do not match directly with the operational data, some manual adjustment was required to align the nearest milemarker for the MVDS and ATM data. The milemarkers for all ATM and MVDS data are detailed in Table 3-8.

Table 3-8 Comparison of mile marker between MVDS reports and ATM reports

Direction	Mile Marker		Direction	Mile Marker	
	MVDS	ATM		MVDS	ATM
SB	43.4		NB	43.4	45.3
SB	45.6	45.6	NB	45.6	45.6
SB	46.2	46.2	NB	46.2	46.2
SB	46.8	46.8	NB	46.8	46.8
SB	47.4	47.4	NB	47.4	47.4
SB	47.9	47.9	NB	47.9	47.9
SB	48.5	48.5	NB	48.5	48.5
SB	49.1	49.1	NB	49.1	49
SB	49.5	49.5	NB	49.5	49.5
SB	50.2	50	NB	50.2	50.2
SB	50.7	50.7	NB	50.7	50.7
SB	51		NB	51	
SB	51.3	51.3	NB	51.3	51.3
SB	51.7	51.7	NB	51.7	51.7
SB	52.1	52.1	NB	52.1	52.1
SB	52.5	52.5	NB	52.5	52.6
SB	52.7	52.7	NB	52.7	52.7

As discussed previously, the ATM reports only indicate when one of the gantry messages changed (e.g., when the Flex lane opened, when the advisory speed changed). No intermediate data are available between these timestamps. Therefore, additional data processing was required in order to integrate the travel speed data with the gantry messages. Basically, the gantry messages were filtered to identify the timestamp at which each unique message was displayed. This same messages was assumed to be displayed until the gantry message changed and the speed and volume profiles were integrated accordingly.

3.3.2.2 Analysis results

Consistent with the preceding discussion of annual trends, Figure 3-16 and Figure 3-17 show that the Flex route is generally operating under capacity, even during peak traffic periods. Congestion was generally only observed at the milemarkers immediately upstream of the lane drop in the northbound direction. This is the one section of the Flex route where additional insights may be drawn as to the operational capacity of the Flex route and each of the travel lanes. To this end, the sample week of speed and volume data were used to develop a series of similar speed-flow plots. The data were extracted from the fall season uner good weather conditions and in the absence of any non-recurring congestion as noted previously.

In contrast the preceding curves, which assumed fixed hours of operation over the calendar year, this analysis considered the actual operation times for the Flex route, which tended to vary slightly from day to day based on an investigation of ATM reports. For instance, during certain days, the Flex route opened at 2:50 PM in the northbound direction rather 3:00 PM. The associated gantry messages displayed on DMS1 from the ATM reports were integrated with the corresponding speed and volume data to discern further details of traffic flow conditions as the Flex route opened. Rather than averaging the speed and volume data (as in the analyses of annual data), this analysis involved the development of higher fideltiy plots using raw data at one-minute intervals.

To that end, Figure 3-18 provides a series of overall speed-flow plots at this level of detail. The trends from these speed-flow curves are largely similar to what was shown in the average annual data presented previously. Southbound traffic consistently operated near free-flow conditions while performane in the northbound direction was similar, except for the speed drops that begin to occur after MM 49.5. As in Figure 3-16, green points are reflective of periods when the Flex route is in operation and red points are reflective of periods when the Flex lane is closed.

In the southbound direction, the maximum flow rates generally cover a range of up to 6,240 to 7,020 veh/hr (2,080 to 2,340 veh/hr/ln). There are a small number of points beyond this range; however, these flows are not sustained and it should be noted these are hourly volume estimates based upon one-minute intervals. The throughput generally tends to increase further downstream along US-23 and there is some oscillation from milemarker to milemarker, which is likely a reflection of segment-specific issues such as the presence of entrance ramps and horizontal curvature in these areas. It is important to note that virtually no congestion is observed in the southbound direction, except for a brief period from MM 51.7 to MM 52.1 when the Flex lane appears to have been opened after some congestion in the two normal travel lanes. When all three lanes were in operation, no significant reductions were observed southbound, which suggests the values above provide lower bounds for capacity.

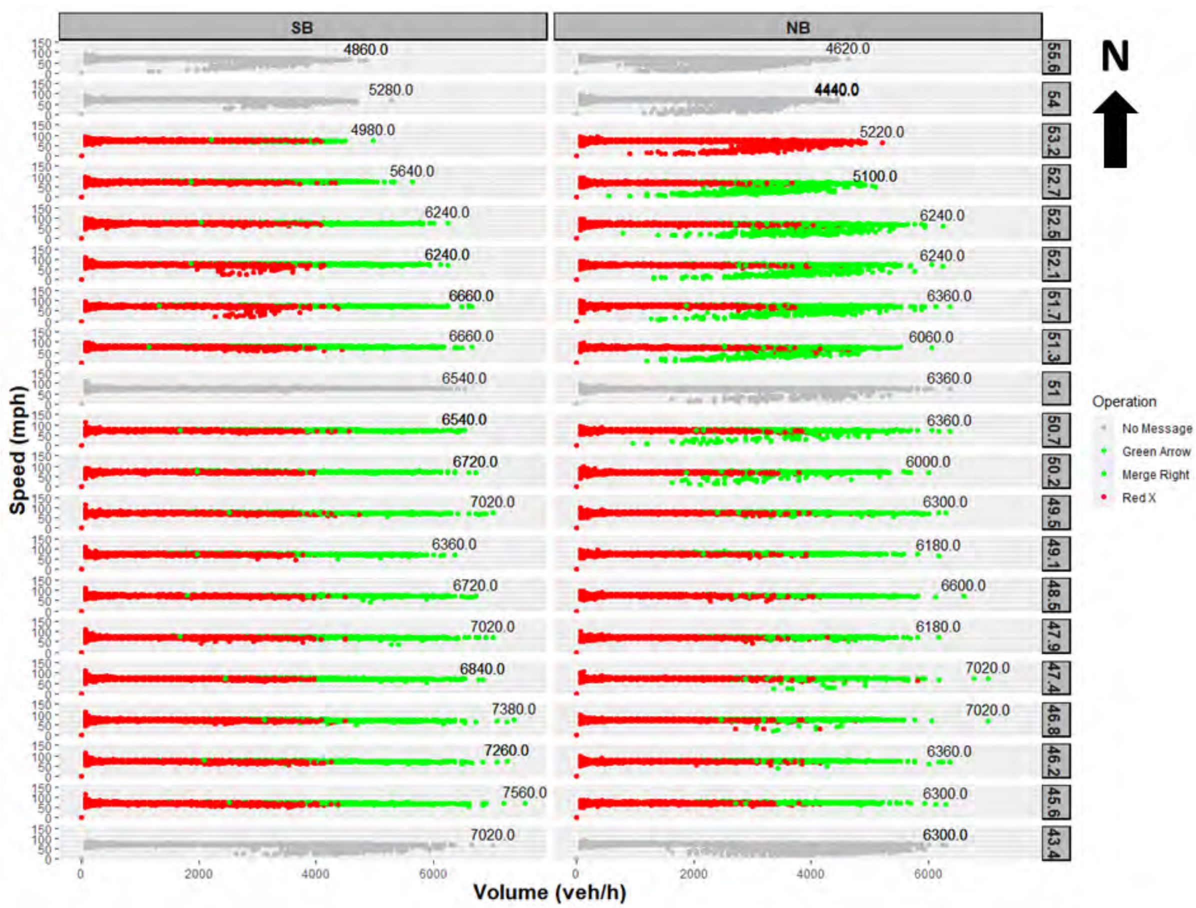


Figure 3-18 Speed - flow curve for US-23 Flex route (weekdays, one-week data)

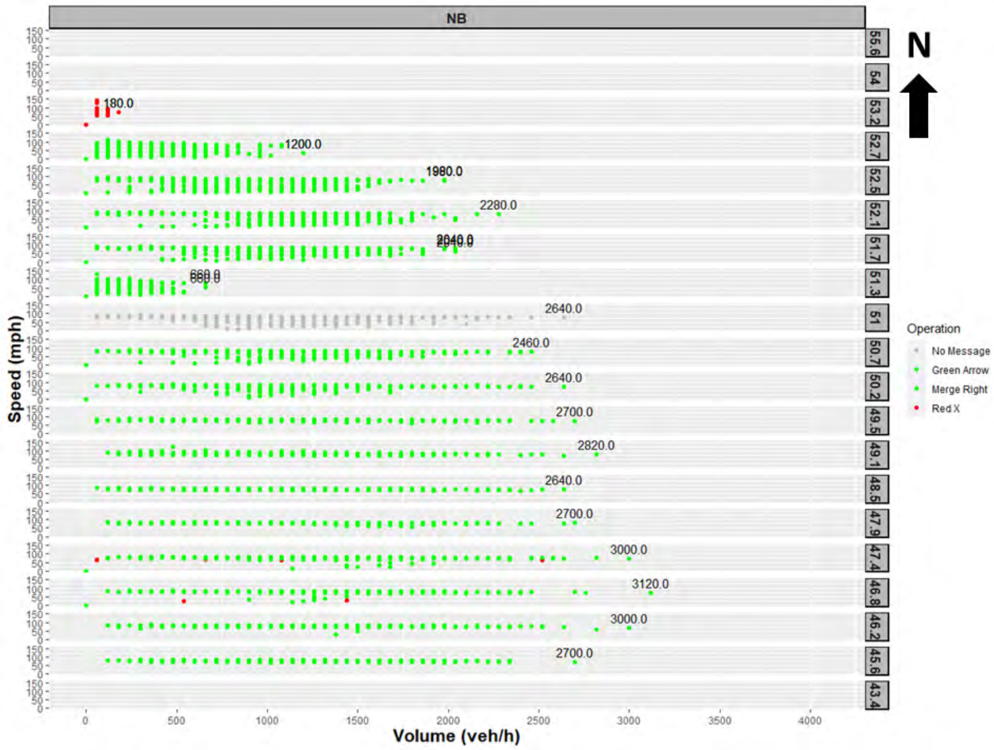
In contrast, northbound flow rates were consistently lower than in the southbound direction, with maximum volumes ranging from approximately 6,000 veh/hr to 6,300 veh/hr

(2,000 to 2,100 veh/hr/ln), again with a limited number of one-minute flow rates beyond these values. There are also marked reductions in travel speeds due to recurring congestion, particularly downstream of MM 49.5.

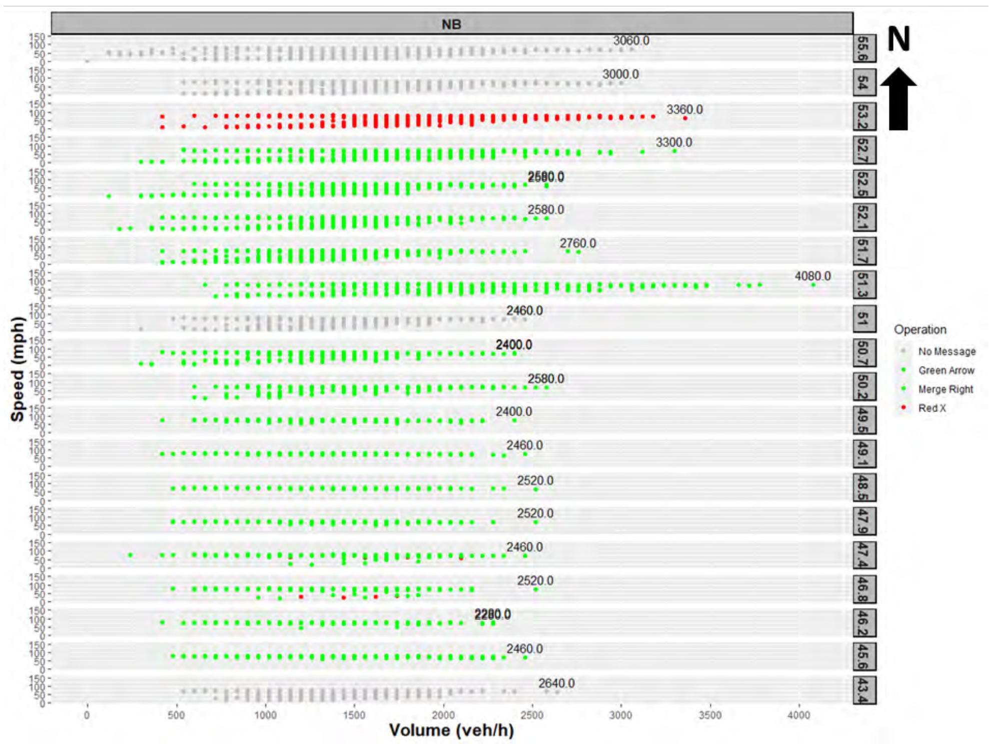
In order to better understand the nature of the congestion in the northbound direction, lane-specific speed and flow curves were also generated as shown in Figure 3-19. Over the southern extents in the northbound direction (from MM 45.6 to 51.0), approximately 39% of the volume was observed in the Flex lane, 35% in the left lane, and 26% in the right lane. Nearer to the northern terminus, this distribution shifted as the corresponding percentages included 31%, 39%, and 30% of traffic in the Flex, left, and right travel lanes, respectively. Traffic largely began shifting out of the Flex lane between MM 52.5 and 52.7 as these percentages changed to 18%, 50%, and 32% at the latter milemarker. Finally, at the final northbound gantry (MM 53.2), approximately 3% of traffic was in the left-shoulder as vehicles approached the merge point/lane drop.

Some caution should be exercised when trying to use the lane-by-lane speed-flow plots to estimate per-lane capacity values. There are some milemarkers where there are obvious discrepancies with respect to the lane-by-lane volume distrbutions, most notably at MM 51.3 where the roadside sensors are assigning much of the left shoulder (Flex lane) traffic to the left travel lane. Over the entire segment, there is considerable variability in the lane-specific volumes and, as such, the total throughout across all travel lanes are likely to provide a more reasonable floor for lane-by-lane capacity as compared to the per-lane volumes.

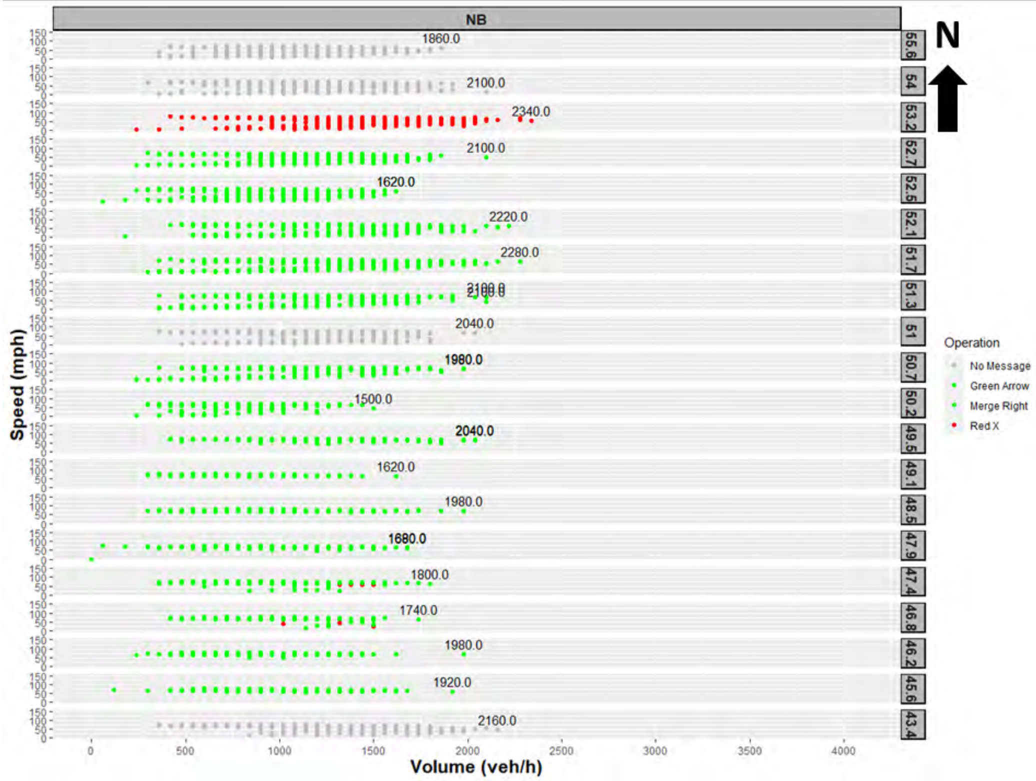
Overall, the plots show that flow rates were generally under capacity regardless of direction and mile marker, except for this northernmost portion in the northbound direction. Immediately beyond the lane drop, capacity values of 4,400 to 4,600 veh/hr (2,200 to 2,300 veh/ln) are consistently observed. As such, the lower throughout at the preceding northbound milemarkers (e.g., MM 52.5 to 53.2) are likely to be lower than what will be observed with the subsequent extension that is planned to I-96.



a. Left shoulder (Flex lane)



b. Left lane



c. Right lane

Figure 3-19 Northbound speed - flow curves for US-23 Flex route during weekday peak period on lane-by-lane basis

3.4 Compliance

Another area of interest from an operational perspective is the degree of driver compliance with the gantry messages. In general, the compliance of drivers on freeway sections with part-time shoulder use is measured by considering lane compliance and advisory speed compliance (Schaefer et al., 1998). In this study, the Flex lane compliance was evaluated by assessing how much traffic was using the lane during periods when the lane was open to traffic (as evidenced by a green arrow) versus when it was closed (indicated by a red X). In addition, compliance with the variable advisory speeds was also evaluated by comparing the average travel speeds to the corresponding advisory speeds. As a part of these investigations, the gantry messages from the ATM reports were integrated with the speed and volume data from MVDS reports. The intergration procedures was detailed previously.

3.4.1 Flex Lane Compliance

The MVDS reports, which provided lane-by-lane volume data, were utilized to determine the Flex lane compliance rates. The violation rate is defined as the percentage of drivers traveling in the lane while it was closed to traffic as indicated by the red X (Schaefer et al., 1998). Table 3-9 provides annual summaries of the Flex lane compliance rates. Violation rates generally ranged from 0.5 to 1.1 percent. These violation rates increased slightly from 2018 to 2019, though it is unclear whether this increase is due to changes in driver behavior (after familiarization with the Flex route) or to some other factors.

Table 3-9 Flex lane violation rates by direction and year

Direction	Year	Number of Vehicles Using Flex Lane During Off-Peak Hours	Number of Vehicles During Off-Peak Hours	Violation Rate (%)
Soutbound	2018	7976	1617935	0.49
	2019	13768	1648073	0.84
Northbound	2018	11517	1390271	0.83
	2019	15705	1427621	1.10

Figure 3-20 provides an illustration of monthly violation rates, again by year and direction. Interestingly, violation rates were fairly consistent in the southbound direction, with the exception of an increase (from approximately 0.5 to 1.4 percent) in September of 2019. Violation rates in the northbound direction tended to be consistently higher, with the rates being highest during the summer of 2019, particularly in August and September. These differences may be attributable to differences in traffic composition during these periods given the transition into the K-12 and university school years.

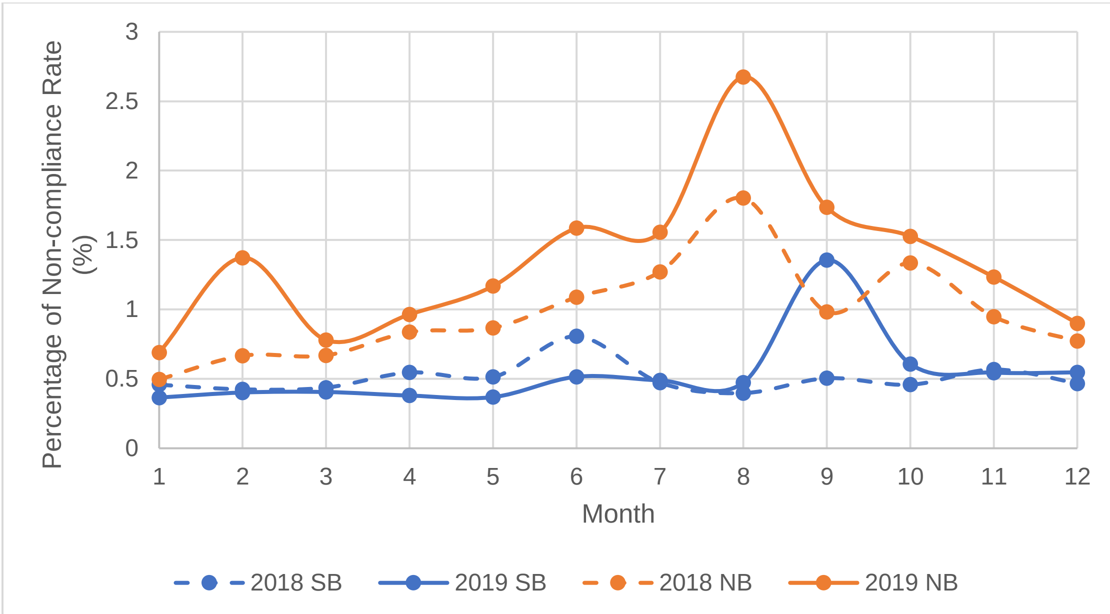
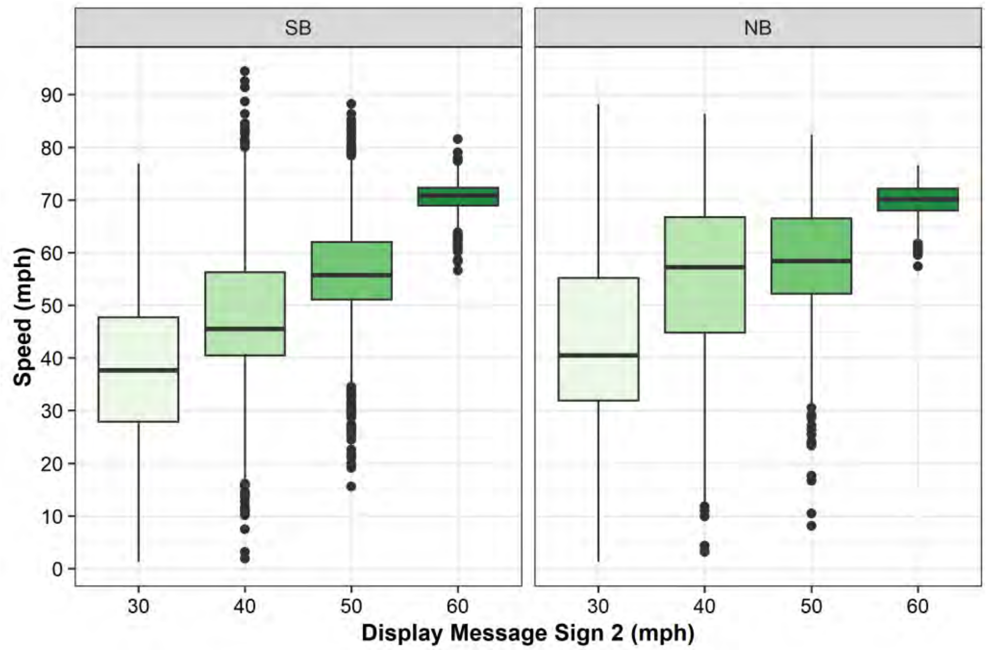


Figure 3-20 2018 and 2019 monthly violation rates by direction

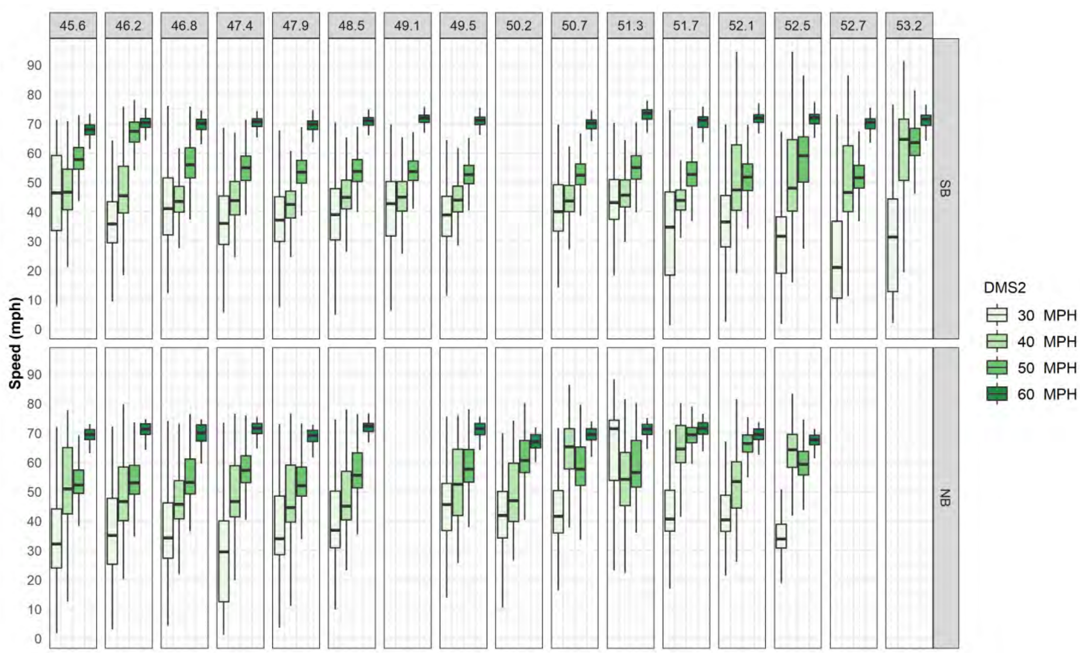
3.4.2 Advisory Speed Compliance

3.4.2.1 Data Summary

Advisory speed compliance was assessed by comparing speed data from MVDS reports with the gantry messages from the ATM reports. After integrating the gantry message and speed data, driver compliance rates were examined by comparing the relative differences between the mean travel speeds and each of the different advisory speeds (i.e., 30 mph, 40 mph, 50 mph, and 60 mph). Box plots were developed, which summarize the minimum, first quantile, median, third quantile, and maximum values of travel speeds both overall (across all milemarkers) and across individual milemarkers. These plots also provides insights as to where outliers occur, which are mean speeds significantly above or below the interquartile range. Figure 3-21 includes the box plots for the entire Flex route and each mile marker. In these plots, the x-axis represents the advisory speeds of 30, 40, 60 mph that were displayed at various times during Flex route operation. The y-axis summarizes average travel speeds along the Flex Route in each direction while these advisory speeds were present.



a. Overall



b. Mile marker by mile marker basis

Figure 3-21 Driver's speed selection behaviors under various advisory speeds on US-23 Flex route

As the figures demonstrated, driver compliance was generally poor, particularly at higher speeds. Under the default advisory speed of 60 mph, which is in effect whenever the Flex lane is open, speeds generally ranged from 67 to 73 mph overall, with a limited number of higher speeds up to more than 80 mph. In general, as the advisory speeds were reduced towards 30 mph, travel speeds also tended to decline and by greater degrees for each subsequently lower speed. In the southbound direction, the mean/median speeds were approximately 71, 56, 45, and 38 mph at advisory speeds of 60, 50, 40, and 30, mph, respectively. Northbound values were similar, with the exception of the 40 mph advisory speed, which showed a significantly higher mean speed of 57 mph.

Overall, there is significantly more variability in drivers speeds when lower advisory speeds are present. This is clearly reflected in Figure 3-21b, which shows comparisons in both directions by milemarker. In general, the variability is much lower in the northbound direction. However, this is only partially reflecting driver behavior as much of this higher compliance rate is driven by increasing levels of congestion (i.e., drivers are not able to travel at speeds significantly above these advisories). To further investigation this issue, additional analyses were conducted in order to better understand how drivers adapted their speeds as they encountered lower advisory speeds.

To this end, the advisory speed displayed on DMS2 was inregrated with the speed corresponding to the milemarker immediately downstream of the gantry in both directions (SB and NB). For example, if the advisory speed of 60 mph is displayed at northbound MM45.6, the speed at MM46.2 and beyond was of primary interest. Figure 3-22 provides a graphical overview of this data integration process.

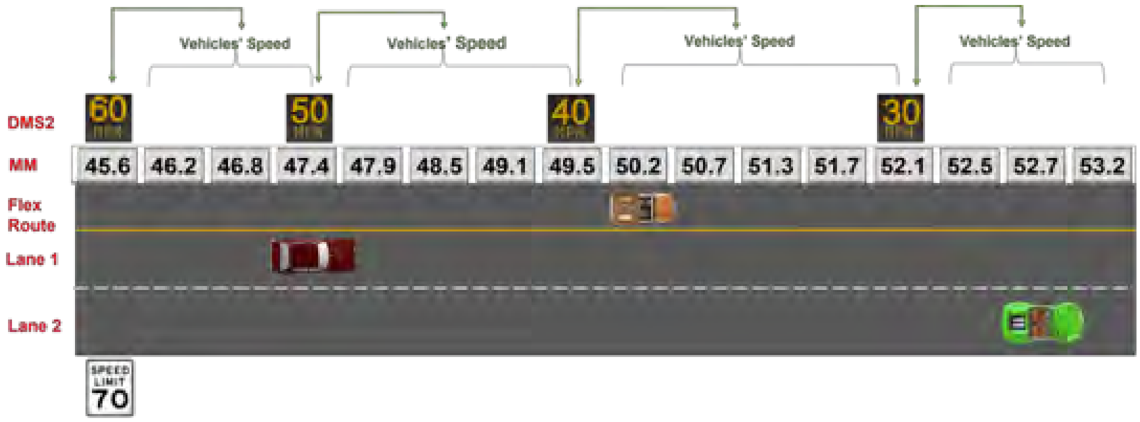


Figure 3-22 Example of travel speed and advisory speed data integration

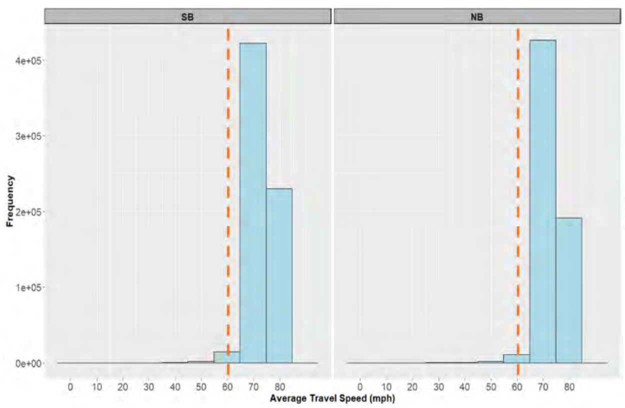
After integration, the data were divided into four groups based on the advisory speeds (i.e., 60 mph, 50 mph, 40 mph, and 30 mph). As discussed previously, these advisory speeds were generally displayed during the regular operational times from 6:00 AM to 9:30 AM and 3:00 PM to 7:00 PM. The Flex lane was also open in response to non-recurrent congestion and special events, such as football games. However, to reduce noise, this analysis focused only on these regular operating times over the entire calendar year.

Figure 3-23 shows a histogram of average speeds under each advisory speed. Each plot includes a dashed veritical line that illustrates how the speed value distribution compares to the stated advisory speed. As Figure 3-23a shows, compliance under the default advisory speed of 60 mph was very poor as the vast majority of speeds ranged from 65 to 75 mph regardless of direction. Only a small portion of drivers demonstrated compliance with the 60 mph advisory.

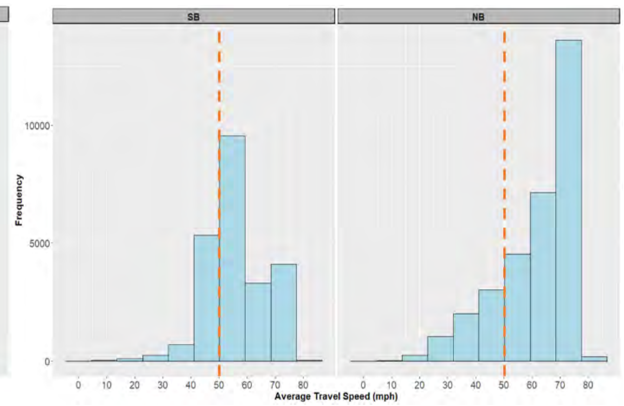
Once the advisory speed was reduced to 50 mph (Figure 3-23b) speeds generally fell into the range of 50 to 60 mph in the southbound direction. In contrast, northbound drivers generally traveled at higher speeds in the range of 68 to 78 mph. While this may initially appear counterintuitive, this result is driven by the fact that these speeds were often displayed further upstream where traffic speeds were higher as congestion had not yet set in, particularly in the northbound direction.

These patterns began to change at the lower advisory speeds. Figure 3-23c shows that speeds were generaly centered around the 40 mph advisory speed in both directions. Speeds tended to be more variable in the northbound direction, which is again due, in part, to some of the messages that were displayed at upstream gantries where congestion had not yet set in.

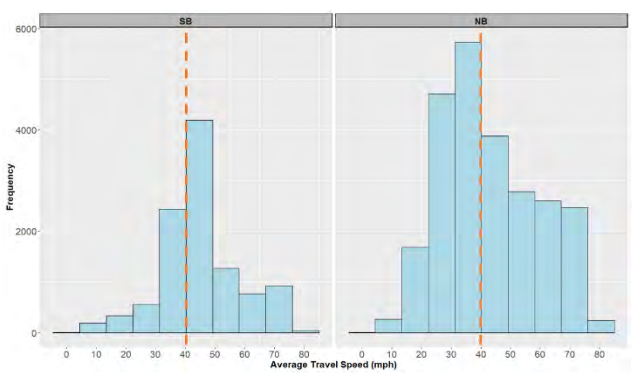
Lastly, Figure 3-23d illustrates speed trends when the lowest 30-mph advisory speed was in place. The southbound direction showed a much smaller sample size of time periods where the 30-mph advisory was in place as compared to the northbound direction. Given how irregularly this advisory speed was in place in the southbound direction, there is not a very pronounced trend in travel speeds and they were largely uniform from 10 to 60 mph. In contrast, speeds were significantly less variable in the northbound direction, where the majority of vehicle speeds were actually below the advisory speed. Again, these results are largely reflective of traffic congestion and, to a lesser degree, changes in driver behavior as they relate to the actual speed advisories.



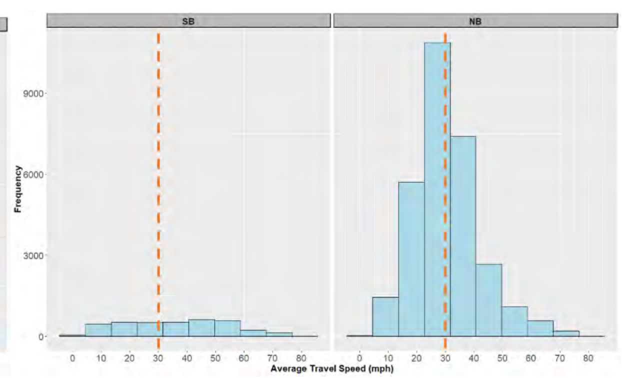
a. Advisory speed of 60 mph



b. Advisory speed of 50 mph



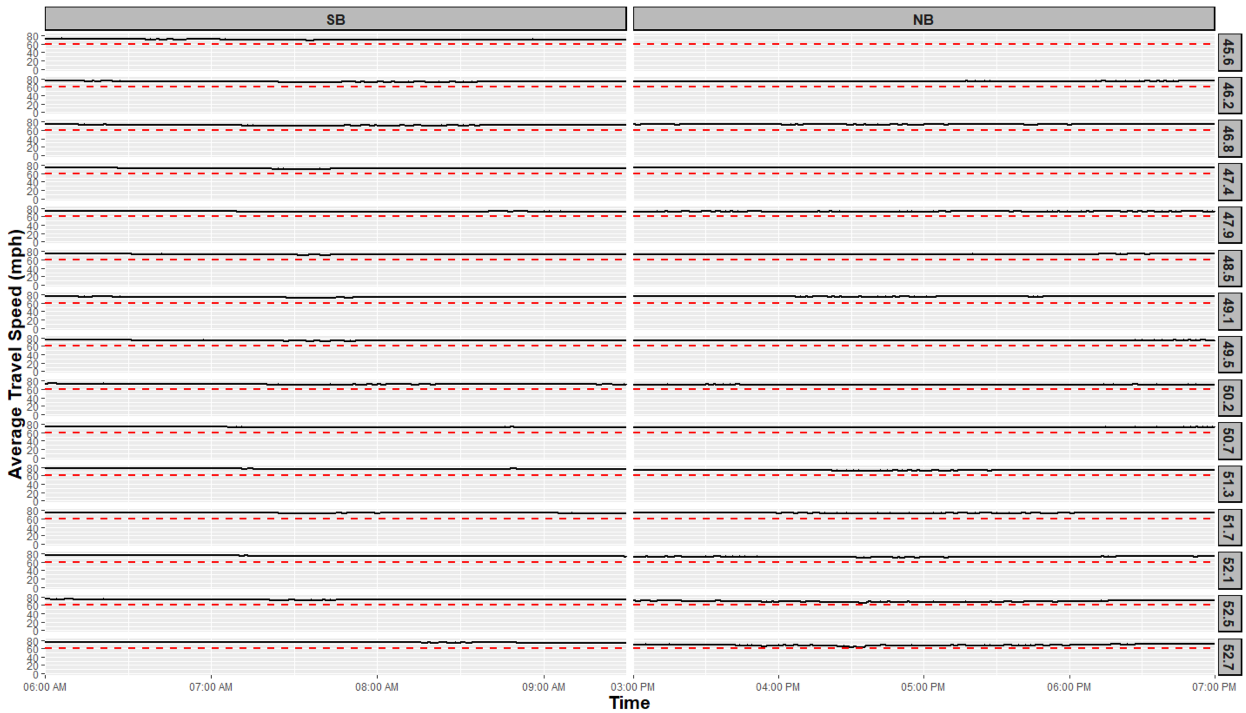
c. Advisory speed 40 mph



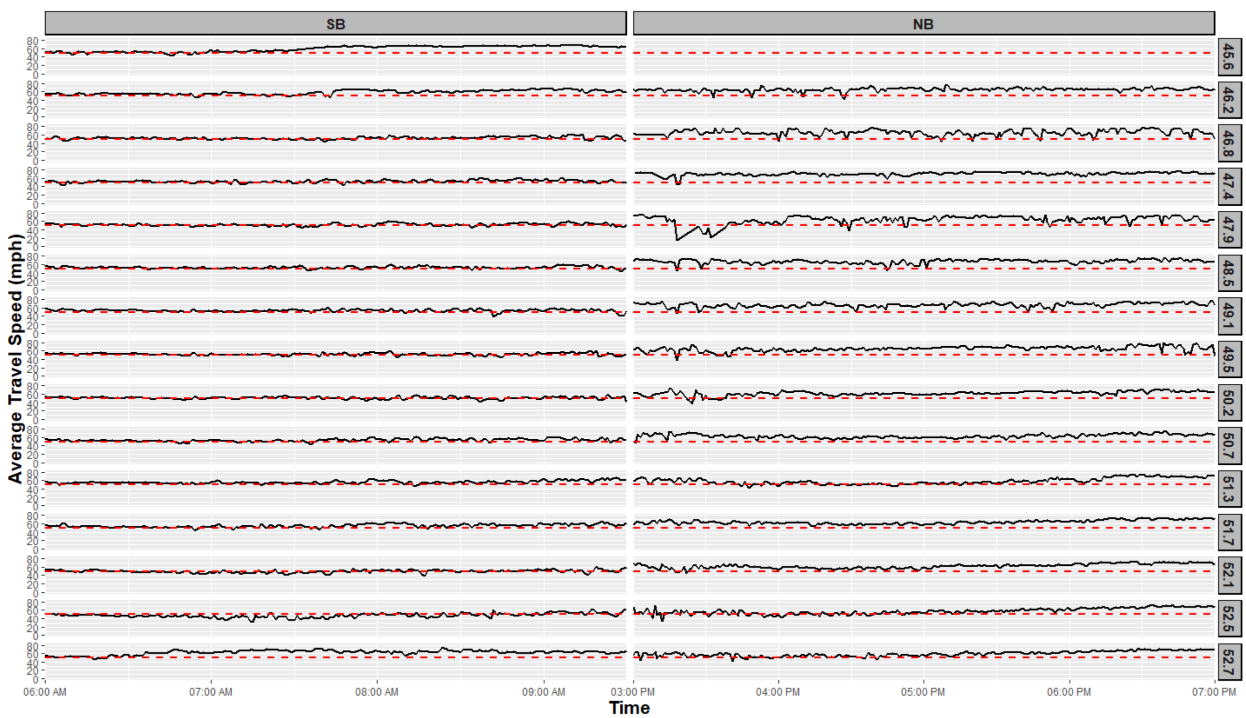
d. Advisory speed of 30 mph

Figure 3-23 Number of observations of actual travel speed under various advisory speeds

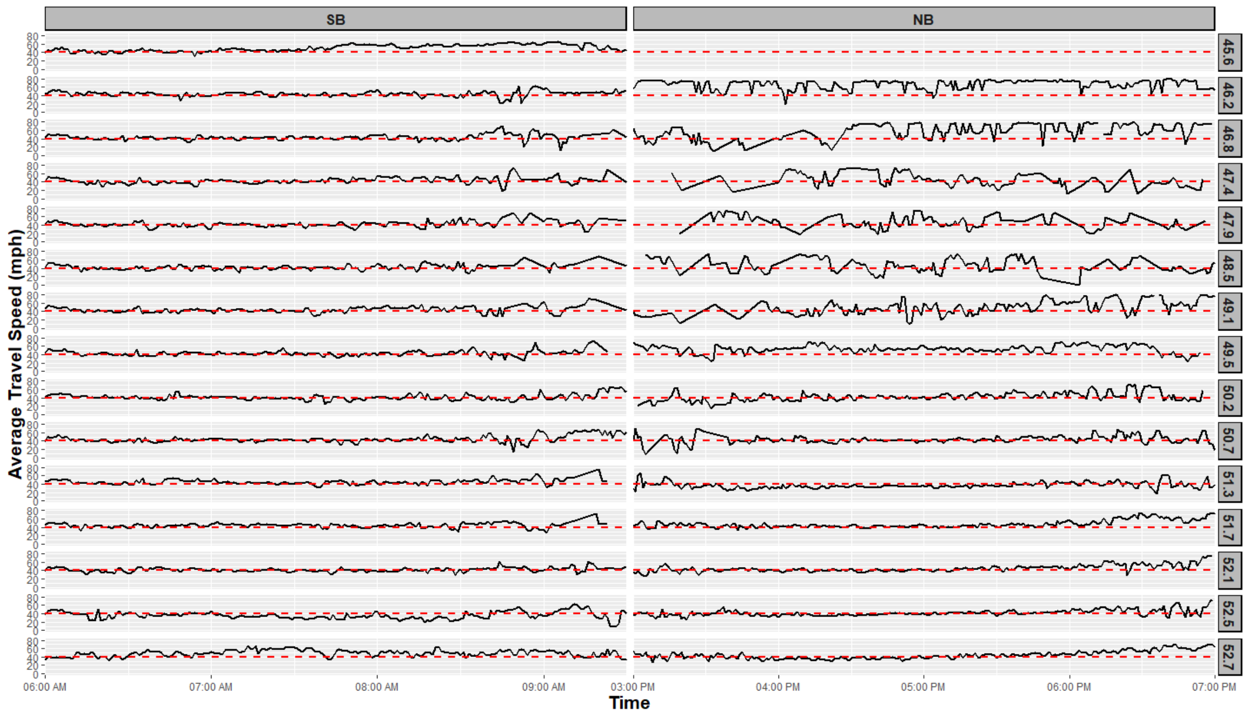
In addition to looking at travel speeds at a very aggregate level over the entire corridor, more detailed speed profiles were also created for each mile marker during the peak period under various advisory speeds in order to better understand changes in driver speed selection as shown in Figure 3-24. In the associated plots, the red dashed lines represent the advisory speed while the black lines are reflective of mean travel speeds.



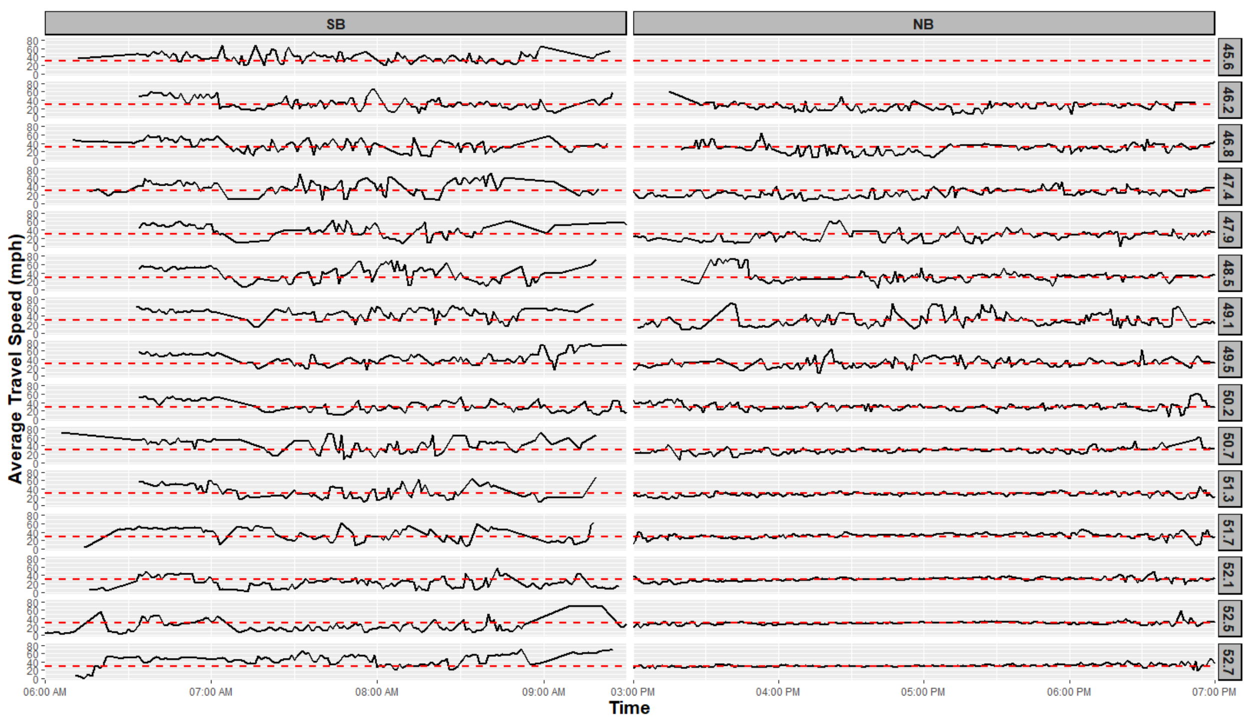
a. Advisory speed of 60 mph



b. Advisory speed of 50 mph



c. Advisory speed of 40 mph



d. Advisory speed of 30 mph

Figure 3-24 Speed profiles under various advisory speeds

Each plot shows how average vehicle speeds changed with respect to the corresponding advisory speeds over the course of the peak traffic periods. Generally speaking, these plots show that speeds were consistently above the 60-mph advisory speed and, as the advisory speeds were reduced, speeds also tended to fall, though there was significantly more variability in speeds when the lower advisories were in effect. The clear exception here is in the northbound direction at the northernmost gantries where speeds were consistently at or around the advisory speeds. This reinforces the prior discussion point in that drivers were essentially forced to reduce their speeds in these sections due to traffic congestion. In contrast, the other milemarkers and higher advisory speeds tend to show greater variability, which is reflective of the underlying variability in driver behavior as traffic conditions are such that drivers can often exceed the advisory speed more easily under these conditions.

3.4.2.2 Regression Analysis

To better understand these relationships, a series of linear regressions models were estimated to assess how mean speeds varied under different advisory speeds. Ordinary least square (OLS) was used to estimate models of the functional form shown in Equation 5 (Washington, Karlaftis, & Mannering, 2011):

$$\mathbf{Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon_i} \qquad \textbf{Equation 5}$$

where Y_i is the mean travel speed at milemarker i; β_0 is the y-intercept; β_1 , β_2 ,…, β_k are estimated regression coefficients for each independent variable; X_1 to X_k are a series of independent variables (e.g., advisory speeds, geometric characteristics); and ε_i is a normally distributed error term with mean of zero and variance of σ^2. The error term is assumed to be independently and identically distributed across mile markers.

Results of seprate linear regression models for vehicle speeds in each direction of travel are shown in Table 3-10, and are reflected graphically in Figure 3-25. For each model, the results include the estimated coefficient, along with the associated standard error and p-value. When interpreting the results, positive parameter estimates indicate the average increase in mean vehicle speeds under that specific context as compared to the baseline condition (e.g., speeds in northbound direction were 4.7 mph higher from 6:31-6:45 pm as compared to 3:00-3:15 pm). In contrast, negative estimates are reflective of conditions when speeds are lower (e.g., speeds were 9.2 mph lower in the northbound direction with a 50 mph advisory speed as compared to 60 mph).

Table 3-10 Variable speed models for Flex route by direction

	Direction						
	Northbound			Southbound			
Parameter	Estimate	SE	P-value	Parameter	Estimate	SE	P-value
Intercept	67.065	0.268	<0.001	Intercept	77.354	0.279	<0.001
DMS2				**DMS2**			
60 mph	*Baseline*	*N/A*	*N/A*	60 mph	*Baseline*		
50 mph	-9.171	0.117	<0.001	50 mph	-17.613	0.126	<0.001
40 mph	-25.908	0.132	<0.001	40 mph	-28.646	0.141	<0.001
30 mph	-42.243	0.131	<0.001	30 mph	-36.973	0.177	<0.001
Mile Marker				**Mile Marker**			
45.6	*N/A*			45.6	-2.166	0.247	<0.001
46.2	5.942	0.240	<0.001	46.2	-4.311	0.252	<0.001
46.8	4.601	0.251	<0.001	46.8	-6.059	0.257	<0.001
47.4	4.509	0.241	<0.001	47.4	-6.039	0.261	<0.001
47.9	1.962	0.257	<0.001	47.9	-6.516	0.262	<0.001
48.5	4.439	0.251	<0.001	48.5	-5.671	0.263	<0.001
49.1	5.498	0.240	<0.001	49.1	-3.776	0.261	<0.001
49.5	5.540	0.229	<0.001	49.5	-4.630	0.261	<0.001
50.2	1.081	0.218	<0.001	50.2	-7.638	0.260	<0.001
50.7	1.339	0.217	<0.001	50.7	-5.017	0.261	<0.001
51.3	-1.183	0.214	<0.001	51.3	-2.895	0.261	<0.001
51.7	4.140	0.211	<0.001	51.7	-4.563	0.263	<0.001
52.1	2.200	0.209	<0.001	52.1	-7.642	0.261	<0.001
52.5	-0.803	0.209	<0.001	52.5	-10.694	0.256	<0.001
52.7	*Baseline*	*N/A*	*N/A*	52.7	*Baseline*	*N/A*	*N/A*
Season				**Season**			
Winter	*Baseline*	*N/A*	*N/A*	Winter	*Baseline*	*N/A*	*N/A*
Fall	2.481	0.130	<0.001	Fall	0.610	0.123	<0.001
Spring	2.316	0.131	<0.001	Spring	2.348	0.150	<0.001
Summer	2.411	0.130	<0.001	Summer	1.770	0.153	<0.001
Operational Time				**Operational Time**			
3:00-3:15	*Baseline*	*N/A*	*N/A*	6:00-6:15	*Baseline*	*N/A*	*N/A*
3:16-3:30	-0.402	0.288	0.163	6:16-6:30	-0.771	0.292	0.008
3:31-3:45	-0.164	0.278	0.554	6:31-6:45	0.491	0.282	0.082
3:46-4:00	-1.779	0.277	<0.001	6:46 -7:00	0.393	0.281	0.162
4:01-4:15	-1.101	0.267	<0.001	7:01-7:15	-0.879	0.273	0.001
4:16-4:30	-1.427	0.268	<0.001	7:16-7:30	-1.514	0.274	<0.001
4:31-4:45	-1.575	0.266	<0.001	7:31-7:45	-2.061	0.269	<0.001
4:46-5:00	-0.407	0.269	0.131	7:46 -8:00	-0.806	0.272	0.003
5:01-5:15	0.225	0.262	0.392	8:01-8:15	-0.572	0.266	0.031
5:16-5:30	0.997	0.267	<0.001	8:16-8:30	-0.729	0.270	0.007
5:31-5:45	2.233	0.268	<0.001	8:31-8:45	0.541	0.272	0.047
5:46-6:00	2.160	0.273	<0.001	8:46 -9:00	0.895	0.284	0.002
6:01-6:15	2.900	0.266	<0.001	9:01-9:15	1.559	0.282	<0.001
6:16-6:30	4.615	0.276	<0.001	9:16-9:30	0.793	0.293	0.007
6:31-6:45	4.661	0.283	<0.001	-	-	-	-
6:46-7:00	3.878	0.286	<0.001	-	-	-	-

In these results, the intercept term is reflective of the mean speed under the baseline conditions. In this case, that corresponds to the mean speed at MM 52.7 when the default 60 mph advisory speed is in place, during the earliest time period (i.e., 3:00-3:15 pm or 6:00-6:15 pm), and in the winter season. The other parameter estimates indicate by how much average travel speeds changed outside of these base conditions. Figure 3-25 shows substantive variability in speeds across some of the milemarkers. These differences are generally due to congestion, whether approaching the northbound terminus or, alternately, near the various entrance ramps in both directions of travel.

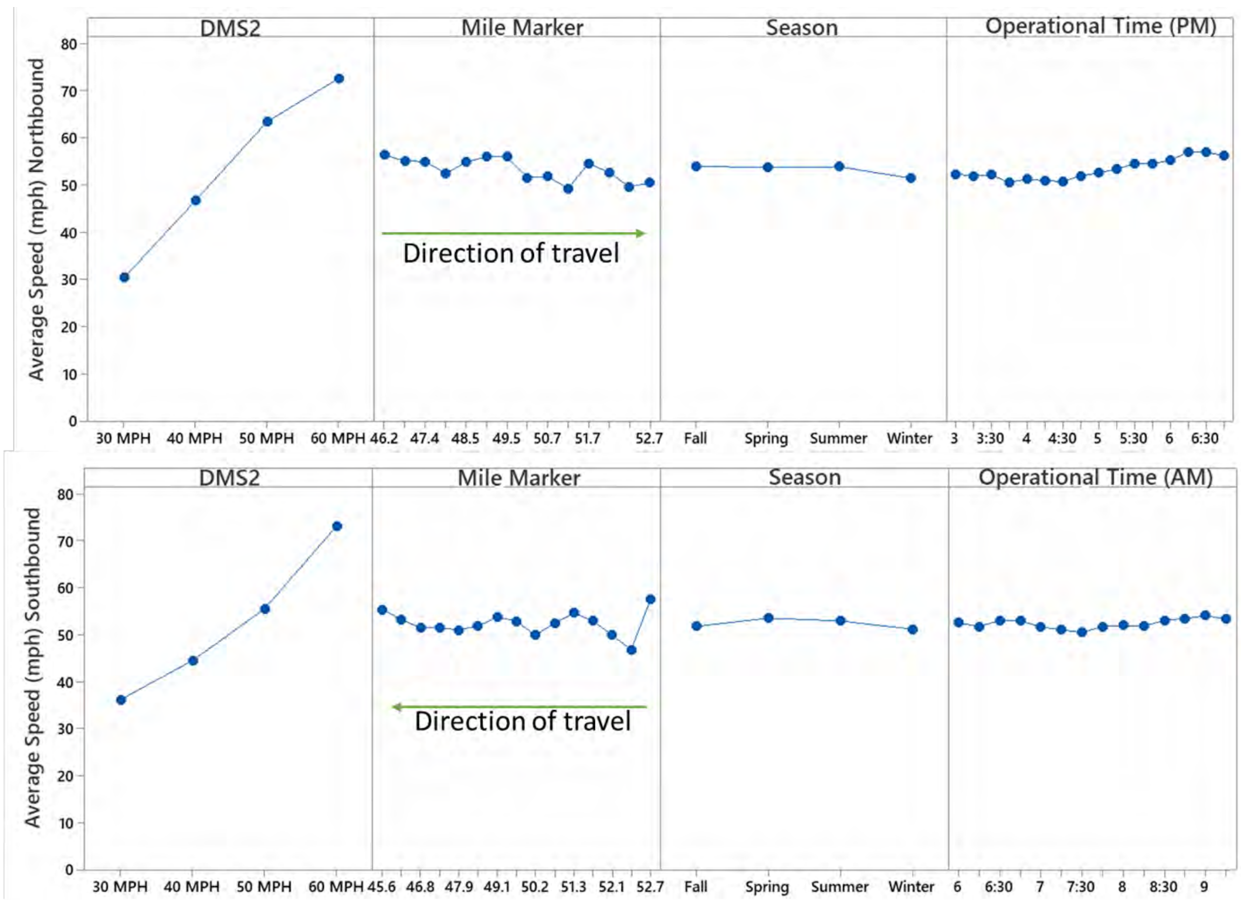


Figure 3-25 Mean speed versus DMS2, mile marker, season, and operational time for both northbound and southbound

The primary variables of interest in this analysis are the changes in speeds that are associated with the advisory speeds that are shown on DMS2. At the onset, it is important to note that the lower advisory speeds were in effect for a significantly longer period of time in the northbound direction as compared to the southbound direction given the more substantive congestion, especially near the lane drop. To that end, when the 50 mph advisory speeds are introduced, the mean speeds are reduced to approximately 58 mph in the northbound direction and 60 mph in the southbound direction. Again, the speeds at individual milemarkers vary as reflected by the parameter estimates in Table 3-10.

