Evaluation of the I-94 Corridor from the Indiana State Line to US-127 South

FINAL REPORT

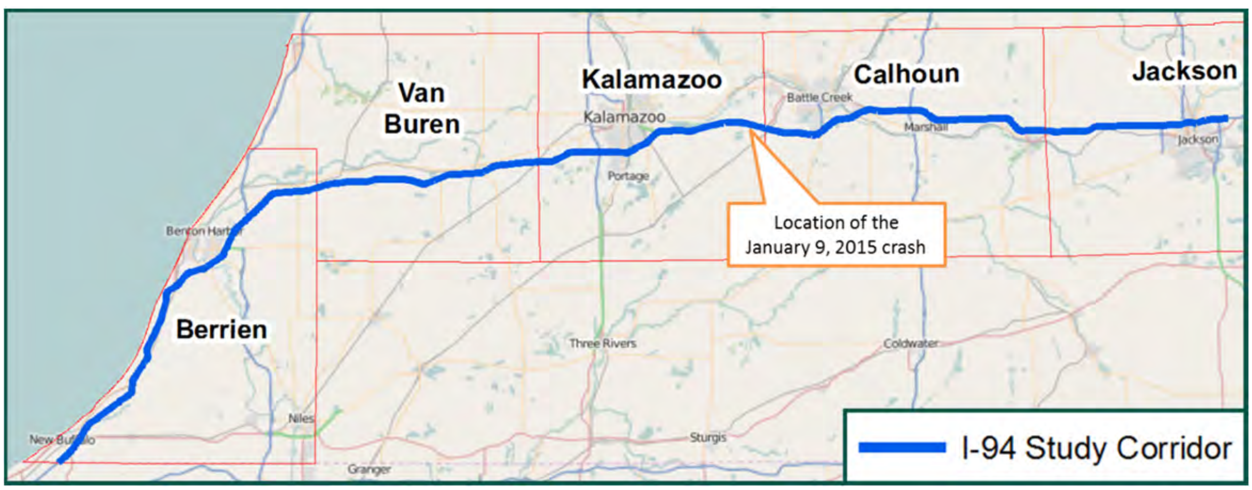
Prepared in cooperation with the Michigan Department of Transportation, Michigan State Police and the Federal Highway Administration.

October 26, 2015

EXECUTIVE SUMMARY

On the morning of January 9, 2015 at approximately 9:20 A.M., first responders were dispatched to address a multiple vehicle crash which had occurred near mile marker 90 along I-94 in Kalamazoo County. Initial units arriving on the scene reported multiple strings of crashes located in all travel lanes as well as the center median and shoulders in both the eastbound and westbound directions. Further, fire was evident in the pile of vehicles located in the eastbound travel direction.

In the wake of this major crash event, State Senator Margaret O'Brien submitted a letter to the Michigan Department of Transportation (MDOT), which was followed by a subsequent inquiry from Governor Rick Snyder, regarding the safety of I-94 in eastern Kalamazoo County. Shortly thereafter, MDOT committed to a safety evaluation of the I-94 corridor between the Indiana border and US-127 South in Jackson County. The decision to expand the corridor boundaries was largely due to MDOT's concern with the occurrence of major crashes in the prior year and associated extensive freeway closure durations. Approximately 143 continuous miles of I-94 were included within this study, including all sections of the corridor in Berrien, Van Buren, Kalamazoo, Calhoun, and the western portion of Jackson County, as displayed in the figure below.



I-94 Study Corridor in Southwest Michigan

This report provides details of the safety evaluation of the I-94 corridor between the Indiana border and US-127 South in Jackson County. The team included engineers, safety experts, and law enforcement officers from the Federal Highway Administration (FHWA), Michigan State Police (MSP), and the Michigan Office of Highway Safety Planning (OHSP), among others. The study incorporated an engineering review of extensive data, including recent crash patterns, roadway geometry, cross-sectional characteristics, barrier locations, related weather conditions, incident management, and initiatives of various agencies. A series of county-level safety reviews were performed, including field reviews of locations with high crash concentrations, in addition to detailed reviews of the crash reports at targeted areas to identify specific safety issues, trends, and patterns, and develop potential safety countermeasures and recommendations. The findings, conclusions, and recommendations (both corridor-wide and site-specific) that resulted from this study are summarized as follows.

Corridor Safety Findings

The findings of this review indicated that the study corridor, as a whole, experiences crashes at a rate that is comparable with other freeway corridors in Michigan. Like other corridors, specific influences of weather, atmospheric conditions, geometry, lighting, traffic volumes, driver behavior, and other factors result in above average crash rates in specific areas. It is worth noting that the portion of the corridor where the 193-vehicle crash occurred in January of 2015 is historically not an area with above average crash occurrence. The specific safety findings are summarized as follows:

- A total of 6,678 crashes occurred along the study corridor (mainline) between 2012 and 2014, including 5,840 (87.5 percent) that did not involve deer. The overall corridor crash rate during this period was 101.12 crashes (88.43 non-deer crashes) per 100 million vehicle miles traveled.
- From 2012 – 2014, the I-94 study corridor had an overall crash rate that was similar to the statewide average for freeways with 70 mph posted speed limits. However, during this same period, the study corridor experienced a winter season (December – February) crash rate that was 24 percent greater than the other statewide 70 mph freeways. Only I-196 and US-131 demonstrated greater winter season crash rates than the study corridor during this period.
- Crashes occurred 16.3 percent more frequently in the eastbound direction compared to westbound. Eastbound crashes were particularly overrepresented in Berrien, Van Buren, and Jackson Counties. This directional disparity may be attributed to differing geometric conditions between the two directions, particularly near interchanges.
- Considering all counties included in the study corridor, crash rates (per 100 million VMT) were greatest in Van Buren County, particularly in the eastbound direction and especially during winter months, when the eastbound crash rate is 65 percent greater than the eastbound corridor average. Overall crash rates in Berrien, Kalamazoo, Calhoun, and Jackson Counties were not significantly different from each other, although winter crash rates were significantly lower in Jackson County compared to the other counties.
- Approximately 65 percent of the winter season crashes involved a vehicle driving "too fast for conditions", compared to only 38 percent of all-season crashes. This suggests that speed plays a greater role in winter-season crashes compared to other seasons. This also supports the Michigan

State Police findings from the January 9, 2015 crash, in which a total of 58 drivers were cited for driving too fast for conditions, including 30 commercial drivers.

- A statistical analysis of crashes on the I-94 study corridor was performed to determine the impacts of various roadway, geometric, weather, and roadside factors. The factors that were found to correlate to a higher rate of overall crash occurrence included:
    - Interchange presence,
    - Significant horizontal curvature,
    - Limited stopping sight distance (due to vertical curvature), and
    - Segments with only two lanes in each direction.
- Similar results were also found for winter crashes. However, in addition, a very strong correlation between average annual snowfall and crashes was also determined. This finding helps explain the extreme overrepresentation of winter crashes in Van Buren County, which typically experiences the greatest snowfall totals along the study corridor.

Corridor-wide Recommendations

Improving roadway safety takes significant efforts from all stakeholders, including the transportation agencies that own, operate, and maintain the roadways; enforcement agencies; first responders; policy makers; and ultimately the motorists traveling along the roadway. The findings of this report compliment the ongoing safety efforts of MDOT and MSP by identifying crash concentrations, contributing factors, and possible solutions. While statewide trends for serious crashes have generally improved over the past several years, opportunities for significant improvement still remain. Several corridor-wide recommendations were made as a result of the findings of this study, which are provided as follows. By incorporating these recommendations (along with the site-specific recommendations, as funding permits), the corridor review team believes continual improvements in crash and severity reductions can be made along the I-94 study corridor.

- MDOT should continue data driven crash mitigation efforts, focusing on the highest priority crash locations, and utilizing the most cost effective strategies to improve safety. Several safety related improvement projects have recently been completed along the I-94 study corridor, and several more are scheduled to occur over the next five years. As future projects become funded, incorporation of crash and crash severity reducing strategies into these projects should continue to be evaluated.
- It is also recommended that MDOT continue improving operational and roadway maintenance procedures to further enhance roadway safety. Utilizing historic crash information along with

implementation of pavement condition forecasting technology can assist with maintaining historically problematic winter crash areas.

- Efforts toward improving driver behavior should also continue to occur. The frequency and severity of crashes can be reduced when drivers maintain a safe speed for the roadway conditions. Continuing campaigns by enforcement agencies is recommended. Additionally, efforts to inform motorists of adverse driving conditions should be continued, but must be timely and specific. This may include communication of roadway conditions via dynamic message signs or other technology or temporary reduction of statutory roadway speed limits via variable speed limit displays. It is recommended that specific legislation be enacted to legally accommodate the latter. At this time only a lower advisory speed could be displayed.

Site-Specific Recommendations

A series of site reviews were performed to help identify specific areas of high crash occurrence and develop recommendations to address the associated safety issues. The following countermeasures were considered:

- Winter Weather Treatments
    - Environmental sensor stations
    - Variable speed limits
    - ITS devices providing weather-related messages
    - Advanced de-icing strategies
    - Living snow fence (strategic planting of roadside vegetation)
- Pavement Surface Treatments
    - Resurfacing
    - High friction course
- Visibility Enhancements
    - Signing
    - Pavement markings
    - Delineation
    - Lighting
- Geometric Improvements
    - Cable barrier relocation
    - Ramp extension or realignment
    - Shoulder widening
    - Increased superelevation

- Congestion Management
    - Crash investigation pull-off site
    - Courtesy patrol
    - Incident management improvements
    - ITS devices providing queue warning messages
    - Add third lane

Environmental Sensor Station

Variable Speed Limit Sign

Severe Weather Warning Sign

Dynamic Message Sign

Examples of Potential Treatments

The following table presents a summary of recommended potential improvements and associated timeframes for the high-crash areas of the study corridor, along with additional projects that have been recently implemented or programmed for future implementation at each location.

Summary of Potential Site Improvements

Location/County	Resurface/ Friction Course	Superelevation/ Slope Improvements	Shoulder Widening	Ramp Extension/ Realignment	Signing/Marking /Delineation	Cable Barrier Relocation	Enviro. Sensor Station	ITS*	Living Snow Fence	Advanced De-icing	Lighting	Crash Investigation Site	Courtesy Patrol/ Incident Mgmt.	Add Lane
Exit 4 (US-12), Berrien				L	S									
Exit 12 (Sawyer Road), Berrien					I									
MM 22-24, Berrien	P/M	P	P			M	M	M	L	S	L			
Exit 29 (Pipestone Road), Berrien				L										
Exit 34 (I-196), Berrien							P							
MM 36-39, Berrien	S/M			M		M	P	M	L	S	L			
MM 40, Berrien	S/M													
MM 43-49, Van Buren	S/M			M/L		M	P	S/M	P	S				
Exit 52 (CR 365), Van Buren	S/M													
MM 52-57, Van Buren	I (WB) P (EB)	I (WB) P (EB)	I (WB) P (EB)	L	S		M	M	P	S				
Exit 60 (M-40), Van Buren							P							
MM 61-64 (EB),Van Buren	S/M				S	M	P	M	L	S				
Exit 66 (CR 652), Van Buren				M/L		M								
Exit 74 (US-131), Kalamazoo	P	M			I/P		M	M		S	L		S/M	
MM 77-78, Kalamazoo	S/M			M/L	P									
MM 79-81, Kalamazoo	P (WB)	I	P (EB)	I	S		M	M		S			S/M	L
MM 81-87, Kalamazoo							P					P		
MM 87-89 (WB), Kalamazoo	P	P	P	P	P		P	S/M		S				
MM 89-92, Kalamazoo						M								
MM 92-93 Calhoun	P	M		I	P/S			M		S				
Exit 96 (M-66), Calhoun					S									
Exit 100 (Beadle Lake), Calhoun					S									
MM 101-102, Calhoun	P				P		M	M		S				
Exit 104 (M-96), Calhoun				M/L	S									
Exit 108 (I-69), Calhoun		M		L	I/P		P			S	L			
MM 130-131, Jackson									L					
MM 138-141, Jackson	P	P	P	P				M		S	L		I	P

Key: Short-Term (S), Medium-Term (M), Long-Term (L); Recently Implemented (I); Programmed (P)
* May include: variable speed limits, weather or pavement surface alerts/messages from environmental sensor station, queue warning devices, etc.

TABLE OF CONTENTS PAGE

LIST OF FIGURES **PAGE**

LIST OF TABLES PAGE

1.0 INTRODUCTION AND BACKGROUND

On the morning of January 9, 2015 at approximately 9:20 A.M., first responders were dispatched to address a multiple vehicle crash which had occurred near mile marker 90 along I-94 in Kalamazoo County. Initial units arriving on the scene reported multiple strings of crashes located in all travel lanes as well as the center median and shoulders in both the eastbound and westbound directions. Further, fire was evident in the pile of vehicles located in the eastbound travel direction.

Additional reports from the scene indicated that exceedingly difficult driving conditions were present due to blowing snow and poor roadway surface conditions. Upon arriving at the scene, first responders began to attempt to control the fire as well as perform extraction and rapid patient removal. These activities were complicated by the additional vehicles continuing to collide into the existing pileup as well as ambient temperatures of 15 degrees Fahrenheit and northerly wind speeds of 10 mph.