When the advisory speeds are reduced from 50 to 40 mph, speeds are lower by 11 mph in the southbound direction and more than 16 mph lower in the northbound direction. The reduction from 40 to 30 mph was associated with reductions of 8 mph and 17 mph in the southbound and northbound directions, respectively. It is interesting to see that the reductions in mean speeds are significantly more pronounced in the northbound direction. As alluded to previously, this is a function of both the lower advisory speed and, particularly, the heightened levels of traffic congestion in this direction. One issue with understanding driver response to these advisory speeds is the very low level of compliance with the default 60 mph advisory speed. Since this specific advisory speed is generally not reflective of actual traffic conditions, it appears to result in some distrust from travelers as to the appropriateness of the advisory speeds more broadly as reflected by the survey and focus group results.

In general, speeds tended to be highest at the start of the Flex lane in the northbound direction, remaining relatively stable up to MM 49, before being reduced over the remainder of the corridor (aside from a small increase around MM 51). In contrast, speeds in the southbound direction tended to be lower upon introduction of the Flex lane, which is largely reflective of the upstream traffic congestion that is present from I-96. Speeds drop due, in large part, to an on-ramp and associated weaving in this area. Speeds peak around MM 51, before a sequence of small decreases and then increases in speeds as drivers approach the interchange with M-14.

Since the data is collected year-round, the effects of seasonal variations were also accounted for in the model for speed distributions. As expected, the speeds were higher (by 1.0 to 2.5 mph) during the spring, summer, and fall seasons as compared to the winter season for both directions.

Speeds were also found to vary by time of day, which is also reflective of the level of traffic congestion. As noted previously, the northbound Flex lane generally operates from 3:00 pm to 7:00 pm, while the southbound direction operates from 6:00 am to 9:30 am. The analysis results show that speeds in the northbound direction were lower from 3:00 to 5:00 pm, with minimum speeds generally occurring between 4:16 and 4:45 pm. Speeds subsequently increased by 1 to 7 mph from 5:16 pm to 7 pm as voulmes decreased. Similarly, in the southbound direction, speeds were lowest from 7:16 am to 7:45 am, and higher from 8:31 am to 9:30 am.

A related item of concern is how drivers adjust their speeds as the Flex route is opened, closed, or the advisory speeds are changed. To better understand behavior during these transition periods, speed profiles were examined beginning 15 minutes before the opening of the Flex lane, through 15 minutes after the closure of the Flex lane. Separate analyses were conducted in both directions using one week of sample data as described in section 3.3 and plots of these profiles are shown in Figure 3-26 and Figure 3-27 for the northbound and southbound directions, respectively. In these profiles, the y-axes are reflective of average speeds during each one-minute interval and the x-axes show the time of day. Separate panels are provided for each mile marker while different colors reflect the various advisory speeds shown on DMS2 (i.e., 30 mph, 40 mph, 50 mph, 60 mph, and no message displayed).

These plots include one full set of weekday (Monday to Friday) data during the fall season under normal conditions (i.e., no crashes or other sources of non-recurrent congestion). Similar analyses were conducted during other periods and these results are generally representative of the broader patterns. In the northbound direction (Figure 3-26), the DMS generally showed the default 60 mph over most of the Flex route operating time from MM 46.2 (start of flex route) to MM 49.5. From MM 50.2 to MM 51.3, the advisory speeds were reduced to 50, 40, and 30 mph between 4:00 and 5:00 pm. At the northern limits, from MM 51.7 to 52.7, the 60-mph sign was only displayed until 3:30 pm, after which these speed reductions occurred until approximately 5:30 pm, after which the travel speeds returned to normal free-flow conditions.

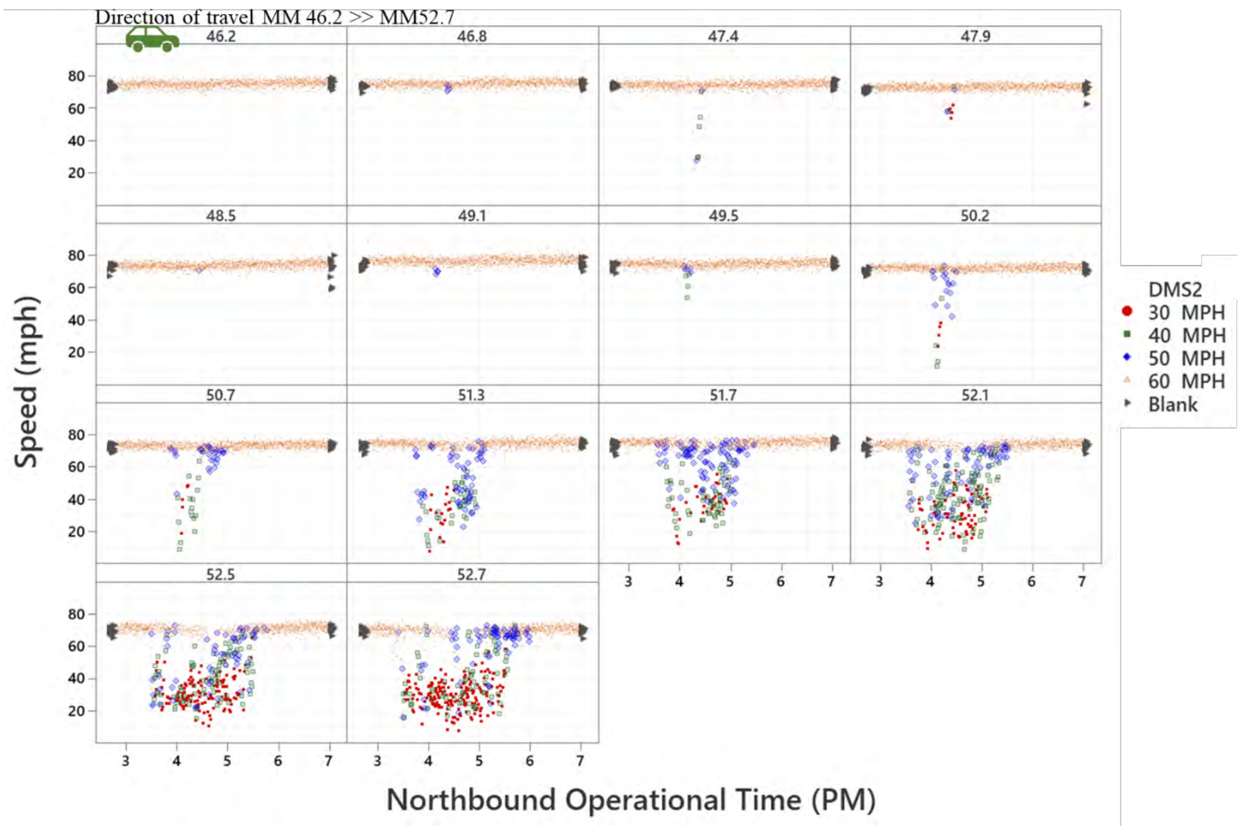


Figure 3-26 Northbound drivers' speed profile during only weekdays, 15 minutes before the operational time, during, and after

In contrast, as shown in Figure 3-27, the southbound direction showed relatively consistent speeds across the peak period. The 60 mph default advisory was in place for the majority of the analysis period regardless of the mile marker. Lower advisory speeds of 40 to 50 mph were introduced, primarily at the start of the Flex lane where upstream congestion was gradually reduced as vehicles entered the Flex Route, as well as at the end of the Flex lane as vehicles approached the M-14 interchange.

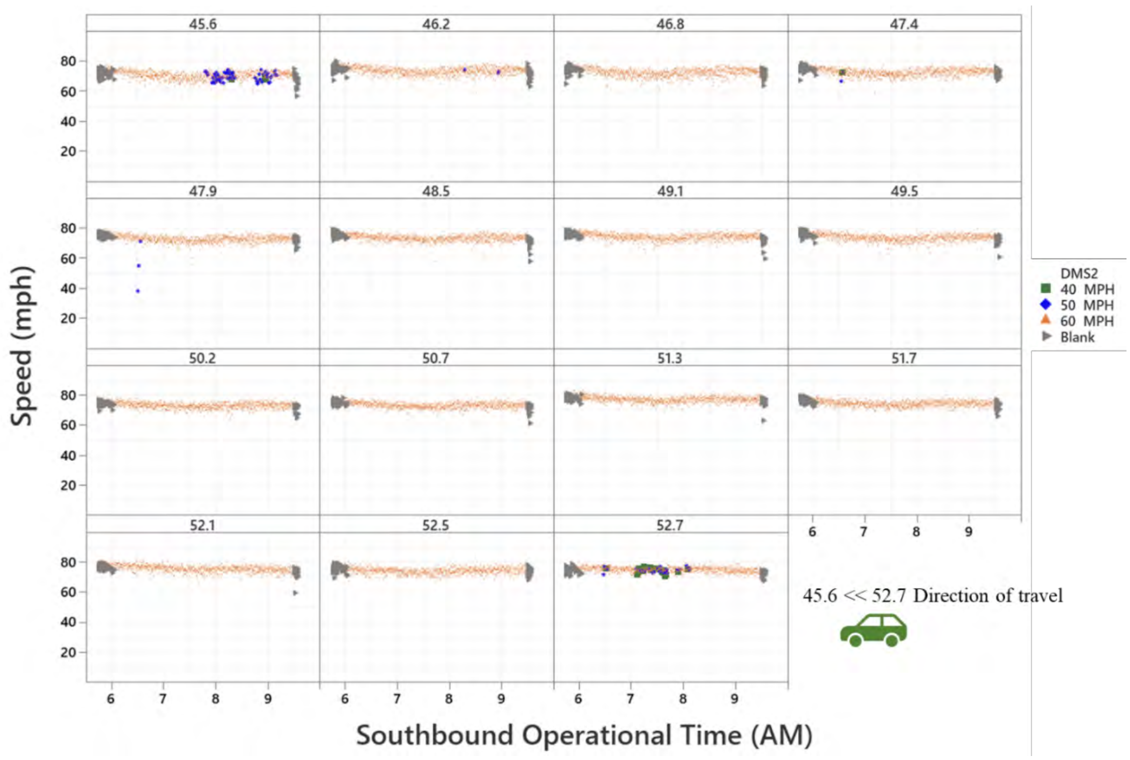


Figure 3-27 Southbound drivers' speed profile during only weekdays, 15 minutes before the operational time, during, and after

To assess average changes in driver behavior, the data from Figure 3-26 and Figure 3-27 were aggregated into two sets of data. These datasets ranged from MM 46.2 to 49.5 (i.e., upstream the flex route for NB and downstream for SB) and from MM 50.2 to 52.7. Then, two-way interaction plots between these two sets of MMs and advisory speeds were prepared for both directions separately, as shown in Figure 3-28. The southern section is illustrated in blue while the northern section is illustrated in red. For reference, horizontal lines are provided to illustrate the difference between average and advisory speeds.

Interestingly, these plots show substantive differences between these sections in the northbound direction, but relatively consistent results in the southbound direction. In both directions there is very poor compliance overall with the default 60-mph advisory speed. The average speeds when the 60-mph advisory speed is I nplace are around 70 mph or more, which is reflective of the normal (i.e., non-Flex) posted limit along the US-23 corridor.

When the advisory speeds are reduced to 50 mph, speeds remained relatively high in the northbound direction as the averaged speeds ranged from 10 to more than 15 mph above the advisory speed. In contrast, southbound speeds were only 5 mph above the advisory speed. It is interesting to note that the reductions in mean speeds were generally consistent in the southbound direction between the northern and southern sections of the Flex route.

Conversely, speeds were significantly higher over the first 3-4 miles in the northbound direction as compared to the final 2-3 miles. This appears to suggest that the advisory speeds have minimal impacts on speed selection and most of the reduction is likely an artifact of the level of traffic congestion that is present along these respective sections. For example, the 40 mph and 50 mph advisory speeds between MM 46.4 and 49.5 generally occur upstream of the congestion and provide advance warning to approaching motorists. However, drivers maintain speeds that are consistently above the advisory speeds until they reach the more congested sections between MM 50.2 and 52.7. The southbound direction also shows some minor deviations at the lower advisory speeds, which is again likely to be reflective of the congestion that occurs upstream of the Flex route (rather than downstream) in the southbound direction on the approach from I-96. Overall, the primary takeaway from this analysis is that the advisory speeds have limited impacts on driver behavior and congestion appears to play a greater role.

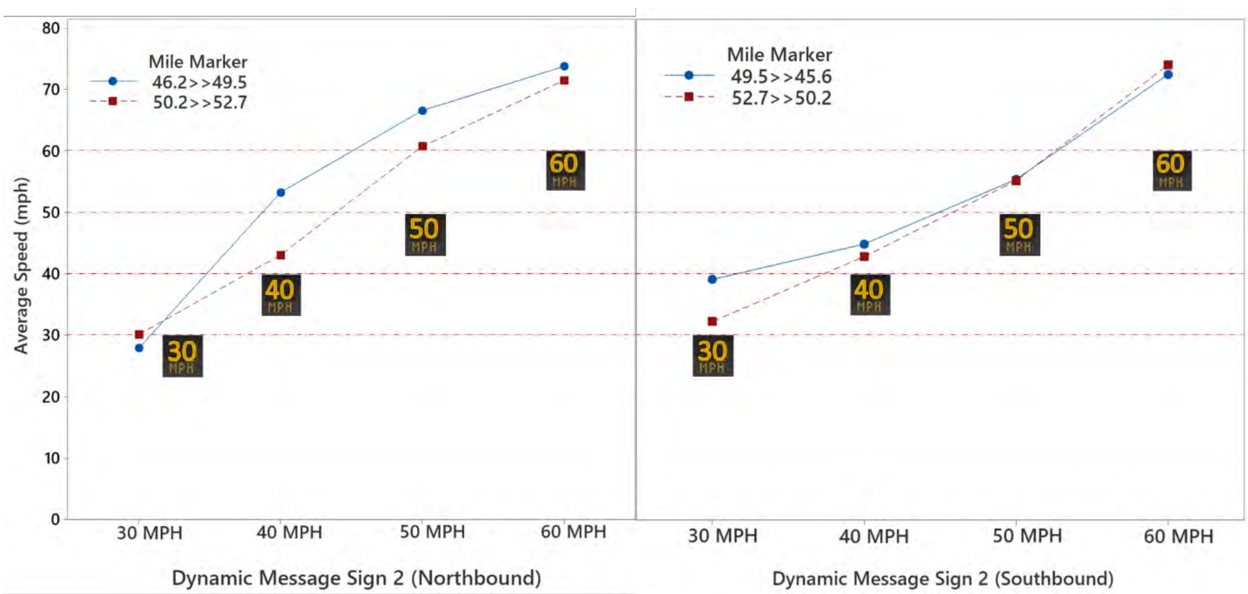


Figure 3-28 Two-way interaction between DMS2 and the aggregated mile markers for both directions on mean speed

3.5 Performance during Special Events

The performance of the US-23 Flex route was also evaluated under various special events. This includes operation on the dates of home football games at the University of Michigan, where the route serves as a primary corridor for gameday traffic. This is one of the limited cases where the Flex route is in operation during weekends. In addition, performance was also assessed on other days where high traffic volumes occurred, including Fridays and holidays. The data utilized in this section include travel speed data from MVDS reports and gantry messages from ATM reports. The data integration can be found in section 0.

3.5.1 *Game Day Performance*

The game day data such as the football schedule, weather, and instances of crashes were determined from three websites, respectively: University of Michigan Athletics (University of Michigan, 2021b), Weather Underground (Weather Underground, 2021), and Michigan Traffic Crash Facts (MTCF) (University of Michigan, 2021a). This data for football games in 2018 and 2019 is summarized in Table 3-11. The corresponding travel speeds with one-minute interval along the Flex route were obtained from the MVDS reports. Additionally, the gantry messages, especially the messages of Flex lane closure during the game days, were obtained from the ATM reports.

In order to determine the effectiveness of the Flex route on game days, the game day data was collected and the gantry messages were integrated with the travel time over game days. The data integration procedures were similar to the procedures introduced in section 3.4.

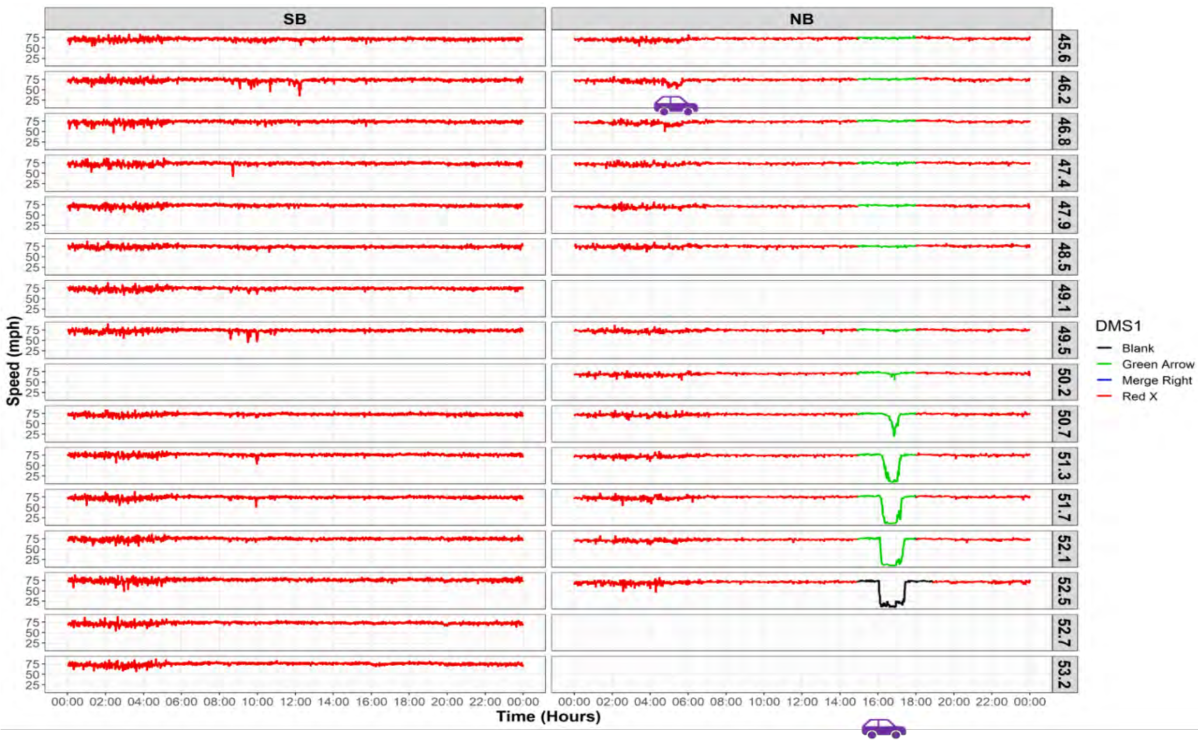
In general, the Flex route operated efficiently during most football games that happened between 2018 and 2019 in Ann Arbor. However, there were several games that deserved additional attention, such as, the home games against Nebraska, Maryland, Army, Rutgers, and Iowa. The following paragraphs will discuss the specifics of each game individually. On the graphs, the blue car icon, raining icon, and the football icon indicate the location and time of crashes, the time of precipitation, and football games, respectively.

Table 3-11 University of Michigan home football games (2018-2019)

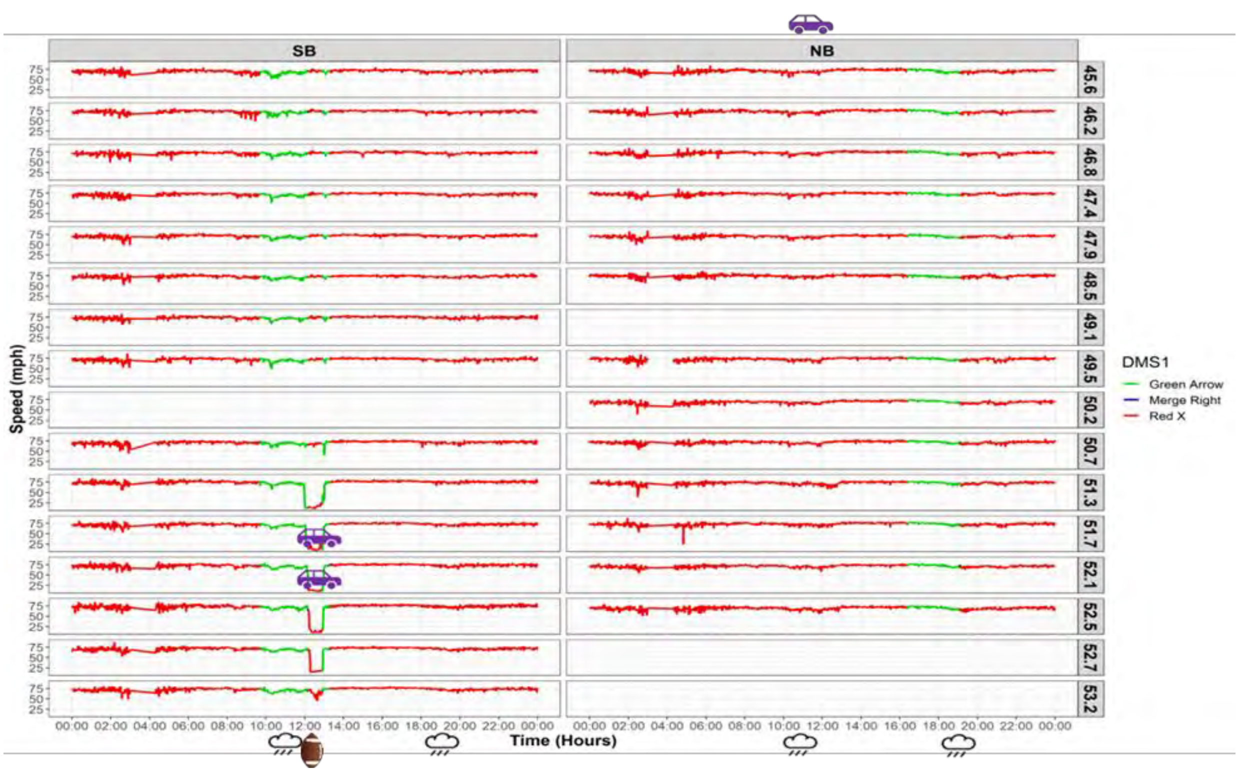
Team	Date	Start Time	Duration	End Time	Attendance	Scores
Western Michigan	9/8/2018	12:00 PM	3:12	3:12 PM	110814	49-3
Southern Methodist University	9/15/2018	3:30 PM	3:24	6:54 PM	110549	45-20
Nebraska	9/22/2018	12:00 PM	3:30	3:30 PM	111037	56-10
Maryland (HC)	10/6/2018	12:00 PM	3:18	3:18 PM	109531	42-21
Wisconsin	10/13/2018	7:30 PM	3:07	10:37 PM	111360	38-13
Penn State	11/3/2018	3:45 PM	3:17	7:02 PM	111747	42-7
Indiana	11/17/2018	4:00 PM	3:38	7:38 PM	110118	31-20
Middle Tennessee State	8/31/2019	7:30 PM	3:26	10:56 PM	110811	40-21
Army	9/7/2019	12:00 PM	3:34	3:34 PM	111747	24-21
Rutgers	9/28/2019	12:00 PM	3:09	3:09 PM	110662	52-0
Iowa	10/5/2019	12:00 PM	3:26	3:26 PM	111519	3-10
Notre Dame	10/26/2019	7:30 PM	3:31	11:01 PM	111909	45-14
Michigan State	11/16/2019	12:00 PM	3:34	3:34 PM	111496	44-10
Ohio State	11/30/2019	12:00 PM	3:41	3:41 PM	112071	27-56

Figure 3-29a shows that the Flex lane was not in operation during the Nebraska game. The Flex route operated in the northbound direction during the afternoon. Several moderate fluctuations of speed were observed at multiple locations without showing any particular trend. It should be noted that two crashes happened on northbound US-23 on that day, which impacted downstream traffic traveling northbound.

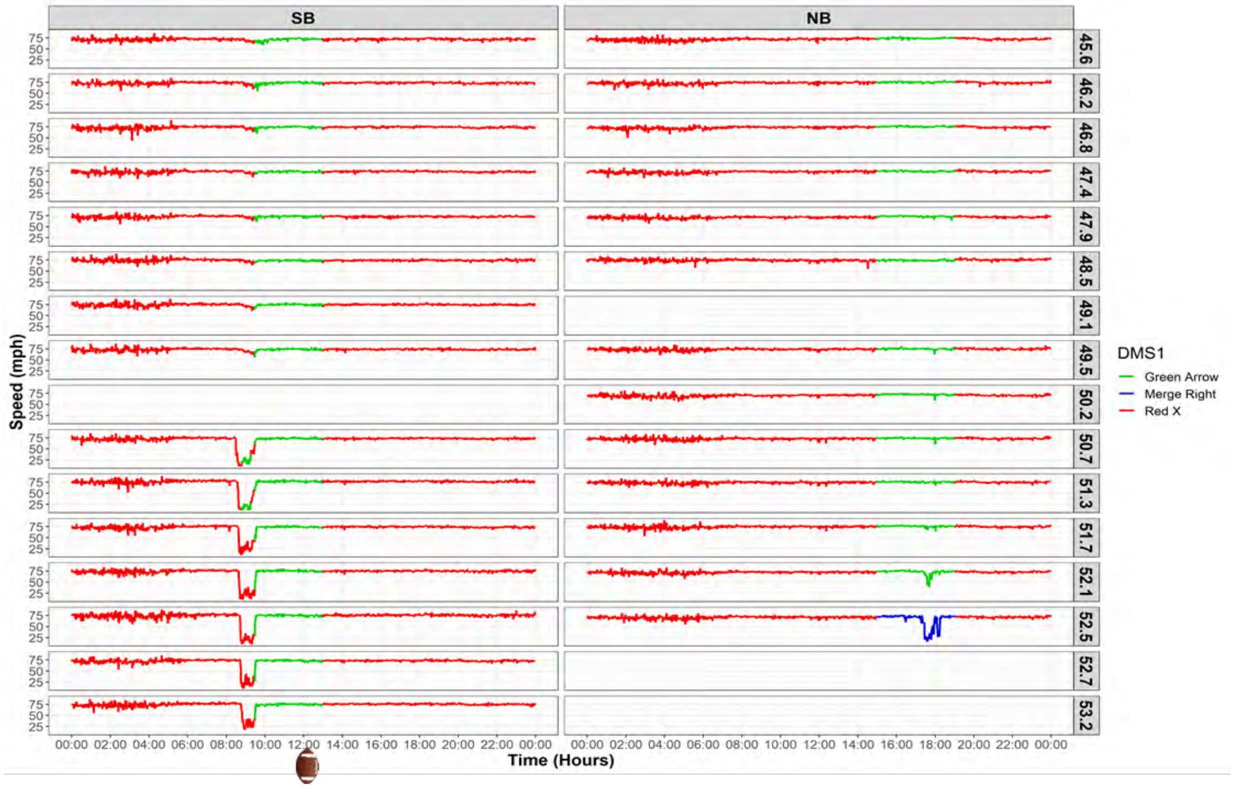
The southbound Flex lane also opened at around 10 AM for the Maryland game (Figure 3-29b). Some fluctuations were still observed on southbound US-23, particularly as traffic neared Ann Arbor. If the Flex lane had opened earlier, it might have been able to accommodate these issues occurring in the southbound direction. Similarly, the Flex route started to operate around 10 AM for games against Army and Rutgers (Figure 3-29c and Figure 3-29d). Speed drops were found in the southbound direction.



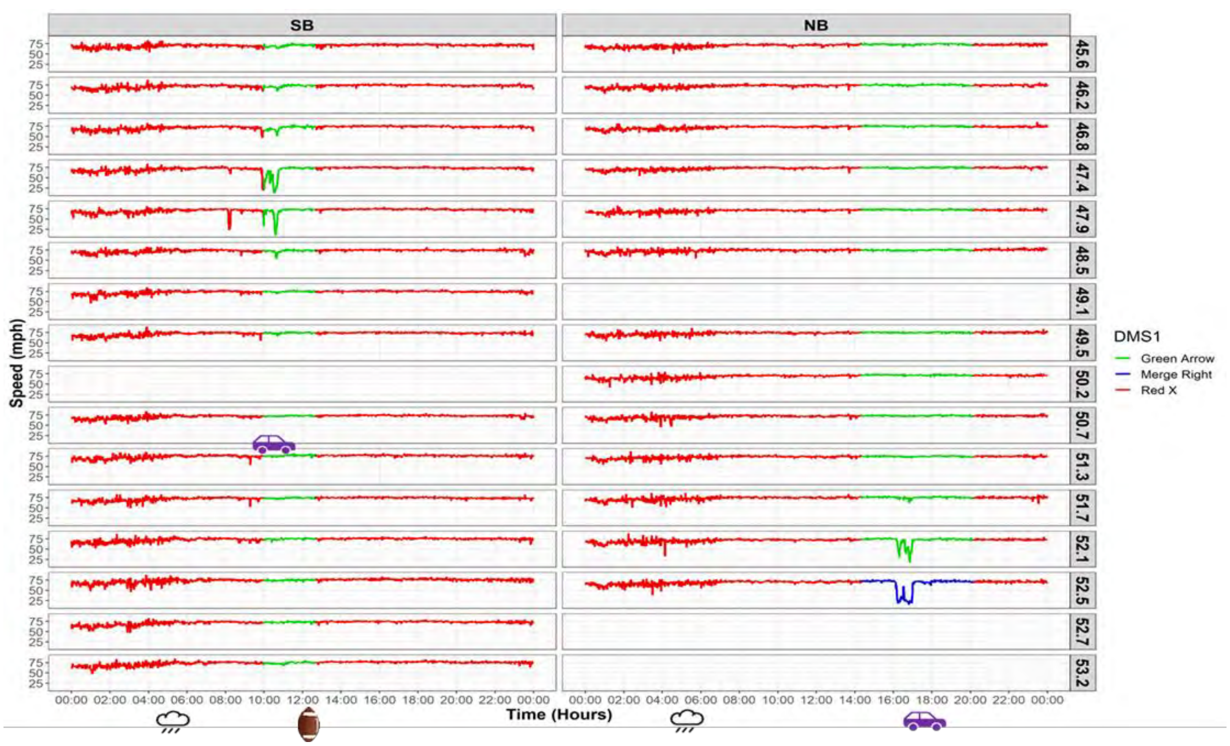
a. September 22, 2018 – Nebraska, 12:00 PM – 3:30 PM



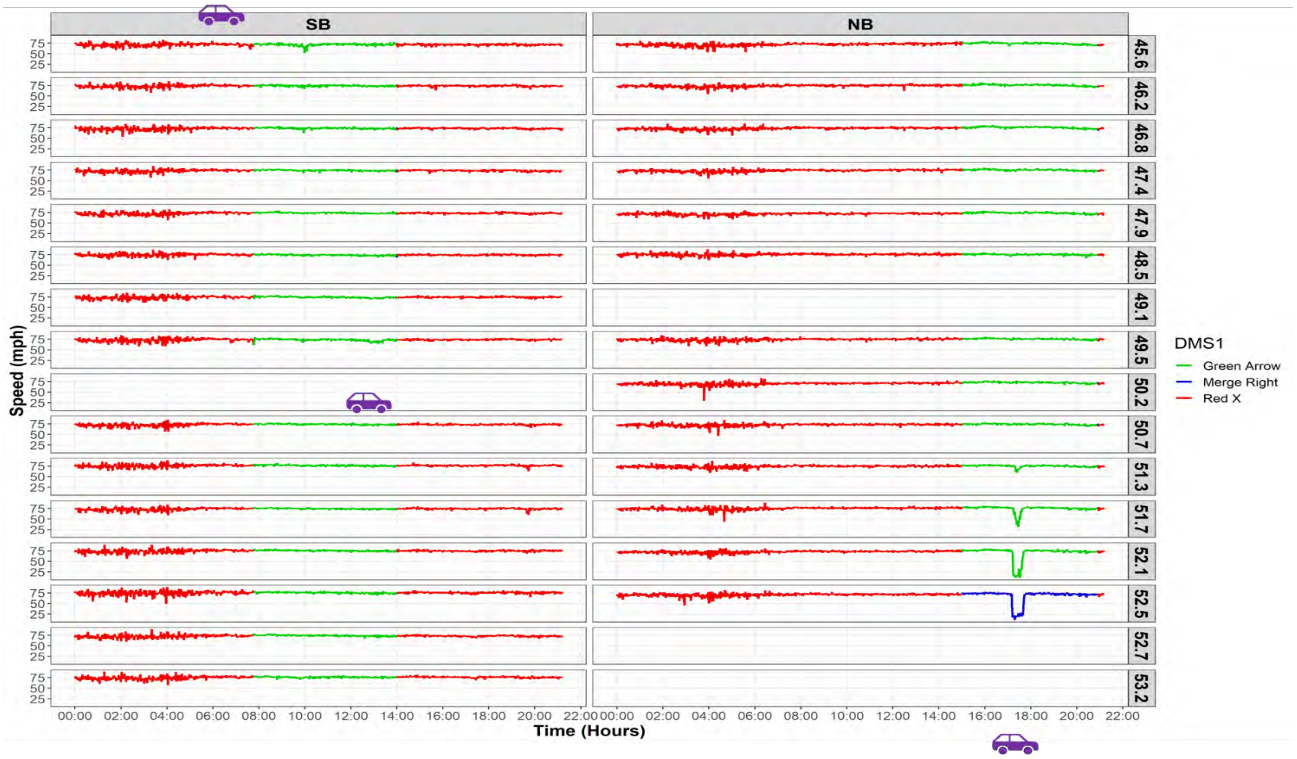
b. October 6, 2018 – Maryland, 12:00 PM – 3:18 PM



c. September 7, 2019 – Army, 12:00 PM – 3:34 PM



d. September 7, 2019 – Army, 12:00 PM – 3:34 PM



e. October 5, 2019 – Iowa, 12:00 PM – 3:26 PM

Figure 3-29 Drivers' speed selection behavior on US-23 Flex route on football game days

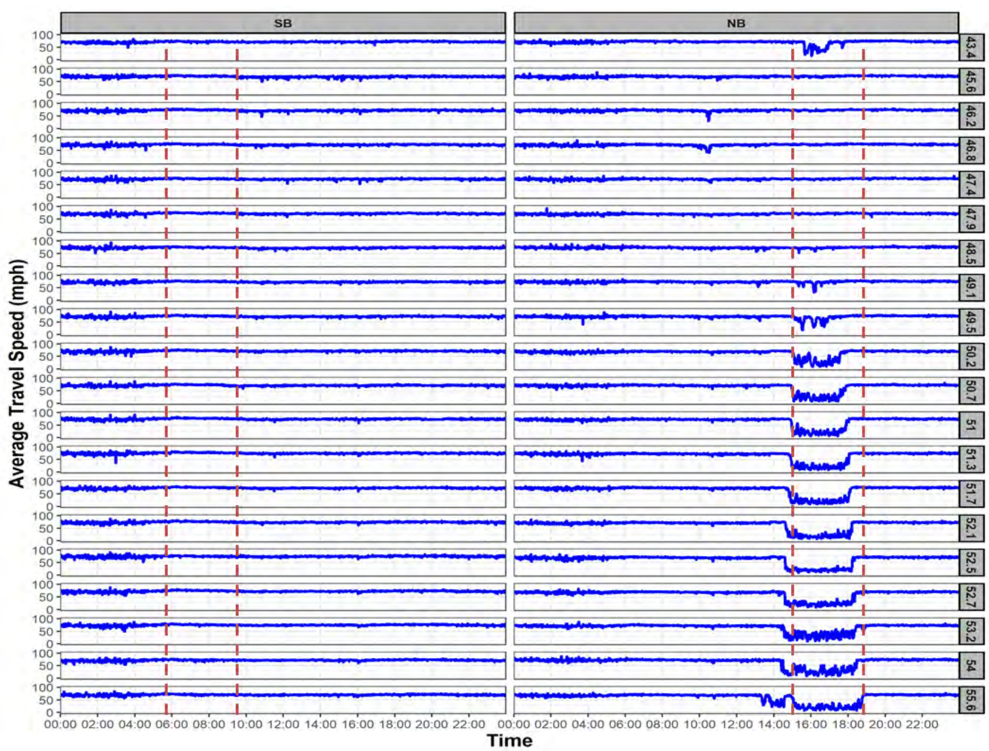
Conversely, the Iowa game (Figure 3-29e) had a similar kickoff time (12 PM), but the operation of the Flex route started around 8 AM in the southbound direction. There were no significant fluctuations of travel speed observed. Based on these collective results, it is recommended that the Flex lane should generally open four hours prior to kickoff on the dates of home football games.

3.5.2 Holiday and Friday Performance

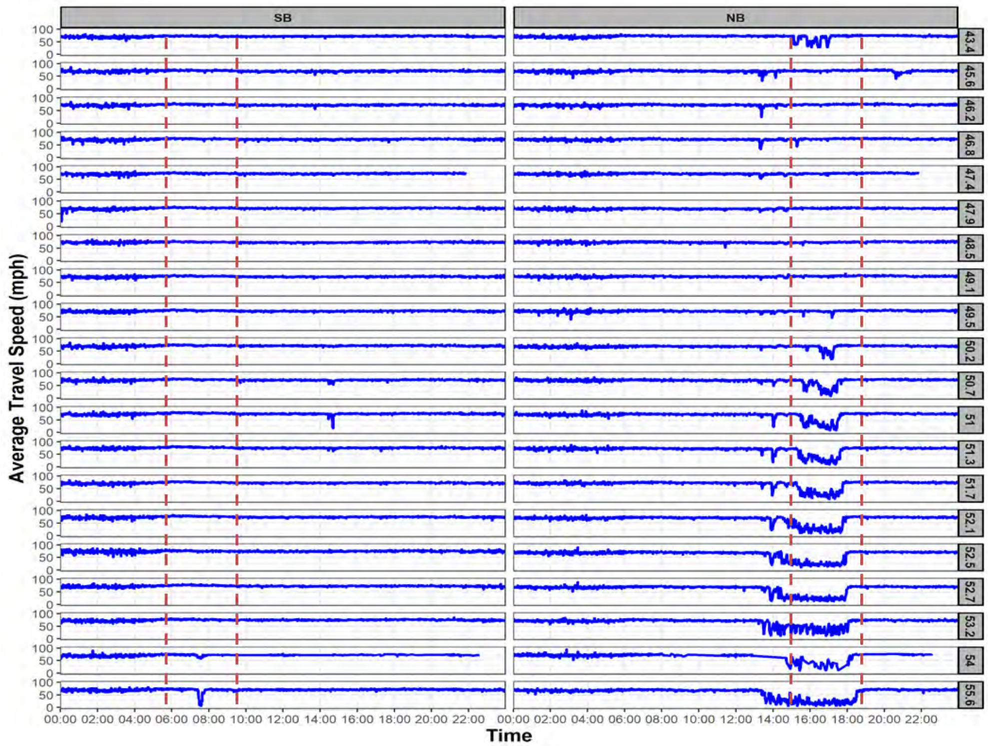
The travel patterns generally change before, during, or after holidays, such as Independence Day, Thanksgiving, Christmas, or New Year. Consequently, the performance of the Flex route was also assessed during these dates in 2018 and 2019. The corresponding travel speed over those days was obtained from MVDS reports. The speed profiles were plotted for each selected date. After inspecting all the speed profiles, the traffic during holiday seasons was generally well accommodated by the Flex lane with a few exceptions.

For example, a few days before some of these holidays may warrant specific attention. These days include the Friday before Memorial Day, the day before Independence Day, the Friday before Labor Day, the Wednesday before Thanksgiving, and the Friday before Christmas. Figure 3-30 exhibits the speed profiles during these special days (Figure 3-30a-e) and an example of holiday performance (Figure 3-30f). The red dash lines on the graphs indicate the range of typical operational time of the Flex lane.

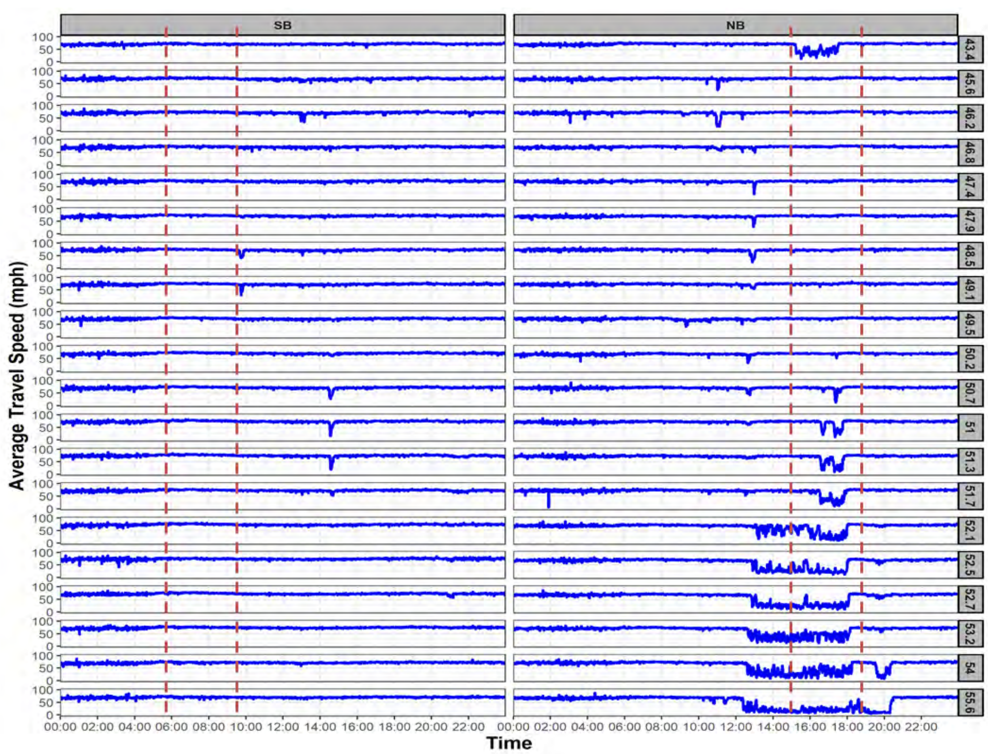
As the figures demonstrate, there were generally no concerns for the southbound traffic. Most congestion was found in the northbound direction near the lane drop as detailed previously. Based on these issues, the Flex lane is recommended to open one to two hours earlier than the normal (i.e., at 1:00 or 2:00 pm) time in northbound direction. On the Friday before Labor Day (Figure 3-30c), it is suggested that the Flex lane opens three hours earlier, at 12:00 pm, to accommodate the additional northbound traffic.



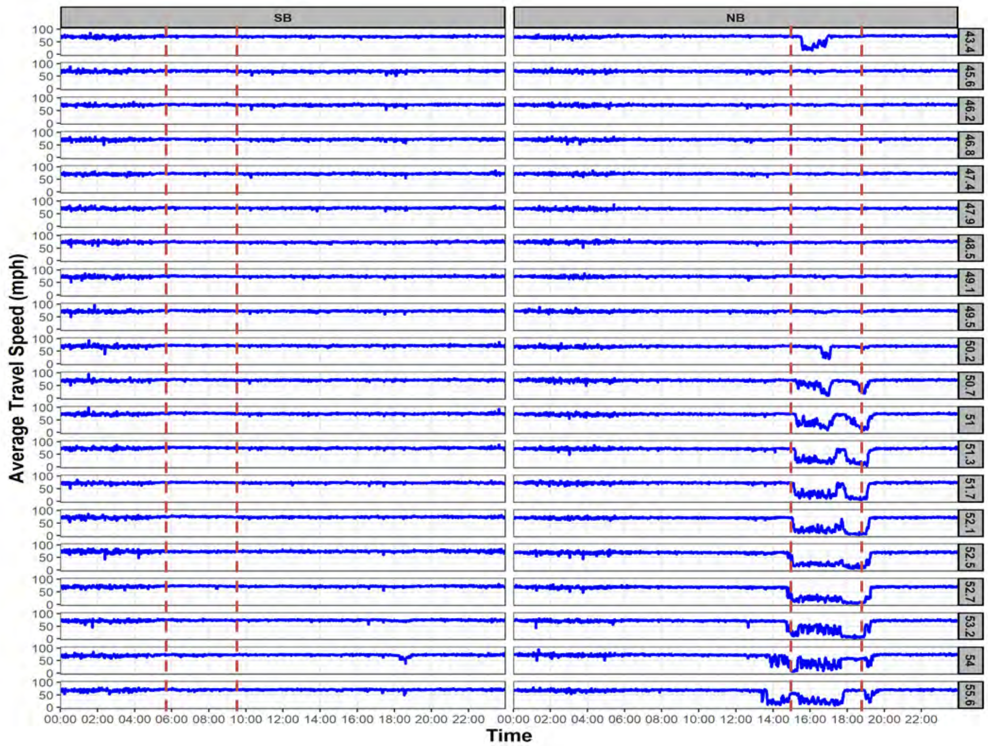
a. Friday before Memorial Day



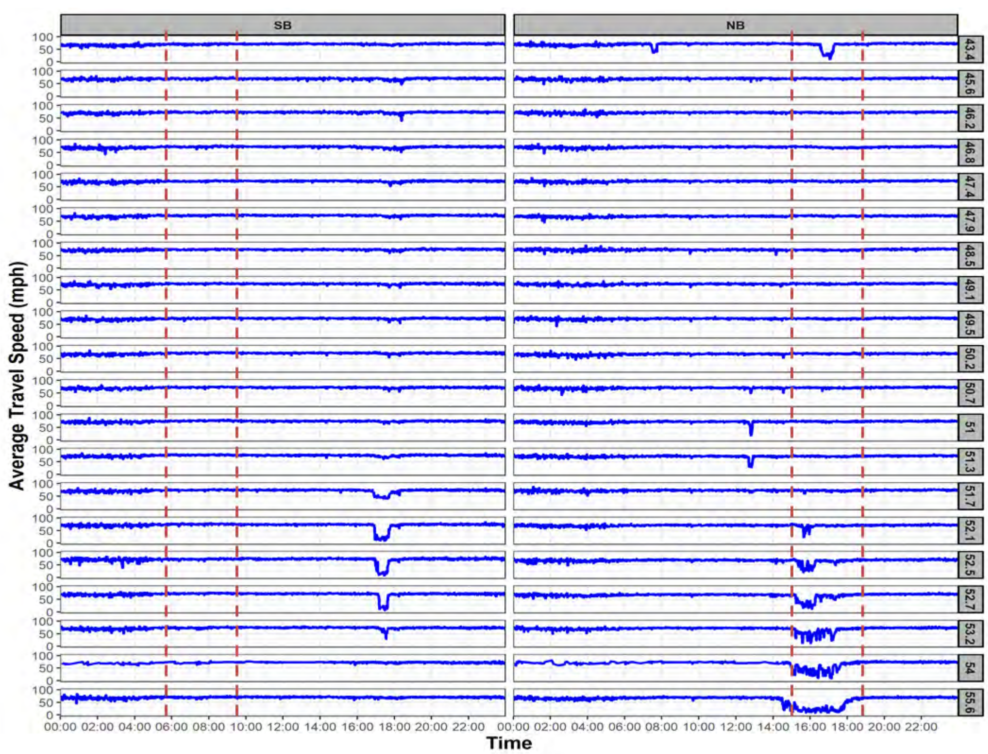
b. July 3rd before Independence Day



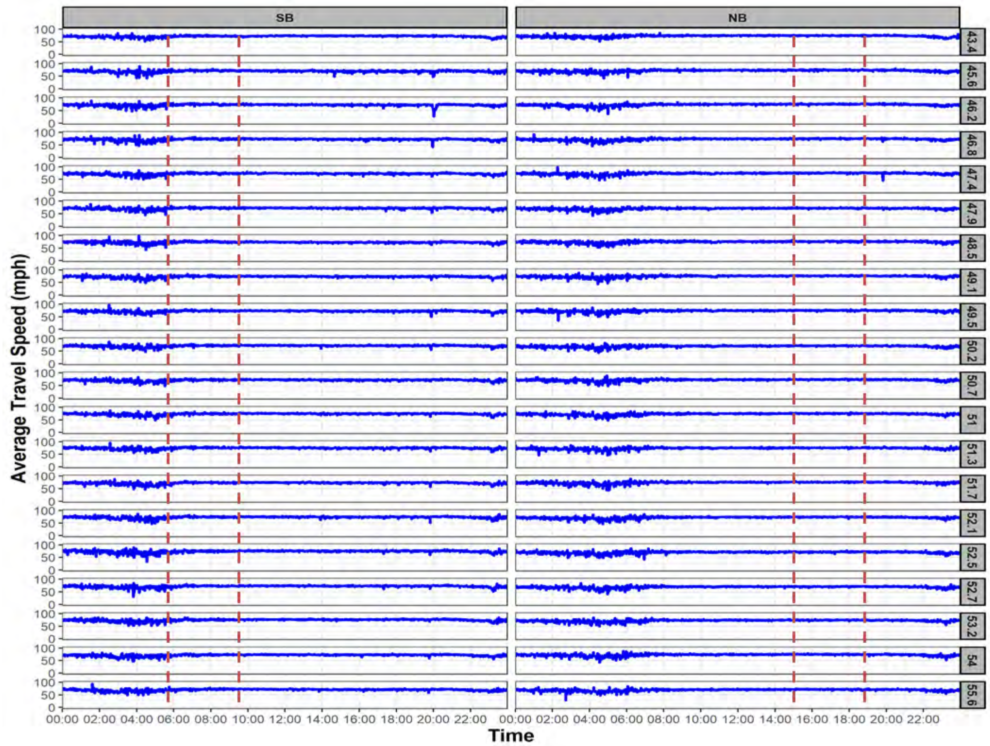
c. Friday before Labor Day



d. Wednesday before Thanksgiving



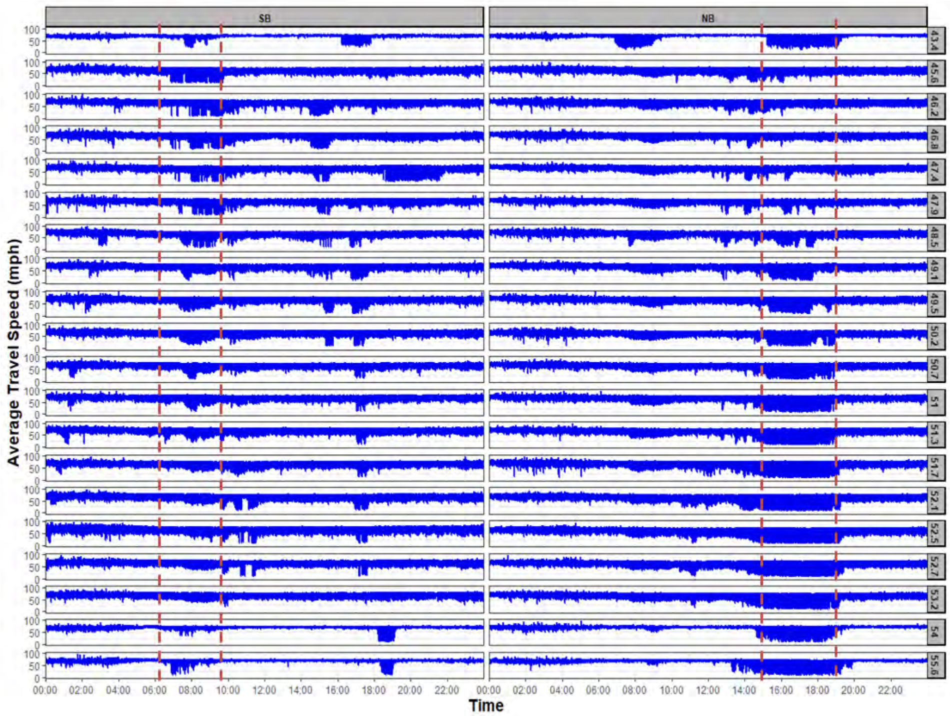
e. Friday before Christmas



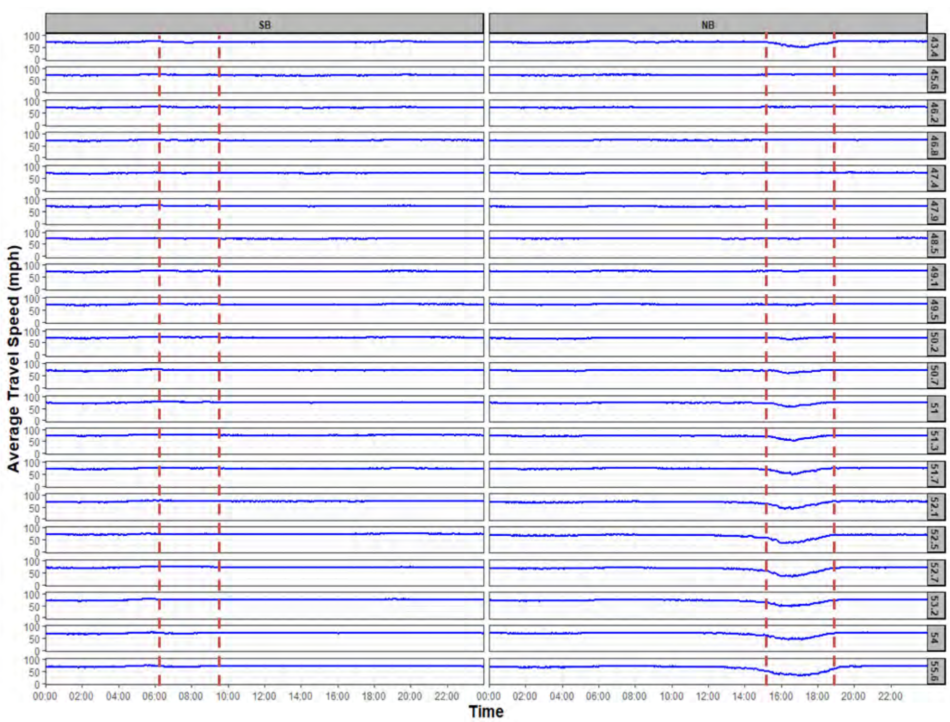
f. Memorial Day

Figure 3-30 Drivers' speed selection behavior on US-23 Flex route on holidays

Additionally, the performance of the Flex route on Fridays was also evaluated (Figure 3-31). Every individual Friday during 2019 was plotted as shown in Figure 3-31a. Figure 3-31b displays average travel speeds over all Fridays during the analysis period. Similar to the general trend during the holiday season, the southbound showed no particular issues. As in the preceding examples, speeds were significantly reduced towards the end of the northbound direction. These issues were more pronounced than on typical wwekdays. As such, it is suggested that the Flex lane could be opened up to two hours earlier (i.e., at 1:00 pm) on Fridays.



a. Speeds from every individual Friday during calendar year 2019



b. Average speed of all Fridays during calendar year 2019

Figure 3-31 Drivers' speed selection behavior on US-23 Flex route on Fridays

3.6 Incident Clearance Data

The performance of the Flex route was also evaluated when various incidents occurred using MDOT's availabile incident clearance data. These data were available before and after implementation of the Flex route. The following sections describe the procedures used to integrate the data, as well as a discuss of the results and findings.

3.6.1 Data Integration

As introduced previously, the incident clearance data were obtained from two different vendors (i.e., MDOT Freeway Courtesy Patrol (FCP) and Incident Clear Data (ICD)). In order to join two datasets together, a shapefile from MDOT was utilized. Aside from the general event information, the data from MDOT FCP also included the location information such as PR numbers and mile points of each event. In each case, the events from FCP can be easily located by using the Michigan sufficiency file. However, unlike the FCP data, the data from ICD provided the coordinates of each event. After using ArcMap to locate the events from ICD, the locations of some events were found to not match with the descriptions from the original dataset. For instance, an event occurred on the US-23 Flex route near the M-14 interchange based on the description from the dataset. However, the corresponding coordinates for this event show that it occurred on the US-23 Flex route near Territorial Road. In such cases, the locations of events were manually modified following the descriptions in the original dataset. Additionally, if no detailed descriptions were provided, it was assumed the location based on the coordinates was correct.

3.6.2 Results

One straightforward method to quantify the effectiveness of the Flex route was to compare the differences in incident cleared time before and after the operation of the Flex route. The incident cleared time was defined as the difference between the timestamps when FCP or emergency services arrived and the timestamp when the incident was cleared. In this study, the incidents were classified into seven categories: Abandoned vehicle, crash, debris, flat tire, mechanical, no gas, and others. The changes of cleared time during before and after period for each event were presented in Table 3-12. After operating the Flex route, the incident cleared time decreased significantly for most types of events, especially for those related to crashes, debris, and mechanical issues. However, an increase in cleared time was found for the events on northbound US-23, which involved an abandoned vehicle or a vehicle that ran out of gas.

Table 3-12 Comparisons of incident cleared time before and after the implementation of US-23 Flex route

Year	Direction	Abandoned Vehicle (mins)	Crash (mins)	Debris (mins)	Flat Tire (mins)	Mechanical (mins)	No Gas (mins)	Other (mins)
Before (2015 – 2016)	SB	3.2	51.2	6.9	17.0	13.4	7.8	13.7
	NB	2.8	39.0	8.3	17.1	14.9	5.8	8.7
After (2018-2019)	SB	2.8	39.6	4.4	14.0	9.7	5.5	4.9
	NB	3.7	28.7	4.5	14.4	11.9	7.7	6.6
Difference (%)	SB	-12.7	-22.7	-36.2	-17.6	-27.6	-29.6	-64.2
	NB	31.2	-26.5	-45.6	-16.0	-20.4	34.6	-24.4

3.7 Summary

In general, the operational performance of US-23 Flex route, in terms of travel time, speed, and flow rate, improved after constructing the Flex route, particularly in the southbound direction. The introduction of the Flex lane created a bottleneck downstream of the end of the Flex lane in the northbound direction, which has led to persistent queuing in that section during peak traffic periods. However, this congestion is likely to be mitigated by the subsequent extension of the Flex route to I-96.