In total, 193 vehicles were involved in the incident. This included 60 vehicles in the eastbound direction (26 of which were commercial vehicles) and 133 vehicles in the westbound direction (50 of which were commercial vehicles). The affected areas included approximately ½ mile of limited access freeway in each travel direction. Further complicating the crash scene, one of the involved tractor trailers was hauling 44,600 pounds of liquid formic acid and another was loaded with 40,000 pounds of commercial-grade fireworks. In total, the pileup incident resulted in 23 injuries which required hospitalization, including one fatality of a tractor trailer driver. A total of 58 drivers, including 30 drivers of commercial vehicles, were ultimately cited for driving too fast for conditions by the Michigan State Police (MSP), a primary cause of many of the crashes comprising the pileup incident. It should be noted that speeds shortly before collision for a sample of vehicles involved in this crash typically ranged between 20 and 45 mph.

In the wake of this major crash event, State Senator Margaret O'Brien submitted a letter to Michigan Department of Transportation (MDOT), which was followed by a subsequent inquiry from Governor Rick Snyder, regarding the safety of I-94 in eastern Kalamazoo County. Shortly thereafter, MDOT committed to a safety evaluation of the I-94 corridor between the Indiana border and US-127 South in Jackson County. The decision to expand the corridor boundaries was largely due to MDOT’s concern with the occurrence of major crashes in the prior year and associated extensive freeway closure durations. Overall, the portion of the corridor included in this study was comprised of approximately 143 miles of freeway in each direction of travel, for a total of 286 directional freeway miles. The section of the I-94 corridor that was included in this study is shown in Figure 1 below.

Figure 1. I-94 Study Corridor in Southwest Michigan

The study corridor incorporates five counties: Berrien, Van Buren, Kalamazoo, Calhoun, and the western portion of Jackson County. The majority of the study corridor is within the MDOT Southwest Region, with the exception of the Jackson County portion, which falls within the University Region. The corridor passes near or through several census urban areas; including New Buffalo, Benton Harbor, Kalamazoo, Battle Creek, and Jackson, Michigan. The corridor also includes 57 interchanges in the westbound direction, and 56 interchanges in the eastbound direction.

The study incorporated an engineering review of extensive data, including recent crash patterns, roadway geometry, cross-sectional characteristics, barrier locations, related weather conditions, incident management, and initiatives of various agencies. The team included engineers, safety experts, and law enforcement officers from the Federal Highway Administration (FHWA), Michigan State Police, and the Michigan Office of Highway Safety Planning (OHSP), among others. Results of post action briefings from prior incidents, including the January 9, 2015 crash, were considered and, as result, appropriate short and long-term actions are recommend within this report for consideration.

2.0 DATA COLLECTION

One of the primary study tasks was to collect data for relevant attributes along the study corridor. Data were collected for the most recently available 3-year period, typically 2012 to 2014, if applicable. The following data were collected for the study corridor:

- Roadway inventory and average annual daily traffic volume data (total and commercial);
- Historical traffic crash data for the most recent three years (2012 to 2014);
- Historical weather data;
- Horizontal curvature;
- Vertical profile;
- Adjacent roadside assessment data;
- Pavement friction data;
- Vehicular speed data;
- Cable median barrier installation data;
- Field safety reviews of the study corridor;
- UD-10 crash review for selected high crash areas; and
- Anecdotal comments from MDOT and MSP staff.

2.1 Roadway Inventory and Traffic Volume Data

Initially, it was necessary to identify the roadway inventory and basic features of the study corridor. This was completed by identifying all corridor segments within the most recent MDOT Roadway Sufficiency Report. The following information was obtained from the MDOT Roadway Sufficiency Report for each study segment:

- County and MDOT region;
- Lane width and number of lanes;
- Shoulder type and width;
- Median type and width (including barrier type); and
- 2012-2013 AADT (total and commercial).

Several available attributes from the sufficiency file are summarized in Table 1. Mean annual average daily traffic (AADT) and commercial annual average daily traffic (CAADT) volumes for the study corridor are displayed in greater detail in Figures 2 through 4 as well as Appendix B. It can be observed from Table 1 that AADT was substantially higher than the corridor average in Kalamazoo County and substantially lower in Van Buren County. Commercial AADT was also highest in Berrien County and lowest in Van Buren County.

Table 1. Basic Characteristics of I-94 Study Corridor

County	Total Miles	Mean Number of Lanes	Mean Lt. Shoulder Width	Mean Rt. Shoulder Width	Number of Interchanges	Mean AADT*	Mean CMV AADT*
Berrien	42.8	2.8	8.7	10.4	17	43,120	10,219
Van Buren	24.1	2.0	8.9	10.2	5	34,320	7,251
Kalamazoo	25.1	2.3	9.9	10.5	10	53,750	9,025
Calhoun	31.4	2.0	8.0	10.3	14	40,226	8,821
Jackson	19.6	2.0	7.8	10.0	11	38,008	8,015
All Counties	143.0	2.3	8.7	10.3	57	42,174	8,900