CHAPTER 4 SAFETY PERFORMANCE

Beyond the impacts on traffic operations detailed in the preceding chapter, the changes in travel times and speeds introduced related impacts on safety performance in terms of the frequency and severity of crashes. This chapter details a before-and-after evaluation of the Flex route to examine changes in these metrics.

4.1 Data

Several data sources were used to perform this evaluation, including historical information detailing traffic crashes, traffic volumes, and roadway characteristics. Detailed information regarding each database and the data integration process is discussed in the following subsections.

4.1.1 Crash Data

All crashes from the Michigan State Police (MSP) crash database were obtained for a period of four years (i.e., 2012 to 2015) before the construction of the Flex route, and two years (i.e., 2018 and 2019) after its completion. As in the case of the operational analysis, 2020 data were not included given significant variations in travel patterns resulting from the COVID-19 pandemic. The MSP database includes details of crash-, vehicle-, and person-level information corresponding to each police-reported crash that occurred in Michigan over this time period. Information such as the worst level of injury sustained in the crash based on the KABCO scale (K-fatal injury, A-incapacitating injury, B-non-incapacitating evident injury, C-possible injury, O-no injury) and the time-of-day when the crash occurred were among the primary factors of interest.

For the purposes of this study, there was particular interest in distinguishing differences in safety performance not just between the before and after periods, but also over different times of day in consideration of when the Flex route is generally in operation. To this end, the crash data were aggregated in three-hour intervals to observe changes in the frequency and rate of crashes between the pre- and post-implementation periods and the times when the Flex route was (not) in operation. Note that the Flex route operates between 6:00 AM and 9:30 AM for southbound direction, and 3:00 PM and 7:00 PM for northbound direction.

4.1.2 Traffic Volume

The real-time traffic volume data were obtained from the MVDS reports between 2018 and 2019. The reports provide disaggregate level information of traffic volumes at every minute interval for the Flex route and the segments upstream and downstream. The reports also provide volume data at one-mile intervals. For the purpose of this research, the volume data was aggregated into one-hour intervals.

However, hourly volume data from the MVDS reports are only available from January 1, 2018 onward. Consequently, in order to estimate hourly traffic volumes at one-hour intervals for the before period, permanent traffic recorder (PTR) data were used to estimate the average increase in traffic between the periods before and after the Flex route went into operation. Based upon these increases, the traffic volumes were assumed to follow the same general time-of-day patterns during both periods as determined from the MVDS data.

Given relatively limited sample sizes of crashes in one-hour intervals, the crash data were subsequently aggregated into three-hour intervals for the purposes of the safety analysis. Consequently, the volume data were also aggregated at the same three-hour intervals. The crash and volume data were used to estimate crash rates per million vehicle miles traveled (VMT).

4.1.3 Data Integration

The Flex route segments and the upstream and downstream segments of it were aggregated into approximately one-mile length based on the Michigan DOT sufficiency file. This file follows the Michigan Geographic Framework, which serves as the base map for the Michigan government. The file contains physical road (PR) number and the beginning and ending mile points, enabling the joining of crash data to the target segments. In order to join the volume data at the segment level, PR number and the mile point were first obtained for the traffic volume data. Consequently, the traffic volume data were joined to the segment level using this information. The process of joining these databases utilizes three different software for specific tasks; ArcGIS to obtain the PR number, and beginning and ending mile post for the volume data, RStudio to aggregate the volume data in one-hour interval, and Excel to join all databases together. As noted above, the number of crashes were calculated for each segment in three-hour intervals and crash rates per million VMT were calculated for the periods both before and after construction of the Flex route.

4.2 Results

4.2.1 Comparison of Crash Frequencies and Crash Rates

Table 4-1 shows a high-level summary that compares the total number of crashes per year between the periods before and after construction of the Flex route. The pre-Flex route data is based upon five years of data (2012-2016), while the post-Flex route data is based upon two years of data (2018-2019). The table shows a comparison of the annual averages of fatal, injury, and property damage only crashes based on the entire analysis period (irrespective of time of day).

Overall, crashes were reduced by 4.5 percent in both directions. The reductions in PDO and injury crashes were 4.2 and 5.4 percent, respectively. While fatal crashes were reduced, it is important to note that only 5 such crashes were observed in total across the seven-year analysis period.

Turning to the individual directions of travel, safety improvements were significantly more pronounced in the southbound direction, where total crashes were reduced by 22.8 percent. Reductions in fatal, injury, and PDO crashes averaged 16.7 percent, 13.3 percent, and 24.8 percent, respectively. In contrast, crashes in the northbound direction increased by 13.2 percent. Increases were also observed for injury crashes (1.3 percent) and PDO crashes (16.3 percent). No fatal crashes were experienced during the after period, compared to one crash during the before period (with this crash occurring outside of the peak congestion periods).

Table 4-1 Comparison of annual numbers of crashes by direction before and after Flex route implementation

Crash Severity	Southbound		Northbound		Both Directions (Total)	
	Before	After	Before	After	Before	After
Fatal Crashes (K)	0.6	0.5	0.2	0.0	0.8	0.5
Injury Crashes (A, B, C)	19.6	17.0	23.2	23.5	42.8	40.5
PDO (O)	96.4	72.5	97.2	113.0	193.6	185.5
Total	116.6	90.0	120.6	136.5	237.2	226.5

When considering only the peak period during which the Flex route is in operation (i.e., from 6:00-9:30 am southbound and 3:00-7:00 pm northbound), these differences are more pronounced. Table 4-2 shows a similar summary of changes in the annual number of crashes on the Flex route focusing on the periods when the Flex lane was in operation. Total crashes and injury crashes were reduced by 1.7 percent and 14.1 percent, respectively, while PDO crashes increased by 1.2 percent. No fatal crashes were recorded during this operational period (before or after Flex route construction).

In the southbound direction, total, PDO, and injury crashes were reduced by 45.2 percent, 43.2 percent, and 53.5 percent, respectively. Meanwhile, in the northbound direction, injury and PDO crashes increased by 17.9 and 33.9 percent, respectively, between the before and after periods. The majority of the increase in crashes experienced in the northbound direction occurred at the lane drop/merge point.

Table 4-2 Comparison of annual numbers of crashes by direction before and after Flex route implementation during peak traffic periods

Crash Severity	Southbound (6:00-9:30 am)		Northbound (3:00-7:00 pm)		Both Directions (Peak Periods by Direction)	
	Before	After	Before	After	Before	After
Fatal Crashes (K)	0.0	0.0	0.0	0.0	0.0	0.0
Injury Crashes (A, B, C)	8.6	4.0	10.6	12.5	19.2	16.5
PDO (O)	35.2	20.0	47.8	64.0	83.0	84.0
Total	43.8	24.0	58.4	76.5	102.2	100.5

Table 4-3 provides a detailed summary of the annual number of crashes experienced along the entire Flex route corridor in three-hour intervals, as well as similar data for the adjacent upstream and downstream segments. For segments adjacent to the Flex route, crashes were shown to increase slightly in both directions, as well as both upstream and downstream of the Flex route. The upstream segments in the northbound and southbound directions showed 18.1 and 4.5 percent increases in crashes during the after period, respectively. The downstream segments recorded 12.2 and 11.5 percent increases in crashes in the northbound and southbound directions.

Table 4-3 Comparison of annual before-and-after crashes by direction on Flex route and upstream/downstream segments by time-of-day

Road	Crash Type	Northbound		Southbound	
		Before	After	Before	After
Flex Route	12:00 AM to 3:00 AM	8.2	2.5	5.8	7.5
	3:00 AM to 6:00 AM	6.0	6.5	6.0	5.5
	6:00 AM to 9:00 AM	7.0	8.5	37.6	22.0
	9:00 AM to 12:00 PM	11.2	7.0	19.4	14.0
	12:00 PM to 3:00 PM	16.6	21.0	14.4	15.0
	3:00 PM to 6:00 PM	46.0	66.5	16.4	10.5
	6:00 PM to 9:00 PM	19.4	15.0	10.4	11.0
	9:00 PM to 12:00 AM	6.2	9.5	6.6	4.5
	Total Crashes	120.6	136.5	116.6	90.0
Upstream	12:00 AM to 3:00 AM	3.6	4.5	1.6	0.0
	3:00 AM to 6:00 AM	4.6	7.0	2.6	0.5
	6:00 AM to 9:00 AM	16.8	22.0	14.8	21.5
	9:00 AM to 12:00 PM	14.4	18.0	4	3.5
	12:00 PM to 3:00 PM	10.4	18.5	3.6	3.5
	3:00 PM to 6:00 PM	29.8	34.0	4.2	2.0
	6:00 PM to 9:00 PM	18.6	13.0	2.8	3.0
	9:00 PM to 12:00 AM	7.6	8.0	1.8	3.0
	Total Crashes	105.8	125.0	35.4	37.0
Downstream	12:00 AM to 3:00 AM	0.8	0.5	1.2	2.5
	3:00 AM to 6:00 AM	1.8	1.0	4.4	1.0
	6:00 AM to 9:00 AM	4.6	9.0	20.0	27.0
	9:00 AM to 12:00 PM	4.6	4.5	13.4	13.0
	12:00 PM to 3:00 PM	10.0	8.5	8.8	10.0
	3:00 PM to 6:00 PM	32.4	35.5	12.6	12.5
	6:00 PM to 9:00 PM	11.0	13.0	10.2	12.5
	9:00 PM to 12:00 AM	3.0	4.5	5.2	6.0
	Total Crashes	68.2	76.5	75.8	84.5

It is important to note that these raw crash counts do not account for the increases in traffic volume that occurred between the before and after periods. Consequently, the raw numbers tend to under- or over-estimate the magnitude of the changes in crashes. To this end, the data from Table 4-3 were used to calculate crash modification factors (CMF) to discern which of these changes in crashes were statistically significant at a 95 percent confidence level. These CMFs are multipliers that represent the average change in crashes that occurred between the before and after periods after accounting for the increases in traffic volumes.

The expected crash frequency was calculated by multiplying the average annual number of before period crashes by the change in volume between the before and after periods. This results in an estimate of the number of crashes that would have occurred during the after period, at similar traffic volume levels, if the Flex route had not been constructed. The actual annual numbers of crashes experienced after the Flex route went into operation are then divided by these expected frequencies in order to arrive at the CMFs shown in Table 4-4. A 95-percent confidence interval was constructed for each crash modification factor. If these intervals included 1.00, it means there is no significant difference in crashes between the before and after periods.

Table 4-4 Crash Modification Factor (CMF) for the Flex Route by Direction and Time-of-Day

Scenario	**Crash Modification Factor**	**Lower Confidence Limit**	**Upper Confidence Limit**
Entire Day			
Total Crashes	0.83*	0.68	0.97
NB – Total Crashes	0.98	0.75	1.22
SB – Total Crashes	0.66*	0.49	0.84
Peak Period (6:00 AM to 9:00 AM and 3:00 PM to 6:00 PM)			
NB – Total Crashes	1.24	0.80	1.69
SB – Total Crashes	0.49*	0.25	0.74

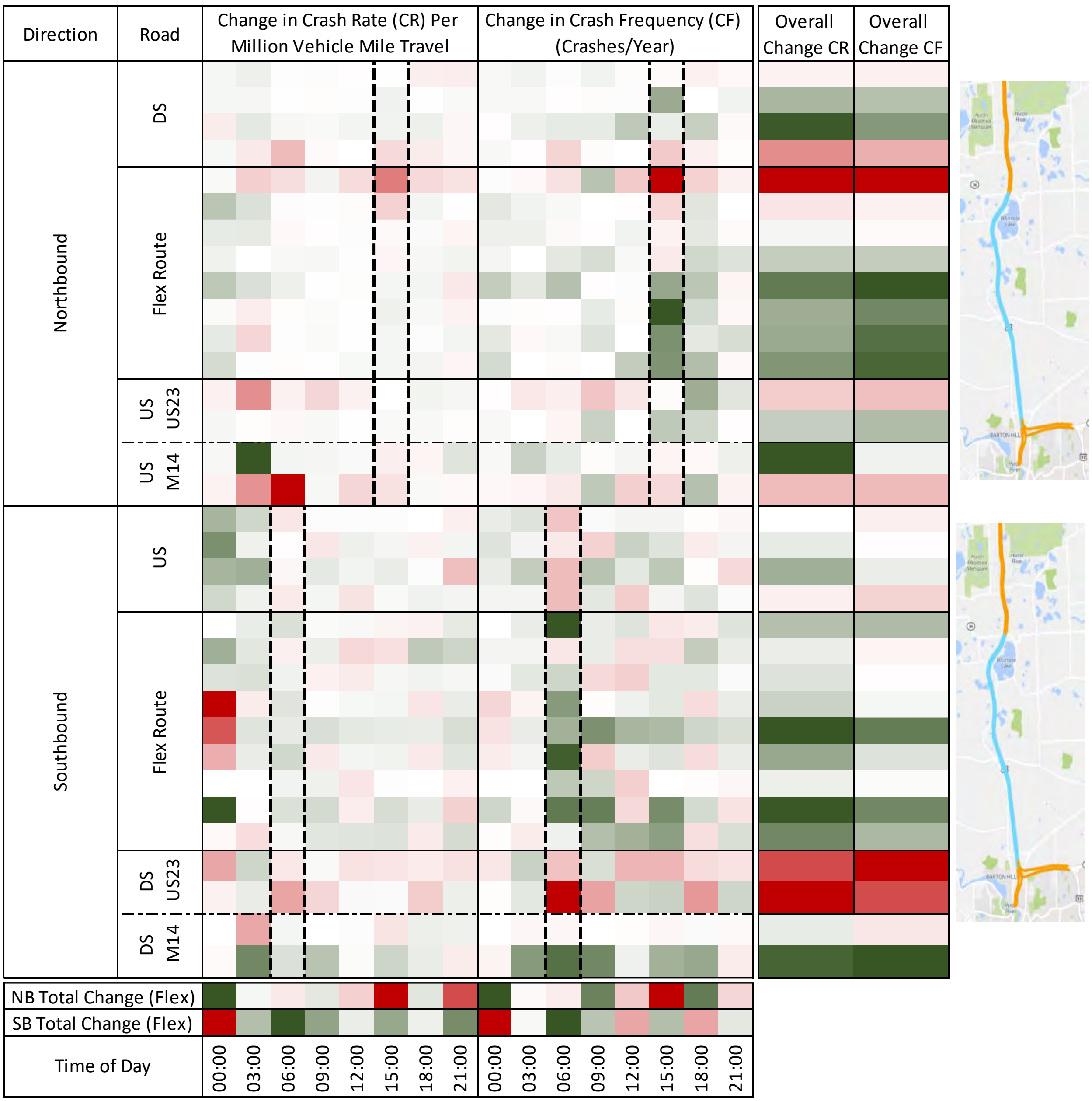
Note: * CMF is significant at 95% confidence level

These results show decreases of 17 percent in total crashes (both directions) and 34 percent for crashes in the southbound direction. Both reductions are found to be statistically significant.

Turning to the three-hour time periods detailed previously, crashes were reduced by 51 percent in the southbound direction (from 6:00-9:00 am). While this result was also found to be statistically significant, the 24 percent increase during the PM peak period (3:00-6:00 pm) in the northbound direction was not.

Figure 4-1 provides a heat map that illustrates changes in both the rate (crashes per million VMT) and frequency of crashes. This includes comparisons of how the safety performance varies both over the physical limits of the Flex route, including the upstream and downstream segments, as well as by time-of-day. In the figure, green-colored cells are indicative of segments and time periods that experienced fewer crashes or lower crash rates after construction of the Flex route. In contrast, the red cells are reflective of segments and time periods where crash frequencies and/or rates were found to increase as compared to the pre-Flex route time period. The intensity of the color depicts the magnitude of change in crash rates and frequencies as the darker the color, the larger the magnitude of the change. The cells bordered by the dashed line indicate the periods where the Flex route is generally in operation.

These figures reinforce the results discussed previously. In general, crash rates decreased across the Flex route corridor beginning in 2018. Since traffic volumes increases, this resulted in significant reductions in crash frequency as compared to the expected number of crashes if the Flex route had not been constructed. Performance in the southbound direction is consistently positive. In the northbound direction, crashes actually decreased along the southern portions of the route prior to a sharp increase at the lane drop. Figure 4-1 also shows that crashes tended to increase both upstream and downstream. This is particularly true on the downstream section of US-23 immediately south of the US-23/M-14 interchange. The improvements along the Flex route appear to have some carryover effects that may warrant consideration in future projects. In contrast, crashes declined downstream of M-14. Collectively, these results suggest that planning for future Flex routes should carefully consider potentially upstream and downstream effects.



Note: **1. Before period crash data is from 2012 to 2016**
2. Three-hour interval

Figure 4-1 Changes in crash rate and crash frequency along the US-23 Flex route

4.2.2 Regression Analysis

To better understand the impact of flex route on traffic safety, several safety performance functions (SPF) were developed. Consistent with the broader research literature, these SPFs took the form of negative binomial regression models. Within the context of this study, the probability of Flex route segment i experiencing y_i crashes in a given year can be calculated using Equation 6:

$$P(y_i) = \frac{\Gamma((1/\alpha)+y_i)}{\Gamma(1/\alpha)y_i!}\left(\frac{1/\alpha}{(1/\alpha)+\lambda_i}\right)^{1/\alpha}\left(\frac{\lambda_i}{(1/\alpha)+\lambda_i}\right)^{y_i}$$ **Equation 6**

where the term Γ(.) is a gamma function and α represents the overdispersion parameter. The expected number of crashes on segment *i*, λ_i can be calculated using Equation 7:

$$\lambda_i = EXP(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k + \varepsilon_i)$$ **Equation 7**

where β_1 to β_k are a series estimate coefficients that are obtained from the regression model, X_1 to X_k are a series of explanatory variables (e.g., AADT, segment length, flex route present, etc.), and $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean equal to one and variance of α.

In this research, a random effect framework is used to account for potential correlation in crash counts due to the fact that each segment is observed eight times (i.e., over this number of three-hour intervals). This correlation may lead to biased or inefficient parameter estimates as individual segments may experience a higher (or lower) number of crashes compared to other similar segments due to factors that may not be captured in the model (e.g., horizontal alignment, weaving/merging behavior). Employing the random effects framework allows the constant term to vary across segments, but remain the same within the eight time periods at each individual segment, as shown in Equation 8:

$$\beta_i = \beta + \varphi_i$$ **Equation 8**

where φ_i is an error term that follows a normal distribution with mean zero and variance σ^2. The Equation 4-2 is then conditional on the distribution of φ_i and the estimation is conducted using simulation-based maximum likelihood.

Since the number of years for crash data between before and after the construction of flex route was different (i.e., five years for before and two years for after the placement of flex route), an offset variable for the number of years was introduced in the analysis to normalize the model based on annual crashes. In addition, segment length was also treated as an offset variable. As such, the results of the SPF express the expected annual number of crashes on a per-mile basis.

Table 4-5 shows the descriptive statistics of analysis segments based on the direction of travel. Based on this table, both directions had similar traffic volumes that ranged from 404 to approximately 10,000 vehicles over the three-hour analysis period. The segment length in this analysis had an average value of one mile with a minimum of 0.45 (i.e., segments toward the end/beginning of flex route).

Summary data are also provided for the average annual number of crashes on a per-segment basis during the periods before and after the Flex route went into operation. As noted previously, these data correspond to the average number of crashes experienced during each 3-hour period of the day. These data are generally similar to the aggregate-level statistics presented previously. The northbound direction experienced an average of 1.88 crashes per segment per year during the before period, which increased to 2.13 crashes per segment per year during the after period. In the southbound direction, crashes were reduced from 1.62 per segment-year to 1.25 per segment-year (again, during 3-hour analysis periods). These summary statistics also show significantly more variability from segment to segment in the northbound direction, particularly during the after period. This is reflective of the fact that the northbound direction generally showed safety improvements, except for the northernmost segments leading into the lane drop, which drove most of the increase reflected in these summary statistics.

Table 4-5 Descriptive statistics for flex route by direction

	Northbound				Southbound			
Variable	**Min**	**Max**	**Mean**	**Std. Dev.**	**Min**	**Max**	**Mean**	**Std. Dev.**
Traffic volume (veh/3-hr interval)	625	9870	4058	2718	404	9381	4224	2637
Segment length (miles)	0.48	1.25	1.06	0.24	0.45	1.16	0.97	0.19
Average crashes per year – Before (3-hour interval)	0.0	16.6	1.88	2.41	0.0	8.0	1.62	1.51
Average crasheds per year – After (3-hour interval)	0.0	45.5	2.13	5.83	0	4.5	1.25	1.04

To further investigate the impacts on crashes, separate negative binomial models are presented for each direction of travel in Table 4-6. Each model presents the estimated coefficient, along with the associated standard error, and *p*-value. When interpreting the results, a positive coefficient indicates that crashes increase with the increase in the independent variable, and vice versa for negative parameter estimates. The model has been estimated such that the baseline condition corresponds to the before (i.e., pre-Flex route) period during off-peak hours. Separate parameter estimates are provided for the before period during the AM or PM peak, as well as for the after period during the peak and off-peak periods in both directions. These parameters provide a quantitative estimate of the average difference in crashes as compared to the pre-Flex route off-peak period.

The results show that crashes increased with traffic volume. A one-percent increase in volume was associated with increases of approximately 0.4 percent in the number of crashes in both the northbound and southbound directions. After the flex route was constructed, the northbound direction saw a slight increase in the number of crashes during off-peak periods, though this increase was not statistically significant. In the southbound direction, there was a marginal decrease in crashes during the off-peak period, though this change was also not statisticaly significant.

Table 4-6 Crash prediction models for flex route by direction

Variable	Northbound			Southbound		
	Estimate	Std. Error	P-Value	Estimate	Std. Error	P-Value
Intercept	-3.152	0.760	<0.001	-3.379	0.596	<0.001
Log (3-hr traffic volume)	0.400	0.094	<0.001	0.435	0.072	<0.01
Before period – off-peak period	Baseline			Baseline		
After period – off-peak period	0.044	0.189	0.815	-0.058	0.153	0.707
Before period – peak period	0.835	0.208	<0.001	0.680	0.128	<0.01
After period – peak period	0.772	0.228	<0.001	0.158	0.168	0.346
Overdispersion	0.334			0.090		

The parameter estimates for each of the before/after and peak/off-peak time periods can be exponentiated to determine the percent change in crashes as compared to the pre-Flex route off-peak period. Prior to the introduction of the Flex route, crashes were significantly higher during the peak periods in both directions. The northbound direction experienced 230% more crashes during the peak period on average while the southbound direction experienced 197% more crashes.

While crashes remained significantly higher during these periods after the introduction of the Flex route, the peak period crashes were actually reduced in both the northbound and southbound directions. The northbound direction saw 6.1% fewer crashes during the PM peak while the southbound direction saw 40.7% fewer crashes during the AM peak. The differences in the number of crashes per mile during each of these periods is illustrated graphically in Figure 4-2 and Figure 4-3. These plots were developed using the model results from Table 4-6.

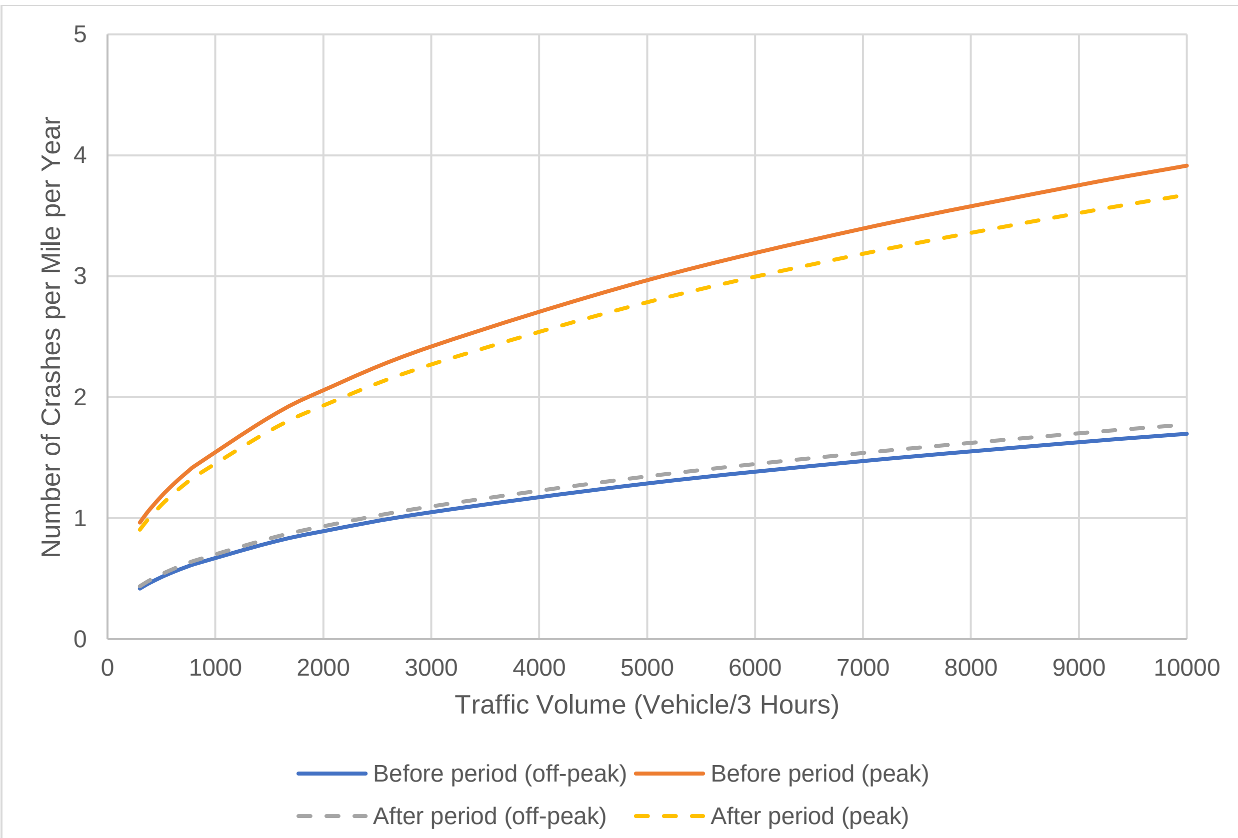


Figure 4-2 Crashes per mile per year by traffic volume on northbound direction

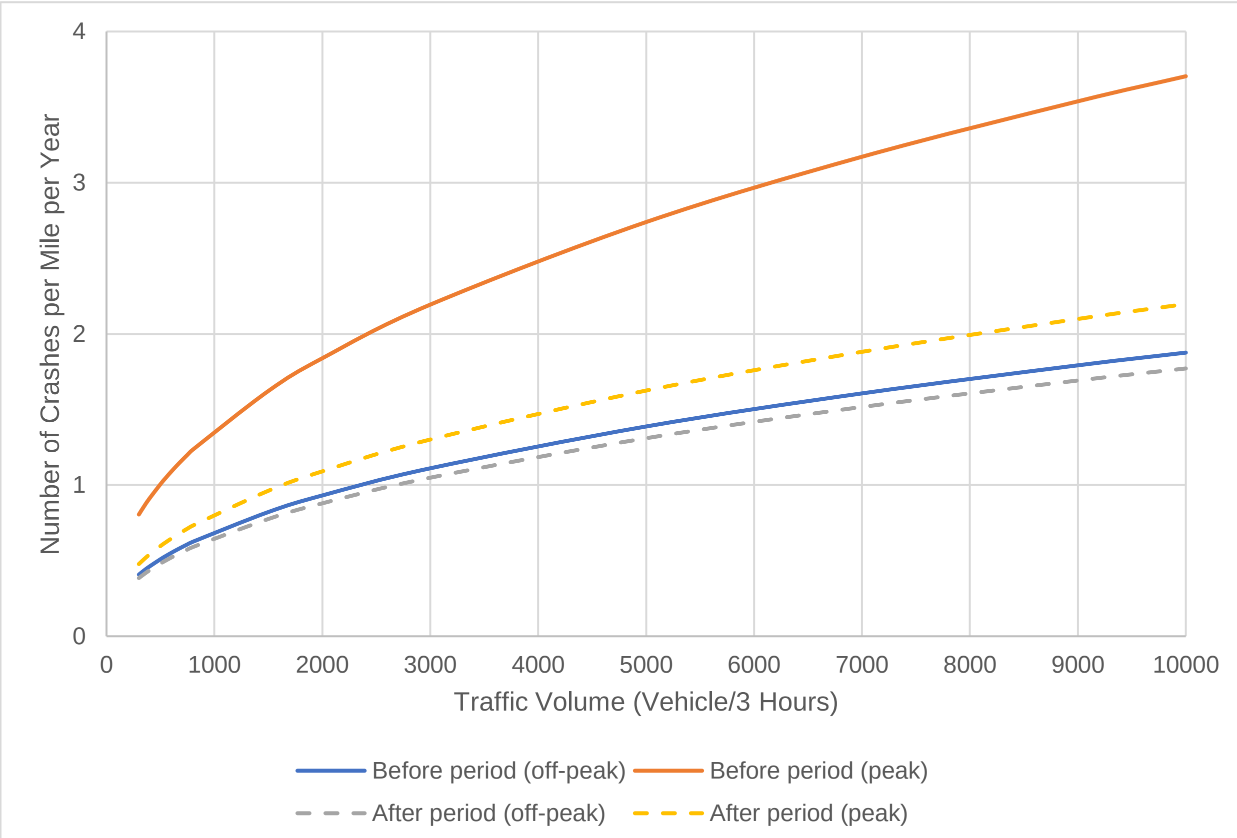


Figure 4-3 Crashes per mile per year by traffic volume on southbound direction

4.3 Summary

Overall, the improvements in traffic operations along the Flex route have corresponded with related improvements in traffic safety through reductions in the frequency and rate of crashes, as well. This is particularly true in the southbound direction. In the northbound direction, crashes did not change significantly overall. However, significant increases were experienced at the northbound lane drop. Many of these crashes occur due to merging traffic and, as such, any efforts to encourage early merging by drivers may help to mitigate this issue. This could include sinusoidal rumble strips or earlier notification of the impending lane drop.

CHAPTER 5 DRIVER SURVEY

Before the Flex route, drivers often experienced delays or were frustrated about congestion. However, since the introduction of the Flex route, commuters and locals have voiced mostly positive opinions regarding its efficacy. In an effort to learn what people thought about the Flex route, data was collected from drivers through surveys and from online platforms.

5.1 Survey Results

Reported demographics show that most respondents (66.9%) were employed and 33.1% were unemployed, retired, or homemakers. The majority (57.3%) of respondents were male and 42.7% of respondents were female. The ages of respondents varied but more than 50% were over 50 years old. Demographics can be summarized as follows (Table 5-1): 0.93% were between 18 and 24, 7.1% between 25 and 34, 16.4% between 35 and 44, 17.8% between 45 and 54, 27.0% between 55 and 64, 22.8% between 65 and 74, and 7.9% of respondents were older than 75. The majority (52.0%) of respondents reported an annual household income of over \$100,000, around 33% reported an income between \$50,000 and \$100,000, and less than 7% reported incomes below \$34,999. The vast majority (94.7%) of respondents identified as Caucasian and the vast majority (93.8%) reported that they do not have any disabilities or special needs. Finally, respondents were asked how many vehicles they own: 16.2% said one, 46.1% said two, 21.7% said three, 10.1% said four, and 5.6% said they own more than four vehicles.

Table 5-1 Demographics of US-23 drivers

	Number of respondents	%
Employment status		
In employment	504	66.93
Not in employment	249	33.07
Gender		
Male	420	57.30
Female	313	42.70
Age		
18 to 24	7	0.93
25 to 34	53	7.06
35 to 44	123	16.38
45 to 54	134	17.84
55 to 64	203	27.03
65 to 74	171	22.77
75 or older	60	7.99

Annual household income		
Less than $10,000	1	0.16
$10,000 to $14,999	6	0.93
$15,000 to $19,999	7	1.09
$20,000 to $24,999	9	1.40
$25,000 to $34,999	19	2.95
$35,000 to $49,999	53	8.23
$50,000 to $74,999	99	15.37
$75,000 to $100,000	115	17.86
More than $100,000	335	52.02
Race		
African-American/ Black	2	0.28
Asian	8	1.12
Caucasian/ White	679	94.70
Hispanic/ Latino(a)	7	0.98
Native-American Indian	2	0.28
Pacific Islander/ Hawaiian	1	0.14
Other	18	2.51
Accommodations, disabilities, or special needs		
Yes	43	6.19
No	652	93.81
Number of cars		
1	118	16.28
2	334	46.07
3	158	21.79
4	73	10.07
5	27	3.72
6 or more	15	2.07

5.1.1 The Flex Route Experience, Habits, and Driving Behavior

The vast majority (69.9%) of respondents were satisfied or very satisfied with their experience driving on the Flex route; only 16.8% of respondents were dissatisfied or very dissatisfied (Figure 5-1). Respondents who reported a better overall satisfaction level were statistically significantly more likely to report higher overall quality in their driving experience ($p < 0.001$). Additionally, those that drive more often were statistically significantly more likely to report an improved driving experience ($p < 0.05$). Since the installation of the Flex route, the majority of respondents rated the overall quality of their driving experience as better or much better 76.4% at the time; only 16.4% of respondents feel that their driving experience remained the same, and only 7.1% felt that it had worsened (Figure 5-2). These results demonstrate how valuable the Flex route is for commuters and locals, as the vast majority report that the Flex lane enhances their commute and overall driving experience.

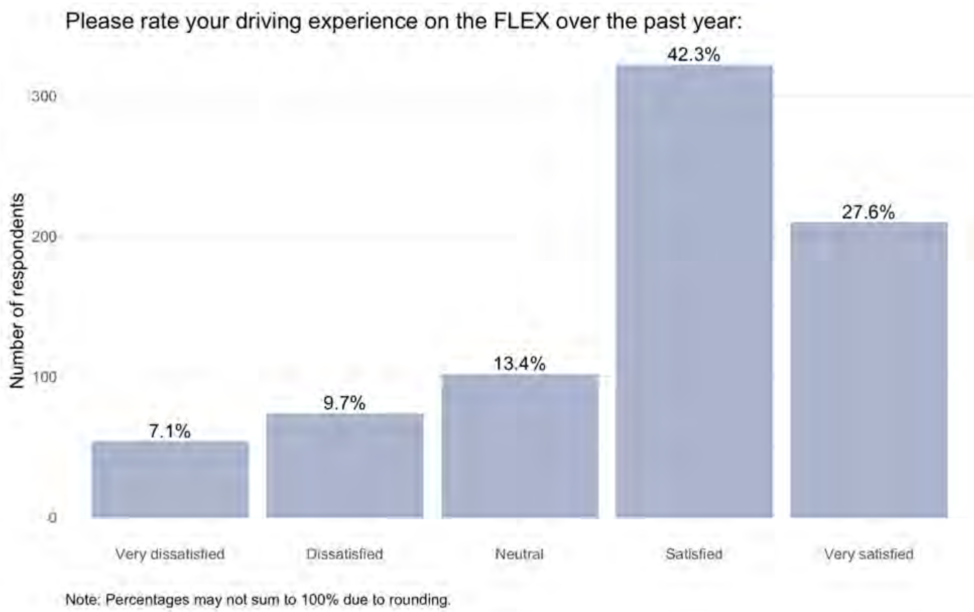


Figure 5-1 Respondent satisfaction with the Flex route over the past year by percentage (n=762)

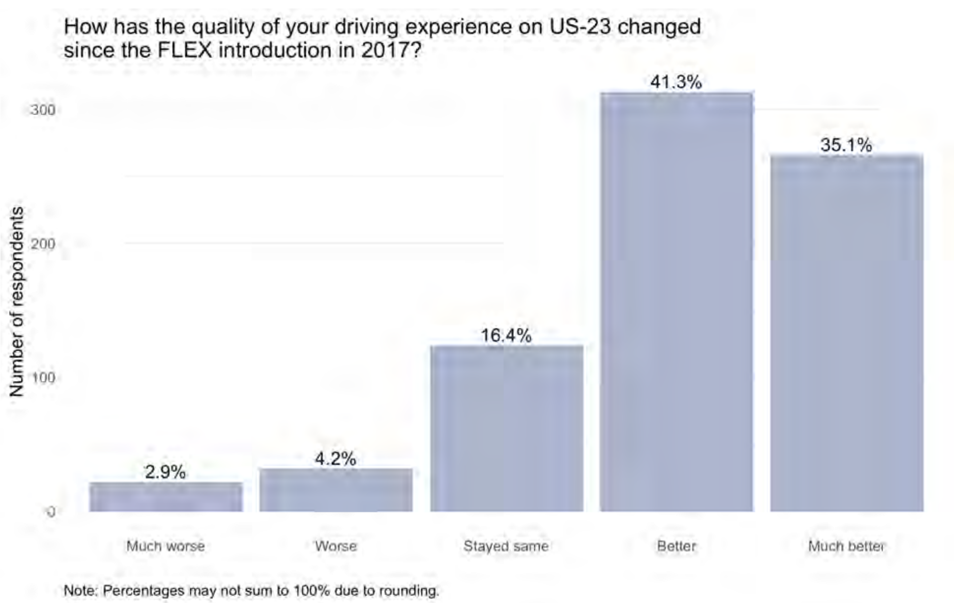


Figure 5-2 Percentage of respondents who believe their driving experience to be better or worse (n=757)

Flex route drivers reported statistically significant differences in their perception of the Flex route depending on which lane they regularly drive in (Table 5-2). Respondents who reported preferring to drive in the Flex lane were statistically significantly more satisfied with their overall driving experience than those who reported driving in the middle lane ($p < 0.01$) or the right lane ($p < 0.05$). Furthermore, respondents who prefer driving in the Flex lane were statistically significantly more likely to report an improved driving experience than were those who preferred the middle lane ($p < 0.01$) or the right lane ($p < 0.001$). Combined, these results mean that those who drive the Flex lane received a greater boost in satisfaction since the introduction of the Flex route than those drivers who still prefer to drive in the middle and right lanes.

Table 5-2 Respondents' socio-demographic characteristics by lane

	Left lane % (n)	**Middle lane** % (n)	**Right lane** % (n)
Employment status			
In employment	83.46 (222)	60.42 (200)	51.82 (71)
Not in employment	16.54 (44)	39.58 (131)	48.18 (66)
Gender			
Male	57.53 (149)	55.86 (181)	61.07 (80)
Female	42.47 (110)	44.14 (143)	38.93 (51)
Age			
18 to 24	1.50 (4)	0.61 (2)	0.74 (1)
25 to 34	9.40 (25)	6.67 (22)	2.94 (4)
35 to 44	27.07 (72)	12.42 (41)	6.62 (9)
45 to 54	24.06 (64)	13.33 (44)	16.91 (23)
55 to 64	26.32 (70)	28.79 (95)	24.26 (33)
65 to 74	8.65 (23)	29.39 (97)	33.09 (45)
75 or older	3.01 (8)	8.79 (29)	15.44 (21)
Annual household income			
Less than to $20,000	1.24 (3)	1.48 (4)	4.39 (5)
$20,000 to $24,999	1.24 (3)	1.11 (3)	2.63 (3)
$25,000 to $34,999	1.24 (3)	4.06 (11)	2.63 (3)
$35,000 to $49,999	4.96 (12)	9.23 (25)	12.28 (14)
$50,000 to $74,999	14.05 (34)	14.76 (40)	17.54 (20)
$75,000 to $100,000	16.53 (40)	18.82 (51)	19.3 (22)
More than $100,000	60.74 (147)	50.55 (137)	41.23 (47)
Race			
African-American/ Black	-	0.32 (1)	0.77 (1)
Asian	1.56 (4)	-	3.08 (4)
Caucasian/ White	92.97 (238)	96.79 (302)	93.08 (121)
Hispanic/ Latino(a)	1.56 (4)	0.64 (2)	0.77 (1)
Native-American Indian	-	0.64 (2)	-
Pacific Islander/ Hawaiian	0.39 (1)	-	-
Other	3.52 (9)	1.6 (5)	2.31 (3)

Accommodations, disabilities, or special needs			
Yes	6.10 (15)	4.56 (14)	10.48 (13)
No	93.90 (231)	95.44 (293)	89.52 (111)
Number of cars			
1	13.51 (35)	15.09 (48)	24.43 (32)
2	45.95 (119)	47.48 (151)	41.98 (55)
3	24.32 (63)	22.01 (70)	17.56 (23)
4	10.81 (28)	9.12 (29)	10.69 (14)
5	3.86 (10)	4.09 (13)	3.05 (4)
6 or more	1.54 (4)	2.2 (7)	2.29 (3)

The majority (51.7%) of respondents utilize the Flex lane to drive to work, 26.0% do so for medical reasons, 21.2% to visit friends/family, 19.8% to shop or eat out, and 16.5% drive on it for recreational purposes (Figure 5-3). The majority of respondents typically drive on the Flex route in the afternoons from 3-7pm (71.4%) and 57% drive on it in the mornings between 6am and 9:30am. The Flex route seems nearly empty from 7pm-6am (Figure 5-4).

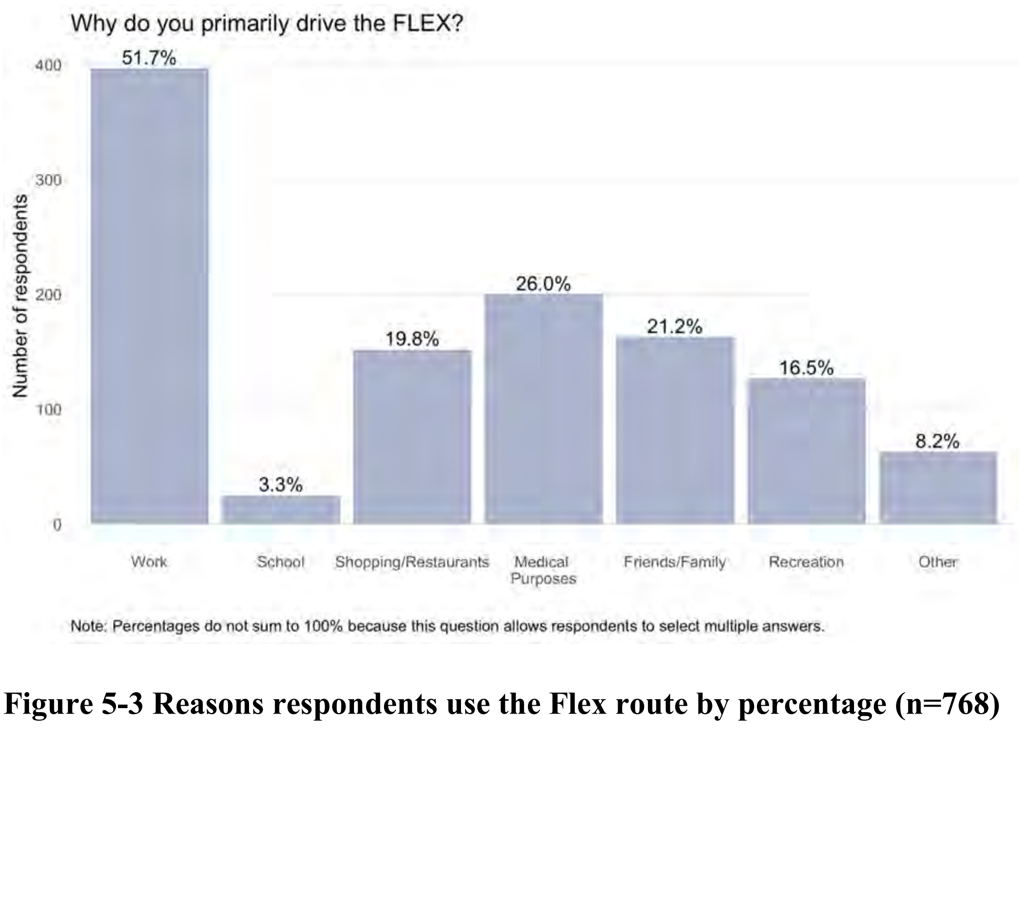


Figure 5-3 Reasons respondents use the Flex route by percentage (n=768)

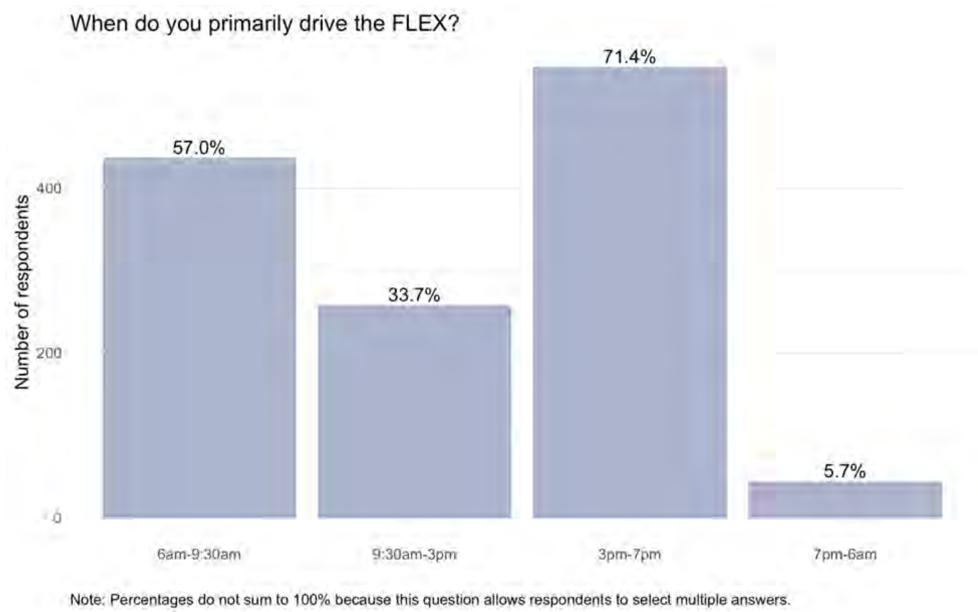


Figure 5-4 Time of day respondents use the Flex route by percentage (n=766)

When asked how often they drive on the Flex route 25.5% of respondents report doing so every day, 28.5% drive on it 3-4 times a week, 22.6% once a week, and 23.4% drive on it once a month or less (Figure 5-5). Respondents who are currently in employment and younger respondents were statistically significantly more likely to use the Flex route more often than those who were unemployed ($p < 0.001$) or older respondents ($p < 0.01$). The plurality of respondents (45.2%) indicated that they prefer driving in the middle lane even when the Flex lane is open, while 36.3% prefer to use the Flex lane (Figure 5-6). Respondents who are currently in employment were statistically significantly more likely to prefer using the Flex lane than were respondents not ($p<0.05$). Younger respondents were statistically significantly more likely to prefer to use the Flex lane than were older respondents ($p < 0.001$).

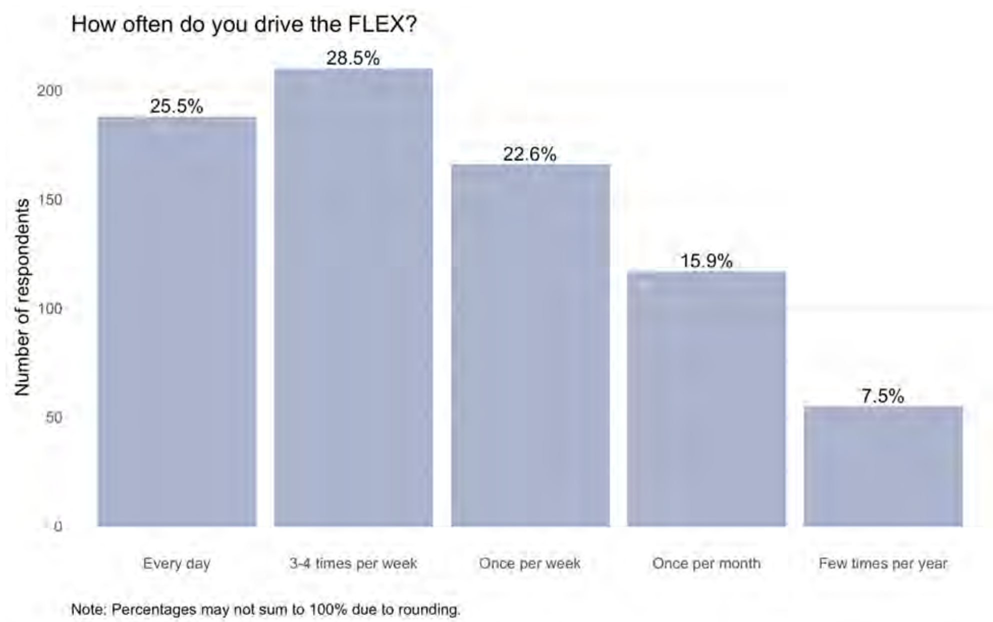


Figure 5-5 Frequency respondents use the Flex route by percentage (n=764)

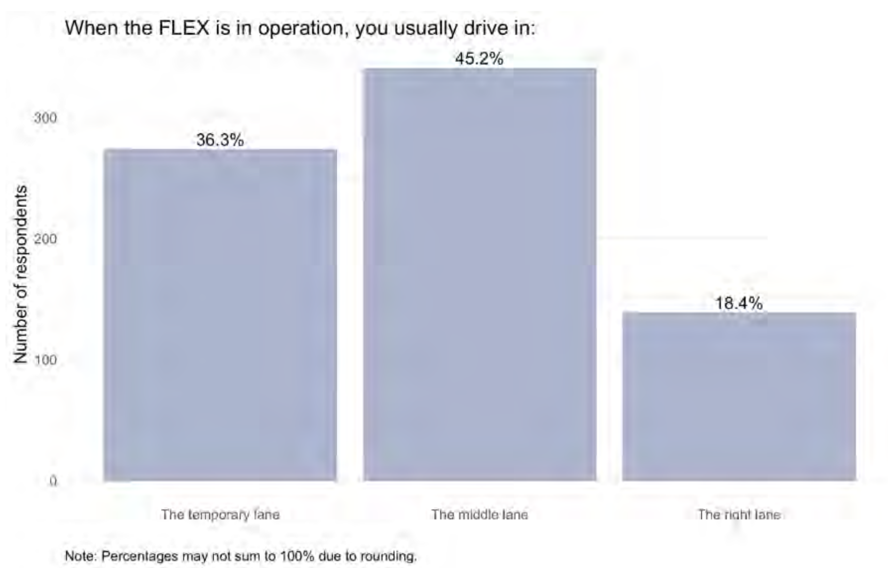


Figure 5-6 Preferred lane of respondents on the Flex route by percentage (n=754)

When asked about different kinds of driving behaviors drivers had observed while traveling on the Flex route, 64.1% of respondents reported witnessing speeding, 47.9% witnessed late merging, 37.5% witnessed tailgating, and 32.5% reported witnessing back and forth lane changing (Figure 5-7).

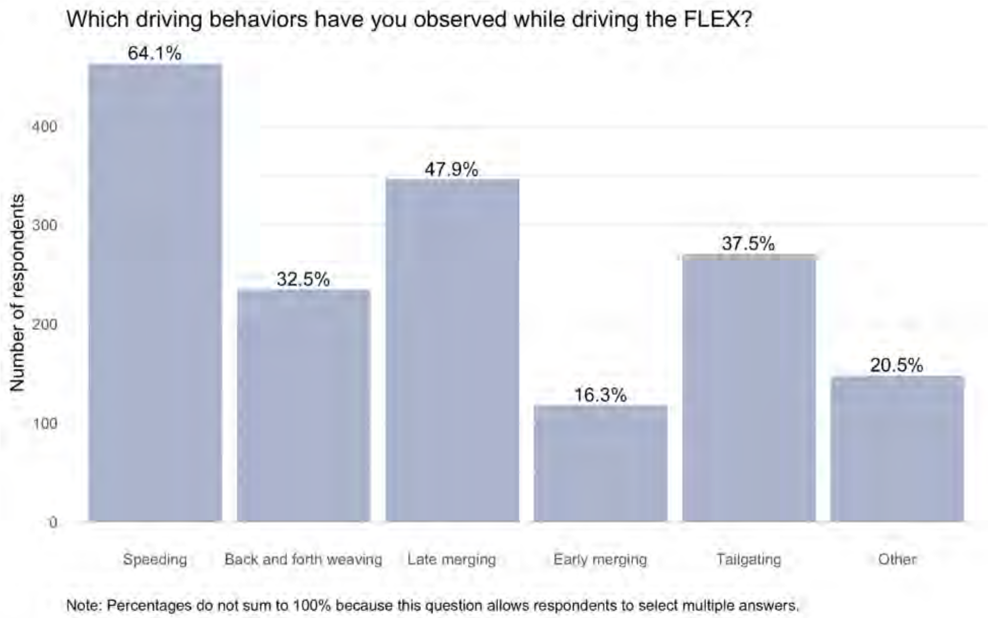


Figure 5-7 Behaviors that respondents have observed on the Flex route by percentage (n=722)

5.1.2 The Flex Route Safety and Performance Perceptions

When asked about their perception of safety on the Flex route, and specifically which lanes and directions of travel are the safest when the Flex lane is open, respondents indicated that the SB middle lane was the safest: 69.4% of respondents noted that they were satisfied or very satisfied with the safety in this lane. The least safe lane, according to respondents, was the NB left lane: 26.9% of respondents noted that they were dissatisfied or very dissatisfied with the safety in this lane (Figure 5-8).

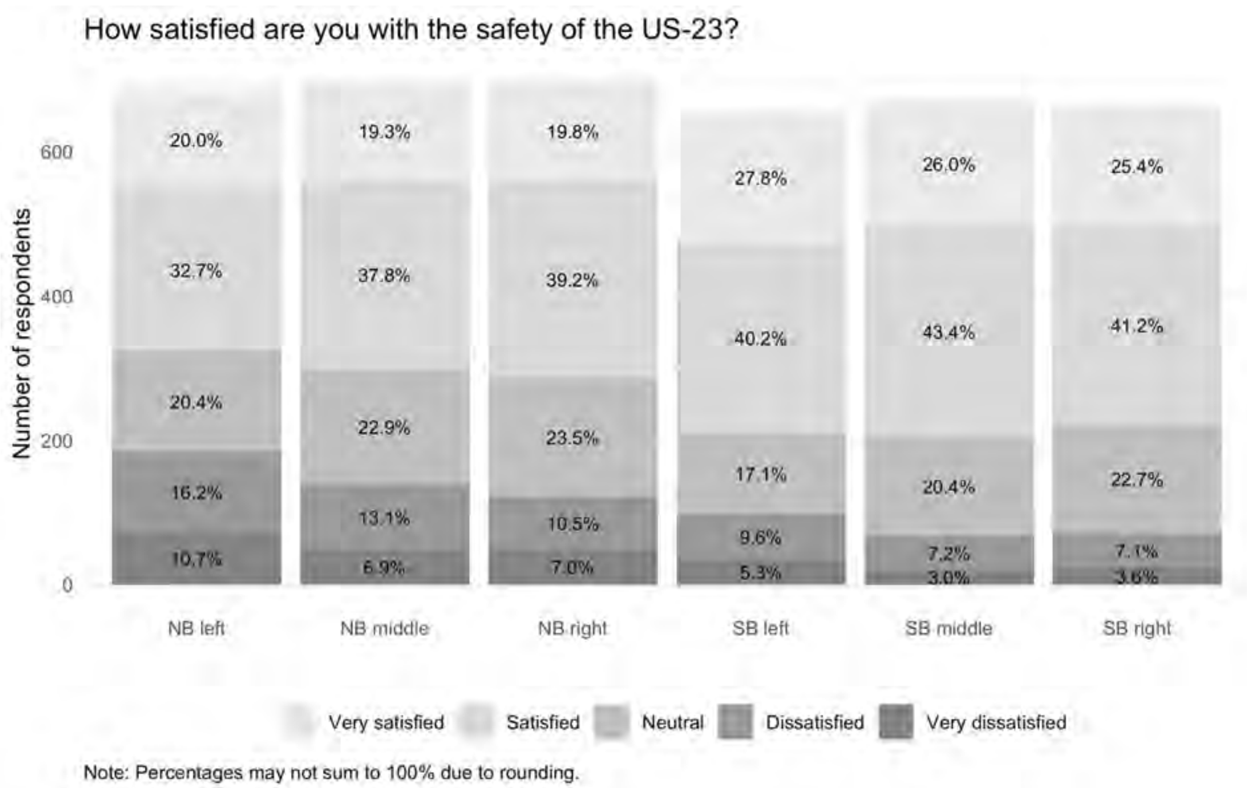


Figure 5-8 Level of satisfaction with safety in different lanes on US-23 by percentage (n=655, 670, 665, 685, 695, and 697 respectively)

As shown in Table 5-3, respondents were statistically significantly more likely to report feeling less safe in all NB lanes when the Flex lane was open than they do while driving in any SB lane ($p<0.001$).

Table 5-3 Average of satisfaction of safety level by lane

	n	Mean (1=very dissatisfied, 5=very satisfied)
SB left	655	3.75
SB middle	670	3.82
SB right	665	3.78
NB left	685	3.35
NB middle	695	3.49
NB right	697	3.54

During the day, when the Flex lane is *not* open, 40.8% of respondents reported being either satisfied or very satisfied with safety, 27.7% felt neutral, and 31.5% were either dissatisfied or very dissatisfied with their perceived safety (Figure 5-9). During the night, when the Flex lane is *not* open, 46.1% of respondents reported being either satisfied or very satisfied with safety, 27.1%

felt neutral, and 26.9% were either dissatisfied or very dissatisfied with their perceived safety (Figure 5-10).

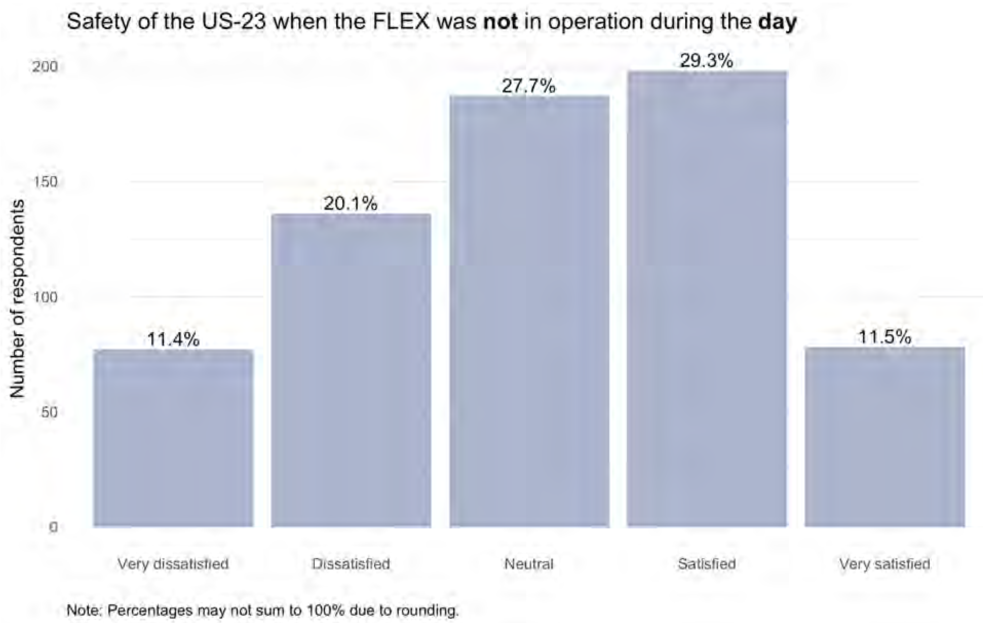


Figure 5-9 Level of satisfaction with perceived safety on the Flex route when it is not open during the day by percentage (n=676)

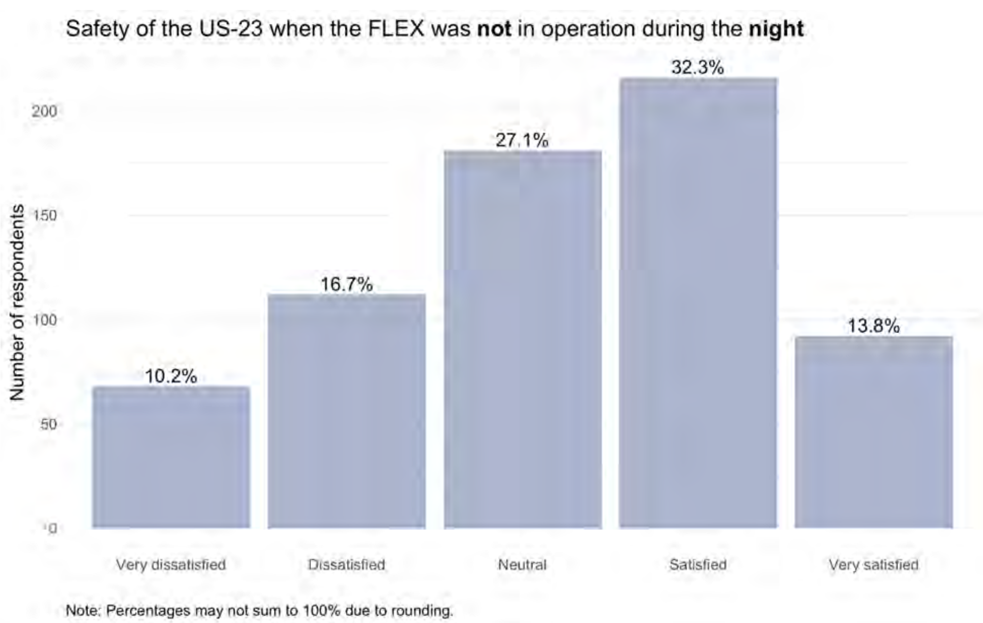


Figure 5-10 Level of satisfaction with perceived safety on the Flex route when it is not open during the night by percentage (n=669)

5.1.3 *The Flex Route During Incidents*

When asked how respondents felt about safety when an incident occurs (and the Flex lane is open), the majority of respondents (51.9%) were either satisfied or very satisfied, only 19.6% were either dissatisfied or very dissatisfied (Figure 5-11). Respondents with lower incomes were statistically significantly more likely to report an increase in perceived safety ($p < 0.05$), as were respondents who prefer driving in the Flex lane as opposed to the right lane ($p < 0.05$). Importantly, respondents were statistically significantly more likely to feel *less* safe when an incident occurred, *and* the Flex lane was *closed* ($p < 0.01$). In contrast, when asked if their overall perception of safety had increased since the introduction of the Flex route, the split was almost even: 52.0% of respondents answered yes and 48.0% answered no (Figure 5-12).

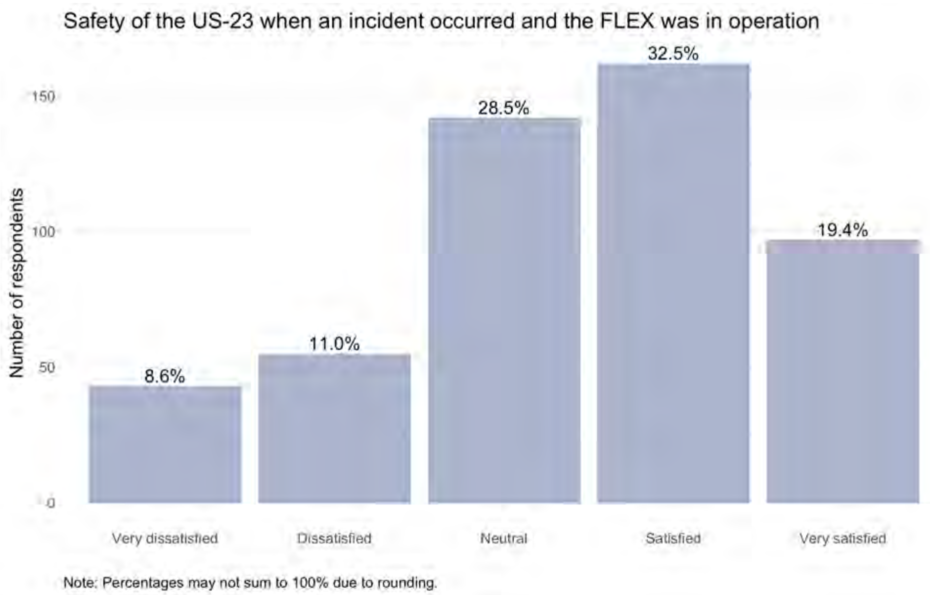


Figure 5-11 Level of satisfaction with safety of respondents when an incident occurs on US-23 (n=499)

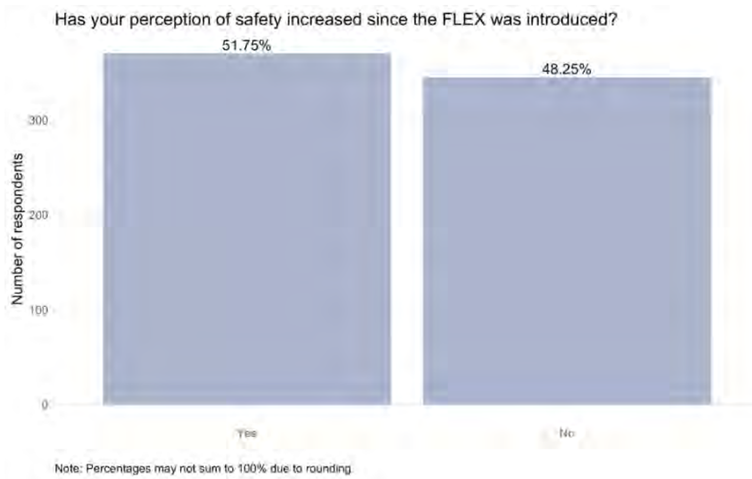


Figure 5-12 Perception of safety increase since the Flex route was installed by percentage

When respondents were asked if they had ever driven on the Flex route when the Flex lane was specifically opened due to an incident or vehicle breakdown, 28.9% answered yes and 71.1% answered no. When these respondents were asked further if they believed that the Flex lane made it easier for them to pass the incident site, 82.9% said yes and 17.1% said no. Females were statistically significantly more likely to believe that the Flex lane made passing incident sites easier than were males ($p < 0.05$). Finally, the same respondents were asked if opening the Flex lane in this situation made them reach their destination faster, 79.9% said yes and 20.1% said no (Figure 5-13).

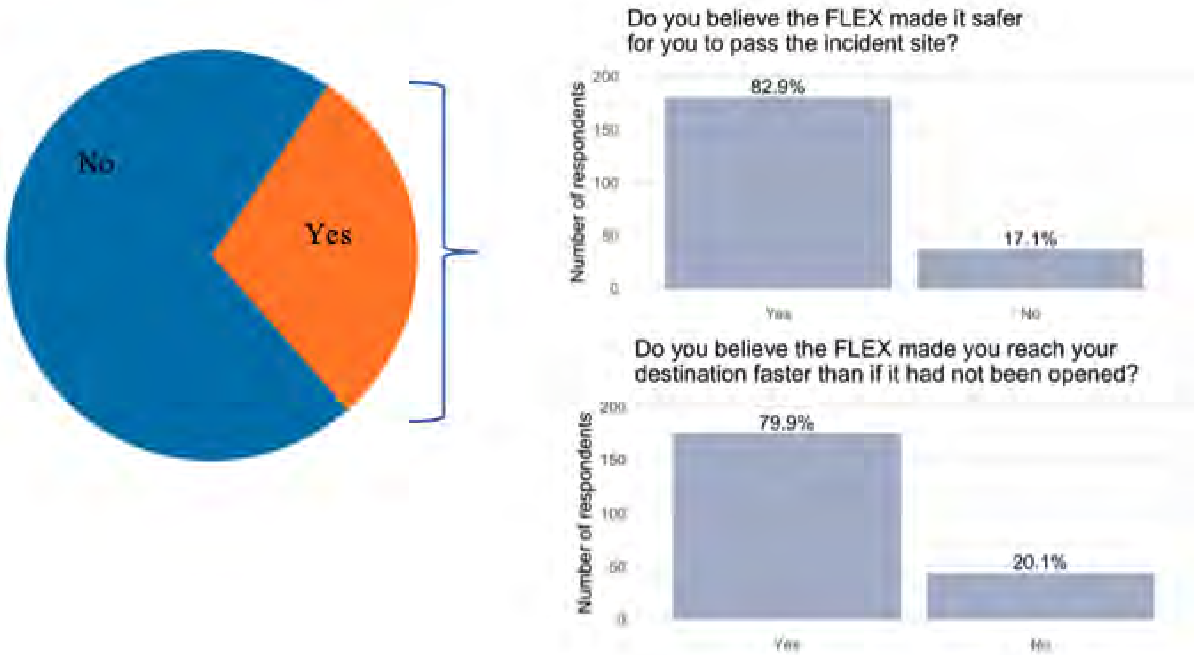


Figure 5-13 Respondents sentiment as to whether or not the Flex lane makes passing incident sites faster and safer, by percentage (n=750)

5.1.4 The Flex Route Understanding: Use of Crash Investigation Sites

When asked how often respondents see crash investigation sites along the Flex route being utilized 63.8% said never, 13.4% said every other month, 16.5% said once a month, and 6.2% said every week (Figure 5-14**).** When asked *how* these sites were being used the vast majority (81.5%) of respondents said it was for a vehicle breakdown, 45.7% said they were being used to investigate a crash, 7.2% said they were being used to make a phone call, and 11.7% said other (Figure 5-15). When asked how the sites *should* be utilized 88.9% said for a crash investigation, 86.3% said for emergencies. 83.1% said for vehicle breakdowns, 21.2% said for phone calls, and 4.4% said for bathroom breaks (Figure 5-16).

Figure 5-14 Frequency respondents saw the crash investigation sites being used along the Flex route by percentage (n=738)

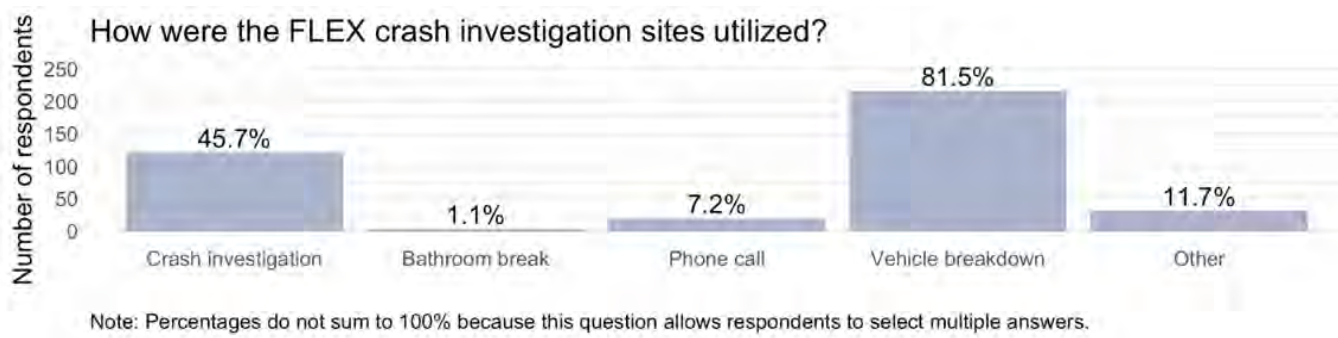


Figure 5-15 Reasons respondents saw the crash investigation sites along the Flex route being used by percentage (n=265)

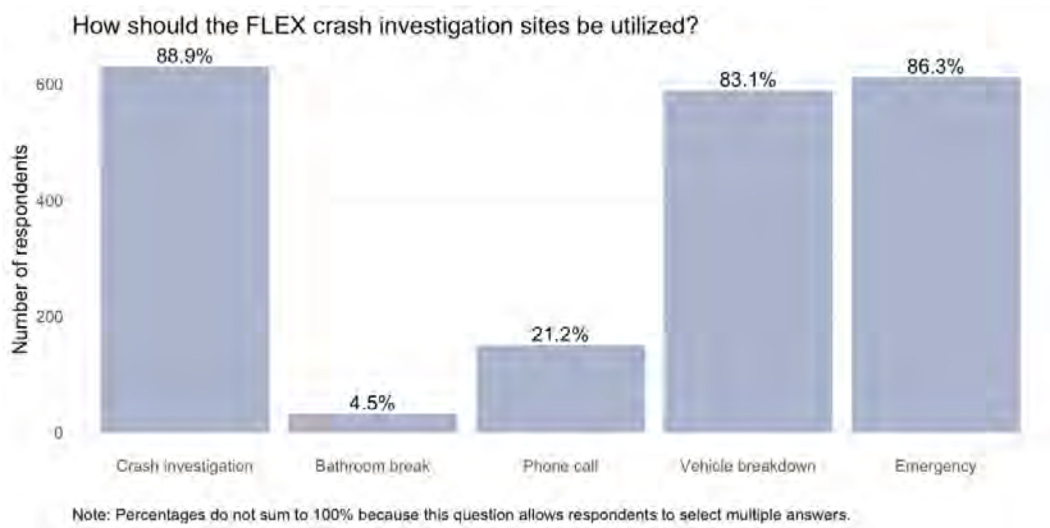


Figure 5-16 Reasons respondents believe that the crash investigation sites along the Flex route should be utilized by percentage (n=709)

5.1.5 The Flex Route Understanding: Rules and Regulations

When respondents were asked if they comply with the rules of the Flex route the vast majority (74.4%) answered “always,” 20.6% responded “most of the time,” and only 5.0% responded either “often” or “sometimes” (Figure 5-17). In contrast, when asked how often *other drivers* comply with the rules of the Flex route, only 9.9% of respondents said “always,” and the majority (63.7%) said, “most of the time” (Figure 5-18).

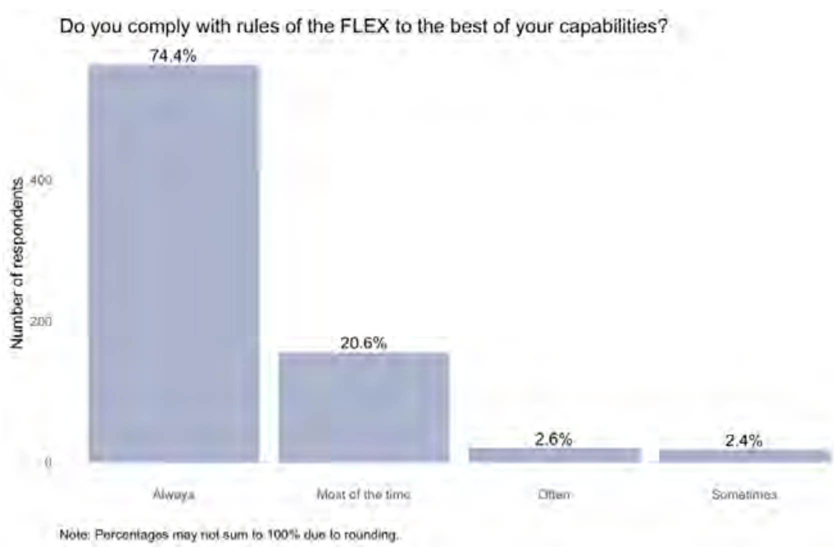


Figure 5-17 Percentage of respondents who comply with the rules of the Flex route (n=757)

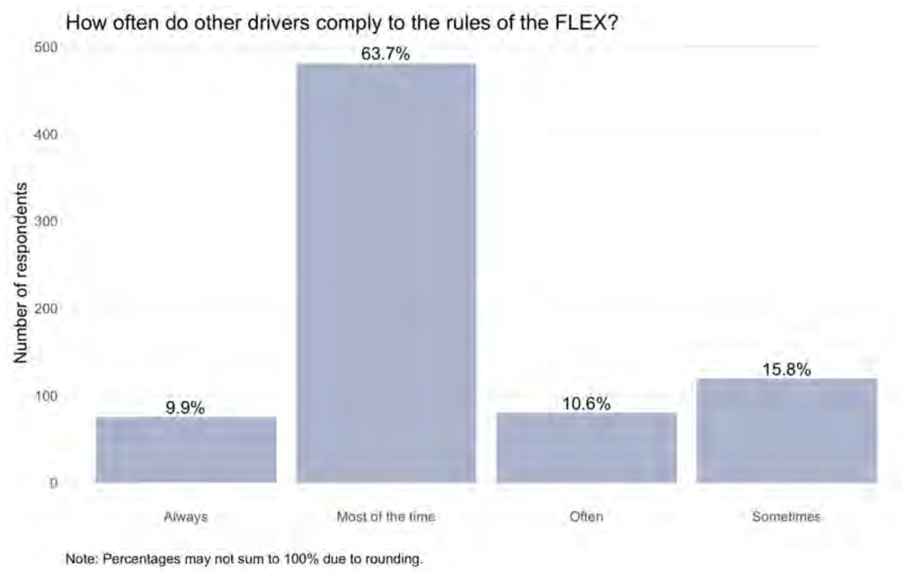


Figure 5-18 Percentage of respondents who believe other drivers comply with the rules of the Flex route (n=755)

Table 5-4 and

Table 5-5 shows respondents' average answers by income and the number of cars they own. Respondents who own more vehicles were statistically significantly more likely to report that they comply with the rules ($p < 0.01$). Respondents with higher incomes were statistically significantly more likely to report that other drivers do not comply with the rules ($p < 0.01$), whereas respondents who own more cars were more likely to report that other drivers do comply with the rules ($p < 0.01$).

Table 5-4 Respondents who believe other drivers comply with the rules of the Flex route by income

	n	Mean (1= sometimes, 4 = always)
Less than $20,000	13	2.54
$20,000 to $24,999	9	2.56
$25,000 to $34,999	19	2.47
$35,000 to $49,999	53	2.38
$50,000 to $74,999	98	2.35
$75,000 to $100,000	113	2.43
More than $100,000	329	2.22

Table 5-5 Respondents who believe other drivers comply with the rules of the Flex route by the number of cars they own

N of cars	n	Mean (1= sometimes, 4 = always)
1	116	2.22
2	329	2.31
3	155	2.40
4	72	2.31
5	27	2.44
6 or more	14	2.50

5.1.6 The Flex Route Understanding: Merging Habits

When asked, "when approaching the end of the Flex and driving north in the left lane towards Brighton, when do you typically merge to the regular lanes?" 64.6% of respondents answered as soon as they could read the merge sign, 25.7% said at the merge sign, and 9.8% said at the end of the Flex lane (Figure 5-19). Females were statistically significantly more likely to merge earlier than males ($p<0.001$). When asked, "how satisfied are you with the ease of merging from the left lane to regular lanes at the end of the Flex going north towards Brighton?" 35.5% of respondents reported being either satisfied or very satisfied, 21.1% were neutral, though 43.3% were either dissatisfied or very dissatisfied (Figure 5-20). This may indicate that the merge causes serious safety concerns for drivers. Respondents who own more cars were statistically significantly less likely to be satisfied with this merge ($p < 0.05$).

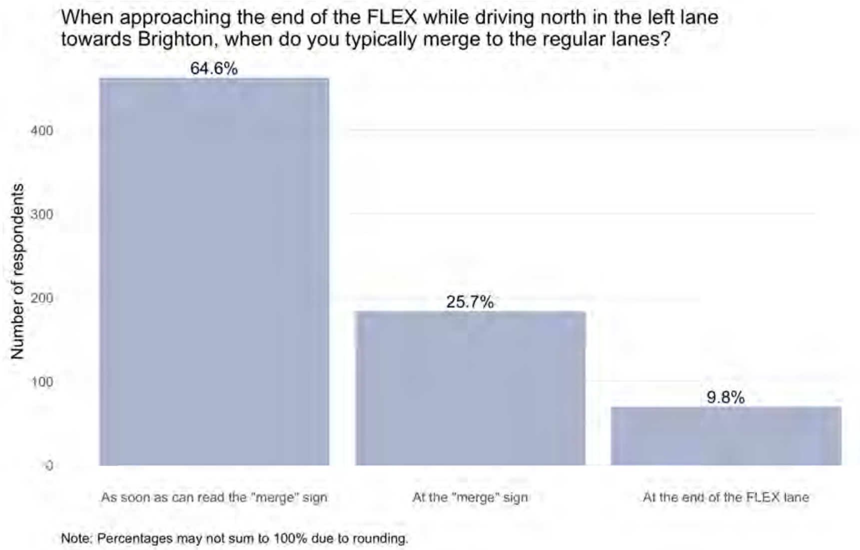


Figure 5-19 Location where respondents merge at the end of the Flex route by percentage (n=717)

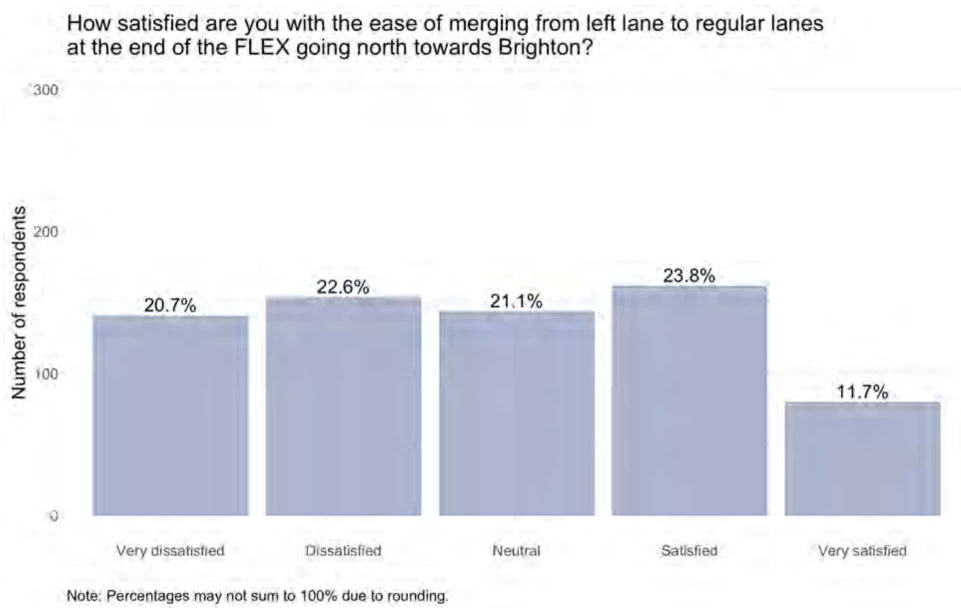


Figure 5-20 Level of satisfaction if merging at the end of the Flex route by percentage (n=681)

When asked if the Flex lane should be open more frequently 71.0% of respondents said yes, and 29.0% said no (Figure 5-21). Respondents who own more cars were statistically significantly more likely to respond in the affirmative ($p < 0.05$). When asked if they felt that the Flex lane should ever be closed when it is open the vast majority (96.8%) said no (Figure 5-22). When asked about their satisfaction with time savings since the opening of the Flex route, 70.7%

of respondents reported being either satisfied or very satisfied, though 13.1% reported being either dissatisfied or very dissatisfied (Figure 5-23).

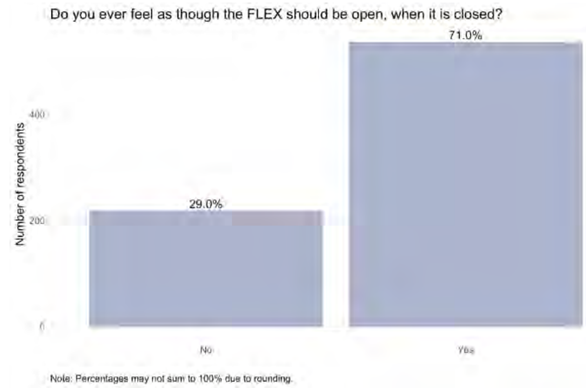


Figure 5-21 Percentage of respondents who believe the Flex lane is closed when it should be open (n=756)

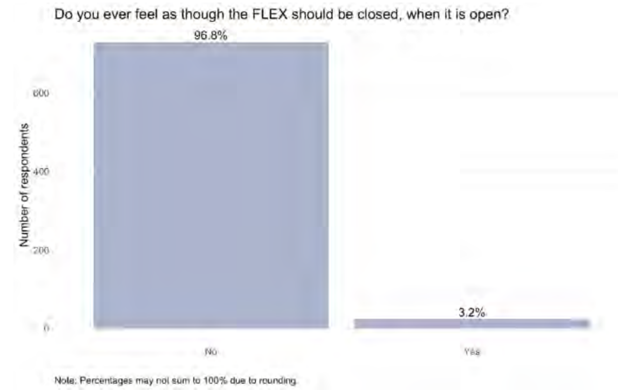


Figure 5-22 Percentage of respondents who believe the Flex lane should be closed with it is open (n=754)

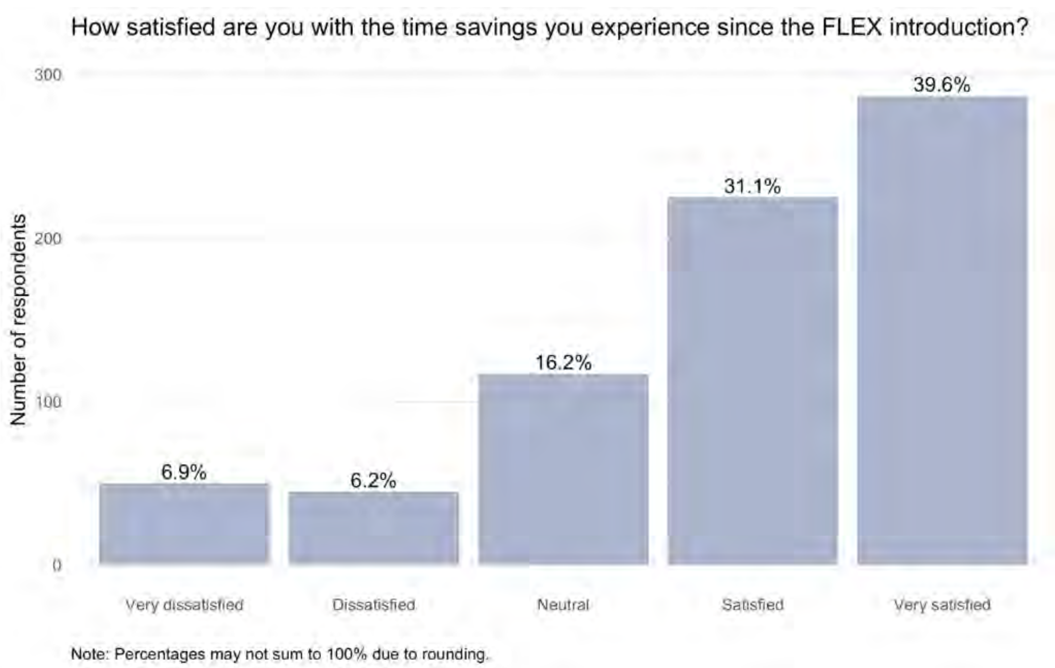


Figure 5-23 Level of satisfaction respondents feel with their time savings since the Flex route's introduction by percentage (n=724)

5.1.7 The Flex Route Understanding: Information Provided to Drivers

When respondents were asked how satisfied they were with the information that is provided to them en route when the Flex lane is *open*, the vast majority (83.1%) reported being either satisfied or very satisfied, 11.8% were neutral, and only 5.1% reported being either dissatisfied or very dissatisfied (Figure 5-24). Similarly, when respondents were asked how satisfied they are with the information that is provided to them en route when the Flex lane is *closed*, the vast majority (77.8%) reported being satisfied or very satisfied, 15.6% were neutral, and only 5.6% reported being either dissatisfied or very dissatisfied (Figure 5-25).

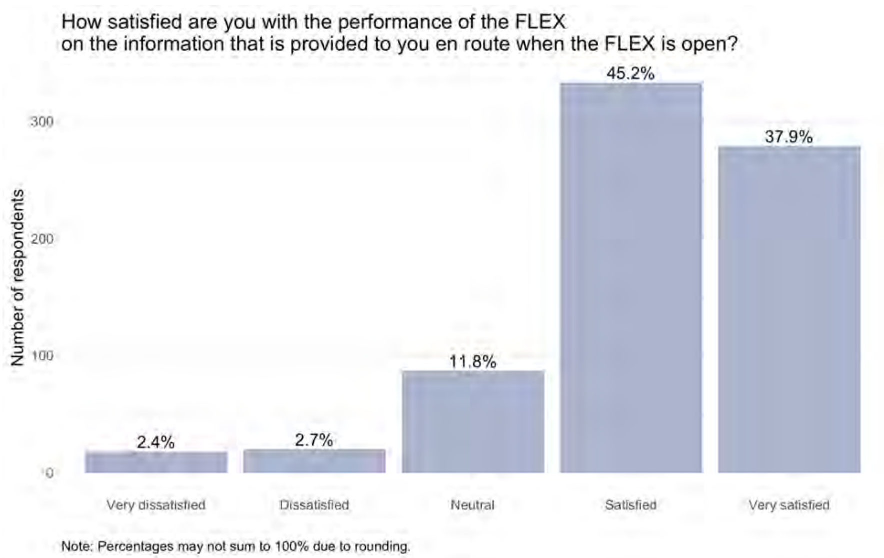


Figure 5-24 Level of satisfaction with information provided to respondents, en route, while the Flex lane is open (n=737)

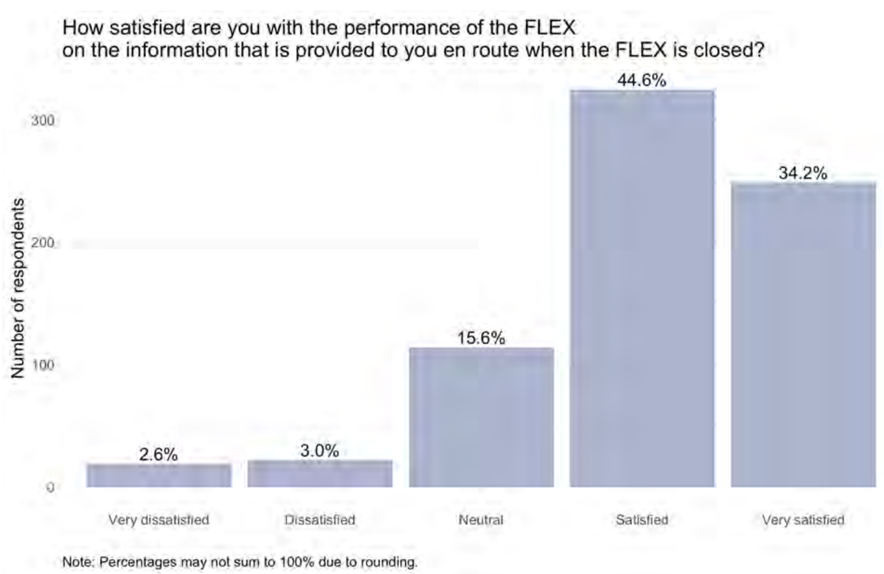


Figure 5-25 Level of satisfaction with information provided to respondents, en route, while the Flex lane is closed (n=729)

When drivers were asked about their satisfaction with the ease of identifying Flex route guidance signs the vast majority (86.5%) of respondents answered either satisfied or very satisfied; only 3.5% were either dissatisfied or very dissatisfied (Figure 5-26). Respondents with a higher income were statistically significantly less likely to be satisfied with the helpfulness of signage ($p < 0.05$). When asked about their satisfaction with understanding messages on the Flex route the vast majority (85.6%) of respondents said they were either satisfied or very satisfied; only 5.3% were either dissatisfied or very dissatisfied (Figure 5-27).

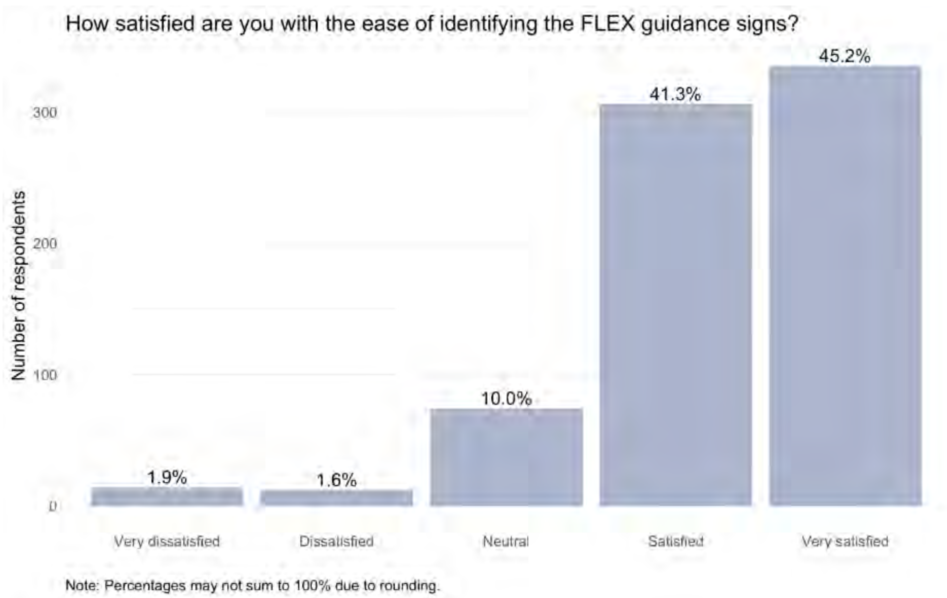


Figure 5-26 Level of satisfaction with the ease of identifying Flex route guidance signs by percentage (n=741)

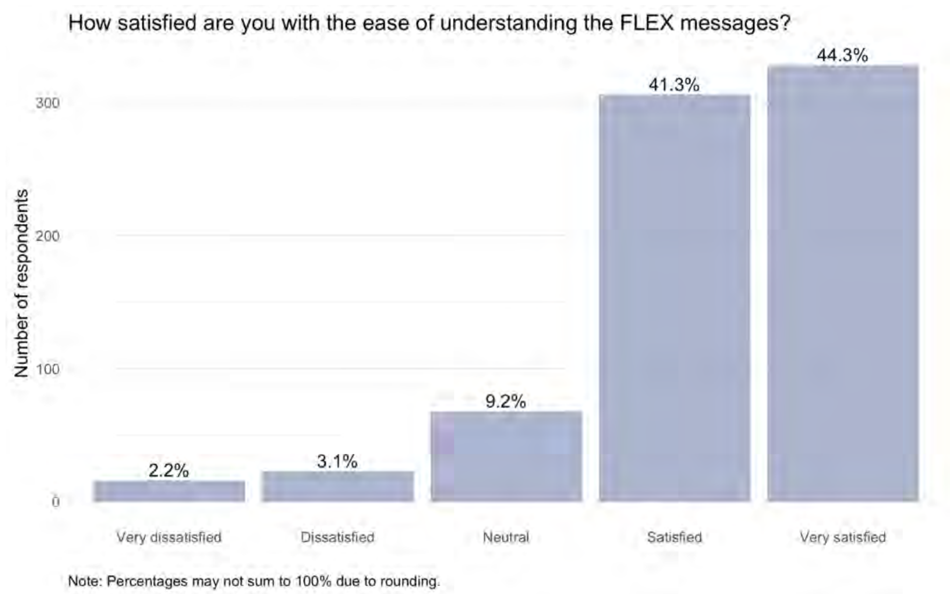


Figure 5-27 Level of satisfaction with the ease of understanding Flex route messages by percentage. (n=741)

When asked their level of satisfaction with the overhead sign system (gantries) along the Flex route the vast majority (81.9%) of respondents said they were either satisfied or very satisfied; only 5.4% were either dissatisfied or very dissatisfied (Figure 5-28). When asked how satisfied they were with the helpfulness of fixed signage the vast majority (80.5%) of respondents answered either satisfied or very satisfied; only 5.2% were either dissatisfied or very dissatisfied (Figure 5-29).

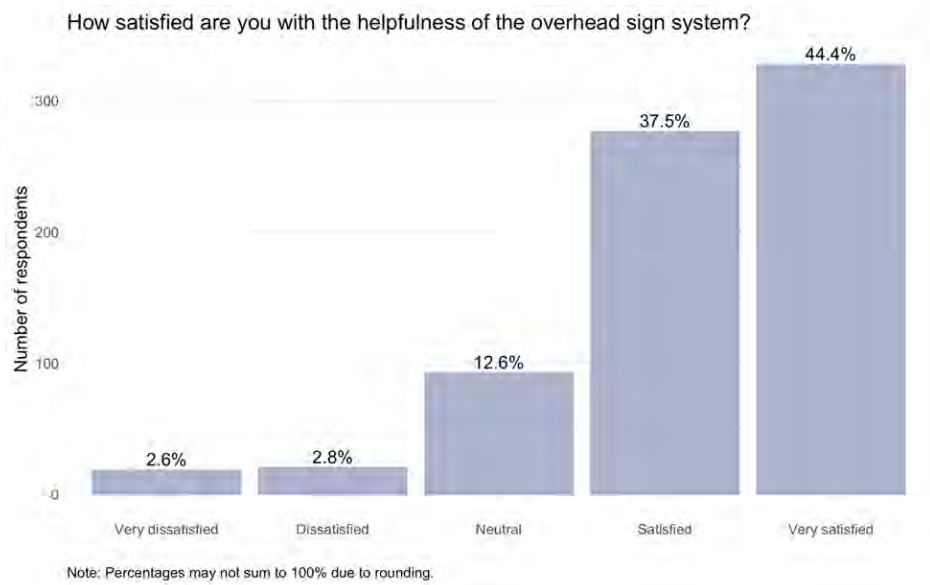


Figure 5-28 Level of satisfaction with the overhead signs along the Flex route by percentage (n=738)

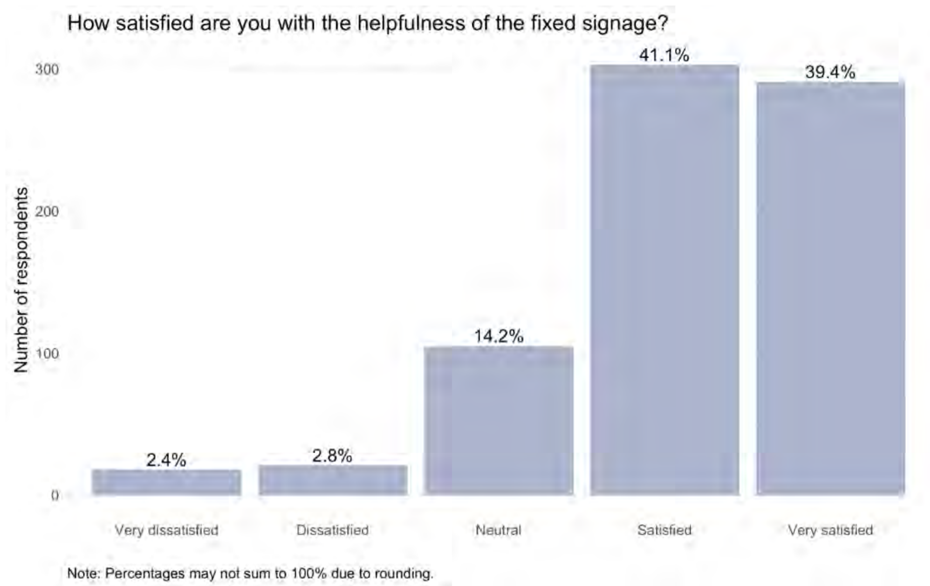


Figure 5-29 Level of satisfaction with the helpfulness of fixed signage along the Flex route by percentage (n=738)

When respondents were asked how satisfied they were with the helpfulness of the yellow lane markings, the vast majority (79.0%) answered that they were either satisfied or very satisfied; only 4.8% were either dissatisfied or very dissatisfied (Figure 5-30). When asked how satisfied they were with the upkeep/maintenance of the Flex route, 83.1% of respondents said they were either satisfied or very satisfied, only 3.9% were either dissatisfied or very dissatisfied (Figure 5-31).

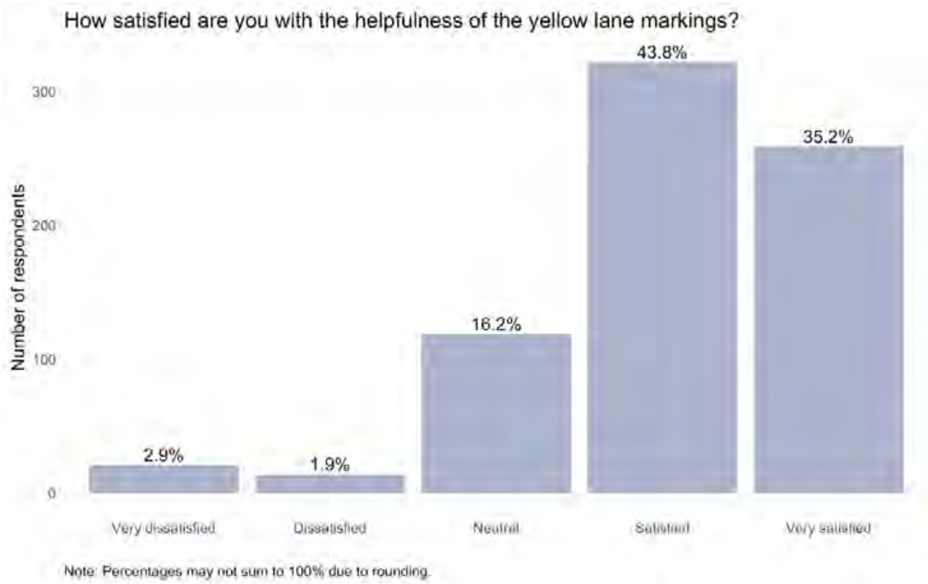


Figure 5-30 Level of satisfaction with the helpfulness of the yellow lane markings along the Flex route by percentage (n=735)

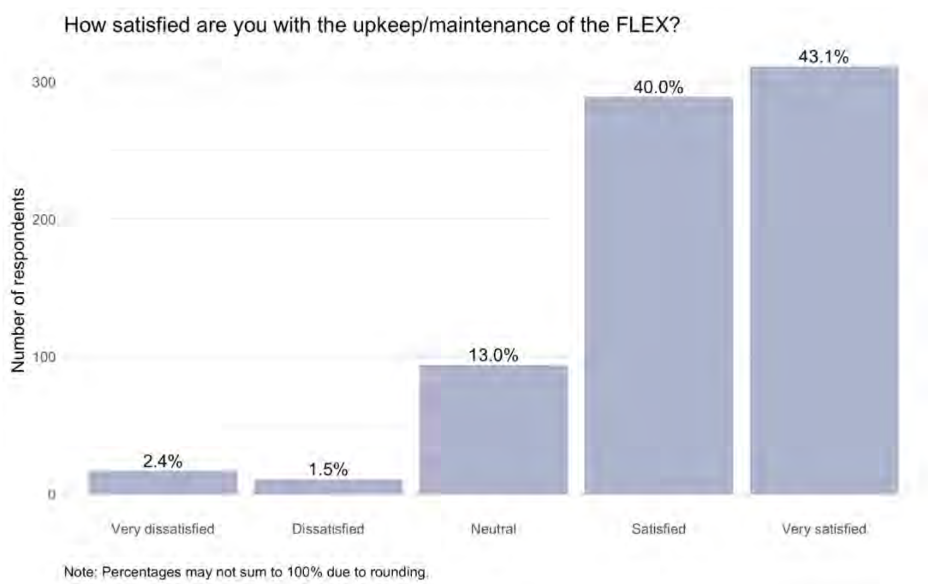


Figure 5-31 Level of satisfaction with the upkeep/maintenance of the Flex route by percentage (n=722)

5.1.8 Support for Additional Flex Lanes in Michigan

When asked if they would support the addition of a Flex lane to other Michigan highways 78.0% of respondents said yes and only 22% said no (Figure 5-32). Female respondents were statistically significantly more likely to support additional Flex lanes than were males ($p < 0.05$), though respondents who owned multiple vehicles were statistically significantly less likely to support additional Flex lanes ($p < 0.05$) (Table 5-6). Respondents who reported a satisfying driving experience along the Flex route were also statistically significantly more likely to support additional Flex lanes ($p < 0.001$), as were those who reported an improved overall driving experience ($p < 0.001$), and those who preferred driving in the Flex lane ($p < 0.05$) (

Table 5-7). Finally, respondents who reported an increased sense of safety were statistically significantly more likely to support the construction of additional Flex lanes ($p < 0.001$). Thus, increasing the sense of safety on the US-23 Flex route and future Flex routes would be paramount to garner and sustain support for these types of projects.

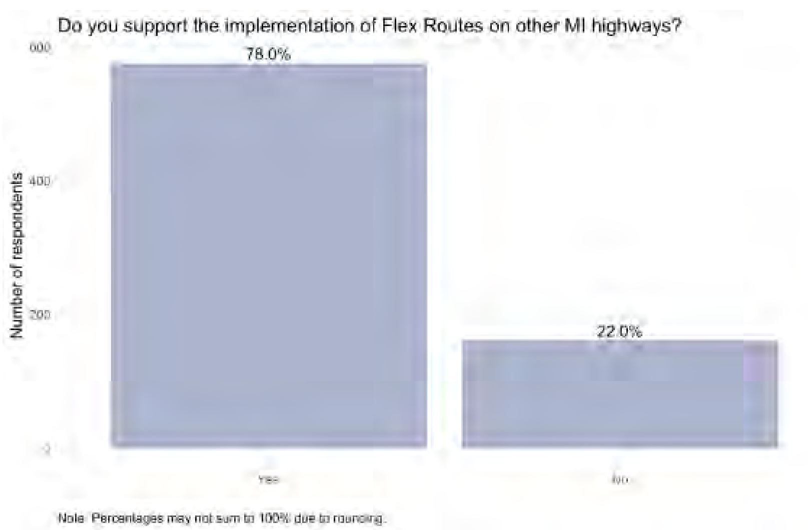


Figure 5-32 Percentage of respondents who would support the addition of other Flex lanes around Michigan (n=738)

Table 5-6 Percentage of respondents who would support the addition of other Flex lanes by the number of cars they own

N of cars	n	% support
1	115	77
2	321	82
3	150	75
4	71	73
5	27	74
6 or more	15	67

Table 5-7 Percentage of respondents who would support the addition of other Flex lanes by the lane they usually drove in

	n	% support
The temporary lane	263	80
The middle lane	328	80
The right lane	131	70

5.1.9 Methodology

To assess driver sentiment, perception, and understanding surrounding the Flex route, a survey was conducted following the methods designed by Dillman (2011); both online and paper surveys were utilized. A random sample of 4000 mailing addresses was selected from within three different Michigan zip codes (48116, 48178, and 48189). These zip codes were within Washtenaw County and Livingston County, both of which border the US-23 Flex route. Paper surveys were mailed out in three separate waves between October and December of 2019. The first mailing consisted of a postcard notifying respondents that they had been selected to provide their opinion about the Flex route, and contained a link to an online survey hosted by Qualtrics (both online and paper surveys were identical). The second mailing occurred four weeks after the postcards were sent and contained a paper survey accompanied by a postage-paid return envelope. Finally, three weeks later, a third mailing was sent out to respondents who had not yet returned a survey. The third mailing contained a copy of the original survey. In total, 892 completed surveys were received, a response rate of 22.3%.

The survey itself consisted of 34 questions (see APPENDIX C); the survey began with a brief description of what the Flex route is and informed respondents as to why their feedback was requested. Respondents were also informed that their responses would be entirely anonymous, that they had the right to refuse the survey or stop at any time, that only adults aged eighteen and over were eligible to complete the survey, and that they agreed to participate by filling out and returning the survey.

The survey began by showing participants a picture of the Flex route's gantry. Then, the survey prompted them to describe the meaning of two possible symbols displayed on the gantry, either yellow arrows or a yellow "X." Immediately afterward, they were asked if they had ever driven on the Flex route, if they answered no they were directed to stop the survey and return it. Participants who had driven on the Flex route were then asked nine questions about their experiences, driving habits, and observed changes in their own and others' driving behavior. The majority of these questions were multiple-choice, with two open-ended questions regarding changes in behavior. The next section of the survey focused on performance and safety perceptions regarding the Flex route. Participants were asked to rate their level of satisfaction about various aspects of the Flex route on a five-point Likert scale, ranging from very dissatisfied to very satisfied. The next section consisted of fourteen multiple-choice questions, another ranked satisfaction section, and one open-ended question; all of which probed respondents' understanding of various features of the Flex route. The survey concluded by asking respondents basic demographic questions such as age, gender, employment, and income, and providing respondents with an option to provide additional comments.

Results of the survey were then collected, coded, and analyzed; statistical analysis was conducted to determine if, and to what extent, demographics influence respondents' perceptions. Binomial, ordinal, and multinomial logistic regression models, as well as Spearman's rank correlation tests, were used to determine statistical significance. Open-ended questions were content analyzed using an emergent coding process (Charmaz, 2008).

5.2 Open-ended Questions

Open-ended questions asked respondents to state their opinions about the Flex route. These questions cannot be answered with a simple yes or no, but instead asked respondents to describe something with sentences, and thus they often provide further insight into how a respondent feels. This section analyzes questions about gantry symbols, lane preference, and driving behavior along the Flex route.

An analysis of these questions shows that there is some confusion regarding the meaning of symbols on the gantries and the speed limit in the Flex lane. Many respondents were unable to accurately answer questions about either. In general, respondents reported that they appreciate the Flex route and that it saves them time. However, they also reported having witnessed some, albeit infrequent, poor driving behaviors from other drivers since its implementation.

5.2.1 The Flex Route: General Impressions and Commentary

Respondents were asked if they had any important comments about the Flex route. Out of 421 comments, 34.6% noted that they would like to see the Flex route extended to I-96/I-94, 13.5% wanted to see the Flex route extended in general, and 22.5% said they would like the Flex lane to be open longer. Few respondents (9.2%) would like to have some clarification about signage on US-23, in particular the Flex lane's speed limit (Figure 5-33).

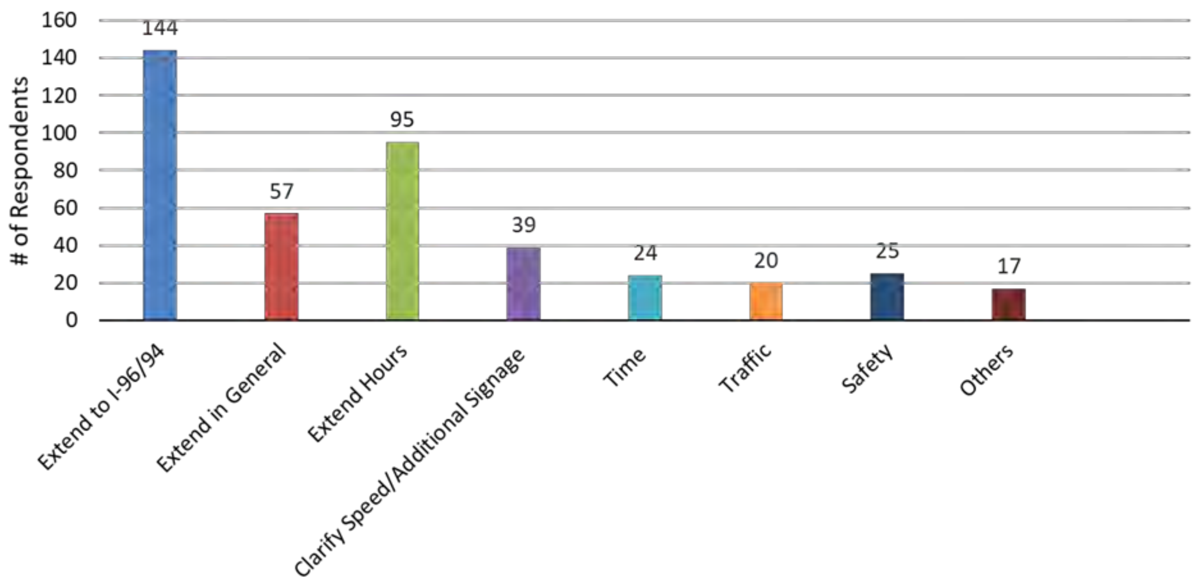


Figure 5-33 Topics and number of additional responses when asked for comments about the Flex route (n=421)

When asked specifically *when* they would like to see the Flex lane opened, in addition to its current routine, 45.6% responded they would like it to be a permanent lane, 16.9% said when traffic is high, and 16.1% said on weekends (Figure 5-34).

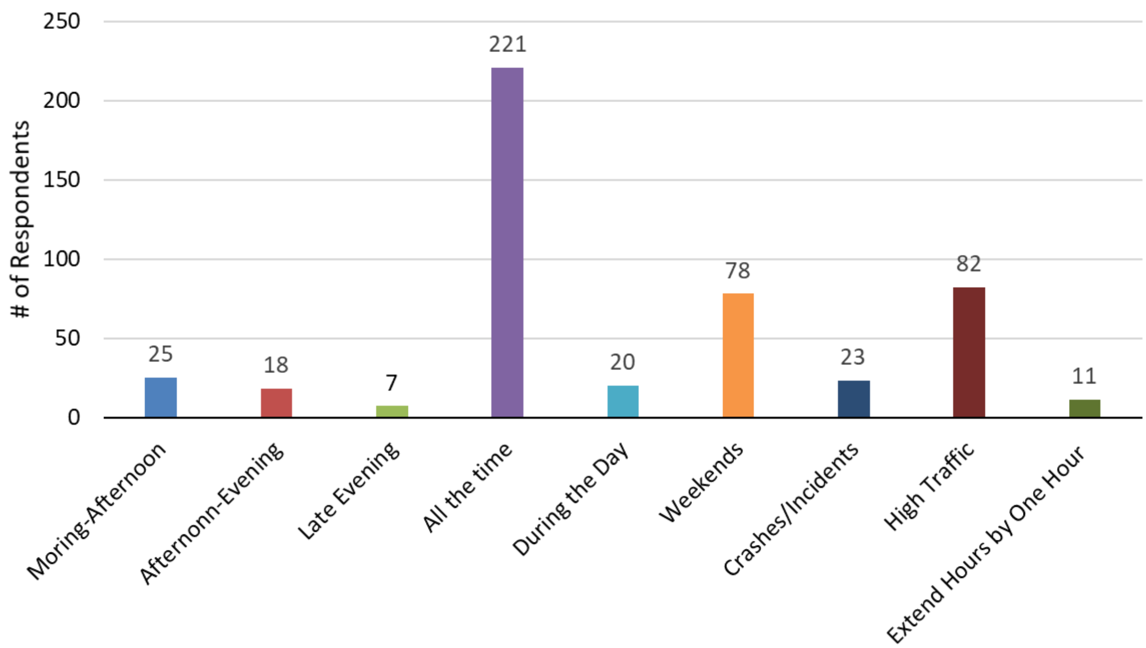


Figure 5-34 Type and number of responses when respondents were asked when the Flex lane should be open, in addition to its current schedule (n=485)

All of the above, reiterates sentiments found in responses to the multiple-choice questions in the previous section: respondents were satisfied with the Flex route and would like to see a physical expansion as well as extended operating hours.

5.2.2 The Flex Route: Gantry Symbols

Yellow arrows: There is some confusion among drivers about the meaning of the triple yellow arrows displayed on gantries. The majority (63.5%) of respondents were correct in believing that the arrows indicate that one should merge. One respondent, which exemplifies the typical comment, correctly noted that: "*This indicates that I should switch lanes and merge into the right lane (one of the current signs is positioned too late- so unfamiliar drivers have very little time to merge)."* However, 6.6% believed the arrows simply meant to use caution while driving, and about 1% of drivers believe that the arrows mean they should not drive in the lane or that it was about to close (Figure 5-35). Further, 29.4% of respondents refused to answer this question.