Lane width = 12 ft. for entire study corridor
*Includes both directions

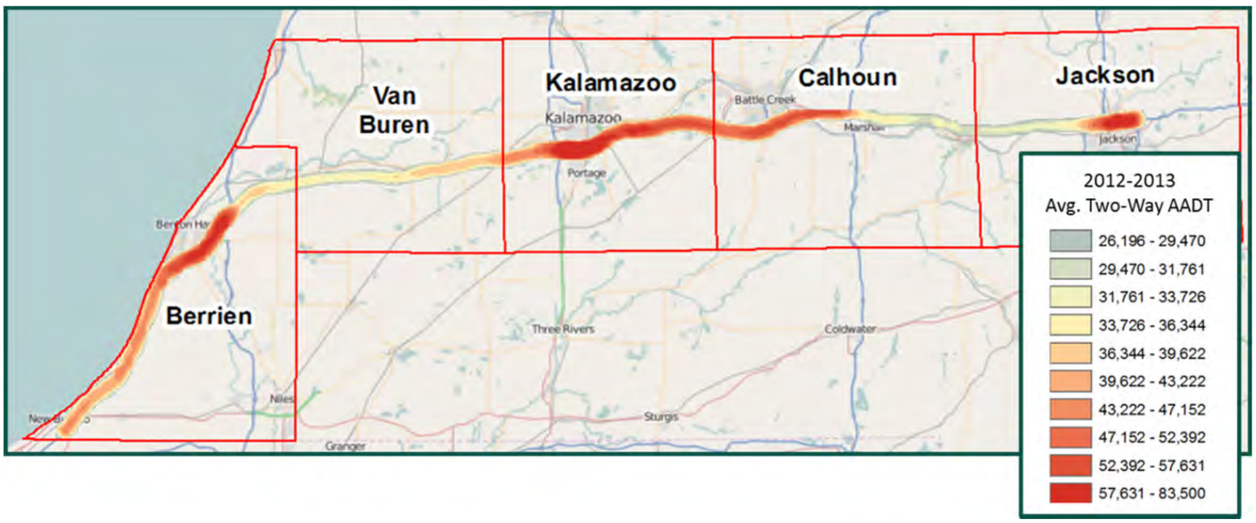


Figure 2. I-94 Study Corridor AADT, 2012-2013

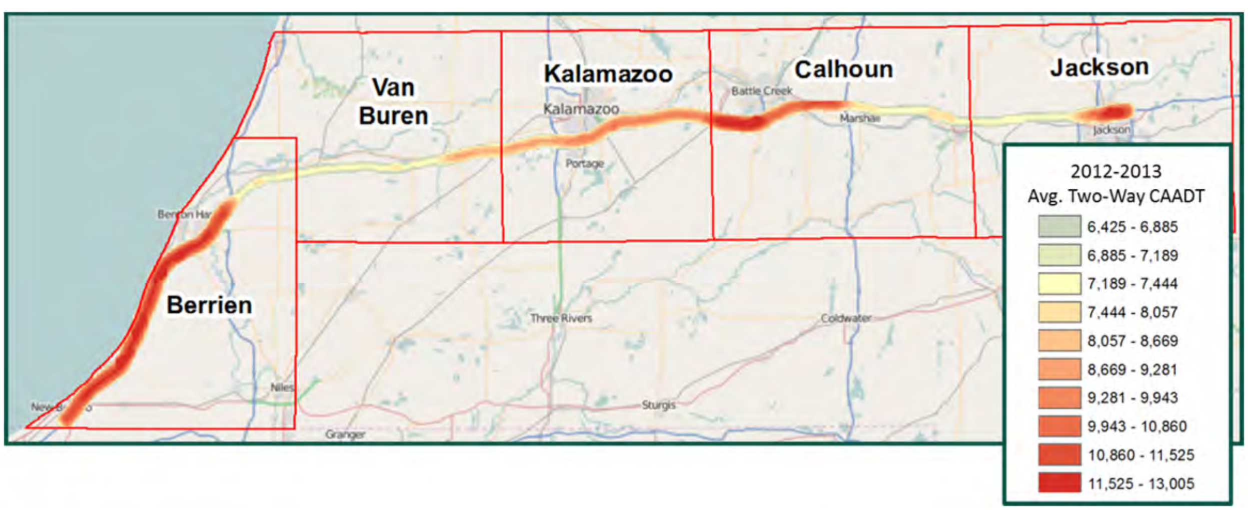


Figure 3. I-94 Study Corridor Commercial AADT, 2012-2013

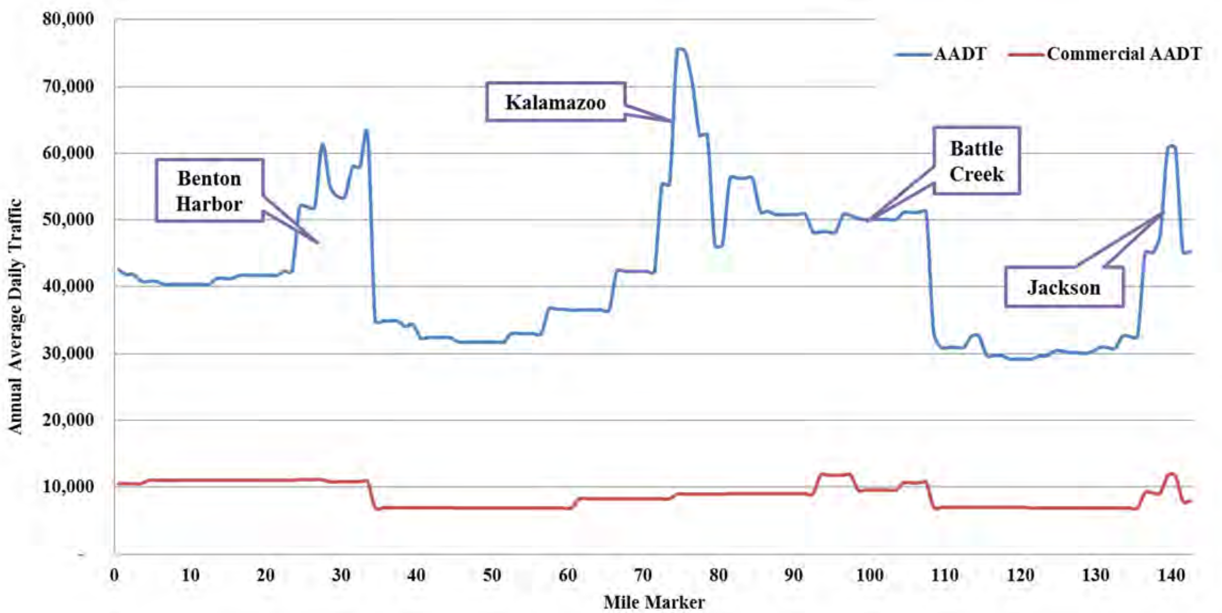


Figure 4. I-94 Study Corridor Mean AADT and Commercial AADT, 2012-2013

2.2 Traffic Crash Data

Upon identification of the appropriate roadway sufficiency file segments for the study corridor, historical traffic crash data from 2012 – 2014 (three most recently available years) were queried from the MSP crash database and merged with the sufficiency file data. The decision to utilize only the most recent three years of crash data follows standard MDOT practice for safety analyses and helps reduce uncontrolled temporal bias from reconstruction performed along the corridor prior to 2012 and also accounts for most cable median barrier installations along the corridor. The following information was obtained from each UD-10 crash report:

- Roadway area type (i.e. interchange vs. non-interchange-related crashes);
- Date and time of the crash;
- Crash type and severity;
- Deer, truck/bus, or work zone involvement;
- Drug or alcohol involvement;
- Light, weather, and road condition during the crash; and
- Number of involved vehicles.

In order to identify multi-vehicle "pileup"- type crashes, defined for this study as crashes involving five or more vehicles, a secondary screening process was also performed. The process for identifying these pileup crashes included:

- Occurred within 30 minutes of each other;
- Occurred within one mile of each other by coded location; and
- Involved five or more total units across all crashes.