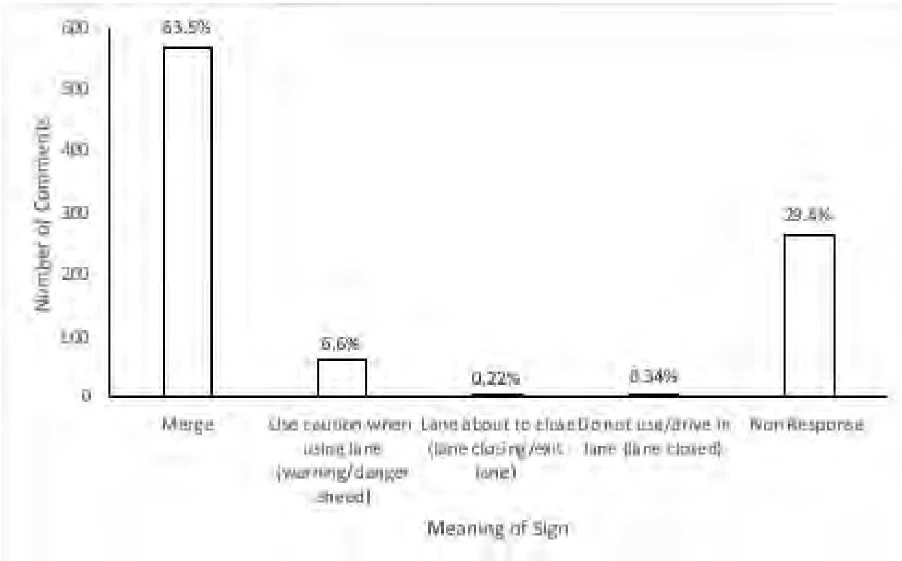


Figure 5-35 What respondents think the yellow arrows mean by percentage (n=892)

Yellow Cross: When a *yellow cross* "X" is displayed on the gantries there is more confusion about its meaning. The majority (66.6%) of drivers wrongly believed that the lane is closed, 3% correctly believed that it was *about* to close, and 2.2% believed that they should drive cautiously (Figure 5-36). One respondent explained their confusion in more detail: *"Caution ahead? yellow normally means Caution/slow and the X normally means stop... very confusing."* Further, 28.8% of drivers refused to answer the question.

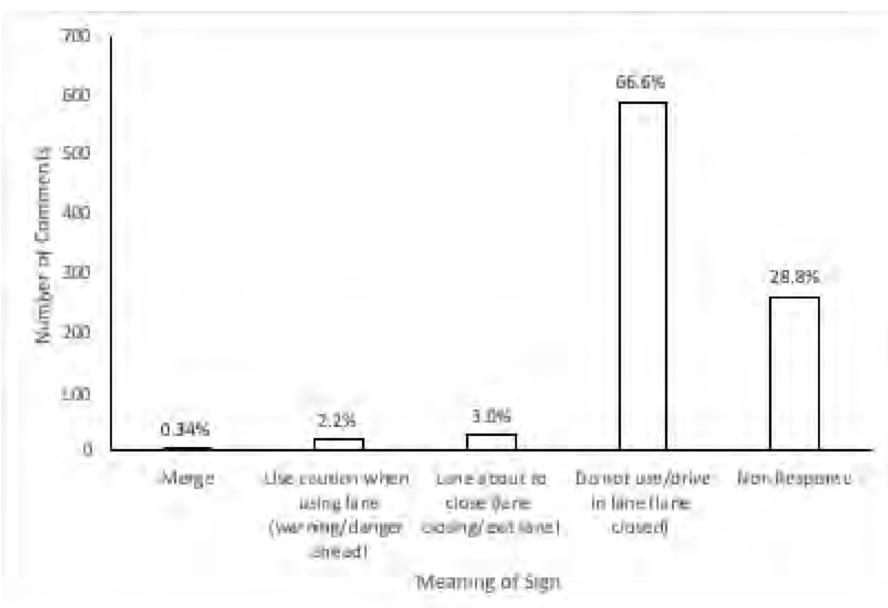


Figure 5-36 What respondents think the yellow "X" means by percentage (n=892)

Green Arrow: Respondents were also asked, "When the green arrow is shown on the overhead sign system, how fast are you allowed to drive in each lane?" For the left lane, 51% said between 60-65mph, 44.9% said between 70-75mph, and less than 5% said either below 60mph or above 70mph. For the middle lane, 60.8% said between 60-65mph, 35.2% said between 70-75mph, and less than 5% said either below 60mph or above 70mph. For the right lane, the majority (61.4%) of respondents said between 60-65mph, 34.1% said between 70-75mph, and less than 5% of drivers said either below 60mph or above 70mph (Figure 5-37, Figure 5-38, Figure 5-39). Drivers experienced some confusion regarding the speed limit in all lanes, though respondents were slightly more likely to believe that the speed limit in the left lane is higher than in the other two lanes.

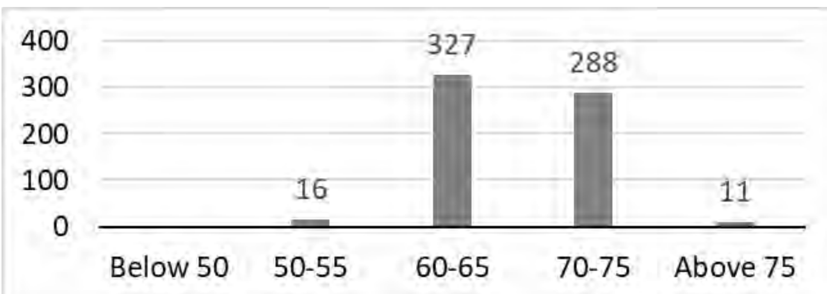


Figure 5-37 Number of respondents and what they believe the speed limit is in the left (Flex) lane (n=642)

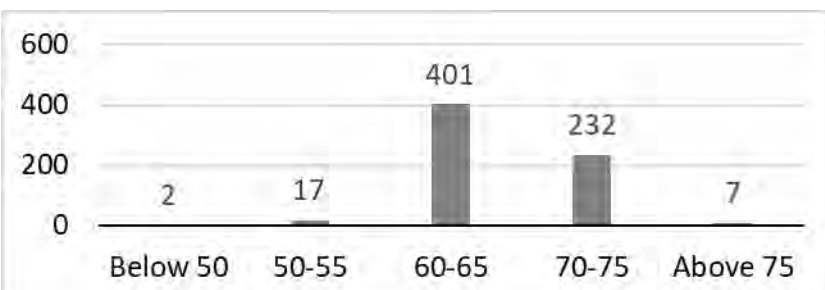


Figure 5-38 Number of respondents and what they believe the speed limit is in the middle lane (n=659)

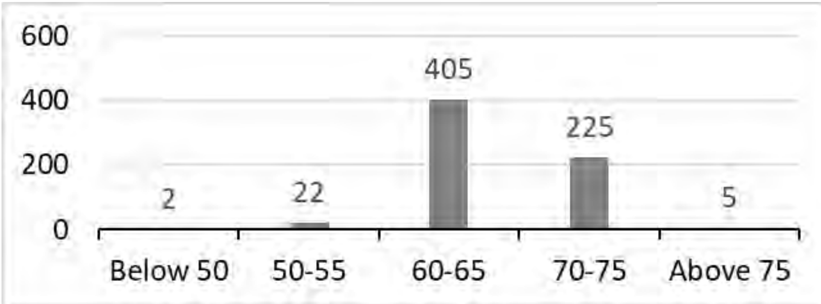


Figure 5-39 Number of respondents and what they believe the speed limit is in the right lane (n=659)

5.2.3 The Flex Route: Lane Preference

When asked which lane drivers prefer to drive in 46.8% of respondents said the middle, 36.9% said the left (Flex lane), and 16.3% said the right lane (Figure 5-40).

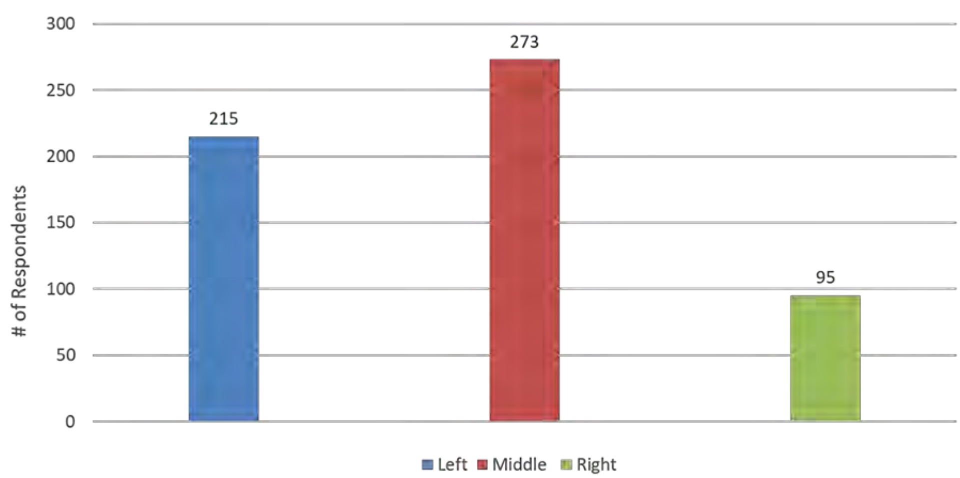


Figure 5-40 Number of respondents by lane preference (n=583)

When the respondents who preferred the right lane were asked why they preferred that lane, the vast majority indicated that the right lane allowed them to drive at a more comfortable (slower) speed, increased their perception of safety, and allowed for easier merging (Figure 5-41).

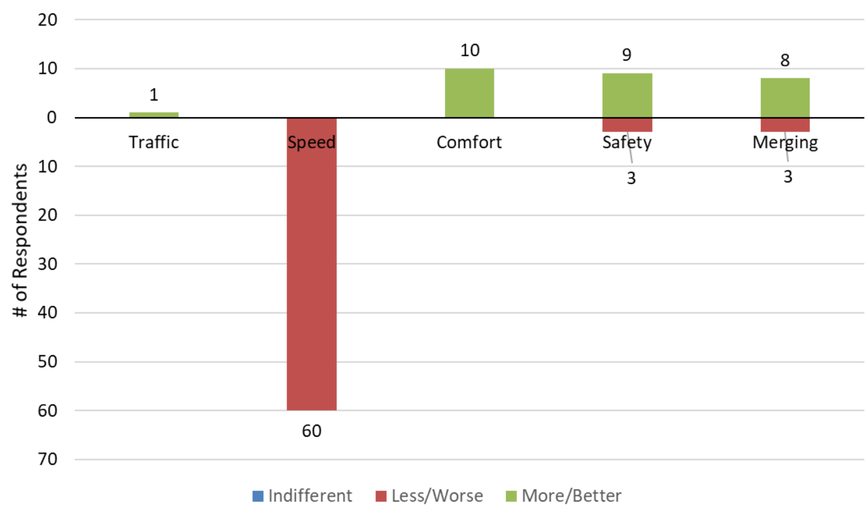


Figure 5-41 Number of respondents and the reasons why they prefer the right lane (n=94)

Drivers who preferred the middle lane did so for a variety of reasons, but mainly because it allowed them to more effectively pass other vehicles. They also felt a stronger sense of safety and comfort in the middle lane, and also felt that merging was easier (Figure 5-42). Drivers who preferred the left lane did so, overwhelmingly, because it is perceived to be faster, though they also felt that it allowed them to travel more smoothly and helped them avoid being stuck behind semi-trucks (Figure 5-43).

Figure 5-42 Number of respondents and the reasons why they prefer the middle lane. (n=272)

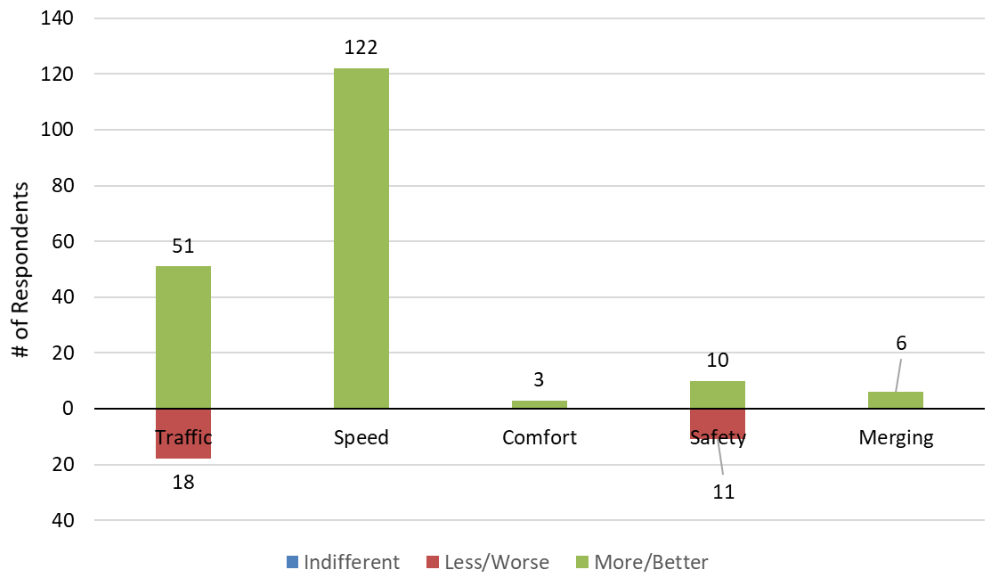


Figure 5-43 Number of respondents and the reasons why they prefer the left lane (Flex lane) (n=221)

5.2.4 The Flex Route: Driving Behavior

When drivers were asked if their driving behavior had changed since the introduction of the Flex route many wrote that it had. When asked further why their behavior had changed people reported being more relaxed while driving US-23. They also felt that they were no longer rushed to leave work or home early in an effort to beat traffic. They also lauded how the Flex route allows them to save time. Some reported an increased sense of safety, though this was not common among respondents (Figure 5-44). Drivers were also asked if they felt as though the driving behavior of others had changed since the implementation of the Flex route. Some respondents wrote that other drivers' behavior had changed, though not always for the better. The vast majority of people felt that speeding has increased on US-23. However, they also reported fewer incidents of aggressive driving, tailgating, and unnecessary lane changing (Figure 5-45).

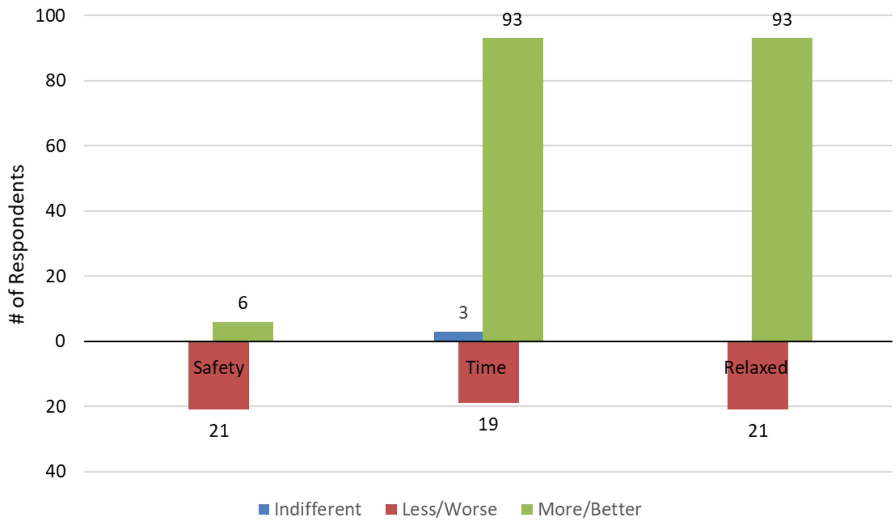


Figure 5-44 Number of and reasons why respondents changed their driving behavior since the Flex route was implemented (n=256)

Figure 5-45 Number of and behavioral issues that respondents feel have changed in others since the Flex route was implemented (n=382)

Respondents were also asked, specifically, what kind of driving behaviors they had witnessed since the Flex route was implemented, in addition to the multiple-choice options (speeding, early/late merging, back-forth weaving, and tailgating) as discussed in previous sections. They reported that the Flex lane is sometimes misused (drivers driving the Flex lane when it is closed), and that they sometimes witnessed some confusion regarding the speed limit. Additionally, they noted other behavioral problems which decrease safety, such as aggression incidences, increased evasive maneuvers due to new infrastructure, and distracted driving (Figure 5-46).

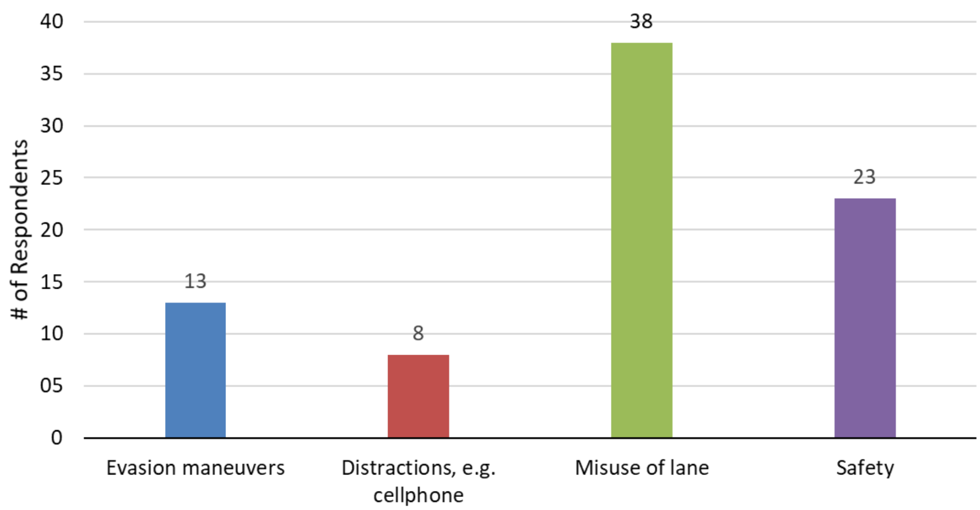


Figure 5-46 Number of and behavioral issues that respondents have witnessed in other drivers since the Flex route was installed (n=82)

5.3 Public Perceptions on the Flex Route

The majority of respondents view the Flex route in a positive light, and it has received consistent praise throughout all steps of its implementation. Respondents lauded the Flex route for reducing congestion and decreasing their travel time. Though, many respondents would have preferred a permanent lane while only a few commenters pointed out that the Flex lane was a cost-effective solution compared to a third permanent lane. Compliments/praise were the most common form of communicating positive perceptions towards the Flex including perceived benefit, followed closely by reduced congestion. However, negative sentiments do exist. Some respondents were dissatisfied with the construction and design of the Flex route (the most prominent concern) and its cost. Furthermore, the end of the Flex lane, at M-36/9 Mile, received consistently negative remarks. The perceptions of the Flex route over time became more positive after the route was open to traffic.

5.3.1 Methods: Data Collection

To measure Michiganders' perceptions on the US-23 Flex route, 1183 comments were collected: 29 emails sent to MDOT, 31 posts on MLive, 1112 posts on social media, 10 comments on Michigan local newspapers, and one letter sent to a newspaper editor. Data was collected from

April 2016, six months before MDOT announced its US-23 Flex route project, through June 2019. No commentary was found dated before April 2016.

Emails: 29 emails sent directly to MDOT were analyzed for public commentary.

MLive: MLive.com is the most read news and information website in Michigan. News coverage related to the US-23 Flex route was found using MLive.com's site search (https://www.mlive.com/search/). Searches were conducted using the term "flex route" as a keyword. 47 relevant news articles were identified. Each article was inspected to determine if there were any conversations associated within the comments. Only one out of the 47 articles had public commentary. In total, 31 comments were collected on MLive.

Social media: Tweets were collected using Twitter's application program interface (full archive/sandbox) and Python package TwitterAPI (geduldig, 2013). In an effort to ensure search terms were related to US-23 and the Flex route, queries were conducted using the keywords "flex" in association with any mention of one of the 13 official accounts owned by MDOT, these included: MichiganDOT, MDOT_MetroDet, MDOT_West, MDOT_Southwest, MDOT_Bay, MDOT_LanJxn, MDOT_A2, MDOT_UP, MDOT_Traverse, MDOT_Rail, MDOT_BlueWaterBridge, MDOT_MediaClips, MackinacBridge. Additionally, the term "#FlexRoute" was queried because it was frequently used as the hashtag to publicize projects. In total, 742 tweets were captured. Data from Facebook was collected using the search term "flex @MichiganDOT" as a keyword. 9 direct MDOT posts, with 17 associated comments, were collected. Additionally, this search returned 21 posts that had public commentary: 219 comments to these 21 posts were collected from Facebook. In total, 245 comments were collected from Facebook. On Instagram, 8 comments associated with 4 different MDOT posts were collected. On Youtube, 117 comments were collected from MDOTs official account posted on videos pertaining to the Flex route.

Local newspapers: Michigan local newspapers were analyzed via NewsBank (https://www.newsbank.com), a news database that covers current and archived content from more than 12,000 titles worldwide. It currently boasts 165 Michigan-specific sources, including the Detroit News, Flint Journal, Grand Rapids Press, and Kalamazoo Gazette. "Flex route" was used as a keyword and the source was set to "newspaper." The search returned 47 articles published in local newspapers from 13 different Michigan cities. Excluding irrelevant topics such as local diala-ride services, Google was used to search for the remaining articles by the title, author, and source as a means to collect the associated comments. Finally, the Lansing State Journal and Macomb Daily were searched, because both newspapers were not included in NewsBank's searches, and they are among the top Michigan daily newspapers by circulation (*Kantar SRDS Media Planning Platform*, 2019). In total, one readers' letter to the editor and 10 public comments were gathered from local newspapers.

5.3.2 Methods: Data Analysis

Comments were then coded by subject matter. In total, thirteen codes were identified which reflect either perceived benefits or concerns. Some codes were used for both benefits and concerns, but coded differently for sentiment analysis (positive, negative, neutral) (Table 5-8).

Table 5-8 Codes used to deduce concerns and benefits from sourced comments

Subject Matter Codes and Examples		
Code	*Definition*	*Type*
Crashes and Incidents	Comments that mention crashes/incidents/accidents occurring on the Flex route.	Concern
Compliment/Praise	Comments that praise the Flex route, claims that it is innovative and/or is working well. Additionally, those that mention awards the Flex route has been nominated for.	Benefit
Congestion	Comments that note increased levels of congestion associated with the Flex route.	Concern
Construction and Design	Comments that specifically mention the construction of the Flex route or its design.	Both
Costs	Comments that mention the cost of the Flex route.	Both
Education about the Flex Route	Comments that attempt to educate others about the Flex route, how it can be utilized, or its intended function.	Benefit
Enforcement and Compliance	Concerns with how laws are enforced on the Flex route, and whether or not drivers comply with them.	Both
Gantries and Signs	Concerns with the gantries and signage along the Flex route.	Concern
Ineffectiveness of Flex Route	Comments concerned with the efficacy of the Flex route.	Concern
Hours of Operation	Comments that mention hours of operation of the Flex route.	Concern
Questions and Responses	When commenters ask questions and MDOT provides responses.	Both
Reduced Congestion	Comments that mention reduced congestion as a result of the Flex route.	Benefit
Safety	Comments that mention safety.	Both

Speed	Comments concerned with the speed limit on the Flex route.	Concern

Comments were coded further as either positive, negative, neutral, neutralized, MDOT responses, or construction information (Table 5-9). Originally, some comments appeared neutral, but further analysis revealed that MDOT comments and construction information were so prevalent that they necessitated the creation of their own codes.

Table 5-9 Definitions of the codes describing the emotion evoked by each comment

Sentiment Codes	
Code	*Definition*
Positive	These are constructive and/or optimistic opinions about the Flex route.
Negative	Concerns that people have about the Flex route.
Neutral	Relays information about the Flex route.
Neutralized	Comments that mention at least one benefit and at least one concern about the Flex route.
MDOT Responses	An impartial response to a commenter from MDOT.
Construction Information	Notifications that provide location of construction work happening along the Flex route.

Comments were also coded based on author, be they individuals, MDOT, Organizations (private companies), or cities/townships, and source. Additionally, comments were coded chronologically based on the phases of the Flex routes implementation (Table 5-10). Finally, comments were coded/analyzed based on location if they mentioned places, lanes, or directions of travel.

Table 5-10 Descriptions of the five time periods of the life of the US-23 Flex route

Time Periods	
Phase	*Description*
Planning Phase (2009-2014)	The time period in which MDOT and the state legislature were discussing active traffic management strategies as a potential solution to reduce congestion in and around Ann Arbor.
Design Phase (January 1, 2015-October 3, 2016)	Comments and discussions stemming from the official public announcement of the Flex route project.
Construction Phase (October 4, 2016-November 14, 2017)	Period when the majority of the Flex route construction was occurring.

Early Implementation Phase (November 15, 2017-March 15, 2018)	Period when the public could first use the Flex route *before* construction ended.
Late Implementation Phase (March 16, 2018-April 27, 2019)	Period after construction had officially finished.

5.3.3 *Public Perception Overview*

Out of 1127 comments 40.0% were positive, 19.2% negative, 7.0% neutral, 1.9% neutralized, 13.3% were MDOT responses to questions or comments, and 18.6% was construction-related information (Figure 5-47).

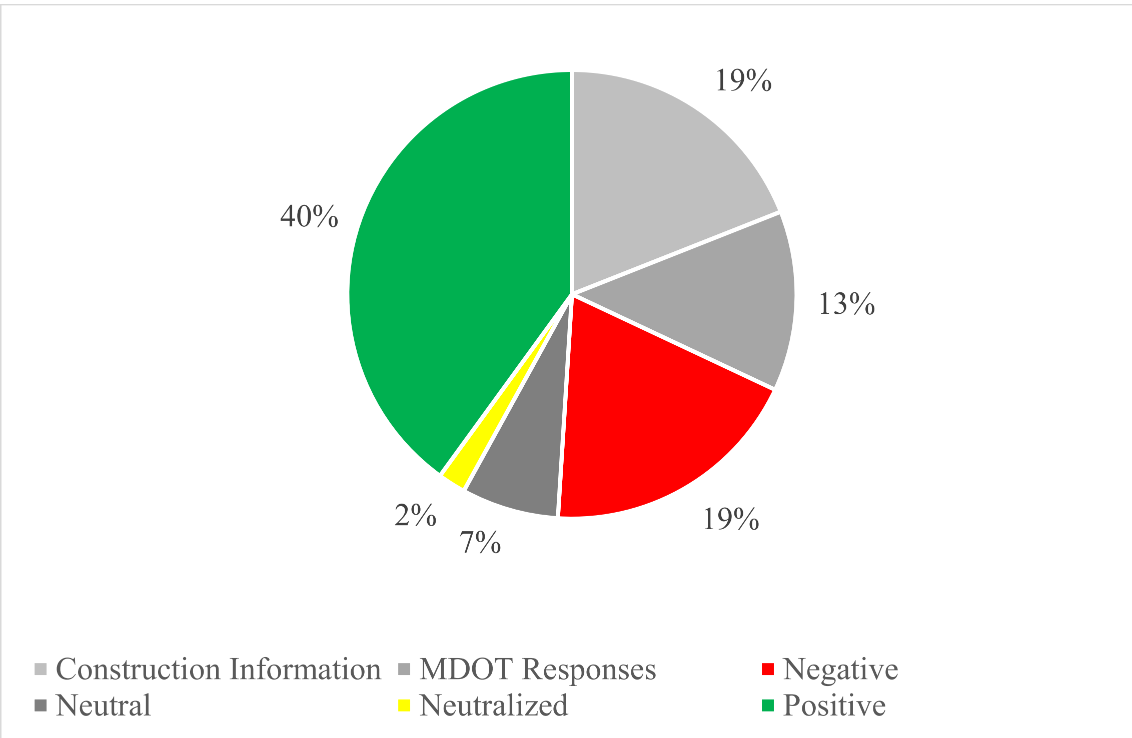


Figure 5-47 Percentage of positive, negative, neutral, neutralized, MDOT responses, and construction information comments (n=1127)

The majority of MDOT responses consisted of comments providing details about the Flex route's hours of operation and emphasizing that the implementation of the Flex lane was less costly than the construction of a permanent third lane. MDOT comments also described a possible extension of the Flex lane if funding could be secured. Finally, MDOT comments warned that Michigan State Police would ticket drivers if they did not follow the rules of the Flex route.

Examples of construction information comments were alerts on the location of lane and ramp closures and on new traffic patterns due to construction.

5.3.4 Perceived Benefits

Of the analyzed comments, 552 (48.9%) mentioned some form of positive benefit. Compliments/praise were by far the most common (61.6%). Some individuals also mentioned reduced congestion (15.6%) or attempted to educate others about the Flex route (11.2%). Other categories of perceived benefits were comparatively rare (each < 5%) including positive commentary on construction design, safety, or enforcement, among a few others (Figure 5-48). Individuals, organizations, and cities/townships describe the Flex route as "*time-saving*", "*innovative*", "*a smooth ride*", "*progressive*", and "*cost-effective*".

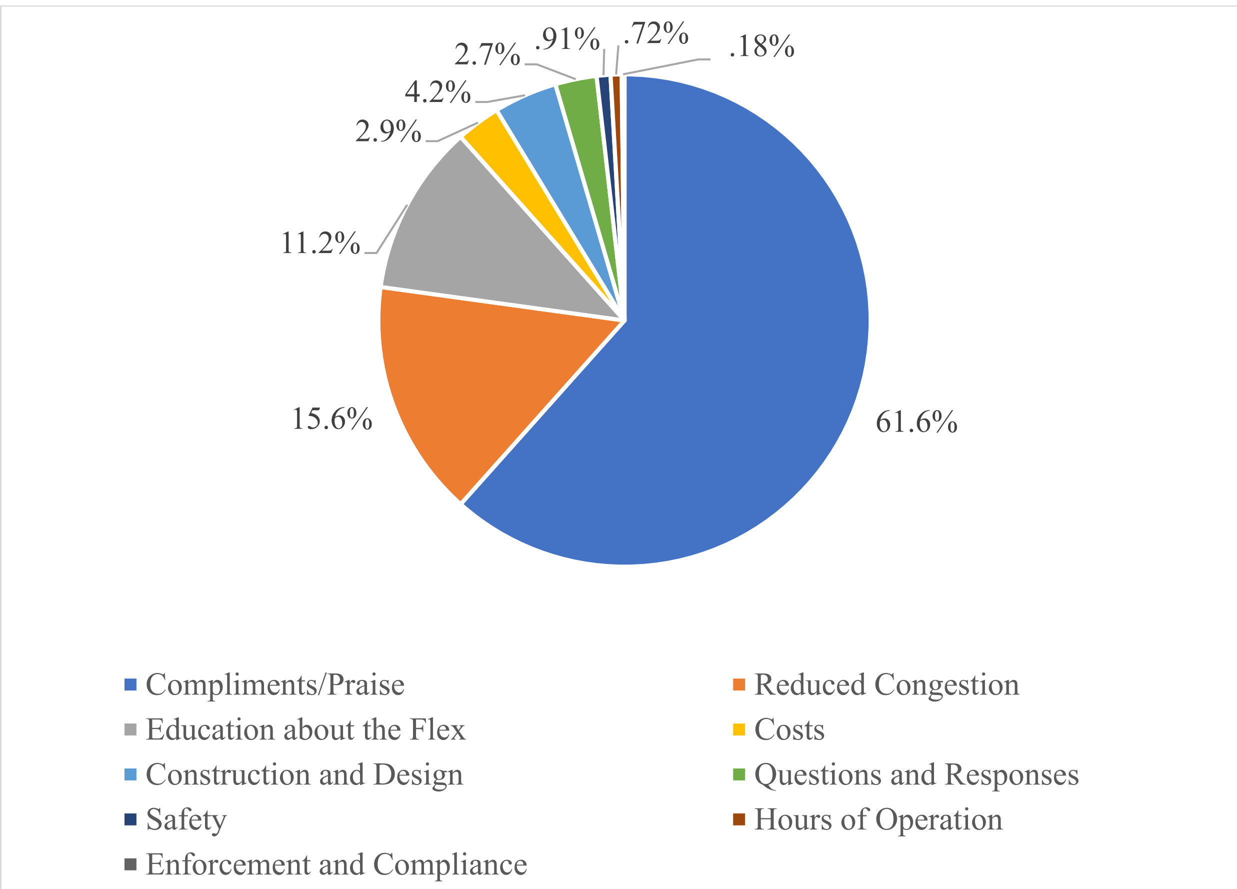


Figure 5-48 Benefit Categories identified in comments (n=552)

Compliments/Praise

The vast majority (61.6%) of positive comments were compliments/praise, totaling 340 comments. These comments were those that called the Flex route innovative, noted that work was progressing well, or other generally positive remarks. Additionally, many commenters urged people to vote for the Flex route to receive the People's Choice in America's Transportation Award. 43.8% of these comments came from MDOT, 35.0% from individuals, 17.6% from organizations, and 3.6% from cities/townships. For example, MDOT and organizations frequently encouraged commuters to vote for the Flex route after nominating it for the People's Choice in America's transportation award. An example being: *RT @MichiganDOT: Vote for the innovative and time-saving US-23 #FlexRoute project north of #AnnArbor #A2 as the People's Choice in America's Transportation Awards."*

Notably, about 75% of these comments consisted of re-tweets. The most common positive updates address milestones completed on the Flex route and announcements of the Flex route's opening date. Other comments included any positive coverage of the Flex route in the media, such as newsletters, meeting announcements, and/or pictures.

Ten comments mentioned that the Flex route was an innovative idea; these comments were retweeted with moderate frequency. Other positive comments noted that MDOT employees (especially construction workers) were doing a good job. Some commenters mentioned that the Flex route improved or will improve their overall quality of life. Still, others were confident that the Flex route would win a national award. A few other comments simply expressed gratitude towards the Flex route's existence.

Reduced Congestion

15.6% of positive comments mentioned reduced congestion, totaling 86 comments; individual users and MDOT were the most common sources. Out of the 86 comments, 53 were retweets (62%). When the plan to construct the Flex route was first announced, and immediately after its implementation, people predicted the Flex route would decrease congestion. Some of these comments also mentioned how the Flex route has continued to be a benefit over a year after its implementation, that it continues to save drivers' time, and that congestion is no longer a 24/7 problem. An example of these types of comments being: *"@MichiganDOT @DemRascals*

@wjrradio @fbtalk @COMTOMichigan The Flex route solution works just fine. I've driven on US 23 in peak travel times and having that extra lane does help tremendously with traffic."

Education about the Flex Route

Comments that were an attempt to educate people about the Flex route totaled 62, and comprised 11.2% of positive comments. These comments came from all sources and were often either a brief definition or a link to an educational video about the Flex route. These posts and videos described how the Flex route reduces congestion by using the shoulder as a temporary third lane. Commenters felt positive about the Flex route and wanted others to use it more effectively. An example being: "*@MichiganDOT Motorists can familiarize themselves with how a #flexroute works by viewing this video: https://t.co/jQE0PD8jxr"*

Construction and Design

These comments included information about the Flex routes construction or its progress, but were specifically positive in nature, comprising 4.2% of positive comments (23 in total). Some of these comments expressed happiness about the completion of roundabouts associated with the Flex route, or the bridge over 8 Mile Rd. One commenter hoped that the new Flex route on I-96 between Novi and Kent Lake Rd works well, and another commenter hoped that there would be enough funding to extend the current Flex route to M-59: "*I think this project was an excellent solution and I hope to see it continued all the way north to I-96! Also, with the success of US-23, perhaps I96/275 near Novi-Wixom could receive a similar renovation to add Flex lanes? Another area which sees heavy commuting traffic Keep it up!"* Comments like these originated from all sources.

Costs

A few commenters (sixteen in total, 2.9%) mentioned how the Flex route is a cost-effective solution for dealing with congestion as opposed to adding a permanent lane. *"The cost of the Flex Lane was less than 25% of the cost of adding new lanes in each direction. It's time for a change but it's time for smart changes to roads and cities."* Similar comments originated from all sources.

Questions and Responses

A few people posed questions about the Flex route (fifteen comments at 2.7%). These types of comments were infrequent. One individual asked when the Flex route would open, three asked whether the Flex route could be used for other construction projects, two wondered if it would reduce the number of incidents, and two asked whether further Flex lanes may be implemented to reduce congestion elsewhere, an example being: *"@MichiganDOT Thanks for the update! Are there any stretches of road that see more traffic for tourism than the US-23 corridor sees for commuting? If not, then why not only use flex lanes moving forward for all construction projects?"*

Safety

Occurring extremely infrequently (0.91%), comments suggested that the Flex route can improve safety. The entire category consists of a single MDOT tweet, that was retweeted four times. The comment promised commuters that the Flex route ensured safety. "*What is #FlexRoute? It's a way MDOT's making operational and safety improvements to the US-23 corridor north of A2: https://t.co/cEXhiQnKVq https://t.co/jWvgYujkjQ"*

Hours of Operation

Another rare category, with only four comments at 0.72%, is comprised of two individual commenters who expressed their excitement about the Flex route being open during special events. Two mentioned football games, and the other two noted potential benefits during a power outage. "*RT @CeeJay4746: Thanks @MDOT_A2 for having the flex lane open after Michigan Football. Definitely makes a difference."*

Enforcement and Compliance

A single individual (0.18%) mentioned enforcement and compliance in a positive light. Noting: *"Michigan Department of Transportation thanks for the follow-up. Now we just need MSP to be visible out there!!"*

5.3.5 Concerns

Of the analyzed comments, 317 (28.1%) entailed some form of negative perception. The most common negative comments (23.6%) referenced the Flex route's construction and design or asked and responded to questions with a negative connotation (16.4%). Other categories included negative comments about congestion (16.1%), cost (9.8%), ineffectiveness (9.1%), enforcement (8.5%), and gantries or signs (5.7%). All other categories contained less than 5% of the comments (Figure 5-49).

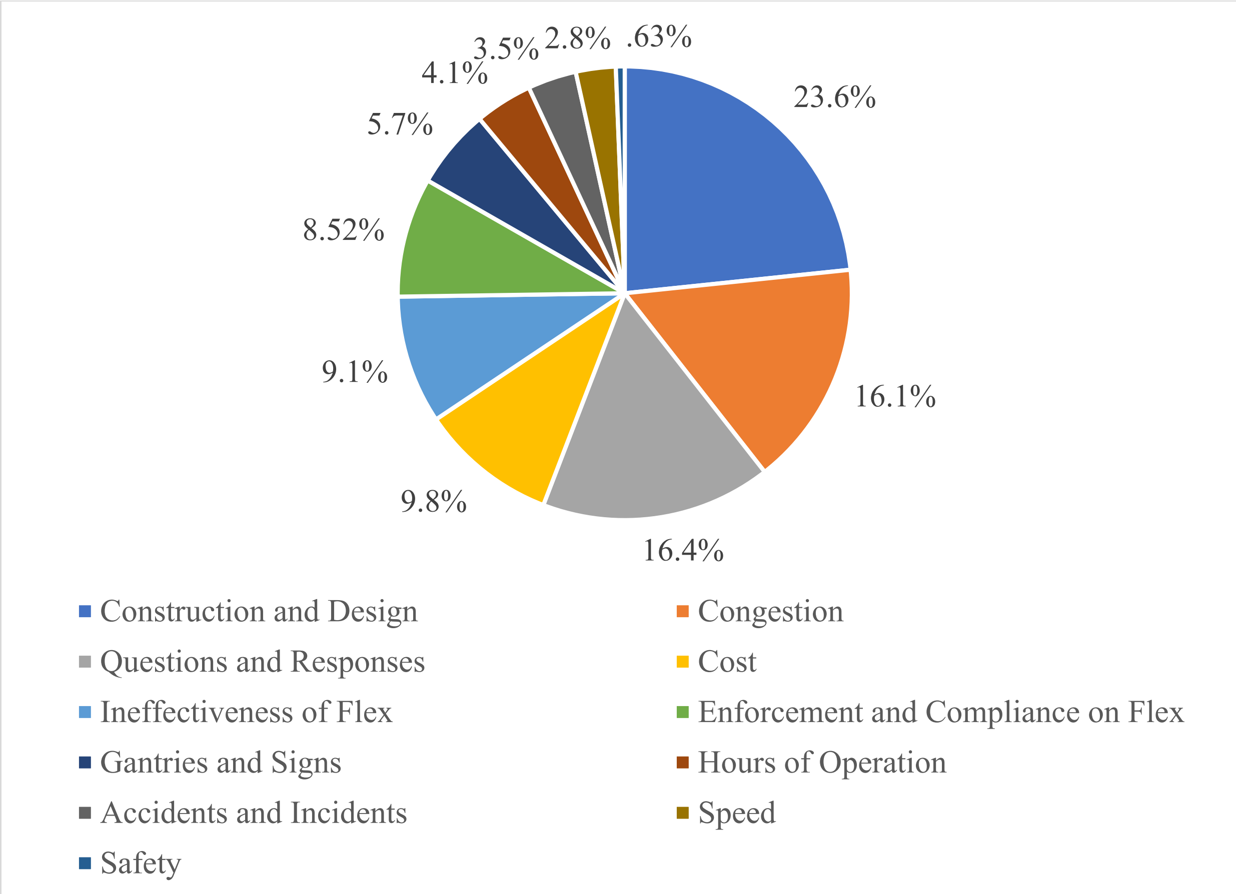


Figure 5-49 Concern categories identified in comments (n=317)

Construction and Design

The most common category of negative comments were those referencing the construction and design of the Flex route, totaling 74 comments, and comprising 23.6% of all negative comments. These comments expressed concern about the perceived poor design of the Flex route. Some believed that the Flex route should have been a permanent third lane instead of a temporary lane. For example, one commenter noted: "*Still think it should have just been a regular lane all the way to 96.*" Several people believed that congestion still forms where the Flex route ends, calling the merging point a "crawl." Some complained that the construction phase took far too long. Others insisted that a sound barrier between the Flex route and adjacent communities was needed. The vast majority of these comments came from individuals.

Negative Questions and Responses

The second most common source of negative comments were questions with a negative connotation, either directed at MDOT or about the Flex route in general. These comments comprised 16.4% of all negative commentary and totaled 52 comments. The most common negative questions either asked why the Flex route could not be open 24/7, or why the US-23 Flex lane could not have been converted into a permanent lane. These comments also posed questions regarding compliance, enforcement, plans to extend the Flex route, construction, hours of operation, congestion, costs, and speed. One commenter noted: "*Why close the lane at any point in the day? Why not just keep it open at all times? Makes no sense to me. #FlexRoute*". The vast majority of these comments came from individuals.

Congestion

The third most common negative category (16.1% of negative comments, totaling 51), came from individuals commenting about how the Flex route leads to more congestion. Some of these individuals believed that congestion had not changed at all since the installation of the Flex route. These commenters primarily wrote about where the Flex route ends at M-36/9 Mile going northbound. At this location, commenters noted that the reduction in lanes leads to more congestion. Other locations mentioned as a problem included: N. Territorial to Pontiac Trail, 8 Mile, and Silver Lake Road. One commenter noted*: "What used to take a 20-minute commute home, now takes me 40-50 minutes..."* Most of these commenters argued that the Flex route actually increased congestion on secondary roads.

Cost

Some commenters, almost exclusively individuals, believed that the costs of the Flex route exceeded its benefits. These comments comprised 9.8% of all negative comments, with 31 instances. These commenters believed that it would have been cheaper to simply add a third permanent lane, as opposed to a Flex lane. For example, they expressed discontent, arguing that the Flex lane was a waste of resources: "*I think this was the biggest WASTE of taxpayers money 💰... why not just make it 3 lanes all the time and call it a day ... no confusion!!!"*

Ineffectiveness of Flex Route

Some commenters believed that the Flex route is ineffective, they used words and phrases such as "*mistake*", "*dumb*", "*failure*", "*does not work*", "*stupid idea*", and "*confusing.*" These comments were moderately rare, totaling 29 and comprising 9.1% of all negative comments. These commenters believed that the Flex route simply does not work well. One individual noted: "*Been on it several times. Overall, I think it was a big mistake. They should have just put in another lane on both sides, drop the fluff.*"

Enforcement and Compliance

A small number of commenters (8.5% with 27 comments) believed that other drivers misuse the Flex route. They reported witnessing people using the Flex lane as a passing lane even when a red "X"s are displayed on the gantries. Two commenters also complained about semi-trucks using the Flex lane; one noted: "*I see all sorts of issues with people using those lanes when they shouldn't, causing additional traffic accidents!!*" Additionally, commenters also pointed out that they rarely see police officers patrolling the Flex route or enforcing its rules.

Gantries and Signs

Complaints about the gantries and signs along the Flex route, in particular, how expensive/unnecessary they are perceived to be, comprise 5.7% of all negative comments, totaling 18. One person mentioned being confused by the signs, and another commuter explained that the signs do not help with traffic:"*@MichiganDOT 4.6 million per mile and you spent 20 million on signs!"* These comments were exclusively made by individuals.

Hours of Operation

Some commenters (4.1% with 13 comments) expressed concern that the Flex route is not open when they think it should be. They gave Thanksgiving and football games as examples: "*MDOT_A2 1st Michigan home game and flex lane is not open on northbound US23? Why?*"

Crashes and Incidents

A small number of individuals (3.5% with 11 comments) mentioned that the Flex route is not open when there are crashes, and some believed that they think the Flex route would actually result in an increased number of crashes. These comments were exclusively from individuals, with one noting: *"Last Wednesday was one of the days. An over-turned gravel hauler closed the freeway."*

Speed

A small number (2.8% with 9 comments) of commenters were concerned that the speed limit along the Flex route is either too high, or conversely not high enough. They believed that the speed limit changes may result in incidents, noting: "*You need to consider changing the 60 mph overhead signs on the new 23 flex route, they are restricting the flow of traffic. If the posted speed is 70 and the overhead signs say 60 it makes people believe the speed limit is 60. This is completely unsafe.*"

Safety

An extremely small number (0.6% with only 2 comments) of commenters were concerned that the Flex route may result in more crashes because there is no room for error with three lanes and no inside shoulder: "*Using that 3rd lane when traffic is heavy doesn't leave much margin for driver error. I really don't want to see an increase in accidents where two cars bump and then the driver in the flex lane slams into the railing (since there is no shoulder) and then takes out a few cars behind as well.*"

5.3.6 Perceptions of the Flex Route by Source

Perception of the Flex route varied by source, as did the total number of comments. Commenters were far more likely to voice their opinion about the Flex route on social media as opposed to other platforms. Individual users sent 29 commentary emails to MDOT (2.5%), posted 31 comments on Mlive (2.6%), but wrote 1,066 social media posts. Of the comments posted on social media, 717 were from Twitter (67%), 227 from Facebook (21%), 115 from YouTube (11%), and 6 from Instagram (1%) (Figure 5-50).

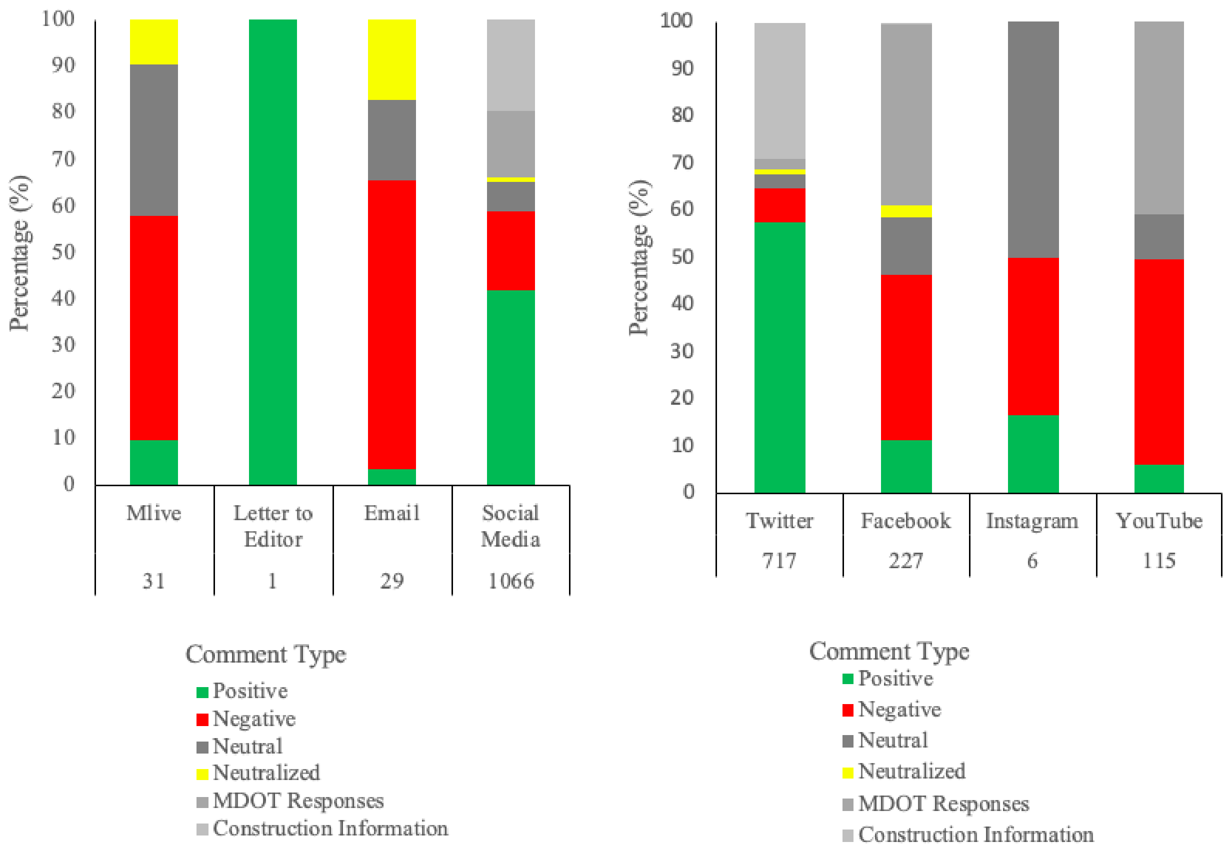


Figure 5-50 Percentage of comments and type collected from social media and other sources - with an inset each social media platform (n=1127 and 1066, respectively)

Around 40% of the comments on social media were positive, mentioning some sort of benefit, while 17.1% expressed concerns. Out of all social media platforms, Twitter hosted the most positive comments at 57.5%. The platform with the most negative comments was YouTube, on which 43.5% of comments were negative.

On Twitter, most of the positive comments (57.5%) consisted of compliments/praise about the Flex route. Many of these comments were updates regarding Flex routes construction progress or mentions of milestone achievements. For example, one commenter noted: "*Good news from our friends @MichiganDOT: The US-23 Flex Route will open by mid-November if not sooner. Details: https://t.co/WH5ItmL6Bl.*" Additionally, all comments mentioning construction information were gathered from Twitter (100%), many of these comments notified drivers of lane closures or if construction was occurring along the Flex route. On Twitter, 7.4% of comments noted dissatisfaction with the Flex route in general, posed negative questions, or complained about the costs. The latter being a moderately common sentiment, highlighted by a particular post: *"MichiganDOT I haven't seen any answers at all...a full lane of traffic was added on each side, giant digital signage was then installed to let people know that they couldn't use the lane. @MichiganDOT response is that it was cheaper to do more than necessary. #BrickWall #FlexRoute #Waste."* This perceived waste of resources was not uncommon across other platforms.

Facebook comments, comprising 21% of all posts on social media, featured more negative comments than positive. Primary concerns (34.8%) included worries about the construction/design of the Flex route, questions, and concerns related to enforcement/compliance. One user noted: "*There will be nothing keeping them from using the shoulder except the red X. Good luck with this in Michigan.*" MDOT representatives (MDOT responses) were more likely to respond to negative comments than positive ones (38.3%), attempting to answer questions and address concerns. Neutralized comments were also more common on Facebook (57.1%), though the content of neutralized comments varied. Of the positive comments posted on Facebook, most were some form of compliment/praise. One commenter exclaimed: "*That is great work, and I'm very happy to see MDOT sharing success stories and crediting the people behind the changes. You guys (and gals!) are doing your best given the lack of funding you have and have had to deal with maintaining and improving our roads. I'm quite happy with the improvements we've seen so far, I hope that this progress continues!*"

YouTube comments, accounting for 11% of all comments posted on social media, were a mix of concerns and perceived benefits, though concerns were more common at 43.5%. Concerns were largely in reference to construction/design, questions, and the potential for increased congestion. Many of the comments that spoke about concerns with the construction/design of the Flex route bemoaned the same issue: these commenters would have preferred a permanent third lane, exemplified by: *"If the shoulder is sufficient and safe to handle traffic for a portion of the day, then it should be sufficient and safe for the entire day. This may make sense within the MDOT bureaucracy but it sounds like folly to those of us paying the bills."* Of the positive comments collected from YouTube, most consisted of compliments/praise or positive sentiments regarding the construction/design of the Flex route. These commenters were pleased with the increased quality of life that they attributed to the Flex route.

Comments from Instagram, MLive, and emails comprised only 6.1% of all collected comments. On MLive commenters focused largely on the negative aspects of the construction/design of the Flex route. Comments by email were frequently concerned with the hours of operation of the Flex route. One emailer asked: "*Why isn't the extra lane on SB US23 open on U of M gameday?*", which was a relatively common question. Instagram comments, consisting of only 6 comments, were varied but the most were neutral.

5.3.7 Perceptions of the Flex Route Over Time

Commenters expressed varied sentiment between the different phases of the Flex routes inception, design, construction, and implementation. Individual users posted the greatest percentage of positive comments during the late implementation phase (60%), and the least positive feedback during the design phase (13.3%). The design phase contained (percentage-wise) the most negative comments (39%), while the construction phase included the smallest percentage of negative comments (12.1%). The highest percentage of neutral comments were posted during the design phase (11.4%), and the lowest percentage of neutral comments during the construction phase (5.9%). MDOT posted the plurality of their comments during the design phase (35.2%), and posted the smallest percentage of their comments during the late implementation phase (8.8%) (Figure 5-51).

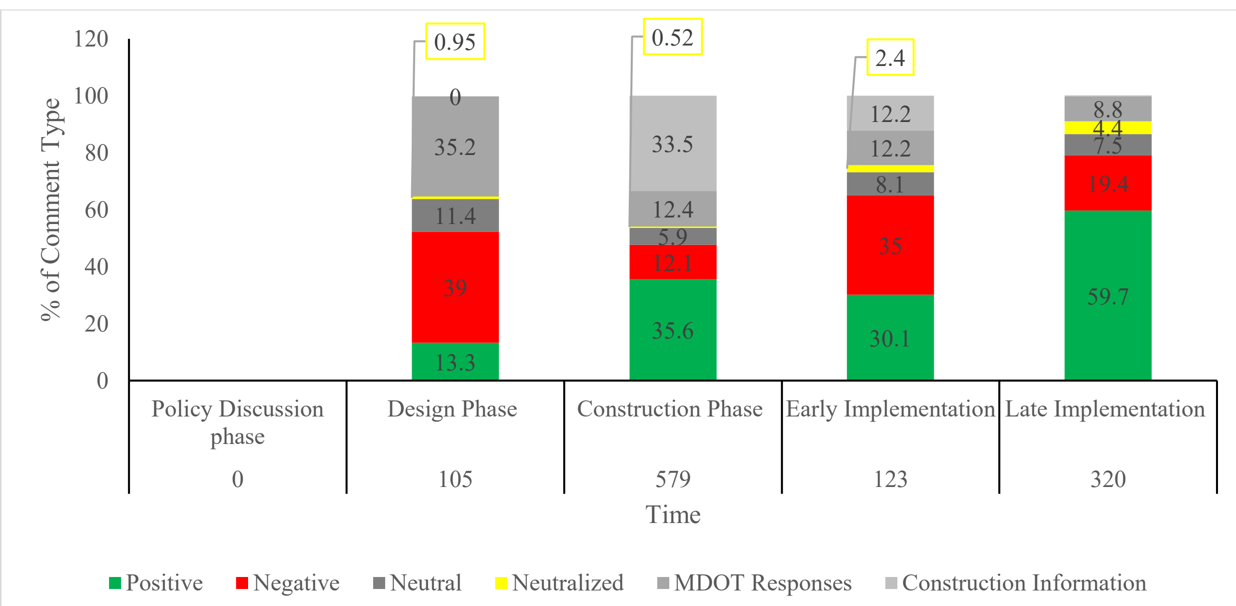


Figure 5-51 Commentary analysis throughout the Flex routes implementation timeline (n=1127)

Comments about the Flex route began to appear in phase two, the design phase, when news broke about the Flex routes implementation. During this phase (January 1, 2015-October 3, 2016), comments were posted almost entirely on social media. This phase also saw the highest percentage of negative comments (39%) compared to any other phase. Most of these commenters were concerned about drivers who would not comply with the rules of the Flex route and expected police to be absent. These commenters were skeptical as to whether or not commuters would actually understand how to use a modern transportation tool like the Flex route: "*I see all sorts of issues with people using those lanes when they shouldn't, causing additional traffic accidents!!*" Other commenters were concerned with efficacy: "*So there will be up to 3 lanes of traffic congestion instead of 2 now. You can add 10 lanes and people would still hog each lane. This doesn't solve anything. Driving used to be fun.*" However, positive comments argued against points made in negative comments. For example, one commenter provided a good explanation as to why the Flex route may work: "*Even though there is hate, I think the US-23 #FlexRoute was a pretty good idea. I may not be able to drive it yet (2 more years...), but it's very sensible to me. As stated, the route would be most effective during the AM/PM rush hours, which makes sense. Good idea.*"

Once construction commenced (phase three), positive comments became more common. During the construction phase (October 4, 2016-November 14, 2017), commenters often praised the Flex route, provided education about the Flex route, and talked about how congestion would decrease as a result of this new traffic management strategy. Most of these compliments expressed excitement regarding the construction progress. "*Here's the latest #FlexRoute 23 newsletter. Still on track to be fully operational by the end of the year.*" However, people also expressed some concerns about the Flex route, though the percentage of comments mentioning a concern was low compared to other phases. The few concerns mentioned in comments were primarily related to requests for a permanent, instead of a temporary, third lane, or the potential for increased congestion.

Phase four, the early implementation phase (November 15, 2017-March 15, 2018), started immediately after the Flex route was first opened to the public. During this phase, comments were split more evenly between concerns (35%) and perceived benefits (30%). Positive comments remained largely the same as they were during the construction phase: drivers complimented the Flex route, excitedly continued to reiterate information about its rules and regulations, and described observations of reduced congestion, and generally praised the Flex route for its effectiveness. In contrast, negative comments refuted the Flex route's effectiveness and these commenters expressed their concern in regard to its perceived inefficient design. One commenter complained: "*Are there plans to extend Flex Route to I-96? Currently, three lanes narrow to two lanes without any reduction in traffic volume.*"

Phase five, the late implementation phase (March 16, 2018-April 27, 2019), started after the Flex route had been open for longer than six months. This phase saw the highest percentage of positive commentary of all phases (60%). Comments during this phase typically expressed the same benefits and concerns noted during the construction and early implementation phases. Of the positive comments, most were praise/compliments, which were generally expressions of satisfaction with the Flex route's performance and increased safety, such as "*works great*." Reduced congestion was a common praise within comments during this phase. This phase also saw commenters increasingly urging the general public to vote for the Flex route to win "The People's Choice in America's Transportation Award," citing the Flex route's innovative design and benefits. "*Last chance to vote for the innovative and time-saving US-23 #FlexRoute project north of #AnnArbor #A2 as the People's Choice in America's Transportation Awards! Voting ends at 11:59 pm tomorrow.*" Of the relatively few comments during this phase, most complained about increased congestion at the end of the Flex route.

Interestingly and notably, the majority of comments suggesting that the US-23 NB Flex lane be extended were posted during the early and late implementation phases.

5.3.8 Comments by Location

The plurality of comments mentioning a specific location were in reference to the NB US-23 Flex lane (30.6%); the SB US-23 Flex lane was a secondary concern (22.4%). The only specific location mentioned multiple times was the merging point from three to two lanes at M-36/9 Mile. All other locations were only referenced by single comments. The primary concern for both locations were congestion and the limited hours of operation. While complaints about hours of operation were equally important for NB and SB travelers, congestion was more frequently mentioned by NB drivers.

5.3.8.1 Northbound

NB drivers sometimes complained about the Flex lanes closure during times of peak congestion, such as football games and when incidents occur. Further, some commenters asserted that congestion had not reduced or had even increased since the Flex routes implementation. Several individuals noted that the NB merging point of the Flex lane (M-36/9 Mile) was particularly troublesome because the reduction in lanes leads to sudden congestion. One commenter highlighted this issue: *"Can anyone tell me why they did not put the Flex lane all the way to Brighton? This was not good planning at all. Now there is a back-up every weeknight where we lose the third lane (M-36)!"* Every comment that mentioned M-36/9 Mile echoed the same concern, though some mentioned the potential for increased crashes (Figure 5-52).

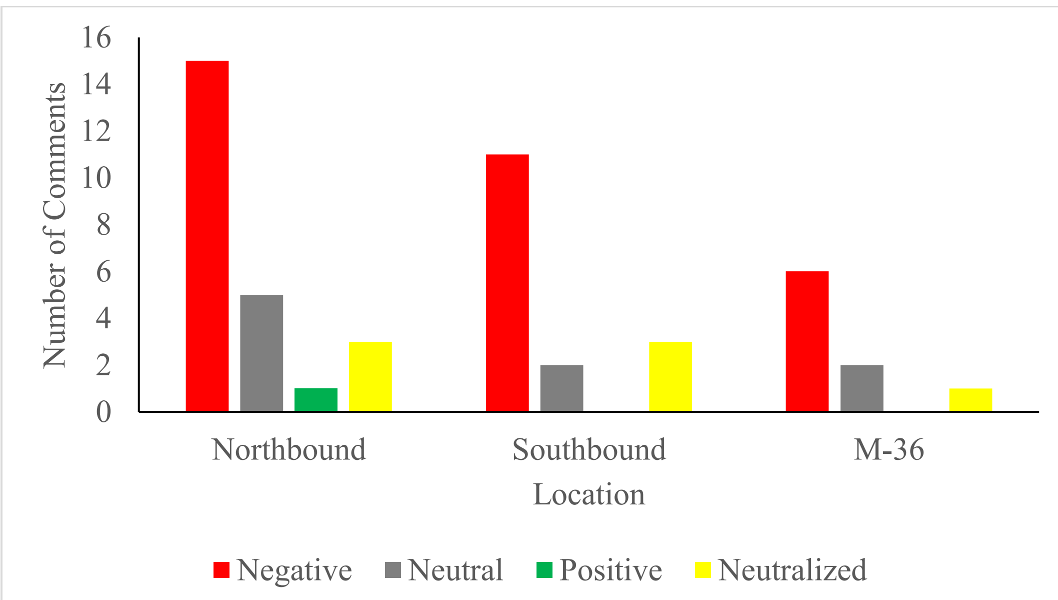


Figure 5-52 Public perception specifying a particular location. There were three primary locations: Northbound US-23, Southbound US-23, and M-36 (n=48)

Of neutral comments, most discussed the NB Flex lane. These comments noted that the NB gantries were not working, or that that the Flex lane was blocked by a vehicle. One person noted heavy traffic in both directions. Neutralized comments about US-23 NB praised the smooth drive up until the Flex lane's merging point but also noted that traffic started backing up before it.

5.3.8.2 Southbound

SB US-23 concerns, similar to NB concerns, were primarily about the Flex lane not being open when drivers wanted it to be. Individuals recalled instances when the Flex lane was not open during incidents, increased congestion, and on Thanksgiving Day.

5.4 Perceptions of Focus Groups

MSU Department of Urban and Regional Planning convened a focus group on behalf of MDOT to explore the performance and safety of the first Flex route in Michigan, located on US-23 from north of Ann Arbor to Whitmore Lake. MDOT's goal is to evaluate the challenges and successes of the Flex lane and identify solutions for challenges based on public input. These potential solutions will be considered for US-23 and in the design and operation of future Flex routes.

Dr. Kassens-Noor, the lead investigator on the project, sent an open invitation to attend focus groups via a flyer to everyone who had emailed MDOT with comments or complaints regarding the Flex route as well as additional contacts provided by MDOT and personal connections. As a condition of their acceptance, respondents were asked to describe their driving habits. Those who emailed back were given the location of the focus group. One person responded with several helpful comments but did not want to attend the meeting.

Each participants' driving habits and generalized age were recorded. The focus group lasted an hour and a half, and covered three main questions:

1. What does not work on US-23?
2. How can we fix it?
3. What works for you on US-23?

Methods for note-taking and data analysis were retrieved from Onwuegbuzie et al. (2009). It was recorded whether one, some, or most of the participants agreed with whomever was speaking at the time. The word "some" meant two-three participants agreed. The word "most" meant four to five participants agreed. An agreement was indicated by a nod of the head or a verbal "yes." Constant comparison analysis was used to group the data into eight categories of problems addressed with their potential solutions (Onwuegbuzie et al., 2009).

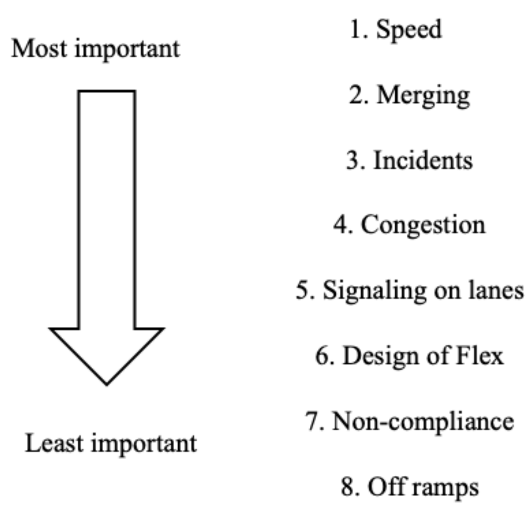
To determine the relative importance of each of the categories discussed, it was examined how long the participants spent on each topic and how many attendees were in agreement. Next, topics ordered by importance from most to least. The discussion was further analyzed to turn it into a structured narrative mixing concerns with potential solutions. The problems discussed and any solutions suggested were listed in order of importance.

5.4.1 Whitmore Lake Focus Group

Seven people attended the focus group. The attendees included: a senior man, a former commuter who still uses US-23 for trips up north and managing a rental property in Whitmore Lake. A senior woman who drives US-23 daily. A middle-aged man who drives US-23 from Brighton to his work every day in Ann Arbor. Another senior man who drives to and from work in Detroit every day, and on weekends. A second woman who uses it to drive from Ann Arbor to Flint; she also occasionally uses it to go to Lapeer and Mt. Morris to visit her family. Finally, another senior man and a middle-aged woman who also drive the Flex route. The meeting was at Captain Joe's Grill in Whitmore Lake. Two recording devices were used to collect audio from the focus group.

5.4.1.1 Concerns with US-23

Eight categories of problems and solutions were identified. Participants were asked what does not work about the Flex route first and then they gave solutions after each issue they discussed.



Speed

Most attendees agreed that drivers of the Flex route do not understand that the speeds listed on the gantries are advisory, and not the actual speed limit. However, they go as fast as they want, especially in the Flex lane, because the legal speed limit is not stated anywhere, and enforcement is almost impossible when the Flex lane is in use. Most of the participants agreed that the digital signs actually distract them more than they help them. One explained that "*drivers see it as an invitation to drive as fast as they like with one green arrow over the Flex and the other two having a 60 mile per hour speed limit*." Another person thought the gantries were a waste of money and that the recommended speed limit seemed very official.

As a solution to this problem, the participants mostly agreed that the gantry should be used for information only, such as when a crash occurs. For example, there could be an X in the left lane and a billboard indicating there is a crash ahead, which would push people to the right. Another participant asked for the gantry to be removed completely since they viewed it as just a distraction.

Participants also mostly agreed that people either go too fast or too slow on the Flex lane. Instead, it would be best if all were going at the same speed. They explained drivers get confused with the signs, which leads to crashes. One participant said that some drivers are worried about being stopped while others just do not care.

To resolve this issue, the participants suggested that the 60 miles per hour speed limit should be removed and replaced with green arrows and red X's or the gantries should be left blank. The suggested speed limit of 60 mph should be posted instead on yellow signs next to the Flex route. Some agreed that speeds should only be listed to slow traffic down. One attendee expressed concern that people do not look at the speed limits anyway, while another suggested that the advisory speed should be 70 mph.

Merging

Most of the participants agreed that people do not know when to merge because signs do not notify people early enough. They ask, "*is it the first time it shows up? Is it the second time? Is it at the end?"* One person explained that depending on the time of day, people are more willing to move over from the Flex lane earlier, while others try to go as far as they can in the Flex lane before merging back into regular lanes. People who speed in the Flex lane sometimes end up crashing into the barrier at the pinch point because there is no shoulder.

Four main solutions were formulated, of which most of the attendees agreed with. First, they suggested to start merge indicators a quarter of a mile earlier in order to make sure drivers finish the merge well before the concrete wall/pinch point at exit 52 and leave the shoulder open for emergencies. Second, some people suggested that installing rumble strips may encourage people to merge earlier. However, one attendee argued that putting down rumble strips may lead to a novice driver getting into a crash. The third solution was to create longer exits on southbound US-23; For example, one attendee explained "*it would be nice for the Barker entrance ramp to go all the way to the 6 mile entrance and then again to N. Territorial, just for those high traffic times to allow more time for people to merge on the highway or merge off.*" Fourth and last, some attendees agreed that arrows on the overhead signs should flash faster as people get closer and closer to the merge. These four solutions would allow people to merge while avoiding crashes and confusion.

Incidents

Most participants agreed that the Flex lane is not opened fast enough when a crash has occurred. They expressed their desire for it to be opened immediately, since "*all it is, is making a quick assessment with the cameras that are already functioning.*"

Participants perceived the Flex lane to be opened by a timer in the morning for southbound and in the evening for northbound. One attendee said that they plan their route when it is open to avoid congestion. To solve this problem, they mostly agreed there should be someone with experience, such as a police officer, to evaluate the situation and open the Flex lane. One person suggested that there should be a hotline for people to learn where incidents are located and then avoid them.

The participants mostly agreed law enforcement should have control of the lane since they monitor the area already. For example, "*law enforcement should say there is a crash on the right lane of US-23, turn the Flex lane on.*" However, some mentioned that the city, county, and state governments should have some input.

Throughout the conversation, the participants mentioned crashes that they had witnessed. One participant said that there was a crash where people slowed down and kept driving in lanes with red X's over them.

Others thought a possible solution would be to have the shoulder open 24/7, but one person argued that it needs to be clear for emergency vehicles and for when cars break down. Another participant noted that they would like it to open longer, but not 24/7. Some suggested that the Flex route needs to be open 24/7 during the Ann Arbor art fair and on game days.

Congestion

Most people agreed that there is still a problem with congestion despite the Flex lane. It seems to them that the northbound bottleneck just moved. They also said it is congested to the point that they "*can't use the highway.*" One attendee stated that they are often forced to get off US-23 and take back roads home.

Some attendees agreed that in order to solve the problem of congestion, the bottleneck should be moved further north. They explained the Flex route should have been extended all the way to I-96 when they built the bridge over the Huron River. They also mentioned that there should be longer exit lanes to encourage people to exit earlier.

Signaling on Lanes

Most attendees agreed that there should not be a solid yellow line between the main highway and the opened left shoulder or Flex lane. It leads to confusion when they need to switch lanes, especially because it is against the law to cross a solid yellow line elsewhere in the state.

The solution the participants mostly agreed on was to replace the solid yellow line with a dashed white or yellow line because it is the national norm.

Design of the Flex Route

Participants questioned whether the Flex route was durable enough to handle more traffic. They agreed that heavy vehicles like tractor-trailers should not use the Flex lane. One participant said that the merge point on the southbound side (past the rest stop going towards Ann Arbor) has a concrete barrier that coincides with the merge point. They explained this was not a good design because it could cause a crash. Another participant mentioned that when they merge on at Barker Road, the Flex route does not take them to N. Territorial. Finally, what worried another participant was that if MDOT fixes anything, there would be inconsistency in terms of their mix of concrete.

Participants agreed that there should be a concrete barrier throughout the Flex route between opposing lanes of traffic. One of the participants talked about when a semi-truck crossed over into oncoming traffic, because of the absence of a concrete barrier, which resulted in fatalities. Most agreed that the concrete barrier was not extended far enough. They believe it will continue to cause crashes.

But the final merge point should not end in a concrete barrier. Instead, there should be some space after the final merge point as a shoulder. Another attendee would like to see the concrete barrier extend as far north as possible. While another would like four lanes from US-23 to I-696, and yet another wanted the road widened and taken to Clyde Road.

Non-compliance

Most attendees agreed that people ignore speed limits when the Flex shoulder is open. A couple noted having seen trucks drive in the Flex lane, despite that being prohibited. Most participants, however, agreed that people usually do not drive on the Flex lane when a red "X" is displayed above the lane. As a solution, most participants agreed that people should get ticketed for improper lane usage.

Off-ramps

One person explained that the visibility on some of the off ramps is terrible. They believe it was the difference in elevation and the road design that caused this. As a solution to the visibility problem, an attendee mentioned the possibility of having a mile-long exit ramp so people getting off could do so earlier. The same person said it needs to be the same at North Territorial.

5.4.1.2 What Works on the Flex Route?

Most attendees agreed that the Flex lane is phenomenal during rush hour. One person explained that southbound works the best because the increased number of lanes has eliminated all bottlenecks. Another person explained there is less congestion near the airport in the evening. Another attendee said that traffic is now flowing to I-96, when in the past it had been slow-moving. Additionally, someone mentioned a sign northbound, near Whitmore Lake, that warns people ahead of possible crashes; the signs then display a slowly decreasing speed limit as drivers approach the crash site. Overall, the participants shared a similar view on what works on the US-23 Flex lane.

5.4.1.3 Recommendations from the focus group

The most important issues with the Flex lane are the uncertainty over advisory speeds on the gantries, how fast people drive the Flex lane, and the merging issues. Specifically, it is recommended:

1. Move the end of the Flex lane away from the concrete barrier ending the Flex lane: leave some room on the shoulder for late mergers and to encourage early merging through sinusoidal rumble strips (i.e., "mumble strips").
2. Remove the green arrow above the Flex lane: either post "60 mph" or keep gantries blank.
3. Enforce 70 mph speed limits, especially on the Flex lane.
4. Build concrete barriers along medians of the Flex route.
5. Change solid yellow lane marking to white dashes on stretches where switching lanes is allowed.
6. Post the 60 mph speed advisory as yellow permanent signs next to the Flex route instead of showing it on the overhead gantries.

If these suggestions are followed, the participants believe the safety and the performance of the US-23 Flex route can be improved.

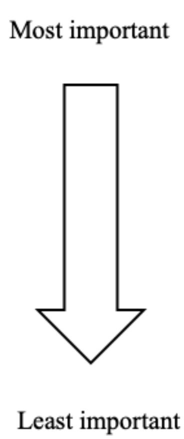
5.4.2 Brighton Focus Group

Thirteen people attended the Brighton focus group, their descriptions and driving habits are as follows. One was a senior man who is the supervisor of the Charter Township of Brighton. He drives US-23 SB from Brighton to Ann Arbor in the mornings and back home on NB three to five days per week. A middle-aged woman who did not give her affiliation, though she lives in Brighton and works in Ann Arbor, she drives US-23 every morning and evening, Monday through Friday. A middle-aged man who also did not give his affiliation, he lives in Hartland and works in Ann Arbor, driving US-23 from M-59 to M-14 five days per week. Another middle-aged man who did not give his affiliation, he drives US-23 daily from Brighton to Ann Arbor and back. A third middle-aged man, living in Brighton, who drives US-23 from the Lee Road entrance ramp to M-14 West in Ann Arbor on his commute to and from Brighton to Chelsea, on weekdays. Another middle-aged man who drives the route daily at 6 am and 3 pm and various other times throughout the week. A middle-aged woman who did not give her affiliation nor describe her driving habits. Another middle-aged woman, who is a Brighton City Council Member, drives the Flex route four or more times a week. A third middle-aged woman who drives the Flex route toward Ann Arbor twice a week. A middle-aged man associated with the MI-SBDC, who lives in Whitmore Lake and uses the route every morning headed towards Ann Arbor, and back in the evening. Another middle-aged woman drives the US-23 route from Brighton to Ann Arbor three days per week, during non-peak times. A middle-aged man who is associated with the University of Michigan, he drives from Brighton to Ann Arbor and back, every day, and has done so for over 6 years. Lastly, a middle-aged woman has been driving the Flex route forth and back to Ann Arbor for medical purposes.

The meeting took place at the Brighton Coffee House and Theater in Brighton. The focus group was audiotaped with two recording devices positioned at either end of the table.

5.4.2.1 Concerns with US-23

Eight categories of problems and solutions were found. They are ordered based on how long participants spent on each topic. Participants were asked what does not work about the Flex route first and then they offered solutions after each issue was discussed.



1. Southbound Bottleneck
2. Shopping Mall
3. Speeds
4. Open Lane Earlier after Crashes
5. Lane Discipline
6. Northbound Bottleneck
7. Winter Operations
8. Enforcement

Southbound Bottleneck

Regarding the merge from I-96 EB to US-23 SB, some attendees agreed that the collector lane on I-96 EB is a dangerous area. One person explained that when the Flex route first opened there were numerous crashes. However, another attendee argued that the area has actually become safer because people now drive at 5-10 mph instead of 60 mph (Figure 5-53). A couple of participants further noted that the backup extends to even Spencer Road. One person noted that another reason the area is dangerous is that the right lane of I-96 EB backs up as people wait to exit onto US-23 SB (Figure 5-54). A participant agreed saying "*I have seen vehicles* ***stop*** *in the middle lane of 96 trying to merge into the waiting lane and almost be rear-ended by drive-through traffic.*" One possible solution would be an extra "acceleration lane" plus an additional lane to give people a mile to accelerate off from I-96 EB to US-23 SB. Another person agreed saying there should be three lanes from EB-96 to US-23 SB.

Figure 5-53 The collector lane from I-96 EB to US-23 SB

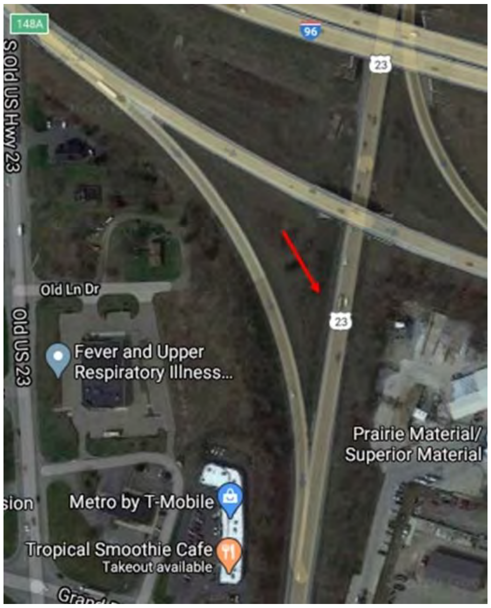


Figure 5-54 The location where the right lane of I-96 EB backs up to allow people to merge on to US-23 SB

There was some agreement about congestion at M-59 and I-96 near Howell. Participants also noted that traffic stops at the M-59 bridge (where M-59 WB turns into I-96 EB) on Fridays until 7 or 8 pm. The attendees agreed that traffic clears from M-59, as one approaches I-96. This may be because as drivers drive over the hill (M-59 Bridge) they can then see where people are merging in from I-96. Because of congestion, drivers must quickly accelerate from a dead stop within a quarter of a mile (Figure 5-55).

Figure 5-55 M-59 bridge over I-96 and the entrance ramp onto EB 96, where one goes from 0 to 70 mph

Some attendees agreed that the entrance onto Old US-23 from Spencer Road needs to be fixed. One person explained that Old US-23 needs to be wider at the merge (Figure 5-56). Some attendees agreed there is not a problem with the oncoming traffic from Spencer Road going east to I-96 EB. If people see the congestion, they will not merge onto US-23 (Figure 5-57). Another attendee noted that the area "*helps me decide which way to go to Detroit because that area is very dangerous*." Because of backups affecting I-96, drivers must reduce their speed from 70 mph to 0 mph, right before the entrance lane.

Figure 5-56 The entrance onto old US-23 south from Spencer Rd WB

Figure 5-57 The entrance onto I-96 EB from Spencer Rd, which continues east and is where Spencer comes to a dead stop from 70 down to 0

Attendees presented two solutions. One mentioned that there should only be one lane when merging onto US-23 NB from Spencer Rd; it should be the same lane as those going SB on US-23. Another participant suggested that there should be an extra acceleration lane and to widen the road.

A couple of participants agreed that the issue arises when one exits at Spencer Road. One participant explained that it was impossible to get on NB-23, then get on at I-96 WB, and finally exit at Spencer Road WB. The heavy traffic in the area where I-96 EB merges on to US-23 SB affects I-96 up until Spencer Road. The same attendee's solution was to exit earlier at Lee Road. A second person countered that the additional lane at the exit ramp allows the driver enough time before merging. It is located where US-23 NB turns into WB-96 and exits onto Spencer Road WB (Figure 5-58).

Figure 5-58 The merge onto Spencer Rd east off I-96 WB

Shopping Mall

Most attendees agreed that traffic is extremely heavy where Lee Road merges onto US-23 SB. "*There are people coming from the left and right, because of all the doubling to the left side and people merging in*" (Figure 5-59). One person noted that as the afternoon progresses, the traffic gets worse, especially because drivers cannot merge. Another person experienced this traffic until 9 Mile. A third attendee stated that the side streets, Fieldcrest and Whitmore Lake Road, are also affected.

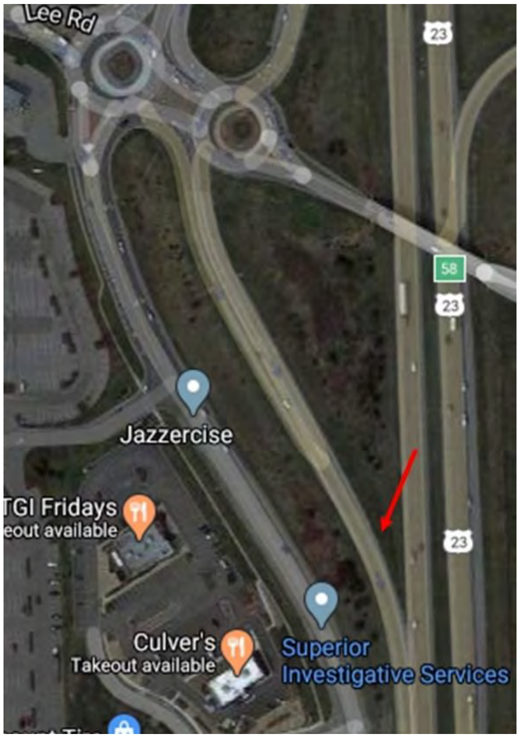


Figure 5-59 Entrance ramp onto US-23 SB from Lee Rd roundabouts

There was some consensus that instead of extending the Flex lane to I-96 past the M36 bridge there could be a left lane exit ramp, opening up into a third lane at Lee Road in order to give a person a mile to merge. Reconfigure the Lee Road exit ramp by building a northbound US-23 exit ramp south of the Lee Road and removing the spiral ramp. This would reduce conflicting US-23 lane changes from the far-left Flex lane to the exit ramp in the area where the Flex lane is dropped (Figure 5-60). One attendee was concerned that there would still be an issue because people would still only have a short distance to accelerate.

Figure 5-60 The Lee Rd Bridge and the merge onto Lee from US-23 NB

Another issue some participants agreed with was that people from out of town, or shoppers, are not used to dealing with the traffic and the three roundabouts at Lee Road across from the Green Oak Village Place. "*Shoppers go the wrong way, stop in the middle of traffic and go different speeds because they do not know how the Flex, and the roundabouts work.*" A proposed solution was to have signage explaining how to use the roundabouts and Flex lane.

Speeds

Most participants agreed that there is confusion about the advisory speed limit of 60 mph on the Flex route. They noted that the signage on the gantries is confusing. Specifically, most attendees agreed that people are confused about what the numbers represent. Dr. Kassens-Noor then asked all the participants directly what they thought the speed limit of 60 mph meant. Seven attendees thought it meant 60 mph and seven thought it meant 70 mph. She then asked what the speed limit was when a green arrow was above the lane. Three people said 60 mph and 10 people said 70 mph.

A suggested possible solution to this problem was to change the signage on the gantries to more clearly indicate the speed limit. A solution to the advisory speed problem that most people agreed on was to have a green arrow instead of the "60." They also mostly agreed that it would be good to have the signs read "slow down ahead**"** during a crash or if traffic ahead has stalled. Some attendees presented the idea that "advisory speed" be displayed on the gantries, which would help clear up any possible confusion. One participant suggested putting up a solid green arrow above lanes that had clear traffic. A different attendee would like to have green arrows when all three lanes are free of traffic. That same person suggested putting a yellow arrow over the blocked lane. Though, another attendee countered that by saying one should not do that unless all three are slowed down. The other lanes would just get backed up.

Most attendees also agreed that there is an increased speed differential which causes problems. One person explained a situation where "*there was no traffic, it was flowing nicely and the speed after the rest stop said 40 mph, and next it said 30 mph*," as seen in Figure 5-61. Some people agreed with him that that was a common occurrence, which caused traffic to slow. But frequently, drivers did not see a need to reduce their speed to what was displayed.

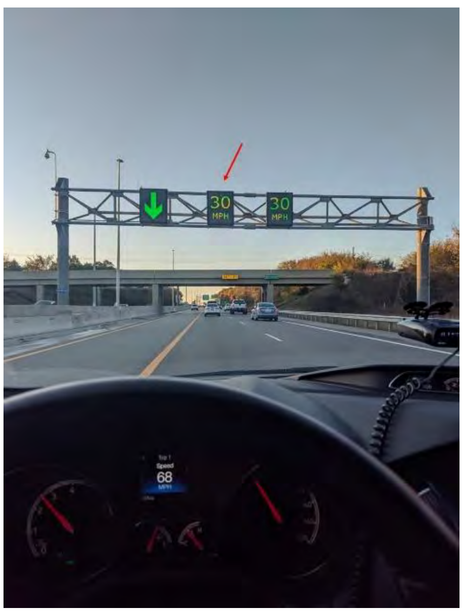


Figure 5-61 Gantries after the rest stop that changed to 30 from 40 mph

A suggested solution was to put up a message on the gantries and change the speed limit to 50 mph before decreasing the speed further so that the change is less sudden.

Another issue some attendees agreed upon was the merge on northbound. One participant explained that "*as one approaches the left lane, there will sometimes be a slow car in what is becoming the middle lane. This person gets over as soon as they can but prevents the people behind them from getting into the lane and passing, since the person is driving too slow*."

Open Flex Lane Earlier after Crashes

Some attendees agreed that it takes at least 40 minutes for the Flex lane to open when there is an incident. They also agreed there is a lag in the summer, implying that the lanes should be open sooner due to the increased traffic volume. Attendees also noted that the Flex lane does not always open when there is increased traffic congestion. A couple of participants explained that "*it's frustrating to see an open lane that you cannot use.*" Some people agree that this happens fairly often.

Some participants agreed that there should be design changes on US-23. A couple of participants asked for the Flex route to be extended further north, or to convert US-23 NB into a three-lane highway full time, so that they would not have to worry about whether or not the Flex lane is open. Another participant just wanted the Flex route to be open 24/7.

Some attendees noted that Fridays are often an issue when driving on US-23. Attendees noted that they were unsure when the Flex route opens on Fridays, and some avoided it altogether. Some attendees agreed that a possible solution would be to extend the hours of operation northbound, especially on Friday evenings.

It is problematic that the Flex lane does not open until after 9 Mile where M-36 ends.

Lane Discipline

Most attendees agreed that people were merging too early, resulting in unused parts of the highways. However, one attendee noted that merging earlier makes them less nervous. Going on M-36 southbound, a participant explained "*there is almost a mile for people to accelerate if they do not panic*." As a result of these behaviors, the same participant explained, with most attendees agreeing, they have their own "private lane" from M-36 to 8 Mile Road. Most participants also agreed that people move to the middle lane immediately even if they have a whole mile. This leads to the right lane being frequently vacant.

Some attendees agreed that exiting US-23 NB Flex lane is very dangerous at the merge point, frequently resulting in crashes. People often wait until the last minute, creating massive backups. Additionally, attendees noted that drivers would drive on the shoulder to the Silver Lake Road exit since they do not want to merge.

Another issue most people agreed on was that drivers do not understand the zipper method. One person noted that the zipper method has to be used by law in construction zones. Some agreed that for zipper merges to work, both lanes, the exit/entrance ramp, and the main lane have to be moving at the same speed. One mentioned that the method is not taught in driver's education classes. Some participants agreed that one solution would be to teach people more about the method, especially when and where it should be used. Another solution would be a sign on the gantries explaining the zipper method, and perhaps a web address to an informational page.

A third issue is non-compliance by trucks. Some participants agreed there needs to be clarification on the "no truck" rule. There have been semi-trucks, large motor homes, busses, and construction vehicles with trailers.

Northbound Bottleneck

Most attendees agreed that traffic is slower and there are more crashes as a result of increased traffic between I-96 EB and the M-59 exit. There are significantly more slow-downs and crashes because there is more traffic NB and it is narrowing to two lanes. There are no exits for six miles on this stretch of highway, making it impossible for drivers to exit.

Another issue that some attendees agreed on was the existence of a bottleneck on US-23 NB. An attendee explained that drivers are stopped after M-14 until North Territorial Road or 6 Mile Road as well as on US-23 SB from Lee Road. Another attendee noted that "*NB is a complete mess since traffic is a nightmare. For example, every day there is a crash between 8 and 9 mile and even to Silver Lake Road. The traffic congestion causes fender benders*." The attendee continued the discussion by explaining more about the area between Silver Lake Road and 9 Mile Road going south. On that section of road, the traffic will come to a complete stop at 9 Mile Road, even though it was flowing well before then despite the extra lane. Some attendees agreed that this was caused by the merge. One participant mentioned it was a result of drivers anticipating the start of the Flex lane.

Some attendees agreed that the Flex lane should continue up to I-96. Another attendee mentioned that there is now actually more traffic on northbound US-23 even though that area only has two lanes.

All suggested extending the Flex lane to I-96 if funding allows. Extending it may prevent crashes. The Flex lane would continue through the ramp once extended to I-96. Additionally, participants suggested adding another exit between M-14 and N. Territorial or 6 Mile to relieve congestion.

Winter Operations

Most attendees agreed that US-23 and the Flex route suffer from dangerous snow and ice conditions during the winter months. Attendees noted that the Flex lane is often not cleared of ice and snow on winter mornings. For example, most participants agreed that "*if there is a light snow overnight, then at 6 am, even at 8:30 am, it is treacherous to drive on.*" One person explained they had gotten onto the Flex lane, noticed how poor the road conditions were, and then immediately merged back into a regular lane. Another person mentioned that there needs to be better drainage during rainy or snowy conditions. A solution proposed was to have the Freeway Courtesy Patrol clear the Flex lane by driving on the shoulder first and activating the salt.

Enforcement

Some attendees agreed that there needs to be better enforcement of traffic laws in the Flex lane since "*80% of people travel in it*." One participant said it should be used only for passing. Instead, people often drive in it all the way to Ann Arbor. The lane also suffers from aggressive drivers. Another person explained that there is an ongoing campaign to create awareness for what the left lane is supposed to be used for. Some attendees mentioned that they heard about it on the news, that one should "*move over or get pulled over*." However, participants also agreed the Flex lane is really hard to enforce because it is difficult to know how long a person has been in the left lane. Additionally, it may be easier for police officers to focus on enforcing the speed limit. One attendee recalled a time when they saw a lone motorcycle hogging the left lane, backing up traffic, and causing other drivers to drive recklessly.

Another participant said that people slowing down in all three lanes to speeds of about 60 mph cause other drivers to gradually slow down behind them in a ripple effect. Thus, most agreed that having law enforcement present during peak congestion times is unproductive; it just causes people to drive even slower. A solution some agreed on was to have a police car pass through the area instead of stopping at one side or another.

5.4.2.2 What Works on the Flex Route?

Next, attendees explained what they think works about the Flex route. Most agreed that it is helpful since the congestion has been reduced significantly. Some agreed that US-23 SB had been greatly improved in the morning, including fewer crashes. A few attendees agreed that the "*emergency pull-outs are great*." Another said the merge from US-23 NB to I-96 WB to Spencer Road WB is a lot better. It offers more cruise time. One person mentioned after the introduction of the Flex route, their travel time had been cut in half where it took him 45 minutes to Ann Arbor. Another mentioned that the signs are useful, especially when they warn of road conditions ahead.

5.4.2.3 Recommendations from the focus group

It is concluded that the most important issues with the Flex lane are the southbound bottleneck congestion, traffic conditions around Lee Road and Green Oak Village Place, and recommended gantry speeds.

Specifically, participants recommended to:

1. Add an extra acceleration lane and widen the road: to accelerate onto US-23 NB from I-96 EB.

2. Reconfigure the Lee Road exit ramp: by building a northbound US-23 exit ramp south of the Lee Road and removing the spiral ramp.

3. Put a green arrow and "slow down ahead" on gantries: these indicators would replace the advisory speeds of 60 mph and the stacked 10 mph decreases when an incident happens on the Flex route.

4. Set up automatic lane opening thresholds: should be set to alleviate congestion before it forms.

5. Extend the Flex lane to I-96 if funding allows.

6. Install an informational sign on gantries explaining the zipper merge method: educating drivers would help them understand it better.

7. Have the Freeway Courtesy Patrol drive on the Flex lane after salt trucks in winter: by driving on the Flex lane first, the salt is activated and will create safer driving conditions.

Another important suggestion that most participants agreed on was to educate drivers through their township hall, newsletters, social media, printed literature, and signs on the road. Most participants also suggested there should be enforced in the left lane to control its use. For example, if a pace keeper was to travel in the Flex lane, traffic flow would be consistent across the three lanes.

If these suggestions are followed, the participants believe the safety and the performance of the Flex route can be improved.

CHAPTER 6 COST BENEFIT ANALYSIS OF FLEX ROUTE

This analysis quantified and monetized the costs and benefits of the US-23 Flex route using the FHWA's Tool for Operations Benefit/Cost Analysis (TOPS-BC) Version 4.0. Results show benefit-cot ratios ranging from 2.15 to 2.95 in the southbound direction, 2.25 to 3.09 in the northbound direction, and 2.20 to 3.01 in both directions.

6.1 Tool for Operations Benefit Cost Analysis

The FHWA's TOPS-BC Version 4.0 was used to determine the overall benefits, costs, benefit-cost ratio, and net benefit of the Flex route. TOPS-BC provides support to state transportation agencies in the application of benefit/cost analysis for a wide range of Transportation System Management and Operations (TSM&O) strategies, such as work zone management, traffic signal systems, and ramp metering. Transportation agencies adopt the tool to choose the most effective strategy given available resources (FHWA, 2016a) or analyze a transportation project already implemented (FHWA, 2012b).

The costs of each TSM&O strategy are broken down into capital costs, and operation and maintenance (O&M) costs in TOPS-BC Version 4.0. Capital costs are one-time, up-front expenditure on capital equipment and soft costs for design and equipment installation (FHWA, 2012b). O&M costs include costs for continuing operation and management of the deployed strategy and are presented as annual values (FHWA, 2012b). Annualized costs are calculated by the tool based on capital costs and O&M costs.

The benefits analyzed within the TOPS-BC represent the monetized values of the impacts that are directly caused by the deployed strategy. The benefits of each TSM&O strategy include travel time, travel time savings (non-recurring delay), energy, safety, and reliability (FHWA, 2012b). The annual benefits of each strategy are determined based on default data and user inputs. The values of default parameters come from national averages of observed effects and vetted parameters in other operations analysis tools (FHWA, 2012b).

A benefit-cost ratio and a net benefit are calculated in the "My Deployments" worksheet. The benefit-cost ratio equals annual benefits divided by annual costs. A higher ratio value indicates greater benefits relative to costs. The net benefit is the difference between the total benefits and the total costs, indicating the net societal benefit of this public investment.

TOPS-BC differentiates data types by color-coding individual cells within each worksheet: data maintained in the tool – yellow; data calculated within the tool – blue; required user-defined inputs – bright green; and optional user-defined inputs – light green or bright green. TOPS-BC allows users to input local values to override default data included in the tool.

6.2 TSM&O Strategy

In November 2017, MDOT opened the first Flex lane in Michigan on an 8.5-mile section of US-23 between M-14 and where M-36 meets 9 Mile Road in an attempt to clear congestion during peak commute times in the mornings and afternoon, as well as during crashes. Thus, the TSM&O strategy "part-time shoulder use" was evaluated in terms of its benefits and costs.

6.3 Data Sources

The capital costs of the US-23 Flex route were obtained from MDOT. Numbers were transferred from MDOT 2018 estimation when possible. In addition, updated cost data were collected through emails with MDOT in June 2021. Default values maintained by the TOPS-BC were used for calculating the O&M costs. The data for benefit estimates were mainly from the operational data provided by MDOT, MDOT open database such as TMDS and open GIS library, and crash data from Michigan Police Department. A summary of each database can be found in chapters 3 and 4.

6.4 Cost Calculations

The total capital costs of the US-23 Flex route include $3 million for software module, $40 million for shoulder construction, and $17 million for ITS construction according to MDOT 2021 correspondence. The quantities and unit costs of items listed in the TOPS-BC were modified to match these (Table 6-1). The annual O&M costs were estimated by the tool, which includes $0.35 million for software module, $0.35 million for ATM Traffic Operations Center (TOC) hardware, $1 million for harden shoulder (2.5% of the capital costs of shoulder construction), and $0.34 million for ITS (2% of the capital costs of ITS construction). Figure 6-1 is a screenshot of the TOPS-BC "part-time shoulder use" worksheet used to estimate the total costs of US-23 Flex route. Costs per direction were also calculated using TOPS-BC. Both the capital costs and O&M costs were split in half when calculating costs per direction (Figure 6-2).

Table 6-1 Capital costs of the US-23 Flex route

	Total	Useful Life	Quantity	Unit Costs	Source
Software Module	**$3,000,000**	15	1 (LS)	$3,000,000	MDOT 6/16/2021 correspondence "The ITS design and software development was an additional $3 million;" and MDOT 2018 "TMC Lane Control Software" (Useful Life).
Harden Shoulder	**$40,000,000**	Default (25)	18 (Lane-mile)	$2,222,222	MDOT 6/16/2021 correspondence "Construction cost for the shoulder widening and work associated with the widening was about $40 million. The total distance of the system was about 9 miles."
Telecommunication (modified to be ITS Construction)	**$17,000,000**	Default (25)	1	$17,000,000	MDOT 6/16/2021 correspondence "Construction cost for ITS was about $17 million."

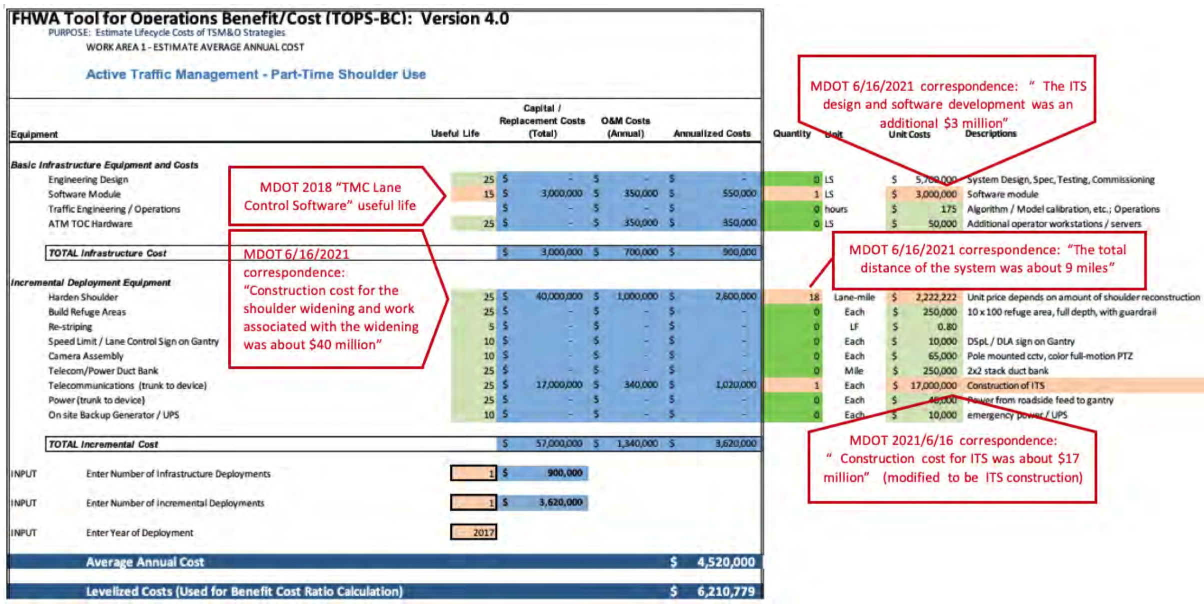


Figure 6-1 Screenshot of the estimation of the total costs of US-23 Flex route by the TOPS-BC "part-time shoulder use" worksheet

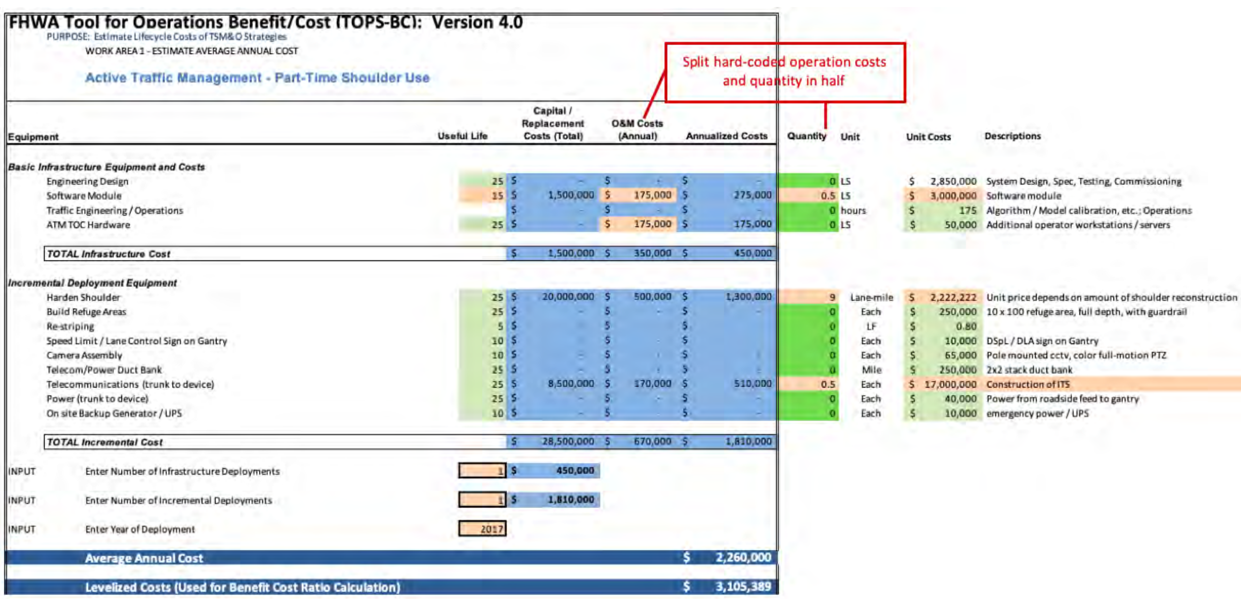


Figure 6-2 Screenshot of the estimation of the costs per direction of US-23 Flex route by the TOPS-BC "part-time shoulder use" worksheet

The total costs of the US-23 Flex route (both directions combined) are estimated to be $4.52 million annually. The costs per direction are estimated to be $2.26 million annually.

6.5 Benefit Calculations

Figure 6-3 illustrates the variables that are required for benefit estimation. A total of nine categories were included in the estimation tool. Because the Flex route generally operated during the peak hours on weekdays, the analysis focused primarily on operations during the peak traffic periods (i.e., southbound: 6:00-9:30 AM; northbound: 3:00 PM – 7:00 PM). The benefit parameters were estimated separately for southbound, northbound, and both directions during the peak hours.

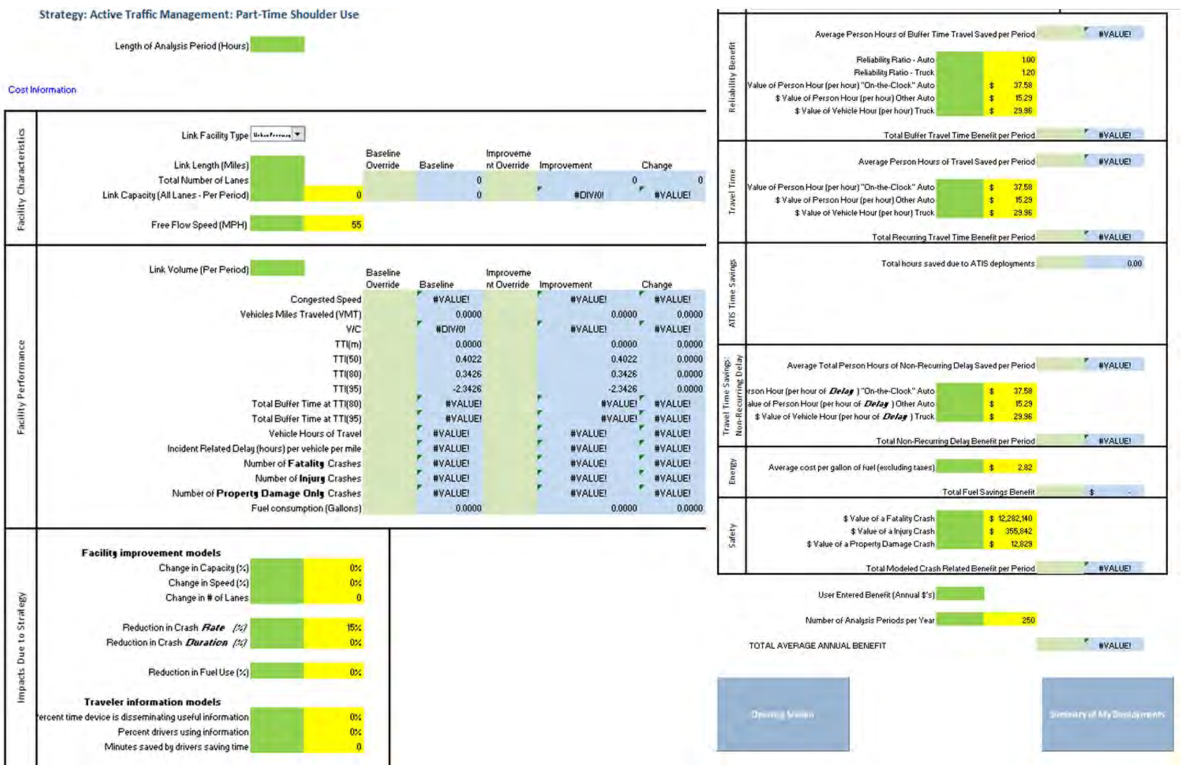


Figure 6-3 Benefit estimation tool under TOPS-BC tool from FHWA

6.5.1 Facility Characteristics

The facility characteristics included four variables:

- **Link length (miles):** the total length of the US-23 Flex route is 9 miles.
- **Total number of lanes:** two travel lanes on north and southbound. A total of four lanes if considering both directions.
- **Link capacity (all lanes per period)**: the capacity of the US-23 Flex route was approximately 2400 passenger cars per hour per lane, which followed the Highway Capacity Manual 2010 Exhibit 10-5 due to the lack of actual data (Transportation Research Board, 2010).

- **Free flow speed (mph)**: the free flow speed was calculated as 85th percentile travel speed for Monday through Friday, between 9:30 am to 3:00 pm and 7:00 pm to 10:00 pm, as well as Saturday and Sunday 6:00 am to 10:00 pm by using 2016 probe vehicle data (Office of Operations, 2015). The specific introduction of probe vehicle data is included in section 3.1.1.

6.5.2 Facility Performance

Two variables were estimated under facility performance:

- **Link volume (per period):** as introduced in Chapter 3, the data from MVDS reports and traffic count data from TMDS were used to determine the volume. First of all, the Flex route volumes were calculated from MVDS data for 2018 and 2019. The pre-Flex route (2012 – 2016) volumes were estimated by multiplying MVDS data by the ratio of VMT between before and after periods.
- **Total number of crashes by severity level:** Michigan Police crash database, MDOT sufficiency file, MVDS data, and traffic count data from TMDS were utilized to obtain the total number of crashes by severity level. The specific procedures were mentioned in Chapter 4.

6.5.3 Impacts Due to Strategy

Most variables in this section were already introduced and determined from previous chapters. The database and methodologies used to calculate the variables are listed below:

- **Change in capacity (%)**: based on 2016 FHWA report, "for system analysis purposes, the capacity of a part-time shoulder should be considered to be half to three-quarters of the general purpose lane" (Jenior et al., 2016). In this case, the capacity of the Flex lane was considered to be 1200 pc/h/ln to 1800 pc/h/ln. In section 6.2.1. The capacity of normal travel lane on US-23 Flex route was assumed to be 2400 pc/h/ln following HCM 2010 Exhibit 10-5. Thus, the change of capacity can be calculated as the percentage of shoulder use.
- **Change in speed (%):** change in speed was calculated by using 2016 and 2019 INRIX probe vehicle data.

- **Reduction in crash rate (%):** Similar to the number of crashes by severity level, Michigan Police crash database, MDOT sufficiency file, MVDS data, and traffic count data from TMDS were utilized to calculate crash rate. Five years of before data (2012-2016) and two years of after data (2018-2019) were considered in the analysis. The calculations are described in Chapter 4.
- **Reducation in crash duration (%):** the crash duration time before and after the operation of Flex route was estimated from MDOT FCP data and ICD data, which were demonstrated in Chapter 3. The crash duration is defined as the difference between crash cleared time and FCP or emergency response arrived time.
- **Reduction in fuel use (%):** The reduction in fuel use was estimated based upon a methodology from the Environmental Protection Agency, which involves calculation of the decrease in idling fuel use based upon the reductions in travel times and resultant emissions. Equation 5 shows how this quantity was calculated using 2016 and 2018 INRIX probe vehicle data.

$$\textbf{Reduction in Fuel Use } (\%) = \textbf{Change in Travel Time} = \frac{\left((\textit{Idling Fuel Use} * \textit{Total Volume}_{before}) * (\textit{Average Travel Time }(before) - \textit{Average Travel Time }(after)\right)}{\textit{Idling Fuel Use} * \textit{Total Volume}_{before} * \textit{Average Travel Time}_{before}} * \mathbf{100} \qquad \textbf{Equation 9}$$

- **Percent time device is disseminating useful information:** 100 percent was assumed considering the peak hour periods were the analyzed time periods.
- **Percent drivers using information:** 100 percent was assumed.
- **Minutes saved by drivers saving time:** Similar to reduction in fuel use. The minutes saved are calculated by change in travel time. 2016 and 2018 probe vehicle data was used.

6.5.4 Other Parameters

Except for the average cost per gallon of fuel, the default values were used for other parameters in the estimation tool. The gas price was estimated based on the gas price in 2019 (AAA, 2019). The final estimations of each variable mentioned earlier are displayed in Table 6-2.

Table 6-2 Summary of input parameters for benefit estimation

	NB	SB	Both Directions

Variables	Peak Hours (3:00 PM - 7:00 PM)	Peak hour (6:00 AM - 9:30 AM)	Peak Hour
Length of Analysis Period (Hours)	4	3.5	3.75
Link Length (Miles)	9	9	9
Total Number of Lanes	2	2	4
Link Capacity (All Lanes – Per Period)	19,200	16,800	36,000
Free Flow Speed (mph) (2016)	71.06	70.22	70.64
Link Volume (Per Period)	10,628	12,218	20,334
Number of Fatality Crashes Baseline(Improvement)	0.002 (0.000)	0.000 (0.002)	0.002 (0.002)
Number of Injury Crashes Baseline(Improvement)	0.117 (0.094)	0.115 (0.068)	0.232 (0.162)
Number of Property Damage Only Crashes Baseline(Improvement)	0.479 (0.452)	0.492 (0.290)	0.971 (0.742)
Change in Capacity (%) shoulder capacity 1200 pc/h/ln (shoulder capacity 1800 pc/h/ln)	25.00 (37.50)	25.00 (37.50)	25.00 (37.50)
Change in Speed (%)	0.85	9.43	4.75
Change in # of Lanes	1	1	1
Reduction in Crash Rate (%)	-18.77	52.31	17.74
Reduction in Crash Duration (%)	28.01	9.3	14.35
Reduction in Fuel Use (%)	-0.56	15.18	7.28
Percent time device is disseminating useful information	100	100	100
Percent drivers using information	100	100	100
Minutes saved by drivers saving time	-0.05	1.43	0.65
Reliability Ratio - Auto	Default (1.00)		
Reliability Ratio - Truck	Default (1.20)		
$ Value of Person Hour (per hour of Delay) "On-the-Clock" Auto	Default ($37.58)		
$ Value of Person Hour (per hour of Delay) Other Auto	Default ($15.29)		
$ Value of Vehicle Hour (per hour of Delay) Truck	Default ($29.96)		
Average cost per gallon of fuel (excluding taxes)	$2.31		
$ Value of a Fatality Crash	Default ($12,282,140)		
$ Value of an Injury Crash	Default ($355,842)		
$ Value of a Property Damage Crash	Default ($12,829)		

Number of Analysis Periods per Year	Default (250)

6.6 Benefit/Cost Comparison

The FHWA suggests that economic analyses for part-time shoulder use evaluate the sensitivity with respect to service life values of 10, 15, and 20 years (Jenior et al., 2016). The B/C analyses also considered shoulder (Flex) lane capacities of 1200 pc/h/ln and 1800pc/h/ln. However, as the results were generally similar and, as such, the 1800 pc/h/ln was assumed for analysis purposes.

The results of these analyses are presented in Table 6-3, Table 6-4, and Table 6-5 for the southbound direction, northbound direction, and both directions, respectively. Collectively, these results show benefit-cost ratios ranging from 2.15 to 2.95 in the southbound direction, 2.25 to 3.09 in the northbound direction, and 2.20 to 3.01 in both directions. In general, the operational benefits were significantly greater in the southbound direction. This is due to the congestion that remains at the northern limits in the northbound direction. In contrast, the safety benefit is more pronounced in the northbound direction, largely due to a decrease in fatalities that occurred between the before and after periods.