A total of 6,678 crashes occurred along the study corridor between 2012 and 2014, including 5,840 that did not involve deer. A summary of the county-by-county traffic crash data for 2012 – 2014 is summarized by in Table 2 and Figure 5. Further assessment of crash rates (normalized by vehicle miles traveled) is provided in section 3 of this report. The complete mile-by-mile list of crash frequencies and rates, both overall and directionally, is provided in Appendix A.

Table 2. Traffic Crash Counts for I-94 Study Corridor, by County, 2012-2014

County	Dir.	Total Miles	All Crashes	Non-Deer Crashes	Injury Crashes (KABC)	Fatal Crashes	Winter Crashes (Dec-Feb)	Truck/Bus Crashes	5+ Pileup Crashes
Berrien	Both	42.8	1,840	1,636	287	7	805	370	14
Van Buren	Both	24.1	1,113	1,010	177	3	622	232	21
Kalamazoo	Both	25.1	1,389	1,257	252	5	582	211	29
Calhoun	Both	31.4	1,442	1,222	209	4	595	218	18
Jackson	Both	19.6	894	715	128	2	289	132	10
All Counties	Both	143.0	6,678	5,840	1,053	21	2,893	1,163	92
Berrien	EB	42.8	1049	938	159	2	461	218	10
Van Buren	EB	24.1	627	569	96	3	340	125	15
Kalamazoo	EB	25.1	690	626	132	2	265	104	14
Calhoun	EB	31.4	736	617	96	2	277	103	7
Jackson	EB	19.6	488	385	62	0	156	68	6
All Counties	EB	143.0	3,590	3,135	545	9	1,499	618	52
Berrien	WB	42.8	805	711	121	5	324	133	4
Van Buren	WB	24.1	476	431	75	0	262	91	6
Kalamazoo	WB	25.1	694	628	115	3	308	95	15
Calhoun	WB	31.4	725	613	106	2	303	101	11
Jackson	WB	19.6	388	322	58	2	116	53	4
All Counties	WB	143.0	3,088	2,705	475	12	1,313	473	40

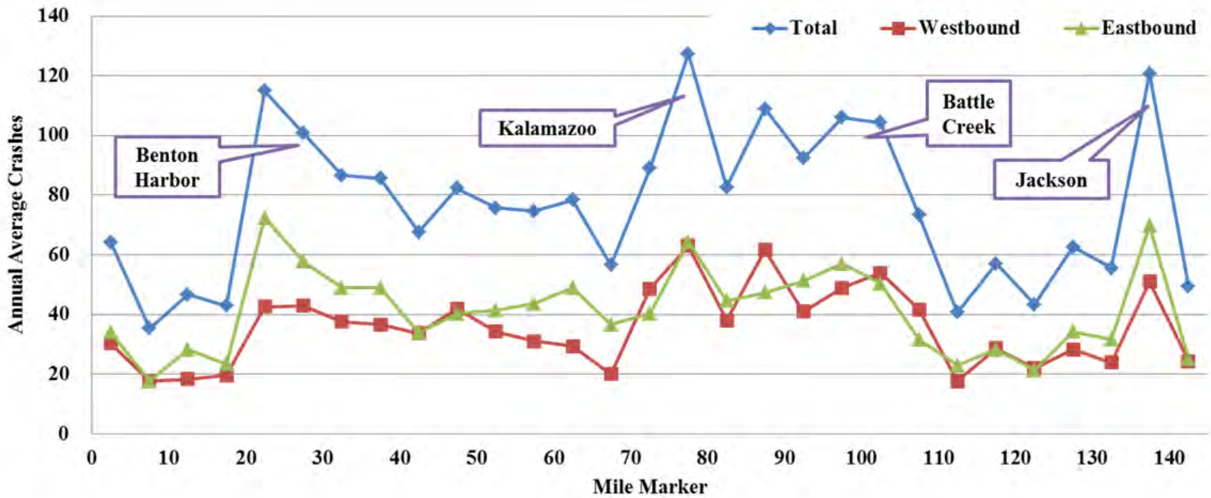


Figure 5. I-94 Study Corridor Average Annual Crashes by Mile Marker, 2012-2014

2.3 Weather Data

In order to assess historical weather conditions along the study corridor, historical monthly weather data was extracted from the National Oceanic and Atmospheric Administration (NOAA) climate data center from 2012 through 2014. The climate data center provides weather data including temperature, precipitation, and snowfall as reported by each weather station across the U.S for the time period selected. To maximize weather prediction accuracy, all weather stations within a 50 mile radius of the study corridor were selected for the analysis. As these weather stations were located at varying distances from the study corridor, the geostatistical method of spatial interpolation was utilized to identify the most likely weather conditions on each specific location along the study corridor at a specified time period.

Spatial interpolation is the procedure of estimating the value of a particular property on an unknown location based on existing observations surrounding the subject area. While many techniques can be used for spatial interpolation, a probabilistic method was utilized in this scenario due to the random dispersion of the weather stations and the number of available stations which reported data for each specific month of the year. The analysis process involved assessing each individual month of weather data and interpolating those known values (e.g. temperature, precipitation, snowfall) across all of Michigan and the northern portions of Indiana. Each dataset was analyzed separately to minimize any potential prediction errors. Once the process of spatial interpolation was complete, predicted historical weather values were then assigned to the centroid of the study segment for further analysis. Table 3 summarizes the resulting predicted average annual snowfall totals for 2012 through 2014. A map depicting these average snowfalls along the corridor from 2012 through 2014 is displayed in Figure 6. Table 3 and Figure 6 suggest increasing snowfall totals from the Indiana State Line into northeast Berrien and Van Buren Counties, beginning to diminish east of US-131 in Kalamazoo County and further diminishing east of I-69. The greatest average countywide snowfall totals occurred in Van Buren County, followed closely by Berrien and Kalamazoo Counties. Calhoun and Jackson Counties observed much lower average snowfall totals. In particular, Jackson County experienced less than one-half of the average snowfall experienced by Van Buren, Berrien, and Kalamazoo Counties between 2012 and 2014. Table 3 also suggests relatively consistent average annual precipitation and temperatures along the corridor.