Table 6-3 Results of benefit/cost analysis for southbound direction

	Peak Period (3:00-7:00 PM)		
Service Life	**10 Years**	**15 Years**	**20 Years**
Annual Benefits			
Travel Time	$ 1,812,274	$ 1,812,274	$ 1,812,274
Travel Time Savings: Non-Recurring Delay	$ 1,550,275	$ 1,550,275	$ 1,550,275
Energy	$ 382,412	$ 382,412	$ 382,412
Safety	$ 4,820,488	$ 4,820,488	$ 4,820,488
Reliability	$ 431,320	$ 431,320	$ 431,320
Other	$ -	$ -	$ -
User Entered	$ -	$ -	$ -
Total Annual Benefits	$ 8,996,770	$ 8,996,770	$ 8,996,770
Net Present Value of Costs	$ 7,648,647	$ 10,217,307	$ 11,633,963
Leveled Annual Costs	$ 4,190,468	$ 3,441,031	$ 3,059,647
Benefit/Cost Comparison			
Net Benefit	$ 4,806,302	$ 5,555,739	$ 5,937,123
Benefit Cost Ratio	2.15	2.61	2.94

Table 6-4 Results of benefit/cost analysis for northbound direction

	Peak Period (3:00-7:00 PM)		
Service Life	**10 Years**	**15 Years**	**20 Years**
Annual Benefits			

Travel Time	$ 262,045	$ 262,045	$ 262,045
Travel Time Savings: Non-Recurring Delay	$ (47,012)	$ (47,012)	$ (47,012)
Energy	$ (12,272)	$ (12,272)	$ (12,272)
Safety	$ 9,175,935	$ 9,175,935	$ 9,175,935
Reliability	$ 67,544	$ 67,544	$ 67,544
Other	$ -	$ -	$ -
User Entered	$ -	$ -	$ -
Total Annual Benefits	$ 9,446,240	$ 9,446,240	$ 9,446,240
Net Present Value of Costs	$ 7,648,647	$ 10,217,307	$ 11,633,963
Levelized Annual Costs	$ 4,190,468	$ 3,441,031	$ 3,059,647
Benefit/Cost Comparison			
Net Benefit	$ 5,255,773	$ 6,005,209	$ 6,386,593
Benefit Cost Ratio	2.25	2.75	3.09

Table 6-5 Results of benefit/cost analysis for both directions

	Peak Period		
Service Life	**10 Years**	**15 Years**	**20 Years**
Annual Benefits			
Travel Time	$ 2,074,319	$ 2,074,319	$ 2,074,319
Travel Time Savings: Non-Recurring Delay	$ 1,503,264	$ 1,503,264	$ 1,503,264
Energy	$ 370,141	$ 370,141	$ 370,141
Safety	$ 13,996,422	$ 13,996,422	$ 13,996,422
Reliability	$ 498,864	$ 498,864	$ 498,864
Other	$ -	$ -	$ -
User Entered	$ -	$ -	$ -
Total Annual Benefits	$ 18,443,010	$ 18,443,010	$ 18,443,010
Net Present Value of Costs	$ 15,297,295	$ 20,434,614	$ 23,267,926
Levelized Annual Costs	$ 8,380,935	$ 6,882,062	$ 6,119,294
Benefit/Cost Comparison			
Net Benefit	$ 10,062,075	$ 11,560,948	$ 12,323,716
Benefit Cost Ratio	2.20	2.68	3.01

CHAPTER 7 CHALLENGES AND SUCCESSES OF ENFORCEMENT AGENCIES

MSU Department of Urban and Regional Planning convened a focus group comprised of first responders on behalf of MDOT to explore the performance and safety of the Flex route. The goal is to evaluate the challenges and successes of the Flex route and identify solutions for challenges. First responders identified the most important issues with the Flex lane are the pinch point at Whitmore Lake, the number of incidents, and the absence of emergency median crossings.

7.1 Methods

Dr. Kassens-Noor, the principal investigator for the project, sent out invitations twice to all first responders in areas surrounding the Flex route; these invitations included options to choose a date and time for the proposed meetings. One meeting was specifically dedicated to first responders, while other meetings included the general public; some demographics and driving habits were recorded. Five participants attended the first responders focus group and one chose to participate in the focus group for the general public. One attendee was the Chief of Police for Green Oak Township. He drives the Flex route daily for his job and as a commuter. The second attendee was a sergeant with the Brighton Police Department, who also drives the Flex route as a commuter and for his position. The third, a dispatcher for local emergency medical services EMS, drives the Flex route daily. The fourth attendee was a member of Freeway Courtesy Patrol (FCP). He works primarily in Ann Arbor and Ypsilanti but occasionally works the Flex route. The fifth attendee was also a member of the FCP, who works the Flex route daily; as a part of his job he opens the Flex lane, clears it, and helps prepare the lane for incoming police officers. The last participant was a first responder, but he preferred to attend the focus group with Brighton community members on October 23.

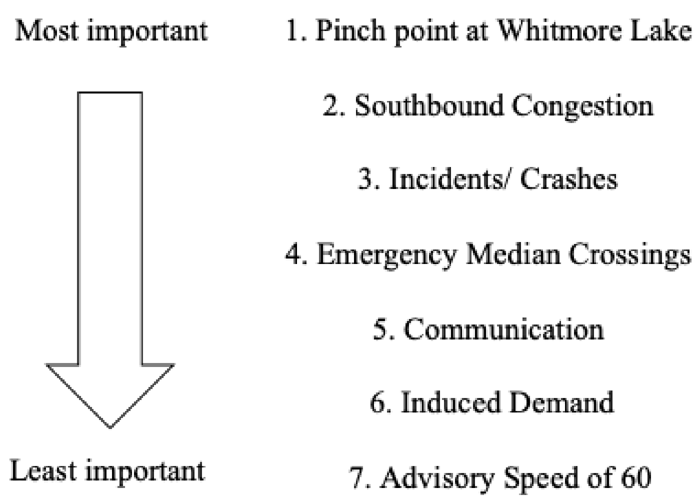
The meeting was held at the Brighton Coffee House and Theater located in Brighton. Two recording devices were placed in the middle of the room to record the ensuing conversation. The focus group lasted for an hour and a half, and five core questions were asked, specifically:

1. What does not work on US-23?
2. How can we fix it?

3. Please give us your thoughts on the concerns from the Whitmore Lake and Brighton focus groups.
4. Are there more or fewer crashes on US-23 since the Flex route was implemented?
5. What works for you on US-23?

7.2 Concerns with US-23

First responders were asked what does not work about the Flex route. Each explained their view of the Flex route in turn and then the topics were discussed individually.



7.2.1 Pinch Point at Whitmore Lake

Most agreed the solution was to extend the Flex route north to I-96.

A police officer noted that the NB Flex lane ends where there is no exit, thus taking away the options to merge off in any direction or disperse the traffic; most other attendees agreed. The participants understood that the Flex route could not be extended due to a lack of funds; though they remained concerned regardless, advocating for an extension to I-96. An FCP member illustrated to the group that the NB Flex lane ends in a curve, changing from three to two lanes. All participants agreed. One FCP member was adamant that the reduction in lanes caused many problems. One of the police officers proposed extending the Flex lane at least a ½ mile to the next exit (54B). This proposed half-mile extension would cause traffic to back up before that exit and allow people a chance to merge. The same first responder added that if the Flex lane ended on a straight section of the road, people would be able to notice any back-ups sooner.

One of the FCP members said after he clears the Flex lane in the mornings a bottleneck in traffic forms, which makes it difficult to merge into the primary lanes of US-23. This bottleneck also makes it difficult for the FCP to reenter the lane. He generalized the issue by saying the bottleneck is worse where the Flex lane ends on US-23 NB.

There was laughter when an FCP member mentioned that they see a lot of people using the Flex lane when there are red X's on the gantries (because it was such a common occurrence). They knew that a red "X" appears on gantries above a lane indicates that it is closed to traffic. The same FCP member said the meaning of the red X's should be self-explanatory to drivers as well, but apparently it is not.

One FCP member explained that traffic gets backed up on evenings and especially Friday nights going northbound. People try to avoid congestion by driving on secondary roads. This behavior ultimately clogs up exits, creates congestion on secondary roads, and causes more frequent crashes on these roads.

Some attendees agreed with a police officer who noted most crashes occur on secondary roads when drivers are in unfamiliar territory. Some of these crashes occur when people try to avoid roundabouts on Lee Road. Drivers also get lost and realize there is nowhere to go during a backup. The dispatcher for EMS explained two miles are lost in the northbound direction of US-23 because there is traffic to 6 Mile Road for people who want to merge back to two lanes. One FCP member agreed.

Additionally, most attendees agreed that people are usually just passing through or are going to the Fenton area. One first responder mentioned that the SB bottleneck was just moved north from M-14 and US-23 to 8 Mile and US-23. Another explained that the Flex lane is opened at various times depending on traffic. They will open the Flex lane up sometimes at 2:40 pm or even 1:40 pm. The dispatcher for EMS agreed that the Flex lane works well for football games.

Most attendees agreed that education was the best solution in order to fix issues regarding the bottleneck. A first responder asked if there was something available to help people understand how the Flex route works; he justified the need for education for several reasons. An FCP member commented that the Flex lane should be on the right shoulder, and two other first responders agreed with him. Another solution was to have a training program for, or better communication with, drivers to explain that the Flex lane should only be used as a shoulder when it is closed; the other FCP members agreed. A third solution, presented by the tow truck driver, was to have the Secretary of State provide training while people are sitting and waiting (on the SoS monitors). A fourth solution that some attendees agreed on was to not use the Flex lane as a shoulder at all, even when the Flex lane was closed, which would theoretically reduce the chances of a driver crashing into a stopped vehicle. One attendee described that his son is learning to drive now and he is instructing him to never use the shoulder of the Flex route, even if the Flex route is not in operation.

7.2.2 Southbound Congestion

Two participants noted that the Flex route takes drivers, going southbound, onto two different freeways when it ends. In the mornings, cars and trucks use the center lane on I-96 WB to US-23 SB, and merge over at the last minute to avoid waiting for Exit 148; or are avoiding the bumpy roads on I-96 WB. A police officer agreed that I-96 WB is in bad shape. Bottlenecks are an issue on US-23 SB, especially on Mondays. An FCP member said, **"***Traffic will backup for three miles from Exit 145, 147 or 148 to go south on US-23 from I-96 WB. This is mainly due to the semis, people not choosing the right lane, and others merging from Grand River*.**"** Some impatient drivers often merge into an exit lane well in front of drivers who had been waiting in traffic. The other FCP member said the backup is because of the merge. A backup occurs north of I-96 on US-23 and continues until south of I-96; this backup can sometimes be as long as five miles. Some attendees agreed with one of the police officers that once drivers pass M-36 going south on US-23, driving the Flex route is easy.

7.2.3 Incidents/ Crashes

An FCP member explained that the Flex lane eliminates the shoulder first responders need to use in order to effectively reach crash sites. The available shoulder is often not open long enough, nor clear enough to quickly traverse. Some agreed there is no place for the first responders to go when there is a crash, meaning that the Flex lane must be shut down. This caused some laughter among attendees. Everyone in attendance agreed and laughed when a first responder noted that everyone should be taught a technique called the "*plus one*," which means they would learn to expect drivers to give them an open lane to respond to a crash. The FCP member explained that his team is taught the plus one, but that emergency medical technicians also need to be taught it. One attendee commented, "*absolutely*." Most attendees agreed that using the Flex lane as a shoulder is dangerous when it is open to traffic. One attendee remembered observing a lady who had stopped her vehicle on a curve in the Flex lane while it was open, right in the path of traffic.

Some agreed that the Flex lane should be cleared for first responders after a crash. An FCP member stated that the lane only clears when an observer (watching traffic cameras) sees the crash and changes the electronic signs. For example, when a truck crossed over the median into the lanes going in the opposite direction, the right lane was shut down and the Flex lane opened in that area just so traffic could be diverted, and the first responders could get to the crash. People followed the directive, so the above plan worked. The EMS dispatcher agreed. However, all attendees agreed that crashes within the Flex lane itself result in chaos. Both drivers and first responders are forced into the right lane after a crash in the Flex lane, which is backed up by traffic.

An FCP member noted that after crashes are resolved and the Flex lane is reopened, it takes longer for people to get past the area affected by the crash. One suggested that if the Flex lane was extended to I-96, people would stay on the highway instead of moving onto secondary roads. One exit, in particular, Lee Road, is a problem for some drivers, especially those unfamiliar with roundabouts. The attendee reiterated the fact that a lot of crashes happen because people are unfamiliar with secondary roads and just want to avoid a backup.

An FCP member noted that one of the best aspects of the Flex route is the crash investigation sites. Some agreed that having them on the right shoulder aids in mobility and allows a safe place for drivers to pull over. These sites also allow first responders to more easily clear crashes. However, people generally do not understand how to use the crash investigation sites effectively. For example, an FCP member expounded that "*people with flat tires pull out of the site because they think they are only useful for crashes. They drive to the right shoulder, which gives little room for the first responders.*" The other FCP member agreed and three people laughed. Additionally, some drivers do not want to move from the site of the crash because they are worried about insurance problems. A police officer agreed. A solution some attendees agreed with was to give an explanation on "*TV bulletins*" (municipal television channels). A police officer suggested, with some laughter, to put it in a manual that every driver should read. Another issue is that some emergency dispatchers do not know the crash investigation sites exist or were never taught about them.

7.2.4 Emergency Median Crossings

Most agreed that emergency median crossings are necessary for first responders and the reduction in turnarounds included in the design of the Flex route is not adequate for first responders, especially fire trucks. The first responders noted that because there are fewer emergency median crossings than before the Flex route, it results in them driving further to reach one. Some agreed the elimination of emergency median crossings is a big problem regarding the Flex route. The dispatcher for EMS and an FCP member agreed that having to use the turnaround four miles away from where they need it to be is difficult and slows their response time. An example the same two first responders agreed on, was the area between North Territorial and the M-14 triple ramp. This problem also occurs at the M-14 WB and US-23 NB ramp. At that location, first responders have to drive to North Territorial, exit the highway, and then reenter in order to reach the crash site. To clarify this situation, the other FCP member stated, "*coming from Nixon to US-23, where the two roads overlap far from the Flex, makes it hard to turnaround from west to north*." Additionally, if first responders are coming from a Plymouth crash and switch from traveling on the north to southbound US-23, their response time is longer due to the lack of emergency median crossings. The EMS dispatcher and the other FCP member agreed. A police officer explained, with two others agreed, that the emergency median crossings were removed because the salt trucks could not use them. The same officer said that a different result of not being able to turn around is that, in order to reach a crash site, police officers are forced to jump over the walls separating the two directions of traffic. Though this action is clearly dangerous, there is no other option that allows officers to quickly reach the crash site. All agreed that first responders such as police officers need emergency median crossings. At the end of the discussion, some agreed with a police officer that "*things such as the 60 mph speed limit and the no turnarounds prevent the Flex from doing what it is supposed to do*."

7.2.5 Communication

An FCP member, with some agreement, noted that the top priority for dispatchers is to clear the Flex lane. Watching the video feed of the Flex lane via cameras, a dispatcher determines when it is safe for people to drive it. Next, an FCP member must physically drive the Flex lane and "clear" it. However, there is a significant lag time between when the FCP member informs dispatch that the Flex lane is clear and when dispatch actually opens the Flex lane. Additionally, FCP drivers must focus on opening the Flex lane; even if there were a crash, they would be unable to stop and determine if people were okay. Opening the Flex lane – they were told - is their top priority.

The discussion further highlighted communication issues among agencies. Some attendees agreed that at the WB I-96 and US-23 NB triple ramp there is always traffic that makes access difficult for first responders. If a crash is on the border of their zone, they will not respond, thinking someone else will.

7.2.6 Induced Demand

Though not much was said about induced demand by the attendees, some agreed that once people get onto the Flex route, and traffic begins to flow well, it has led over time to more and more people driving on it.

7.2.7 Advisory Speed

There was agreement among attendees that drivers do not understand that the advisory speed is only a recommendation. The actual speed limit on the Flex route is 70 mph, though due to recommendations from the Federal Highway Association, the "recommended" speed is 60 mph. "*The Flex brings together people not familiar who go 60 with those who are educated and think it is not enforceable and drive fast. These behaviors create congestion.*" Most first responders then agreed with an FCP member that the speed limit is hard to enforce during high traffic times because it is more imperative for them to respond to crashes and the Flex route is very dangerous without a shoulder. First responders do not want to be on the Flex route during those times**.** Some further agreed that if making the advisory speeds enforceable, traffic would flow better. A police officer revealed that he receives calls from people asking if they will get a ticket for traveling over 60 mph. The same police officer believed that if everyone went that speed, the Flex route would work and there would not be a bottleneck.

Most agreed that the speed does not help anyone, and it negates the purpose of the Flex route. An FCP member explained that the people opening the Flex lane are too far away to see how the Flex lane actually works. A police officer agreed.

There was some agreement on several solutions. One attendee suggested educating people about the advisory speed. Another attendee recommended that if the speed is not enforceable, then do not post it. A police officer said that people should travel at 60 mph because then there would not be any backups. The dispatcher for EMS said 60 mph should be the speed limit to slow traffic down.

7.3 First Responders Reaction to Other Focus Group Concerns

Next, the first responders were prompted to comment on the themes developed during the two non-first responders focus groups in Whitmore Lake and Brighton. They were asked about the following Whitmore Lake Concerns: pinch points, presence of a police car at the end of the Flex route, confusion on the advisory speed of 60 mph, and the presence of "X" on the Flex route gantries. First responders were also asked about the following Brighton concerns: the bottleneck at the US-23 and I-96 intersection, the Oak Village Place and Lee Road backup, Freeway Courtesy Patrol activating the salt used in the winter, and lane discipline on the Flex route. In general, there was at least some agreement from the first responders on each issue.

7.3.1 Responses to Whitmore Lake Concerns

One main issue brought up at the previous two focus groups was specific locations of congestion. First responders all agreed that pinch points cause significant congestion. One suggestion from the Whitmore Lake focus group was to place a police car at the end of the Flex route. Two first responders agreed, though they found the suggestion amusing, noting that the presence of a police officer may make the area even more complicated. One police officer also mentioned people would slow down and not pass a police car going 60 mph in the Flex lane. Another concern was that there is no crash investigation site at the end of the Flex route. Thus enforcement is difficult and dangerous at the Whitmore Lake pinch point.

An FCP member said they see people driving as fast as they want on the Flex route. Most agreed that drivers are confused about the advisory speed of 60 mph. The first responders suggested removing the 60 mph signage and putting up nothing or displaying a green arrow. They said these actions would clarify that the speed is only advisory.

An FCP member and the dispatcher for EMS agreed that the "X" is confusing when they are displayed on the gantries. Two other attendees explained that the "X" meant the Flex lane was shut down. An FCP member stated that the Flex lane might have already been cleared and there might be a delay between when the first responders clear a crash and when the message board indicates the Flex lane is cleared. Another first responder agreed. The dispatcher for EMS supported him when he said the people controlling the signs do not respond quickly. Their response time depends on the weather and everything else going on in Michigan. Two possible solutions some agreed on were to educate drivers and to add a second sign saying "crash ahead."

The first responders were then asked whether there were more or less crashes on the Flex route. The dispatcher for EMS agreed with the FCP member that there are fewer crashes in the mornings because the lane is open. There were also some agreement that there are more crashes in the evening because of the visibility at the I-96 and US-23 bridge. The number of crashes is also impacted by the end of the Flex route. Once traffic gets to I-96, it starts flowing and people can make up for their lost time. At the hill which leads to Silver Lake Rd, there is another bottleneck. Some agreed that there are more crashes and a backup at the I-96 entrance ramp towards Lansing because people are merging left, where more people drive in that area going north, and people compensate for lost time by driving faster. There is also congestion around 8 and 9 Mile roads, as explained by the dispatcher for EMS.

The first responders agreed with Whitmore Lake residents that another important issue was the length of time it takes to clear the Flex lane and reopen it after a crash. Some also noted that the Flex lane has to be physically cleared by an FCP member driving down the Flex lane instead of it just being cleared through cameras. The dispatcher for EMS agreed that it takes time to open the Flex lane after an FCP member clears it.

It was once more mentioned that FCP's priority is to open the Flex lane on time, even if one of their members has to be pulled from a crash site. An FCP member explained that he does not care if it takes a while for people to get to work when someone is injured. There was some agreement with that FCP member's comment that it is *"terrible to skip over hurt people."* According to the attendees, there is either miscommunication or no communication in these situations.

Next, the first responders mentioned a few other topics that were not brought up by participants from Whitmore Lake, specifically communication issues. Some agreed with an FCP member stating, *"one of the most frustrating things about the Flex is having to tell dispatchers to look at what is happening near the cameras in Washtenaw on the CLARIS system."* The Claris

Mobile vehicle-mounted camera intends to provide information to transportation agencies on accidents/incidents or weather that may not be caught by fixed cameras. The dispatcher for EMS explained that the system is complicated. There are individual usernames and passwords for each dispatcher. Because of this complication, dispatchers do not know what is happening in Washtenaw County towards Livingston County. The system is worse, not better, than before it was "fixed." An FCP member admitted that rather than use the CLARIS system, he uses WAZE, a navigation app from Google. WAZE is GPS based; commuters input information about crashes and road conditions to alert other drivers.

The same member of FCP said there are also issues with WAZE. Police officers do not know to call FCP on the radio. Instead, the FCP members use WAZE and Washtenaw dispatch. Some agreed with an FCP member that WAZE has helped tremendously. He further explained that they should not have to use an app to find out there is a crash on the Flex route.

Another issue some attendees agreed with was a problem with the medians on US-23. An FCP member mentioned a crash where a truck smashed through the median into the opposite lane of traffic. People injured in the incident had to be airlifted to a hospital since there was not enough space for ambulances to avoid continuous traffic. An attendee noted that *"the two guard rails mean everything to somebody."* The dispatcher from EMS agreed.

The EMS dispatcher inquired whether guard rails are supposed to be safer than wire since it is supposed to stop traffic. Another first responder answered affirmatively. Another first responder was concerned that they might not be an improvement. An FCP member explained that *"The guard rail prevents the most serious crashes and slows down traffic."* There was some agreement that wire barriers cut into everything, and another attendee noted that wires could easily slice through someone. An FCP member gave an example where a first responder saw a wire had cut through a truck's engine and a driver's seat. In addition, a police officer asked whether there is a difference between concrete walls and guard rails. Attendees explained people do not usually get through a wall. One FCP member noted that he *"saw a regular trailer get hit and then ran into the barrier into oncoming traffic. It does not happen with guard rail or wire."*

7.3.2 Responses to Brighton Concerns

Some first responders agreed that the SB bottleneck at I-96 and US-23 is an issue and all agreed that the bottleneck impacts further roads. There was some agreement when a police officer remarked that "*I have experienced this for 27 years and it never used to back up onto I-96, unless there was an accident when US-23 was a two-lane road. Now it backs up for three miles.*" Two first responders agreed with the police officer when he stated that SB US-23, north of I-96, backs up because of traffic. The same police officer further explained that commuters from Ann Arbor used to avoid the area by traveling on secondary roads. Since the introduction of the Flex route, more people have started using the highway, which has created more congestion. The amount of traffic depends on the day of the week. The dispatcher for EMS laughed when the police officer said that the worst day for traffic is Monday. There was some agreement that the backup leads people to use secondary roads such as Whitmore Lake and Fieldcrest. Some agreed that people in Michigan like driving themselves and will not use public transportation.

Most attendees agreed that the Friday backups on Lee Road next to Green Oak Village Place was a problem. An FCP member described how shoppers use secondary roads to avoid the congestion on I-96: they drive to an on-ramp past the congested points. A police officer noted that they mostly see residents going faster on the side roads because they are familiar with the area. Additionally, an FCP member and the dispatcher for EMS agreed that many drivers are trying to get to Brighton, but there are no good exits off I-96. So drivers use secondary roads such as Whitmore Lake Rd and Fieldcrest Dr. People then usually drive fast and get into crashes. An FCP member bluntly said, "*as a commuter it is terrible*."

As far as activating road salt goes, both FCP members agreed that they could not "activate" the salt to make it safer for commuters. They are up before the salt trucks and therefore cannot drive on the Flex lane first. An issue most agreed on is that the Flex lane will always ice over if it is shut down. A police officer and one FCP member agreed with the other FCP member that drivers have to activate the salt themselves. In order to relieve the issue, an FCP member proposed that lower speeds need to be considered.

All attendees agreed that people need to be educated about the zipper merge method. One possible solution is to require it to pass a driver's test. Some agreed that in the morning trucks use the center lane until US-23 SB and merge at the last minute, which causes a traffic backup. They also explained that people get angry when others aggressively pass them, especially when they are passed by someone on the shoulder. Most agreed with a police officer that there are very aggressive drivers in Michigan, who are destination focused and ride on people's bumpers.

Some attendees noted that trucks pass people going slower in the left lane so they could keep going at 70 mph. An FCP member indicated that this happens to him often. One first responder saw someone get pulled over for it, which caused some laughter. The attendee, who is a tow truck driver, suggested putting public "stress" out there to enforce the purpose of the Flex lane through marketing techniques so that trucks don't use it. This education may solve the problems of speeding and aggressive passing. An FCP member revealed that state police officers would park in front of FCP's emergency services vehicles to write civil infractions for people not changing lanes. He noted, "*I am very thankful for it*." Additionally, the tow truck driver noted that when he left the Detroit airport Monday morning around 8:30 am, people were going 60 mph in both the middle and left lanes while the right lane was vacant.

There was also a small discussion on what slows people down. An FCP member mentioned that the color of certain emergency lights innately slows some drivers down. However, he explained that FCP vehicles could not have red and white lights, even when it would help them stay safe. The tow truck driver suggested that any "*blinky-flashy lights slow people down, like tow trucks*."

7.4 What Works on the Flex Route?

The first responders were asked about what works on the Flex route. There was some agreement that the Flex route works great for 8 and/or 9-miles on US-23 NB. The number of crashes has decreased, and the entrance ramps have improved. An FCP member explained that once one gets five miles south of I-96, traffic goes a lot faster since people are eager to "*press the pedal on the gas.*" A police officer noted that they thought it was great from Silver Lake Road going south.

A couple of attendees agreed with an FCP member that the intelligent freeway signs work great. For example, it informs people about crashes and reacts effectively. The FCP member then said, *"he can call dispatch and have people start merging over two miles before the scene of the accident."*

Most agreed with a police officer that the Flex route works great on a clear sunny day. He then suggested that there is only a traffic problem on game days and rush hour, so there is no need to spend the money building an additional permanent lane. Some agreed and added that the extended ramps helped with the backup.

First responders mostly agreed with a police officer and laughed, when he noted that people could express their frustration by going faster such as 90 mph in the left lane. An FCP member further explained that people drive 80 mph at the green arrow, and then as soon as they merge into the Flex lane, they slow down to 60 mph. A police officer agreed. Another police officer mentioned that *"what demonstrates the Flex works is that the biggest complaint is that it was not extended to I-96."*

Most agreed with a police officer when he noted that the electronic message boards help educate drivers on future operations and give them something to pay attention to other than the advisory speed. They familiarize people with traffic investigation lanes and signage. Most attendees also agreed when an FCP member, who noted that people are also confused about the three red X's. *"Sometimes a red X in the right lane might mean there is an accident in that lane. The X demonstrates that people should be driving in the Flex. In another situation, there might only be a red X in the Flex, making that kind of education important."*

After providing reasons why the Flex route works, the first responders discussed the future Flex route on I-96 and its implications. A police officer was concerned with where the Flex route begins and ends. The new Flex route starts at the intersection of I-275 and I-96 and will terminate at Kent Lake Road. The officer noted that the budget was a constraint to end the Flex lane. He would have preferred it be extended to I-96. Additionally, the police officer predicted that Novi would start having the same issues as Brighton since the city is already "*packed,*" and I-275 may be affected. Most attendees agreed that MDOT should invest in the Flex route they started, which caused some laughter. An FCP member said that if "*investors*" see how well the Flex route works at full capacity, they would fund more of them. The dispatcher for EMS and a police officer agreed. A police officer explained that extending the current Flex route would solve the first responders' and community's complaints.

Most attendees then agreed with an FCP member who noted that extending the Flex route would also lead to more traffic because people enjoy driving it. Some agreed that fixing the secondary roads and bridges is the biggest conflict between MDOT and the local municipality. There was some agreement that neither wants to pay to fix the secondary roads unless there is a federal grant for emergency traffic needs.

7.5 Recommendations

The most important issues with the Flex lane are the pinch point at Whitmore Lake, the number of incidents, and the absence of emergency median crossings for emergency vehicles.

Specifically, the following are recommended by first responders for the current Flex route as well as any planned and future Flex routes:

1. Find natural merging and exit points: avoid any pinch points by connecting one highway with the other to avoid any lane reduction.
2. No concrete barrier to mark the end of Flex lane: to give drivers space to maneuver at the merge, leave some distance between the end of the Flex lane and the concrete barrier.
3. Design an emergency stop next to the ends of the Flex lanes: the merging point from three to two lanes when the Flex lane ends is perceived to be a hot spot for crashes.
4. A clear explanation of speed advisories on Flex route: commuters are confused about the difference between speed limit and speed advisory.
5. Frequent emergency median crossings: to decrease response time to crashes and incidents.

Another suggestion the first responders made was to finish and fix the US-23 Flex route rather than add a new one on I-96 between I-275 and Kent Lake Road. They explained that it would solve their own and communities' complaints and would prevent another pinch point.

If these suggestions are followed, participants believe the safety and the performance of the Flex route can be improved.

CHAPTER 8 CONCLUSIONS

The purpose of this study was to assess the operational performance, safety performance, and public perception of Michigan's first Flex route along the US-23 corridor. Therefore, the comprehensive research approach involved quantitative and qualitative evaluations including (1) utilization rates for the Flex route (i.e., the frequency and duration of hard shoulder running by day-of-week and time-of-day); (2) throughput during active and inactive periods of Flex route operation; (3) average travel times and delay; (4) travel time reliability, including metrics such as planning time index and buffer index, which relate the variability in travel times to average/free-flow values; and (5) safety performance, including the frequency, rate, and severity of crashes along the US-23 Flex route and its adjacent upstream and downstream segments. Qualitative methods include: (1) surveys to analyze drivers' perceptions and their driving behavior of US-23; (2) content analysis of public commentary to track community perceptions; and (3) focus groups in adjacent communities to US-23 and with different enforcement agencies to identify challenges and solutions.

Ultimately, the findings suggest that the first temporary Flex lane in Michigan is a success story. Further, many of the performance, safety, and perception issues are likely to be remedied once the extension to I-96 has been completed.

8.1 Operational Performance of US-23

Performance of US-23 has improved across several operational metrics including maximum throughput, travel time during peak periods, and level of travel time reliability. After the Flex route went into operation, the maximum throughput in the northbound direction increased by 11.0 percent and in the southbound direction by 35.4 percent. Average travel speeds increased significantly during weekdays, especially during peak hours, but not during the weekends. Average travel times during the peak periods were reduced by 16.5 percent and 11.2 percent in the southbound and northbound directions, respectively. Similarly, reductions of 37.3 percent and 20.8 percent in the 95th percentile travel times were observed southbound and northbound, respectively. Consistent with the metrics detailed previously, the level of travel time reliability (LOTTR) was also found to generally improve from the upstream to downstream Flex route segments in both the northbound and southbound directions. The Flex route was also shown to alleviate congestion related to special events, specifically holiday seasons and home football games at the University of Michigan during the 2018 and 2019 seasons.

The average travel time during weekdays reduced from 8.4 to 8 minutes in both directions and 95th percentile travel time decreased approximately 22 percent. There was no significant difference found in travel time reliability metrics. The Flex route is generally operating under capacity, even during peak traffic periods. As such, the study is not able to provide a capacity estimate for either direction (all lanes), or for the Flex lane specifically. In general, volumes tended to be highest in the middle (i.e., left) lane as compared to the right lane. This finding is consistent with the driver survey as most drivers preferred to drive in the middle lane. Volumes also tended to be higher in the southbound direction as compared to northbound.

Performance of the Flex route was significantly reduced as drivers approached the NB pinch point at Whitmore lake, particularly near MM 52.7 and MM 53.2, which is where the lane drop occurs. When the Flex route was in operation, the speeds and hourly flow rates on the left shoulder (Flex lane) gradually reduced while approaching the northern portion of the northbound direction. The northernmost section of northbound US-23, saw the largest decline in speeds as congestion began to occur close to the land drop.

Even though the advisory speed is 60 mph, the average travel speed on the route was approximately 70 mph. Speeds were largely consistent across most flow rates. The INRIX probe vehicle data generally show increasing speeds in both the southbound and northbound directions, except for the northernmost extents in the northbound direction at the lane drop.

Drivers tended to comply with the rules of the Flex route. Only a small percentage of drivers traveled on the Flex lane while the gantry displayed the red X. In addition, the travel speed was consistent under the advisory speed of 60 mph, and more variability was found while the advisory speed reduced to 30 mph. After a detailed inspection, the drivers tended to travel at a speed 10 mph higher than the advisory speed of 60 mph in both directions. This is also true when the advisory speed of 50 mph was displayed in the northbound direction. The drivers complied with that advisory speed in the southbound direction. The travel speeds were also similar to the advisory speeds, while the advisory speeds of 40 and 30 mph were displayed regardless of the directions. This finding is more pronounced at the terminus of the Flex route in the northbound direction where the merging point occurred. The results of the linear regression model also had similar findings. It is suggested that most drivers reduce their speed because of the reduction in overall speed, not because of the displayed advisory speed.

The impacts of COVID-19 on the operational performance of the US-23 Flex route were also preliminarily investigated. Fewer vehicles were found on the roadway, and the travel speed increased compared to before. There was no reduction in speed observed during the peak period.

8.2 Safety Performance of US-23

In general, the reduced levels of congestion that occurred after Flex route implementation were also associated with reductions in traffic crashes. Overall, crashes were reduced by roughly 17 percent across the entire corridor in both directions. The improvements were significantly more pronounced in the southbound direction, where crashes were reduced by 34 percent overall and more than 50 percent during the peak traffic periods. In contrast, crashes increased in the northbound direction, though these increases were not statistically significant.

As with the operational issues, the crashes tended to increase predominantly in the bottleneck area where the lane drop is present. While crashes were generally reduced along the Flex route, some increases and decreases occurred on the adjacent upstream/downstream segments. Given shifts in traffic volumes and latent demand, this is a challenging area to forecast for future Flex route projects.

The safety performance of US-23 Flex route during COVID-19 was also evaluated. The total number of crashes decreased after the COVID-19 (i.e., 2020) except for the late-night (i.e., 9 PM-12 PM). After considering the volume, the results indicated that the crash rates were higher during 6 PM and 12 AM regardless of the direction. It is also true for the time period of early morning in northbound direction (12 AM - 6 AM). Further investigation can be conducted once more data is available.

8.3 Perception of US-23

Perception of the US-23 Flex route was deduced from three sources, a driver's survey along the US-23 corridor, a social media analysis of public commentary, and focus groups of adjacent communities and first responders.

8.3.1 Driver Survey of US-23 Drivers

Almost 70% of US-23 drivers were satisfied or very satisfied with the Flex route; to such an extent that there is significant support for both an expansion of the current Flex route and additional Flex routes throughout the state of Michigan. Moreover, drivers overwhelmingly desire the current Flex route to be open for additional hours, especially on weekends. Demographics collected for the analysis show that US-23 Flex route drivers were generally over 50 years old, Caucasians, owned two cars per household, and had a combined annual household income of over $100,000. Younger respondents who were employed were statistically significantly more likely to prefer using the Flex lane than were respondents not employed or older respondents. Additionally, the plurality of respondents prefers to drive in the middle lane even when the Flex lane is in operation, yet those who prefer driving in the Flex lane were more satisfied with their overall driving experience than those who drove in the middle lane.

Respondents were more likely to report feeling less safe in all NB lanes than they do while driving in any SB lane. The SB middle lane is perceived to be the safest lane, while the perceived least safe lane is the NB left lane. The section of the Flex route which causes the most dissatisfaction among drivers is the merge at Whitmore Lake along US-23 NB, which almost 50% of drivers were either dissatisfied or very dissatisfied with. Reports of increased congestion in this area were common. This may be due to confusion and uncertainty over when and how to merge; additionally, confusion as to the meaning of symbols displayed on gantries may compound this issue. Perceptions as to whether or not safety has improved since the Flex routes implementation are split near evenly, nonetheless when an incident occurs respondents were more likely to feel less safe when the Flex lane was closed. Respondents report that crash investigation sites are used in a few ways, though there is some confusion regarding how they should be used.

Compliance when using the Flex route is high: most drivers report that they themselves, as well as other drivers, comply with the Flex routes regulations either always or at least most of the time. The vast majority of respondents were overwhelmingly satisfied with the information that is provided to them, via signs or gantries, irrespective of when the Flex lane is open, or their direction of travel. Drivers are also satisfied or very satisfied with the information they are provided while driving the Flex route no matter the time of day or night, or whether information is displayed on the gantry systems, or via Flex route signage.

An analysis of the open-ended questions shows that there is some confusion regarding the meaning of symbols on the gantries and the speed limit in the Flex lane. Many respondents were unable to accurately answer questions about either. In general, respondents reported that they appreciate the Flex route and that it saves them time. However, they also reported having witnessed some, albeit infrequent, poor driving behaviors from other drivers since its implementation.

8.3.2 Focus Groups of US-23

Most focus group members agreed that the US-23 Flex route significantly reduced congestion and made the morning and evening drive safer, faster, and more comfortable. Across the focus groups, solutions for improving the Flex route were proposed. Of utmost importance was the extension of the Flex route north to I-96, because it would solve the pinch point at Whitmore Lake. The pinch point had, in their opinion, created unsafe driving conditions and did not solve the congestion for those living in Brighton. As MDOT announced that exact extension in mid 2020, many driver concerns will be effectively addressed. Regardless, the pinchpoint issue brought valuable lessons for future Flex lanes in Michigan.

Communicating with drivers on the Flex lane was a challenge as the signage remained unclear for drivers. Focus group participants reported on the tendency that drivers drive fastest in the temporary shoulder, as they also were under the impression that it had higher speed limits than the two regular lanes. Thus, the focus group members recommended removing the 60 mph messages from the gantries and instead of posting them as advisory speeds (yellow signs) next to the Flex lane. Similarly, the lane markings came with similar communication challenges, some participants suggested MDOT change the solid yellow lane markings to white or at least yellow dashes on stretches where switching lanes is allowed.

Crashes on the Flex lanes posed significant challenges to first responders for multiple reasons. In particular, they requested more frequent emergency median crossovers, and prioritized care for crash victims over allowing the Flex lane to reopen.

8.3.3 Social Media Analysis of US-23 Commentary

The majority of people who commented on social media view the Flex route in a positive light, and it has received consistent praise throughout all steps of its implementation. They lauded the Flex route for reducing congestion and decreasing their travel time. Though, many people would prefer a permanent lane, while only a few commenters pointed out that the Flex lane was a cost-effective solution compared to a third permanent lane. General compliments/praises were the most common form of communicating perceived benefit, followed closely by reduced congestion commentary. However, negative sentiments do exist. Some people were dissatisfied with the construction and design of the Flex route (the most prominent concern) and its cost. Furthermore, the end of the NB Flex lane, at M-36/9 Mile, received consistently negative remarks.

8.4 Recommendations for Future Flex Routes

Michigan's first Flex route on US-23 provides important lessons for future Flex routes and guidance on best practices.

8.4.1 Best Practices from the Literature

Best practices for active traffic management (ATM) strategies vary by location since specific design requirements, laws, and policies are unique to the location. The literature provides best practice categories based on the assessment of temporary shoulder use, variable speed, and queue warning operations in Europe and the US. These guidelines are shown in Table 8-1 and include data needs (necessary for successful implementation), essential and preferred elements (general criteria), key factors (useful for successful implementation), and benefits (impacts). FHWA (2016b) suggests ATM best practices include emergency turnouts, enhanced ITS equipment for monitoring, prohibition of truck use on temporary lanes, and a maintenance plan. Freeways that implement ATM techniques must also have adaptable infrastructure and a flexible incident management plan.

Table 8-1 Best practices for shoulder use in Europe and the US

Guidelines	Best Practices: Shoulder Use
Data Needs	• Traffic information: volume/capacity, speeds, crash locations, shoulder availability
Essential Elements	• ATM strategy at least 3 mi in length • Avoid bottlenecks further downstream when planning future flex routes • Minimum shoulder width 10ft. • Construction of emergency refuge or tapers • Utilize proper pavement conditions for traffic use on shoulders
Preferred Elements	• Incident management and enforcement strategies • Sensors and ITS installed on future flex lanes • Speed harmonization

Key Factors	• Signs used should be visible and placed on gantries • When the shoulder lane is not operating, signs should be blank • Use of right or left shoulder, not both • Video monitoring • Additional tapers on right shoulder
Benefits or Impacts	• Increase throughput, capacity, trip reliability • Reduce freeway disruptions • Reduce the chances and severity of crashes

Sources: Levecq et al., 2011; Sullivan & Fadel, 2010; Xiong et al., 2021

8.4.2 Best Practices for Planning the Roadway/Path Design of Future Flex Routes

To optimize performance, safety, and perceptions, future flex lanes should ideally terminate into auxiliary lanes near interchanges. Corridors ending with a lane drop adversely affected operations and safety, which subsequently led to negative public perception. Ideally, future flex routes can terminate into a deceleration lane or at a system interchange as is currently planned for the US-23 extension onto I-96. Similarly, there are operational advantages to starting a future flex lane near an entry ramp or the conclusion of an acceleration lane to provide a smooth transition. This design decision would be influenced by the lane configuration as speed-change lanes are generally introduced on the right-side of the road.

The US-23 Flex lane provides ample evidence for this recommendation, especially the merge at the Whitmore Lake pinchpoint where the left (inside shoulder) lane terminates and results in queue spillback, increasing the risk of related crashes, and negative perceptions among travelers.

If a lane drop must occur when there is no exit present, the future flex lanes should:

- extend a wide shoulder beyond the lane drop to allow additional space to accommodate late mergers between the end of the future flex lane and a narrower shoulder, particularly if concrete barrier is present as in the case of US-23.
- terminate the future flex lane on a flat, tangent section of roadway where possible to allow sufficient decision sight distance for drivers. Currently, the US-23 lane ends in a curve that inhibits the line of sight.
- have additional camera coverage at both ends of future flex lanes to aid in monitoring incidents at these locations.
- locate a crash investigation site on the opposite side of the freeway near merge points to allow space for enforcement and crash-involved drivers to pull over after crashes.

- Message lane drop points on gantries further upstream as it is currently practiced on the US-23 Flex route. The US-23 NB merging point is located at MM 53.1. The first merging sign is at MM 52.6. The distance between the merging point and the first merging sign is 0.5 miles as FHWA currently stipulates. However, focus groups advocated for a gantry display notifying them of the merger further upstream, leaving possibly a 1-mile distance between the merging point and the first merging sign.

Future Flex route design processes should consider shortening the distance between emergency median crossings. Focus groups of first responders suggested that they preferred more frequent emergency median crossings and advocated making those a priority in the design of future flex routes; especially on 1-2 mile stretches that currently do not have exit or entrance ramps. This request from emergency responders is below the minimum distance of 3 miles required by other state departments like North Carolina. However, ensure that emergency median crossings are located at least ½ mile from any overhead structures at least one mile from the terminus of an acceleration or a deceleration lane.

8.4.3 Best Practices on US-23 Signage

The MUTCD advises using the TRAVEL ON SHOULDER BEGINS 1/2 MILE sign ahead of the location where part-time travel on the shoulder first begins in order to provide drivers with adequate information regarding the use of the shoulder. On US-23, currently, the first dynamic message sign is located exactly at the merging point on the northbound of US-23 Flex route.

Merging displays and lane changing indicators should occur earlier than is currently practiced on the NB US-23 at Whitmore Lake at ½ mile even though it follows FHWA current guidelines. However, findings from the driver survey and focus groups suggest that the yellow-X as proposed by the draft MUTCD may create significant confusion, the recommendation resulting from this study is to use different signage on gantries, i.e., MERGE 1 MILE AHEAD and MERGE ½ MILE AHEAD, instead.

There was significant confusion as to the meaning of the advisory speeds. To this end, it is recommended that the advisory speeds are either set at the prevailing speed limit or, alternately, blanked out. In the case of US-23, the 60 mph advisory speed is dictated by stopping sight distance, so this may be unavoidable in some cases. However, as the average speeds on the Flex lane are generally 70 mph or above, some drivers found the posted gantry advisory speeds confusing as they are different from the regularly posted speed limit on US-23. Incident displays advising of speed reductions as currently spaced on overhead gantries (0.5 mile apart on average) were infrequently adhered to. As the speed limits reduced towards 30 mph, more variability was observed in drivers' speed, particularly as the speeds lowered to 30 mph. Thus, safety messages such as "caution, slow moving vehicle ahead or congestion ahead, be prepared to stop" or "slow down" might be more effective as suggested by drivers.

Future flex routes should consider changing the lane marking from solid to dashed lines on stretches where switching lanes is allowed. Though the MUTCD does not provide specific recommendations on lane markings of dynamic shoulders, results from the driver survey show that lane marking confusion exists as drivers felt the solid yellow lane markings prohibited lane changes.

8.4.4 Best Practices on US-23 Operations

If possible, US-23 Flex route should consider extending its operational hours. Drivers requested extended hours on Fridays, especially during the summer and on long weekends, as well as earlier opening of the Flex lane on special event days. Analysis results from operational performance suggest that the Flex lane should be opened at least three hours in advance of UM home football games and four hours in advance of games starting at 12:00 pm. For other dates of interest, a 1:00 pm start time would generally accommodate congestion (in the northbound direction) on Friday before Memorial Day, July 3rd, Wednesday before Thanksgiving, Friday before Christmas, and Fridays during summertime/special events. A 12:00 pm start time (northbound) would work for the Friday before Labor Day.

MDOT might expect that most drivers of future flex routes will choose to drive in the centermost (middle) lane(s). This driving behavior makes merging from the left more challenging in instances where a lane drop occurs. Encouraging early merging may help to address this concern. In addition, educating the public on the zipper merge method and enforcing its compliance could minimize congestion and crashes related to bottleneck congestion.

Further, constant monitoring is required as travel demands might shift after any new flex lanes go into operation in Michigan. Shifts of the morning and afternoon peak hours might occur, so might upstream and downstream crashes – new flex lanes will be context specific and adaptation to these changes is recommended.

8.4.5 *Best Practices on Cost-Benefit Analysis*

Splitting the cost benefit analysis into three separate analyses is recommended: one for each direction and one combined. Collectively, these results show benefit-cost ratios of US-23 Flex route ranging from 2.15 to 2.95 in the southbound direction, 2.25 to 3.09 in the northbound direction, and 2.20 to 3.01 in both directions.

In general, the operational benefits were significantly greater in the southbound direction, because of the congestion that remains at the northern limits in the northbound direction. In contrast, the safety benefit is more pronounced in the northbound direction, due in large part to a decrease in fatalities that occurred between the before and after periods. It is worth noting that the crashes have an undue effect on the cost benefit calculations. The TOPS-BC itself also has some weaknesses that deviate from best practices in the literature. In particular, three components regarding costs and benefits of road projects are missing from the TOPS-BC: road ecology, local housing values, and impacts on health (Boardman et al., 2017; Huijser et al., 2009; Karraker et al., 2008; Reponen et al., 2003).

8.4.6 *Best Practices and the MUTCD*

Amendments are proposed to the next edition of the MUTCD that are pertinent to the design, maintenance, and operations of flex lanes. While the research has largely supported the guidance proposed in the MUTCD regarding signage, one exception remains as it 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." The driver survey has shown that the yellow X creates confusion as to when merging should occur and in fact whether they are allowed to travel in the lane at all, if a yellow cross is displayed.

While most of the results of this study are consistent with the recommendations from the FHWA, the public feedback suggests that the signage for mergers should generally be displayed as an arrow instead of a yellow cross and sooner than the currently advised ½ mile. The exact distance could not be determined based on the available survey data. Ultimately, MDOT's future policy should consider the final language that is approved for the next edition of the MUTCD.

8.5 Limitations and Directions for Future Research

This study provides valuable insight on several topics; however, some limitations are associated with the research methods (e.g., data availability, data analysis). Due to the COVID-19 pandemic, 2020 data could not be utilized in the before-after analyses, though the following section provides some high-level summary information. Missing data were also observed in each dataset, though this had minimal impacts on the overall analysis. One exception is the MVDS reports, which were only available after the construction of the Flex route. Speed information before the operation of the Flex route was obtained from the INRIX probe vehicle data and PTR data platform without lane designation. So, drivers' speed selection behavior on each lane could not be evaluated before opening the Flex route. Another important caveat, the PTR data was the only dataset containing the traffic volume from the before-period and the only nearby PTR station was located at Barker Road.

While the results clearly illustrate the cost-effectiveness of the Flex lane, indirect and ancillary costs, especially the increase in crashes near the lane drop, provide strong motivation for extending the Flex lane to I-96. Further, a more comprehensive look into reasons for increased upstream and downstream crashes of the Flex lane remains warranted. While our study found such an increase per se, understanding the reasons and suggesting remedies were not part of this study

Moreover, the capacity of the Flex route could not be determined based on the available data. As the speed-flow curves presented in the previous sections indicate, the capacity of the Flex route was generally not reached, except near the lane drop. At this location, congestion was largely due to the downstream bottleneck and, as such, the capacity values of 2100-2300 veh/hr/ln provide reasonable floors for estimating future performance at other locations. Given this is the first Flex route in Michigan, our findings may not be representative of future flex routes in Michigan or elsewhere. This is especially true for perceptions studies, be it surveys or content analysis of social media posts, because bias is inherent in individuals' perspectives.

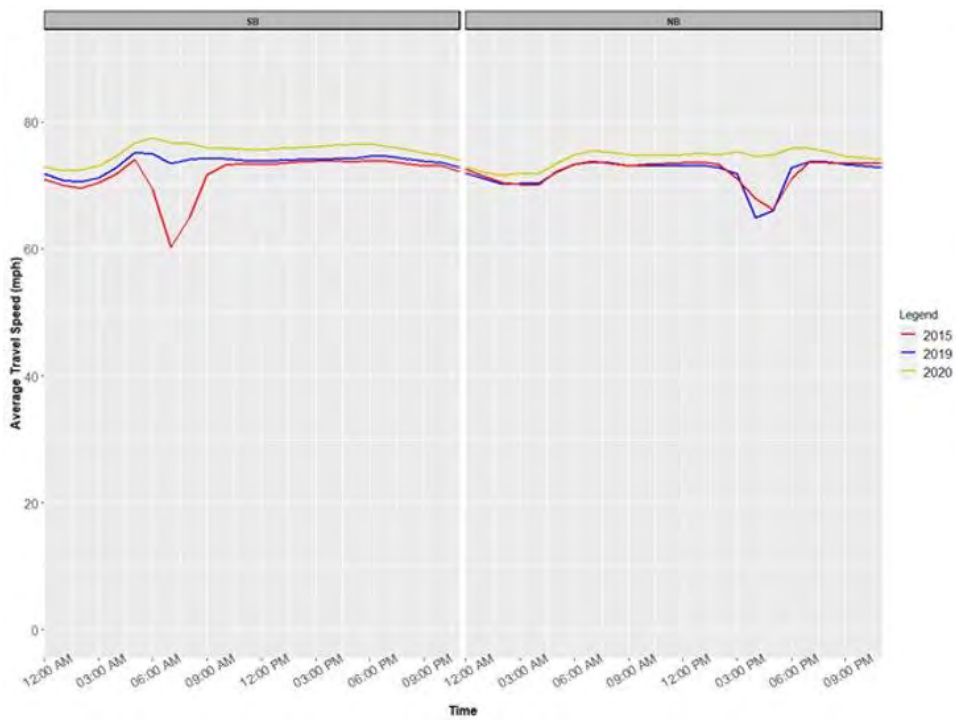
Moving forward, additional research is warranted to understand potential advantages or disadvantages of the Flex lane design as compared to a full third travel lane. This study exclusively focused on the Flex lane alternative that was implemented on the US-23 corridor. Evaluations for other prospective Flex corridors should include considerations such as shoulder width (with 12 ft generally preferred and 11 ft as a minimum), structural depth/capacity of the shoulder, as well as the underlying surface condition. Additional cost considerations may include needs to move drainage structures and guardrail, new shoulder installation or repairs, and other detailed design decisions that are beyond the scope of this report.

8.6 Impacts of the COVID-19 Pandemic

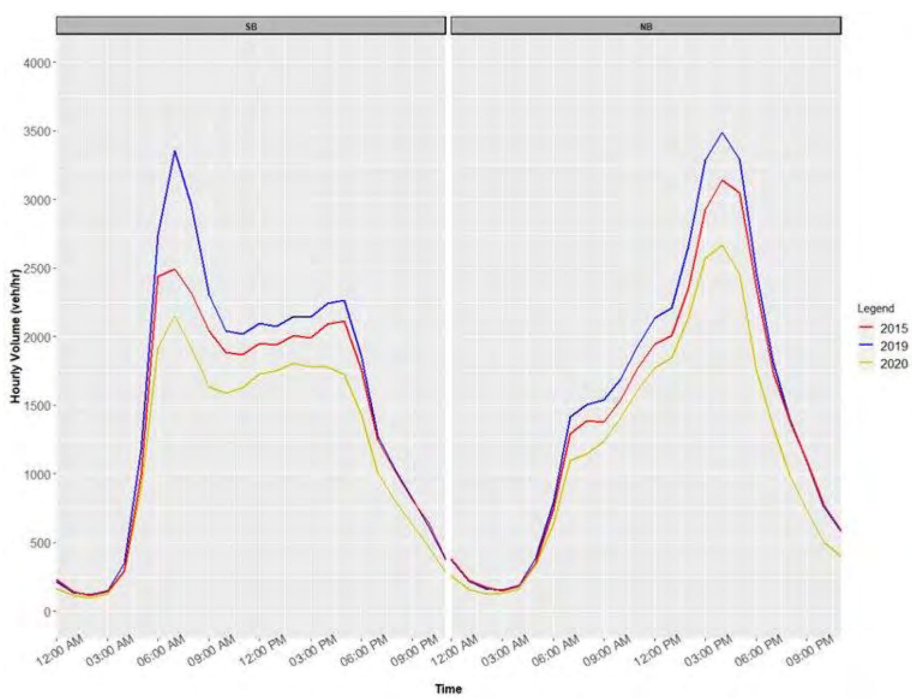
This evaluation was originally intended to focus on the three-year period immediately after the Flex route went into operation from 2018 through 2020. However, in March 2020, the World Health Organization (WHO) formally declared a pandemic due to the Coronavirus Disease 2019 (COVID -19) (WHO, 2020). In response to this pandemic, many countries implemented social distancing measures (e.g., stay-at-home orders, travel restrictions) to prevent the transmission of the disease. This included states across the U.S., including Michigan. Several studies found a significant reduction in personal trips and public transportations throughout the country as a result of those measures (Shannon et al., 2020; Newburger, 2020; Lazo et al., 2020; Tomer et al., 2020; Davis, 2020). Considering the impacts of pandemic, the performance of flex route during this period is also of interest. To that end, an evaluation of changes in travel speeds, traffic volumes, and traffic crashes was conducted to provide insights into impacts of the pandemic.

First, speed and volume data from 2015, 2019, and 2020 were obtained from the same PTR station at Barker Road described earlier in the report. The speed and volume trends from this PTR station are shown graphically in Figure 8-1**Error! Reference source not found.**. As detailed previously, volumes increased significantly from 2015 to 2019 with the introduction of the Flex route. Despite these increases, speeds generally increased from 2015 to 2019 with the exception of the northbound lane drop. Due to the travel restrictions that were introduced, traffic volumes were reduced by as much as 25 to 40 percent during the AM and PM peak periods. With these reductions in volume, speeds increased by 2 to 3 mph generally, and by a much larger amount during the peak periods, particularly in the northbound direction where traffic largely operated under free-flow conditions, even during the PM peak.

These findings are reinforced when considering the probe vehicle data from RITIS for calendar years 2019, 2020 and during the first half of 2021. Figure 8-2 shows average travel speeds separately for weekdays and weekends. Overall, speeds were largely similar during most of the day. However, the speed drops that occurred near the lane drop in the northbound direction in 2019 are largely absent from 2020 and 2021. This appears to be largely a function of the lower levels of traffic volume, though speeds have been shown to increase at various other locations throughout Michigan, as well. It is interesting to note that speeds decreased slightly in 2021.