Table 3. Historical Weather Data Summary from NOAA, 2012-2014

County	Annual Average Snowfall (Inches)	Annual Average Precipitation (Inches)	Annual Average Winter Temperature (Dec-Feb)
Berrien	69.3	36.9	27.7
Van Buren	75.9	38.0	28.2
Kalamazoo	65.9	38.2	27.7
Calhoun	45.2	36.0	26.6
Jackson	32.9	32.7	26.2
All Counties	58.9	36.5	27.3

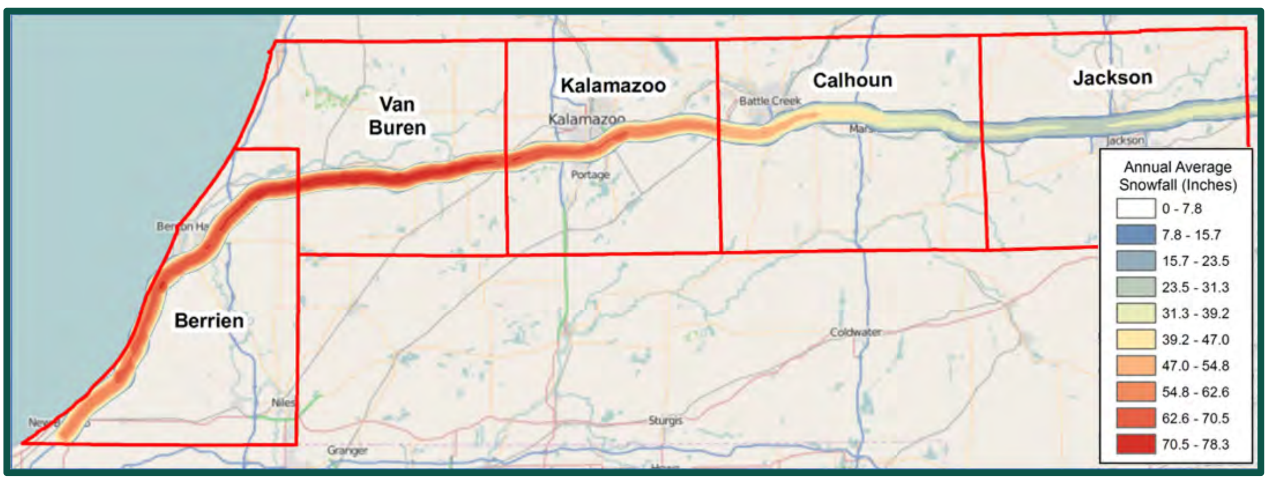


Figure 6. Corridor Average Annual Snowfall, 2012 – 2014

2.4 Adjacent Roadside Assessment Data

In order to evaluate the impact of the adjacent roadside characteristics on the traffic safety performance of the corridor, a basic assessment of the types of land cover both in areas beyond the right-of-way (ROW) line and within the ROW line was performed, along with an assessment of the elevation of the roadside with respect to the roadway. These assessments were completed by examining roadside imagery at 0.10 mile intervals on the right side of the freeway independently for each direction of travel across the entire study corridor. The roadside imagery was visually assessed and subsequently scored on the following basis for each of following three attributes:

- General land cover beyond ROW line: (0) = generally open, (1) = generally forested or developed
- Tree coverage within/near ROW line: (0) = generally open, (1) = generally tree-lined
- Roadside elevation: (-1) = below roadway grade, (0) = at grade, (1) = above grade

The results of the adjacent land cover and roadside assessment are summarized in Table 4. County-level maps depicting the overall land cover were generated in GIS using the National Land Cover Database and are displayed in Appendix B.

Table 4. Roadside Assessment Summary

County	Mean General Land Cover Score	Mean Adjacent Roadside Land Cover Score	Mean Roadside Elevation Score
Berrien	0.351	0.389	-0.045
Van Buren	0.306	0.398	0.038
Kalamazoo	0.314	0.330	-0.027
Calhoun	0.275	0.385	0.064
Jackson	0.171	0.062	0.024
All Counties	0.295	0.329	0.004

Land cover was generally consistent across the corridor, both beyond the ROW line immediately adjacent to the corridor, although Jackson County contained more open space, including both in within and beyond the ROW. Berrien and Kalamazoo Counties tended to have slightly more areas where the roadside was below the roadway, while Van Buren, Calhoun and Jackson Counties tended to contain slightly more sections where the roadside was above the roadway.

2.5 Pavement Friction Data

In order to assess the impact of pavement friction on historical traffic crashes within the study section, pavement friction data was also incorporated. This data was collected and assembled by MDOT in 2013 and 2014. Friction data was provided for various points of both Eastbound and Westbound I-94 for at least one location within each sufficiency file segment. These data were ultimately aggregated by each sufficiency file segment in which the measurement was taken. Table 5 summarizes the pavement friction data incorporated in the study. A map depicting friction values is provided in Figure 7.

Table 5. Pavement Friction Data Summary

County	Count of Friction Measurements	Mean Friction Value	Minimum Friction Value	Max Friction Value
Berrien	849	45.03	26.60	70.47
Van Buren	286	48.57	23.52	62.82
Kalamazoo	385	43.77	24.00	63.00
Calhoun	403	47.49	32.00	65.00
Jackson	269	45.76	37.00	61.00
All Counties	2,192	45.96	23.52	70.47

The insets displayed in Figure 9 indicate locations where friction measurements have fallen below acceptable levels. The following study corridor locations possessed substandard friction levels:

- Berrien County
    - WB near mile marker 1
    - EB near M-63 Exit (mile marker 27)
    - EB near M-140 Exit (mile marker 39-40)
- Van Buren County
    - EB/WB near mile marker 49-50
- Kalamazoo County
    - EB/WB Westnedge to Lovers (mile marker 76-77)
    - WB near I-94BL (mile marker 81)

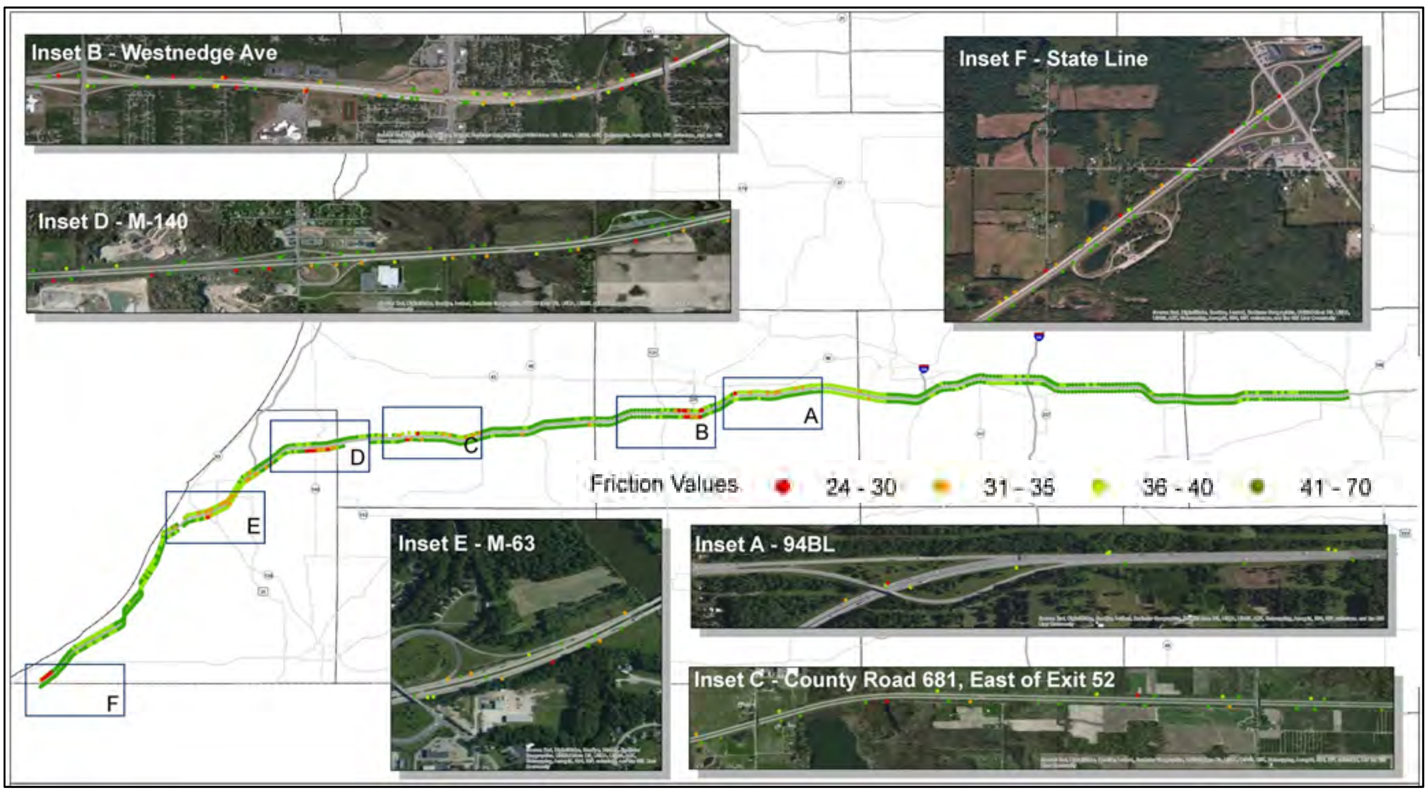


Figure 7. MDOT Friction Values, 2013-2014

2.6 Vehicular Speed Data

Passenger and commercial vehicle speed data were also evaluated. These data were obtained using LIDAR from covert overpass locations during 2013 as a part of prior statewide MDOT speed limit related research conducted by Wayne State University. Sites were selected at 20 to 30 mile intervals along flat, tangent segments of selected freeway corridors statewide to reduce the influence of geometric characteristics (e.g., horizontal and vertical alignment). Six (6) locations along the current I-94 study corridor were included within the statewide speed data collection effort. The speeds of 100 passenger vehicles and 50 trucks and buses were collected per direction per site during non-congested periods. Once the speed data were collected, they were aggregated and appropriate sample statistics (e.g., mean speed, 85th percentile speed, and speed variance) were calculated separately for passenger vehicles and commercial vehicles along with overall combined estimates. The speed data collected a part of this prior project is shown in Table 6, including data within the study corridor as well as data for all other Michigan freeways posted at 70 mph.

Table 6. Passenger Vehicle and Commercial Vehicle Speed Data, Study Corridor vs. Other 70 MPH Freeway Locations

		Passenger Vehicle			Truck/Bus			Overall		
Location	Sites	Mean	85th	Std. Dev	Mean	85th	Std. Dev	Mean	85th	Std. Dev
I-94 @ East Road (MM 9)	1	74.28	78.0	5.03	62.32	64.0	2.90	70.57	74.0	7.13
I-94 @ Britain Ave (MM 32)	1	75.28	80.0	4.43	61.72	64.0	2.73	71.07	75.0	7.28
I-94 @ Almena Road (MM 62)	1	73.87	78.0	4.31	62.42	65.0	2.99	70.98	75.0	6.79
I-94 @ Columbia Road (MM 92)	1	74.04	78.0	4.04	62.4	65.0	2.44	70.57	74.0	6.58
I-94 @ Verona Road (MM 106)	1	73.29	78.0	4.21	62.57	65.0	2.95	70.51	74.0	6.40
I-94 @ Dearing Road (MM 133)	1	74.23	78.0	4.08	62.28	65.0	2.87	70.45	74.0	6.76
I-94 Study Corridor	**6**	**74.17**	**78.0**	**4.35**	**62.29**	**65.0**	**2.81**	**70.69**	**74.0**	**6.82**
Other 70 MPH Michigan Freeways	**40**	**73.50**	**78.0**	**4.81**	**62.24**	**65.0**	**3.32**	**71.84**	**76.0**	**6.86**

The overall mean and 85th percentile speeds along the corridor were 70.7 mph and 74.0 mph, respectively. Mean and 85th percentile passenger vehicle speeds were 74.2 mph and 78.0 mph, respectively. Mean and 85th percentile truck/bus speeds were 62.3 mph and 65.0 mph, respectively. As expected, trucks displayed lower speed variability compared to passenger vehicles. In general, the speed statistics did not vary greatly over the corridor, particularly for trucks, although passenger vehicle speeds at mile marker 32 in Berrien County were approximately 1 mph and 2 mph greater than the corridor average for mean and 85th percentile speeds, respectively. Mean passenger vehicle speeds along the study corridor were also slightly greater than other 70 mph freeways statewide, while truck speeds were nearly identical to other statewide freeways. However, due to the relatively high truck volumes compared to the other comparable 70 mph freeways statewide, the overall mean and 85th percentile speeds along the study corridor were lower than the comparison freeways by 1.15 mph and 2.0 mph, respectively. Speed variability was not substantially different between the study corridor and the comparison freeways for both passenger vehicles and trucks. Like other freeways there is a noted speed differential between passenger vehicles and trucks.

2.7 Barrier Locations

In an effort to reduce median-cross over related crashes, MDOT began installing high-tension cable median barrier on many of Michigan's freeways in 2008. This included numerous sections of I-94 in southwest Michigan, including a significant portion of the study corridor, approximately 86 miles, with the most recent sections of barrier installed in 2011. Wayne State University developed a database of these installation locations and dates, in addition to the location of other types of median barriers as a part of another MDOT project completed in 2014, the *Study of High-Tension Cable Barriers on Michigan Roadways*. Summary statistics for cable and other barrier installations along the study corridor is summarized in Table 7. A map depicting 2014 median presence (cable, guardrail, or concrete) is provided in Figure 8.