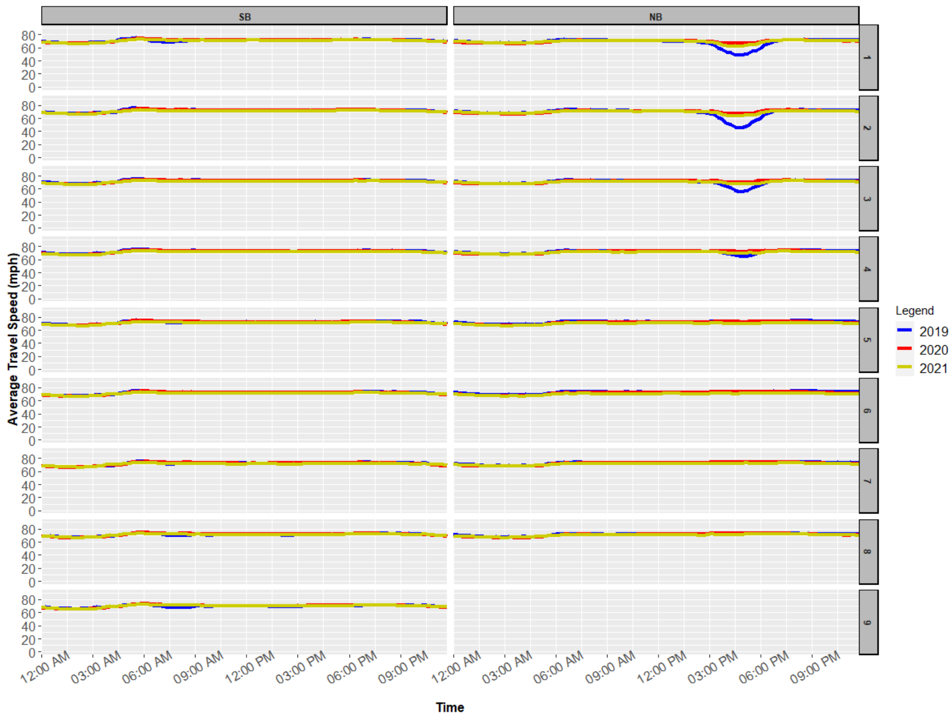


a. Average travel speed

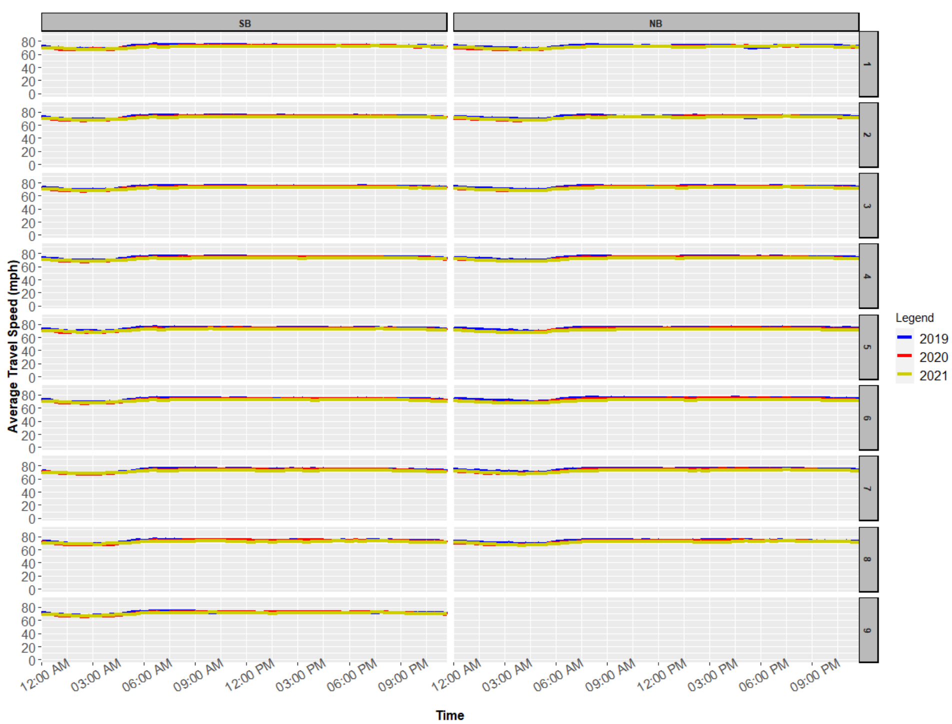


b. Hourly volume

Figure 8-1 Yearly US-23 Flex route average travel speed and volume over time



a. Weekdays



b. Weekends

Figure 8-2 Yearly US-23 Flex route average travel speed at segment-level

In addition to the operational performance, the COVID-19 pandemic was also associated with marked increases in traffic fatalites across the United States. As such, potential impacts on the safety performance of the Flex route is also of great interest. To this end, year-end crash data from 2020 were obtained from the Michigan State Police. These data were merged with corresponding traffic volume from the PTR station at Barker Road, allowing for determination of changes in both crash frequency and crash rate.

Table 8-2**Error! Reference source not found.** shows a comparison of changes in the annual number of fatal, injury, and property damage only crashes between the two-year period before the COVID-19 pandemic (2018-2019), as well as for calendar year 2020, which includes roughly nine months of post-pandemic data. Interestingly, these results show that crashes decreased by more than 50 percent regardless of the type of crashes and direction of travel.

Table 8-2 Annual numbers of crashes by direction before and after COVID-19 pandemic

Crash Severity	Southbound		Northbound		Both Directions (Total)	
	2018-2019	2020	2018-2019	2020	2018-2019	2020
Fatal/Injury Crashes (KABC)	17.5	8.0	23.5	8.0	41.0	16.0
Property-Damage-Only (O)	72.5	30.0	113.0	54.0	185.5	84.0
Total (KABCO)	90.0	38.0	136.5	62.0	226.5	100.0

When considering only the peak period during which the Flex route is in operation (i.e., from 6:00-9:30 am southbound and 3:00-7:00 pm northbound), the same general trend was observed as shown in Table 8-3. Overall, crashes were shown to decrease by 60 percent in both directions. Injury crashes reduced by 50 and 68 percent in the southbound and northbound directions, respectively.

Table 8-3 Annual numbers of crashes by direction during peak traffic periods, before and after COVID-19 pandemic

Crash Severity	Southbound (6:00-9:30 am)		Northbound (3:00-7:00 pm)		Both Directions (Peak Periods by Direction)	
	2018-2019	2020	2018-2019	2020	2018-2019	2020
Fatal/Injury Crashes (KABC)	4	2	12.5	4	16.5	6
Property-Damage-Only (O)	20	8	64	26	84	34
Total (KABCO)	24	10	76.5	30	100.5	40

Further details are provided for total annual crashes by time-of-day in Table 8-4**Error! Reference source not found.**. As in the prior safety analysis, data are aggregated into three-hour analysis intervals. As shown above, significant reductions in crashes (76 percent) occurred during the morning and afternoon peak periods, while the greatest reduction in crashes (87 percent) was observed during the early morning (12:00 AM to 3:00 AM) in the southbound direction. In contrast, crashes actually increased during the nighttime period from 9:00 PM to 12:00 AM. Crashes were found to increase by 11 percent and 26 percent in the northbound and southbound directions, respectively, during this period.

Table 8-4 Annual crashes on Flex route under pandemic by time-of-day

Time	Southbound		Northbound	
	2018-2019	2020	2018-2019	2020
12:00 AM to 3:00 AM	7.5	1.0	2.5	2.0
3:00 AM to 6:00 AM	5.5	2.0	6.5	5.0
6:00 AM to 9:00 AM	22.0	8.0	8.5	2.0
9:00 AM to 12:00 PM	14.0	6.0	7.0	3.0
12:00 PM to 3:00 PM	15.0	5.0	21.0	5.0
3:00 PM to 6:00 PM	10.5	2.0	66.5	25.0
6:00 PM to 9:00 PM	11.0	9.0	15.0	8.0
9:00 PM to 12:00 AM	4.5	5.0	9.5	12.0
Total Crashes	90.0	38.0	136.5	62.0

Lastly, these data were integrated with the PTR volume data in order to calculate crash rates during each three-hour interval. These summary results are shown in Table 8-5. As the pandemic occurred in early 2020, there is less than one full year of post-pandemic data. As such, there is variability in trends during most of the day. Overall, crash rates were 10.3% higher in the southbound direction and 14% higher in the northbound direction over the entire day. When considering the individual time periods, there were small increases or decreases in crash rates across the Flex route corridor with a few notable exceptions.

Table 8-5 Crash rate of Flex route under pandemic by time-of-day

Time	Southbound		Northbound	
	2018-2019	2020	2018-2019	2020
12:00 AM to 3:00 AM	2.46	0.83	0.52	1.20
3:00 AM to 6:00 AM	0.53	0.48	1.45	2.58
6:00 AM to 9:00 AM	0.39	0.42	0.37	0.23
9:00 AM to 12:00 PM	0.35	0.39	0.23	0.23
12:00 PM to 3:00 PM	0.38	0.30	0.50	0.28
3:00 PM to 6:00 PM	0.25	0.12	1.11	1.05
6:00 PM to 9:00 PM	0.42	0.87	0.43	0.63
9:00 PM to 12:00 AM	0.39	1.14	0.63	2.37
Overall	0.39	0.43	0.64	0.73

First, in the southbound direction, crash rates were 7.7% higher during the AM peak period. Even though there were fewer vehicles on the road, the reduction in volumes was more pronounced than the reduction in crashes. In the northbound direction, the crash rate actually decrdased by 5.4% during the PM peak. However, this rate is still significantly higher than any of the other time periods and this result is again largely attributable to the lane drop at the end of the Flex lane.

A primary concern with these results is the pronounced increase in crash rates that was experienced during the evening and nighttime periods in both directions. In the southbound direction, crash rates more than doubled from 6:00 to 9:00 pm and nearly tripled from 9:00 pm to midnight. Similarly, northbound crashes incrased by 46.5% from 6:00 to 9:00 pm and by 276% from 9:00 pm to midnight. These trends are largely reflective of broader statewide trends, as well, which have generally been accompanied by increases in fatal crashes among those who are under the influence of drugs or alcohol, riding without a seabelt, or speeding at the time of the crash. This highlights a broader concern for the design of future Flex routes as there appear to have been some general changes in driver behavior, which are reflected by higher travel speeds and more severe crash outcomes. At a planning level, these differences can be considered when trying to forecast potential operational and safety performance.

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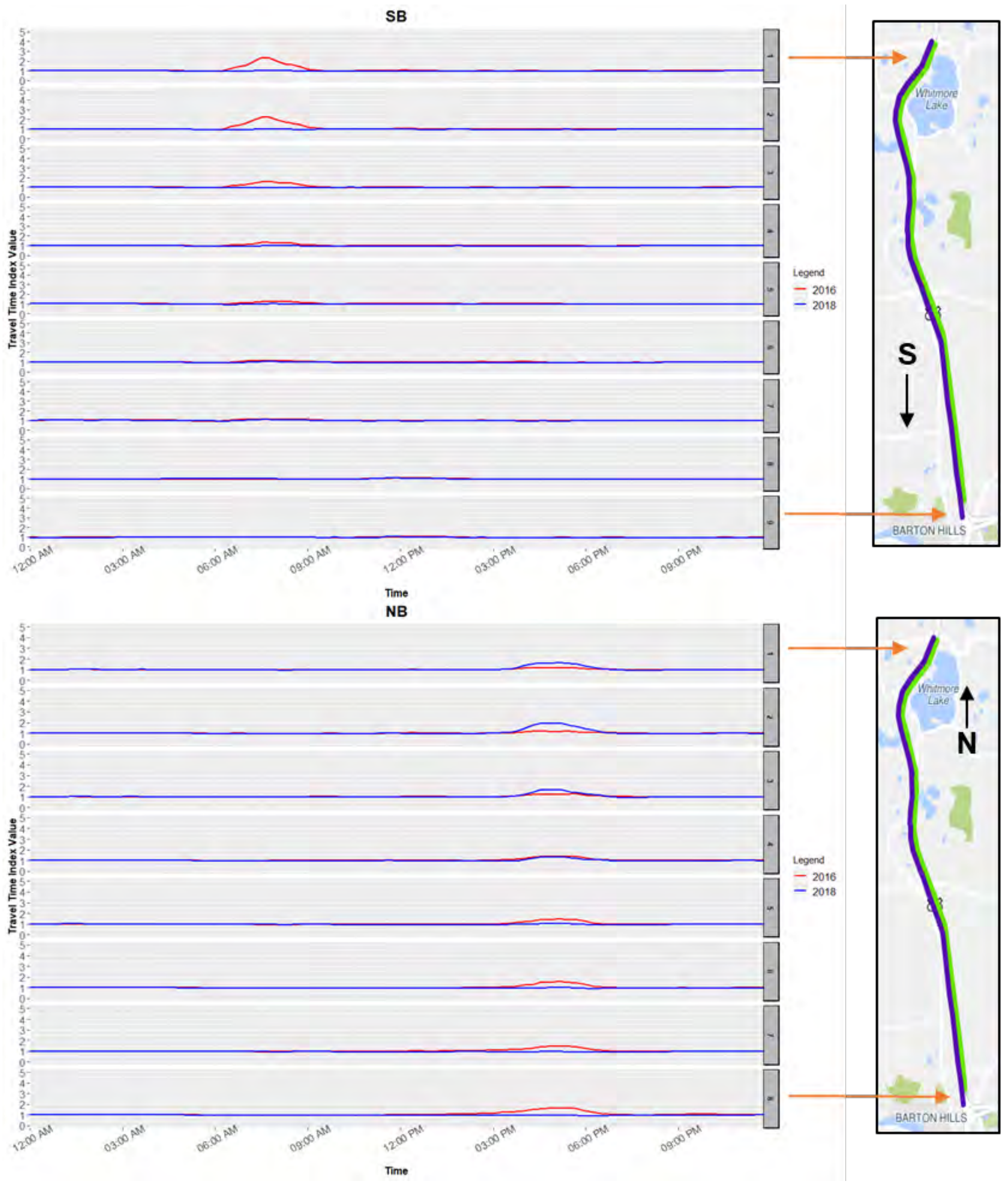
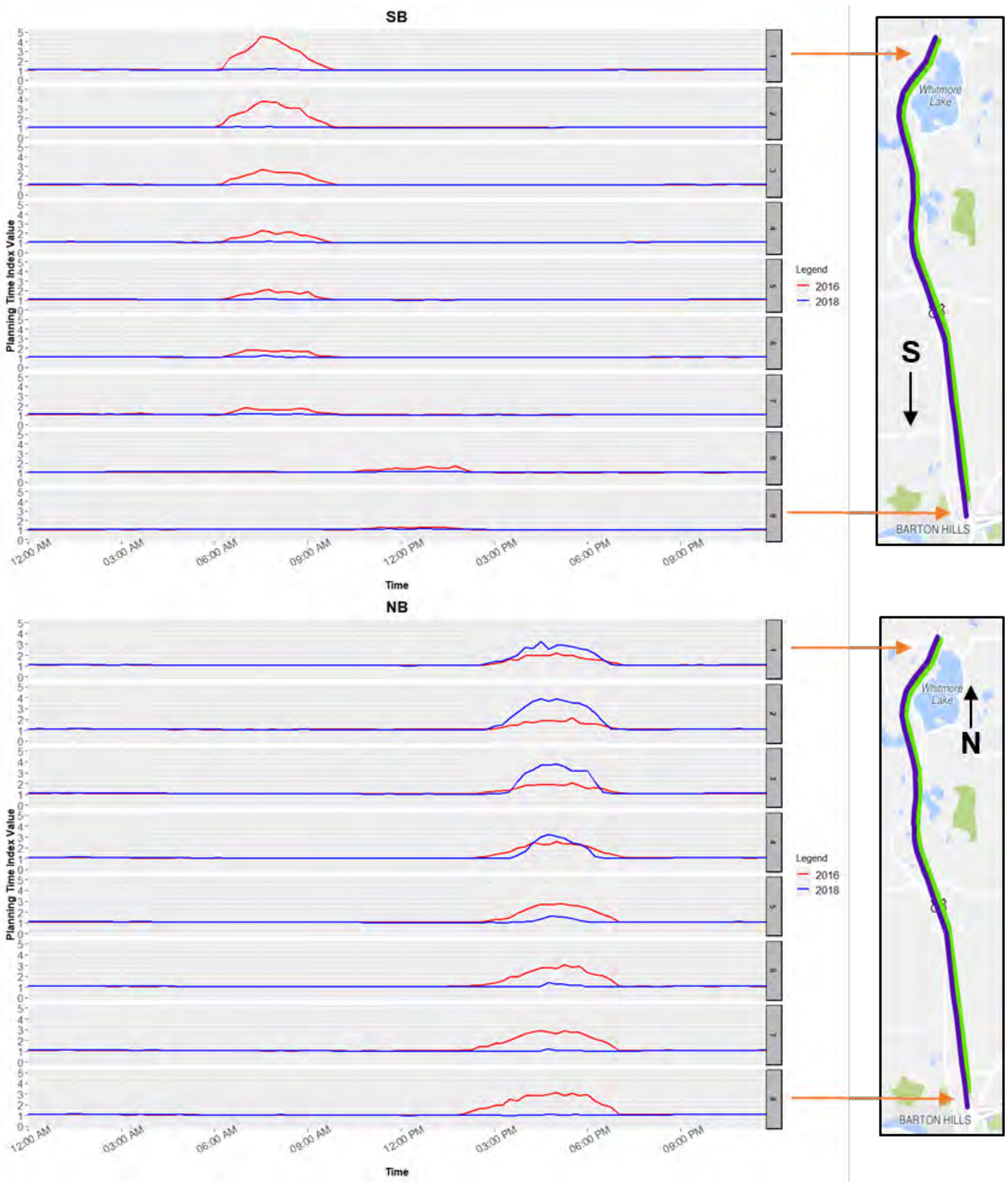
APPENDIX A

Travel Time Reliability Results

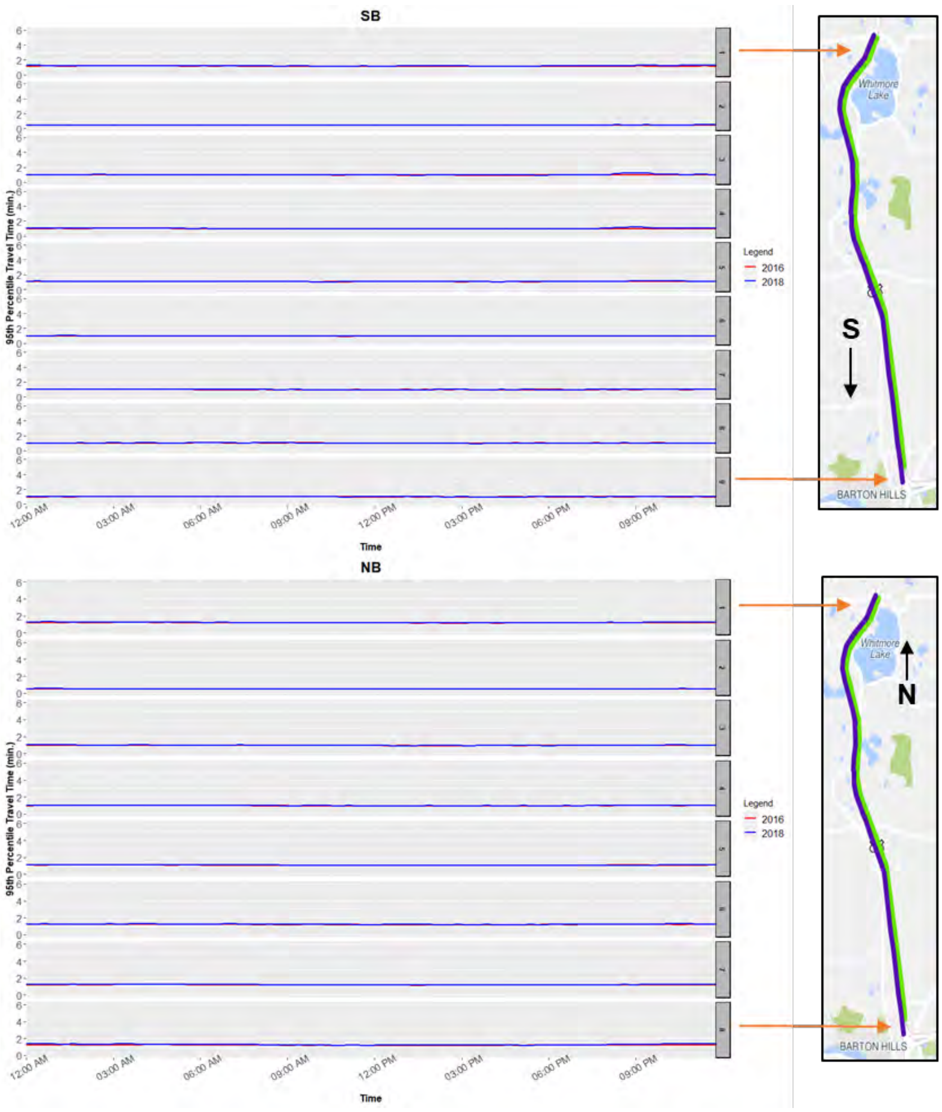


a. Plot of travel time index during weekdays

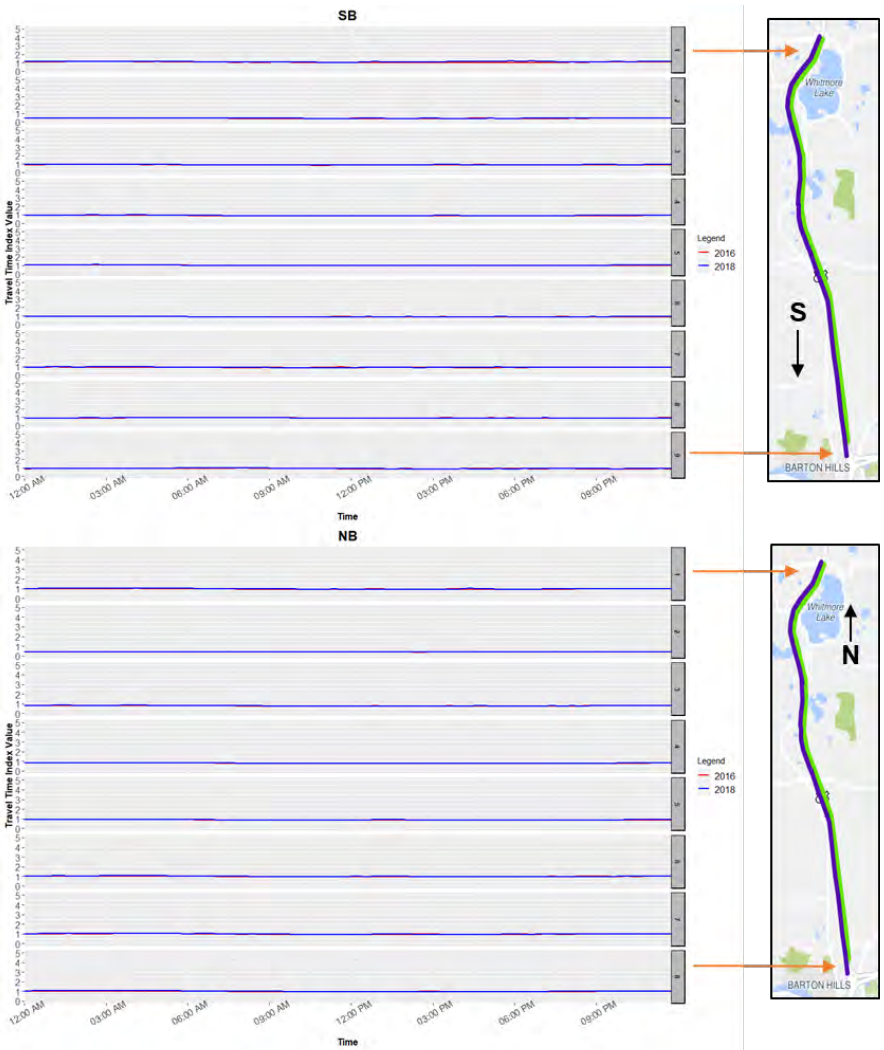


b. Plot of planning time index during weekdays

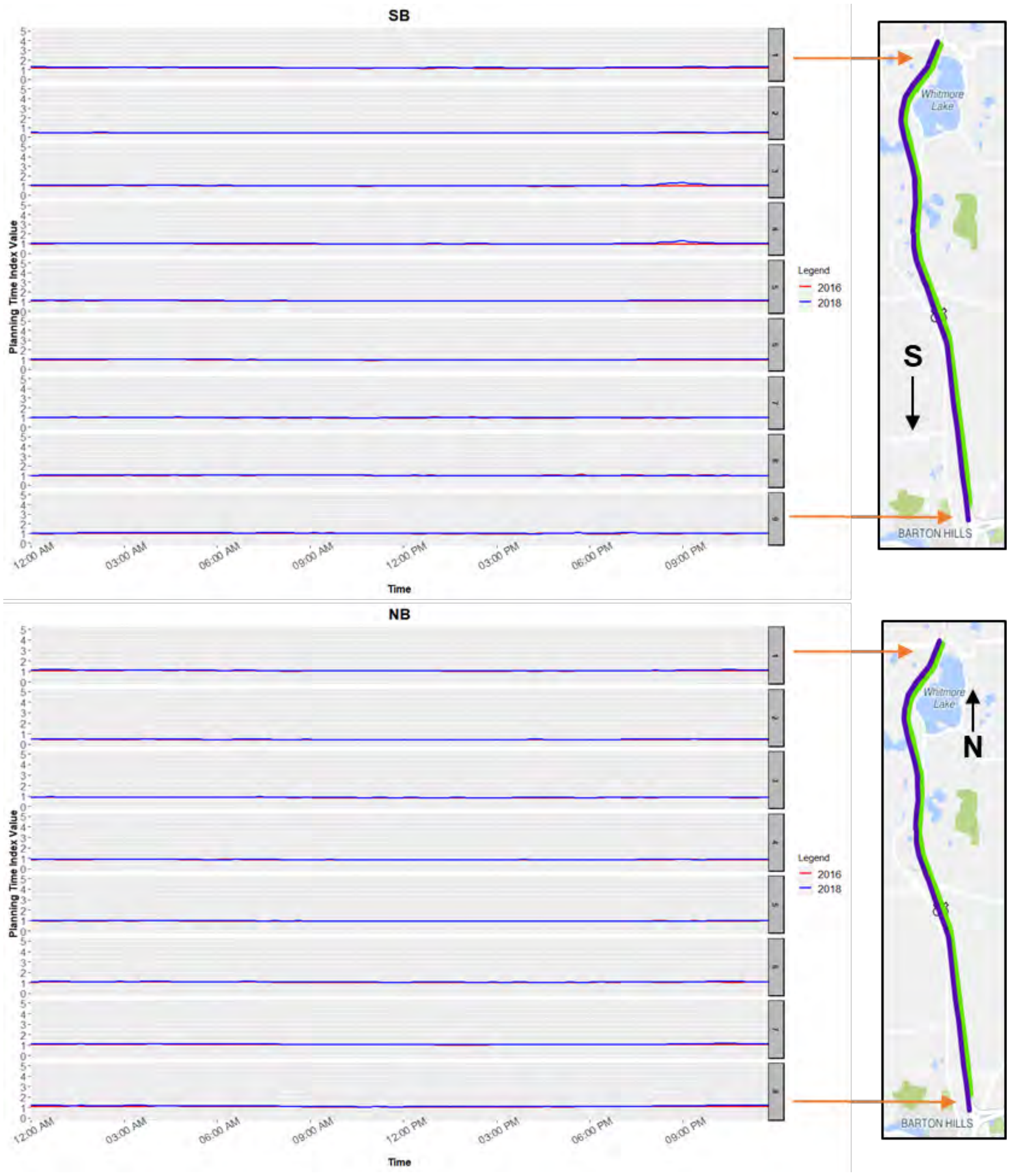
Figure A1 Additional plots of travel time reliability over time at segment-level during weekdays



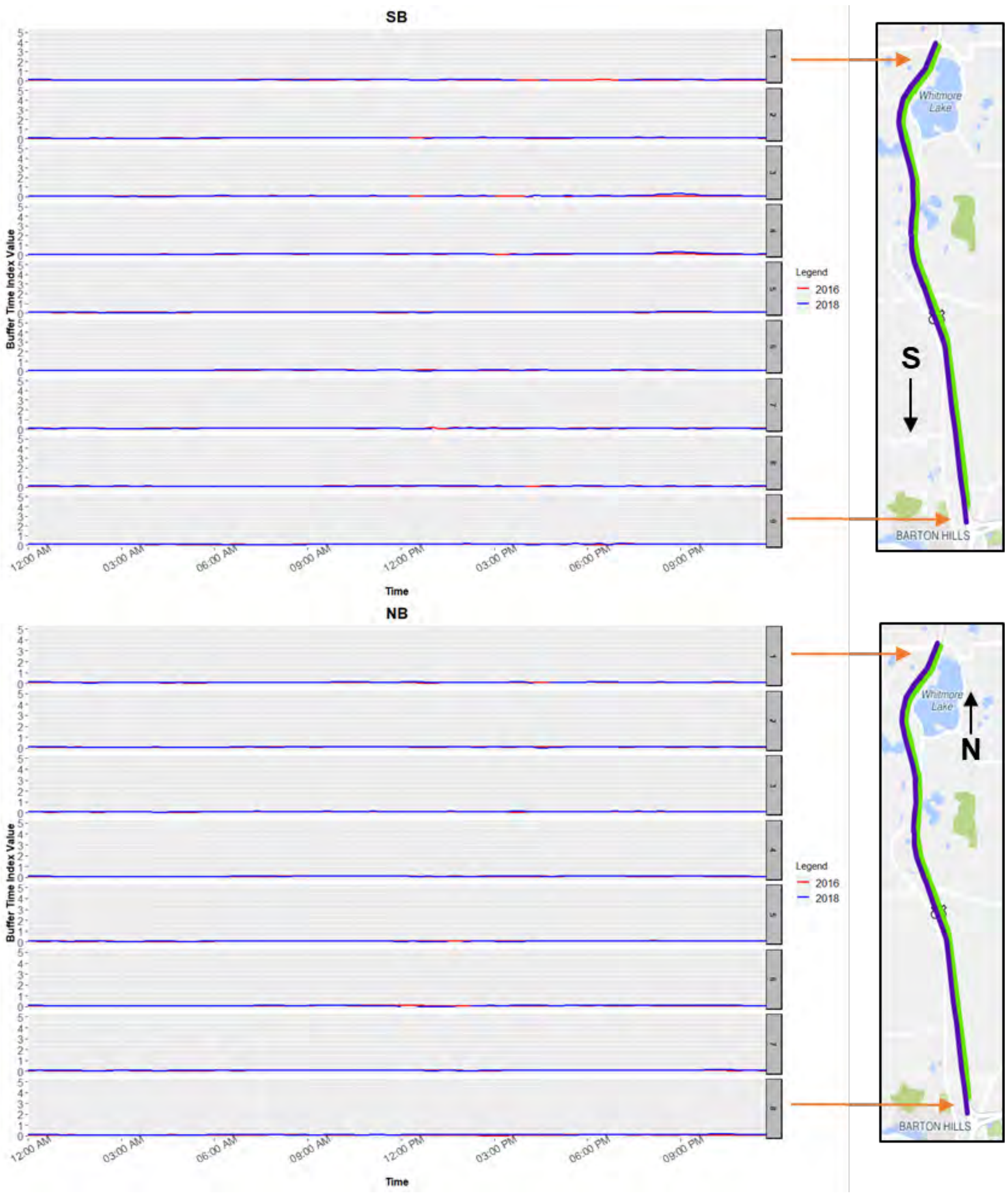
a. Plot of 95th percentile travel time during weekends



b. Plot of travel time index during weekends



c. Plot of planing time index during weekends



d. Plot of buffer time index during weekends

Figure A2 Additional plots of travel time reliability over time at segment-level during weekends

APPENDIX B

Speed and Flow Relationship for US-23 Flex Route

Table A 1 Descriptive statistics of 2018 MVDS reports

2018						
	Direction	**Variable**	**Min**	**Max**	**Mean**	**Std. Dev.**
Peak Hour	Southbound (6:00 AM - 9:30 AM)	Volume-Weight Speed (mph)	53.69	76.75	71.50	2.98
		Flow Rate (veh/h)	1370.00	3627.00	2713.00	457.08
	Northbound (3:00 PM - 7:00 PM)	Volume-Weight Speed (mph)	46.70	75.31	68.55	6.01
		Flow Rate (veh/h)	1642.00	4007.00	2887.00	459.03
Off-Peak Hour	Southbound (0:00 AM - 5: 59 AM; 9:31 AM - 11:59 PM)	Volume-Weight Speed (mph)	48.60	76.75	69.71	4.66
		Flow Rate (veh/h)	86.02	3627.37	1479.37	982.30
	Northbound (0:00 AM - 2:59 PM; 7:01 PM - 11:59 PM)	Volume-Weight Speed (mph)	46.70	75.37	69.99	3.96
		Flow Rate (veh/h)	109.80	4007.50	1270.80	877.15
Overall	Southbound	Volume-Weight Speed (mph)	48.60	76.75	70.16	4.35
		Flow Rate (veh/h)	86.02	3627.37	1463.38	938.64
	Northbound	Volume-Weight Speed (mph)	46.70	75.37	69.87	4.19
		Flow Rate (veh/h)	109.80	4007.50	1406.00	960.74

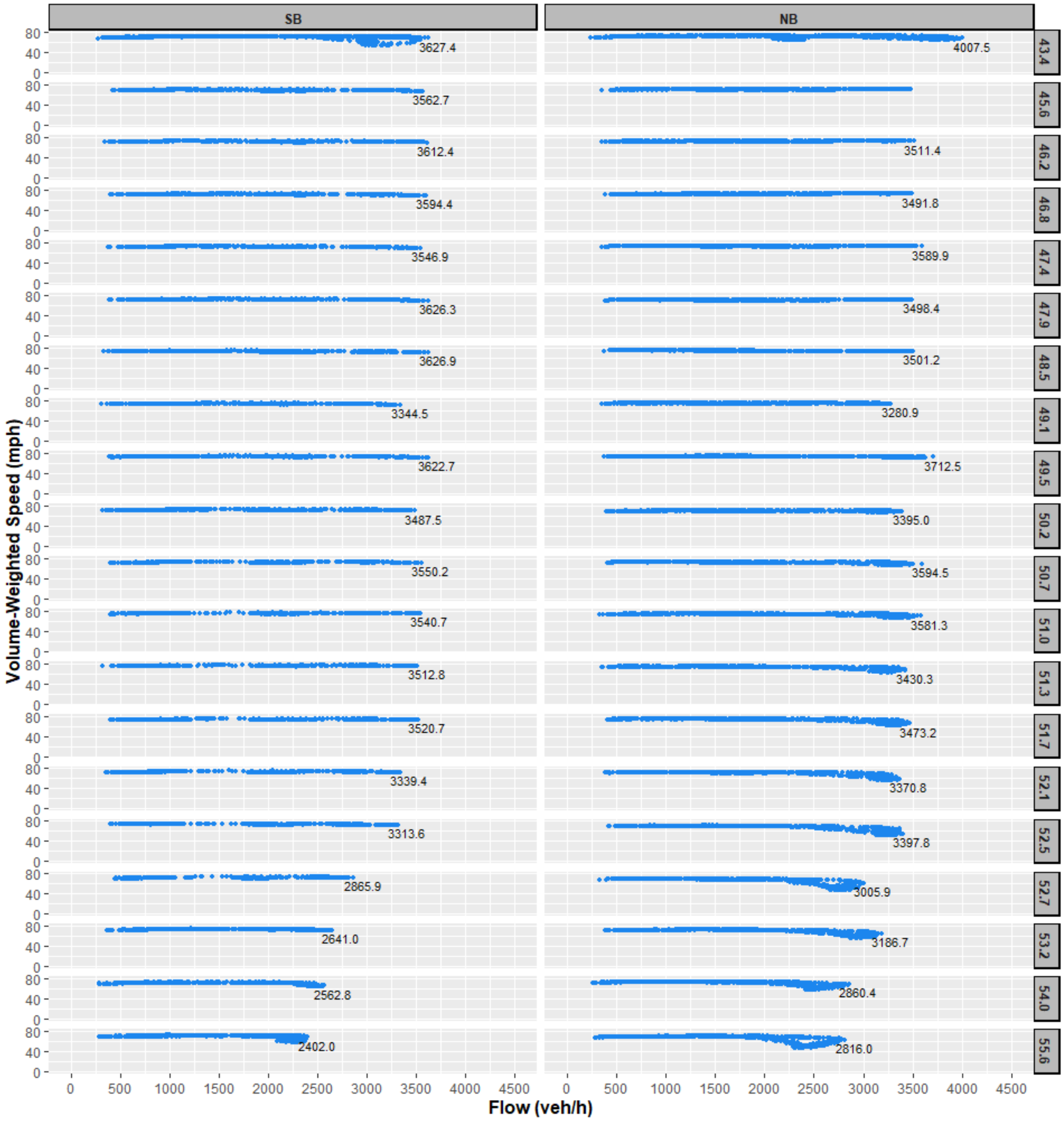
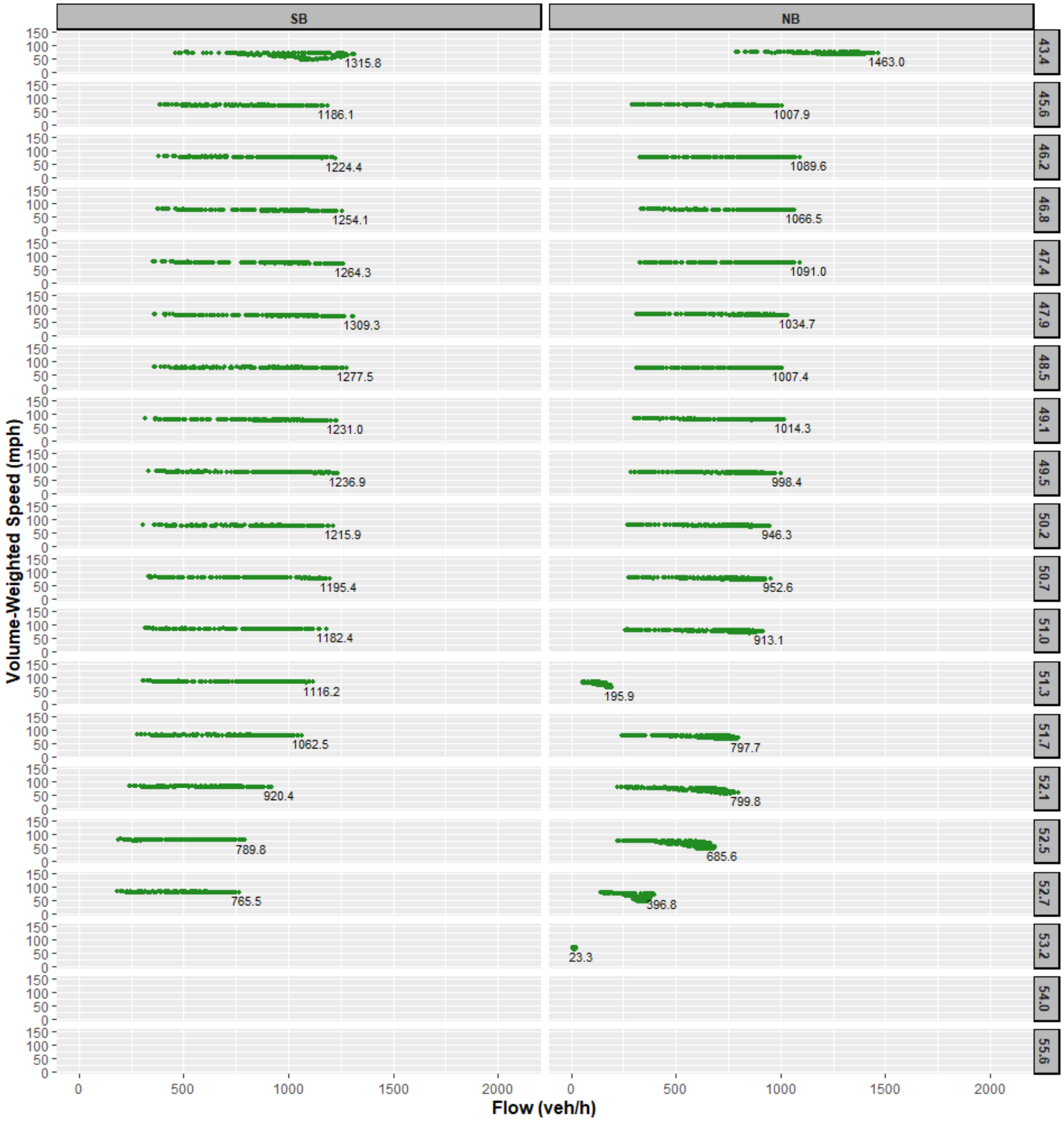
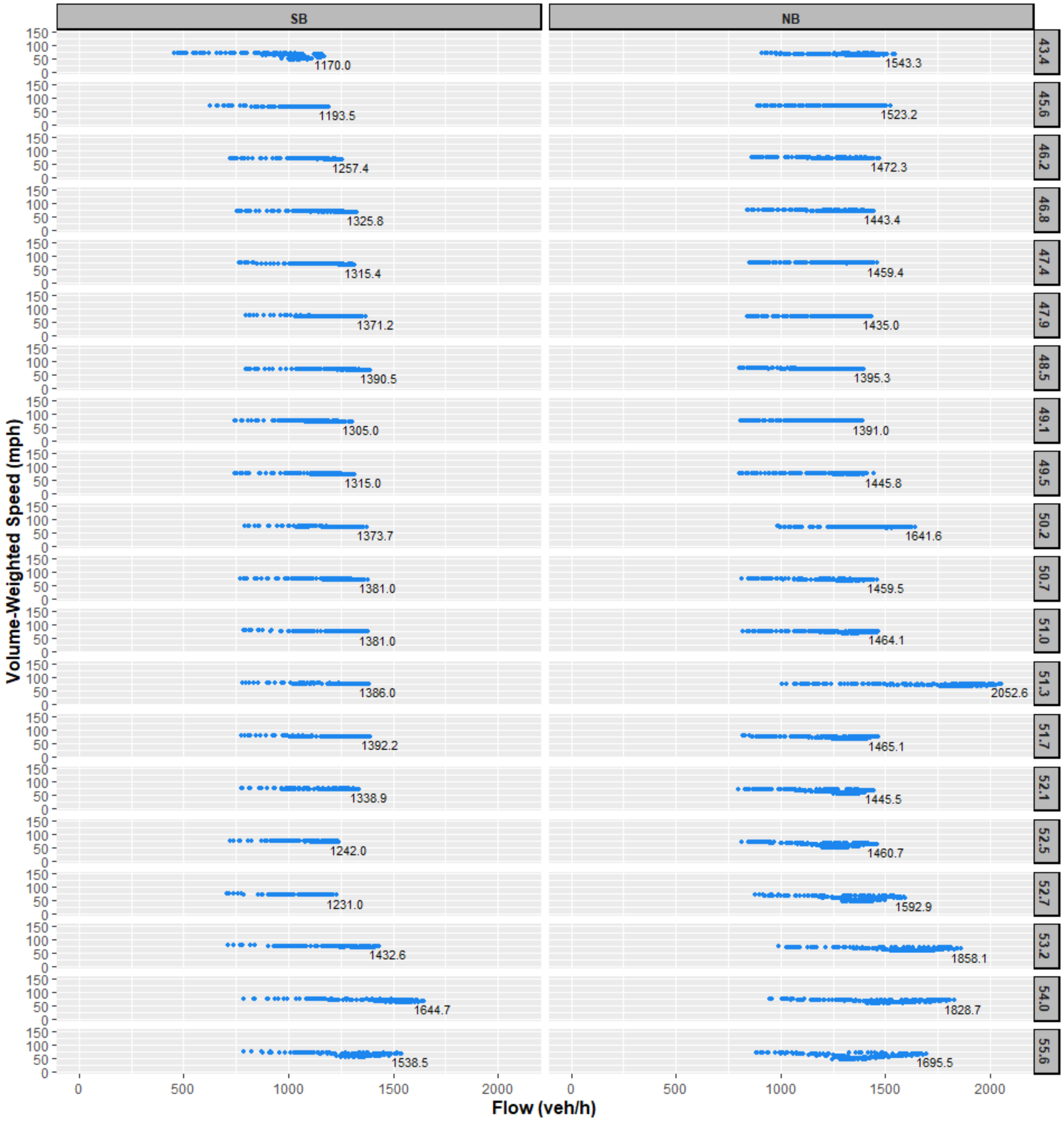


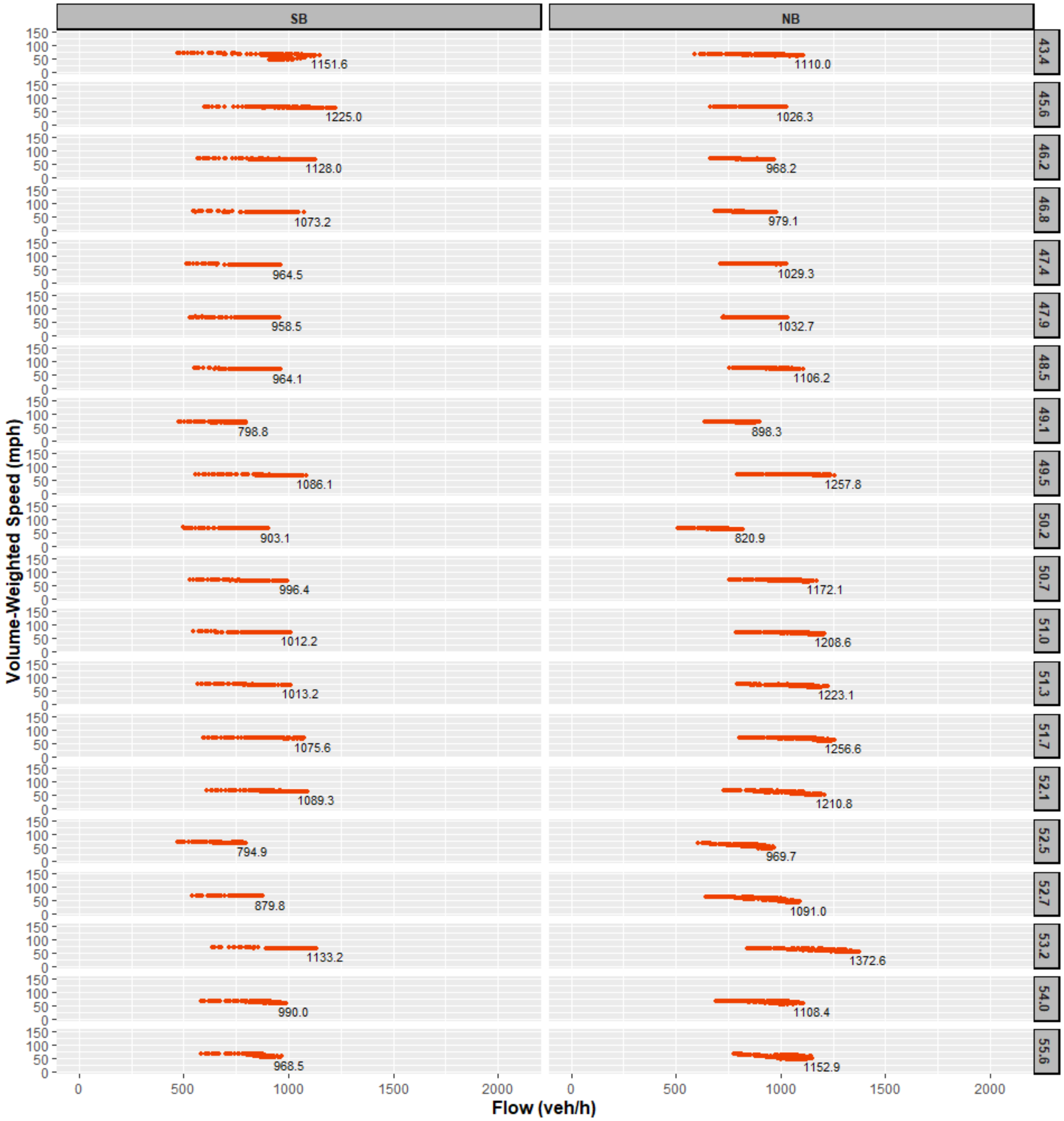
Figure A3 Speed -flow curve for US-23 Flex route in 2018 (24 hours)



a. Left shoulder (Flex lane)


SB
NB
Volume-Weighted Speed (mph)
Flow (veh/h)
1170.0
1543.3
1193.5
1523.2
1257.4
1472.3
1325.8
1443.4
1315.4
1459.4
1371.2
1435.0
1390.5
1395.3
1305.0
1391.0
1315.0
1445.8
1373.7
1641.6
1381.0
1459.5
1381.0
1464.1
1386.0
2052.6
1392.2
1465.1
1338.9
1445.5
1242.0
1460.7
1231.0
1592.9
1432.6
1858.1
1644.7
1828.7
1538.5
1695.5
43.4
45.6
46.2
46.8
47.4
47.9
48.5
49.1
49.5
50.2
50.7
51.0
51.3
51.7
52.1
52.5
52.7
53.2
54.0
55.6

b. Left lane



c. Right lane

Figure A4 Speed - flow curves for US-23 Flex route during peak hours on lane-by-lane basis in 2018

APPENDIX C

US-23 Flex Route Driver Survey

Survey code: xxxx

US-23 Flex Route Driver Survey

Implemented in 2017, the US-23 Flex Route, stretching from M-14 north of Ann Arbor to M-36 near Whitmore Lake, is a **section of highway where driving on the left shoulder is allowed** during congested periods to help improve traffic flow. In this survey, we will call this section the "**FLEX**." As this roadway concept is new to Michigan, we are seeking your feedback to help improve the operation, safety, and management practices of the Flex Route. We pictured the FLEX roadway design and its overhead sign structure on the back side of this page for reference purposes.

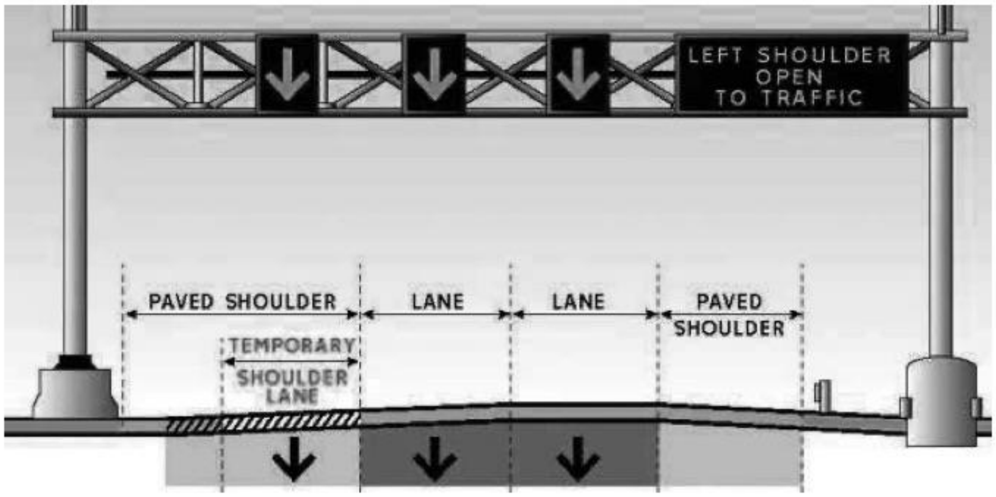
The Michigan Department of Transportation (MDOT), in collaboration with Michigan State University (MSU), have implemented this survey to assess the impact the US-23 Flex Route has had on your driving experience. Your responses will be treated as confidential and will be combined with other responses. You must be 18 years of age or older to participate in the survey. Participation in this research is voluntary and you have the right to refuse to participate in the survey or withdraw at any time.

Dr. Eva Kassens-Noor, Associate Professor at Michigan State University, is available to answer any questions you may have and can be reached at ekn@msu.edu.

Your voluntary agreement to participate is indicated by completing and returning this survey in the return envelope (*no postage necessary*) OR by filling out the survey online here: http://tinyurl.com/y6bwz482. The survey should take between 15-20 minutes to complete.

Thank you for your participation.

School of Planning, Design & Construction
101 Human Ecology
Michigan State University
East Lansing, MI 48823
517-353-5460



Suppose that the below black and yellow signs were displayed on the overhead sign structure. What do you think you should do for each? (Please describe.)

Have you driven the FLEX over the past year? (Circle one): Yes No

- If no, please return the survey (all remaining questions pertain to the FLEX)

2

The FLEX Driving Experiences, Habits, and Changes in Driving Behavior

1. Please rate your driving experience on the FLEX **over the past year**:
   a) Very dissatisfied b) Dissatisfied c) Neutral d) Satisfied e) Very satisfied
2. How has the quality of your driving experience on US-23 changed since the FLEX introduction in 2017?
   a) Much worse b) Worse c) Stayed same d) Better e) Much better f) N/A
3. **Why** do you primarily drive the FLEX?
   a. Work
   b. School
   c. Shopping/ restaurants
   d. Medical purposes
   e. Friends/Family
   f. Recreation
   g. Other long distance: ______________________
4. **When** do you primarily drive the FLEX? (please circle **up to two**)
   a. 6-9:30am
   b. 9:30am-3pm
   c. 3pm-7pm
   d. 7pm-6am
5. **How often** do you drive the FLEX? (please circle **only one**)
   a. Every day
   b. 3-4 times per week
   c. Once per week
   d. Once per month
   e. Few times per year
6. When the FLEX is in operation, you usually drive in: (please circle **only one**)
   a. The temporary lane (left shoulder)
   b. The middle lane
   c. The right lane (next to the outside shoulder)

   Please tell us why: ____
7. Has **your** driving behavior changed since the FLEX introduction? Please tell us how:
8. Has the driving behavior of **other drivers** changed since the FLEX introduction? Please tell us how:
9. Which driving behaviors have you observed while driving the FLEX (Please circle all that apply):
   a. Speeding
   b. Back and forth weaving
   c. Late merging
   d. Early merging
   e. Tailgating
   f. Other: ____________________

The FLEX performance and safety perceptions

Please rate your satisfaction with the following: (5-point scale)

Very Dissatisfied	*Dissatisfied*	*Neutral*	*Satisfied*	*Very Satisfied*	*N/A*
1	2	3	4	5	0

10. Safety: "How satisfied are you with the safety of the US-23...."
    a. ... On the **inbound** towards Ann Arbor (**in the morning**)
        - On the left/temporary lane ___
        - On the middle lane ___
        - On the right/outside lane ___
    b. ... On the **outbound** towards Brighton (**in the evening**)
        - On the left/temporary lane ___
        - On the middle lane ___
        - On the right/outside lane ___
    c. ... When an incident occurred, and the FLEX was in operation ___
    d. ... When the FLEX is **not** in operation during the day ___
    e. ... When the FLEX is **not** in operation during the night ___

The FLEX understanding

11. Do you comply with rules, e.g. the signs, markings, and regulations of the FLEX to the best of your capabilities? (Please circle one).
    a. Always
    b. Most of the time
    c. Often
    d. Sometimes
12. How often do other drivers comply to the rules of the FLEX? (Please circle one)
    a. Always
    b. Most of the time
    c. Often
    d. Sometimes
13. When the green arrow is shown on the overhead sign system, how fast are you allowed to drive in each lane?

    a. left ______________ b. middle ____________ c. right_________________
14. When approaching the end of the FLEX while driving north in the left lane towards Brighton, when do you typically merge to the regular lanes? (Please circle one)
    a. As soon as you can read the "merge" sign
    b. At the "merge" sign
    c. At the end of the FLEX lane
15. Do you ever feel as though the FLEX should be open, when it is closed?
    a. No b. Yes, when ____________________________
16. Do you ever feel as though the FLEX should be closed, when it is open?
    a. No b. Yes, when ____________________________

Please rate your satisfaction with the following: (5-point scale)

Very Dissatisfied	*Dissatisfied*	*Neutral*	*Satisfied*	*Very Satisfied*	*N/A*
1	2	3	4	5	0

17. Performance: "How satisfied are you with the performance of the FLEX on…."
    a. … the information that is provided to you en route when the FLEX is **open** ___
    b. … the information that is provided to you en route when the FLEX is **closed** ___
    c. … the ease of identifying the FLEX guidance signs ___
    d. … the ease of understanding the meaning of the FLEX messages ___
    e. … the helpfulness of the overhead sign system ___
    f. … the helpfulness of the fixed signage ___
    g. … the helpfulness of the yellow lane markings ___
    h. … the upkeep/maintenance of the FLEX ___
    i. … the time savings you experience since the FLEX introduction ___
    j. … the ease of merging from left lane to regular lanes at the end of the FLEX going north towards Brighton ___
18. Has your perception of safety increased since the FLEX was introduced? a. Yes b. No
19. How can we improve the safety and performance of the FLEX?

20. How often have you seen the crash investigation sites along the FLEX being utilized? (Please circle one).
    a. Never (skip to question 22)
    b. Every other month
    c. Once a month
    d. Once a week
21. How were the FLEX crash investigation sites utilized? (Please circle all that apply)
    a. Crash investigation
    b. Bathroom break
    c. Phone call
    d. Vehicle breakdown
    e. Other: ______________________
22. How should the FLEX crash investigation sites be utilized (Please circle all that apply):
    a. Crash investigation
    b. Bathroom break
    c. Phone call
    d. Vehicle breakdown
    e. Emergency
23. Have you ever driven on US-23 when the FLEX was opened due to a crash, vehicle breakdown, or other incident?
    a. Yes b. No (please skip to next page)
24. Do you believe the FLEX made it safer for you to pass the incident site? a. Yes b. No
25. Do you believe the FLEX made you reach your destination faster than if it had not been opened? a. Yes b. No

Demographic Information

26. Do you support the implementation of Flex Routes on other MI highways?
    a. Yes   b. No
27. Which one of the following best describes you? Are you (circle only one):
    a. Employed for pay outside your home
    b. Self-employed
    c. Student
    d. Homemaker
    e. Unemployed
    f. Retired
28. Are you?
    a. Male   b. Female   c. Other / prefer not to answer
29. What is your age?
    a. 18 to 24
    b. 25 to 34
    c. 35 to 44
    d. 45 to 54
    e. 55 to 64
    f. 65 to 74
    g. 75 or older
30. What is your total combined annual household income?
    a. Less than $10,000
    b. $10,000 to $14,999
    c. $15,000 to $19,999
    d. $20,000 to $24,999
    e. $25,000 to $34,999
    f. $35,000 to $49,999
    g. $50,000 to $74,999
    h. $75,000 to $100,000
    i. More than $100,000
31. Which do you consider yourself:
    a. African-American / Black
    b. Asian
    c. Caucasian / White
    d. Hispanic / Latino(a)
    e. Native-American Indian
    f. Pacific Islander / Hawaiian
    g. Other:_________________
32. What accommodations, disabilities, or special needs do you require assistance with?
    a. I do not have any special needs / I do not require any accommodations
    b. Blindness / visual impairment
    c. Deaf / hard of hearing
    d. Mobility disabilities
    e. Psychiatric disabilities
    f. Other:_________________
33. How many cars does your household own? _____
34. Do you have any other comments about the FLEX?