Table 7. Median Barrier Coverage for I-94 Corridor (2014)

County	Total Miles	Miles of Cable Barrier Installed	Cable Barrier Coverage	Other Barrier Percent	Mean Median Width in Feet
Berrien	42.8	28.0	65.4%*	10.6%	53.5
Van Buren	24.0	24.0	99.8%	0.0%	70.0
Kalamazoo	25.1	9.7	38.5%	62.5%	41.9
Calhoun	31.4	24.5	78.0%	0.0%	70.0
Jackson	19.6	0.0	0.0%	74.3%	32.0
All Counties	143.0	86.2	60.3%	24.4%	53.9

*Berrien County cable barrier coverage was nearly 100 percent at the time of this report.

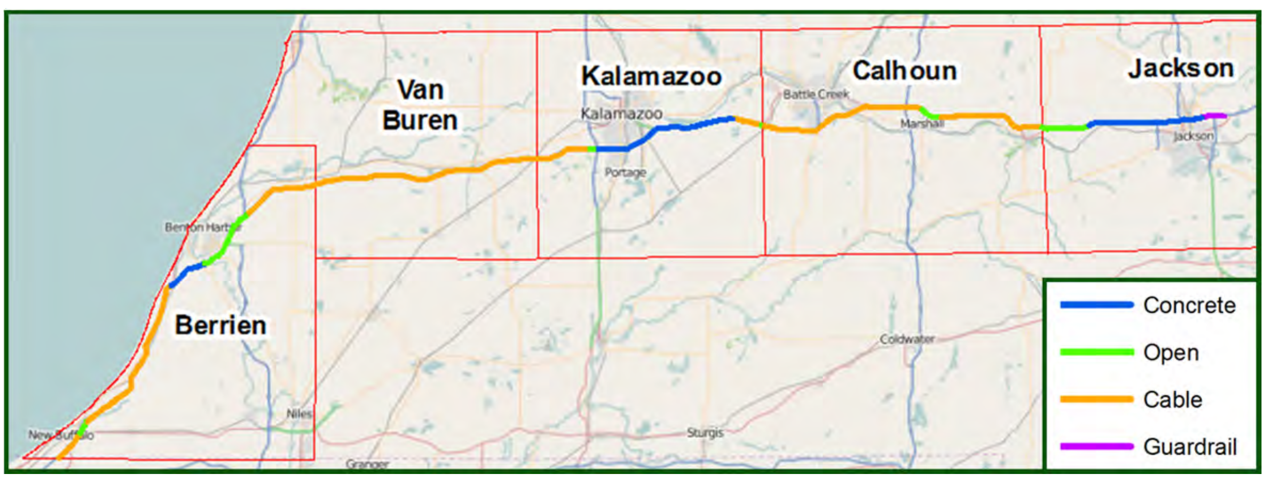


Figure 8. Median Barrier Presence, 2014

2.8 Anecdotal Observations

While this safety evaluation is designed to be data-driven, anecdotal evidence from individuals involved with the daily operation of the study corridor can provide important insight into the types of safety issues which may exist. Specifically, anecdotal comments from both MDOT regional staff and MSP staff were provided in order to assess the recurring safety issues experienced within the corridor. These comments were subsequently aggregated on a county-by-county basis to help facilitate discussion during meeting and help guide subsequent field reviews of areas with high crash concentrations. The summarized anecdotal comments are displayed on a county-by-county basis in Appendix B.

3.0 CRASH EVALUATION

After completion of all data collection activities a comprehensive safety evaluation of the I-94 study corridor was performed. After compilation of all necessary data, several safety analyses were performed for the I-94 study corridor, including the following:

- Comparison of crash rates for the study corridor versus other Michigan freeways with 70 mph posted maximum speed limits;
- County-by-county comparison of crash rates within the study corridor, by direction; and
- Statistical analysis of crashes on study corridor as a function of roadway and site factors.

3.1 Crash Rates for Study Corridor Compared to Other Michigan Freeways

Prior to evaluating the safety performance observed within the I-94 study corridor, it was initially necessary to compare the crash rates between the study corridor and similar comparison freeways statewide. For the purposes of this study, the comparison freeway facilities included 70 mph sections of I-94 (exclusive of the study section), I-69, I-75 (disaggregated by the segments north of Bay County versus the segments located in Bay County and south to the state border), I-96, I-196, US-23, US-127, and US-131. A map of the comparison freeways and the study corridor is provided in Figure 9. Table 8 provides the historical traffic crash rates from 2012-2014 for the noted comparison freeway facilities.

Figure 9. I-94 Study Corridor and Comparison Freeways

Table 8. Crash Rates - I-94 Study Corridor vs. Comparison Michigan Freeways, 2012-2014

Route	Length (miles)	3Yr-VMT (millions)	Total Crashes	Winter Crashes (Dec-Feb)	Total Crash Rate*	Winter Crash Rate*
I-69	193	5,445.36	4,680	1,576	85.94	28.94
I-75 North of Bay County	203	2,125.47	2,827	899	133.01	42.30
I-75 Bay County and South	177	13,542.70	14,562	4,996	107.53	36.89
I-96	189	12,824.48	13,016	4,405	101.49	34.35
I-196	77	2,274.08	2,847	1,067	125.19	46.92
I-94 - Non-Study Section	109	8,106.33	7,164	2,360	88.38	29.11
US-23	93	5,155.44	4,604	1,502	89.30	29.13
US-127	157	2,891.42	3,775	1,085	130.56	37.52
US-131	167	5,359.29	7,120	2,493	132.85	46.52
All Comparison Freeways	**1,365**	**57,724.56**	**60,595**	**20,383**	**104.97**	**35.31**
I-94 Study Corridor	**143**	**6,603.82**	**6,678**	**2,893**	**101.12**	**43.81**

*Crashes per 100 million vehicle miles traveled

Several important conclusions can be drawn from Table 8 regarding the total and winter season (December through February) crash rates along the I-94 study corridor compared to other comparable freeway facilities in Michigan. First, the I-94 study corridor experienced slightly fewer crashes per 100M VMT (101.12) compared to the overall rate observed on other Michigan freeways (104.97). However, the winter season crash rate (43.81) for the study corridor was 24 percent greater than that of the comparison freeways (35.31). Only I-196 (46.92) and US-131 (46.52) possessed greater winter season crash rates than the study corridor. Greater than 43 percent of the crashes along the study corridor occurred during the winter season, compared to 33.6 percent for the comparison freeways, clearly suggesting an overrepresentation of winter season crashes.

3.2 County-by-County Corridor Crash Rates

To further explore the relative safety performance along the study corridor, a county-by-county analysis was performed. Table 9 displays county-by-county crash rates (per 100 million vehicle miles traveled [VMT]]) along the corridor, both overall and directionally.

Table 9. Crash Rates for I-94 Study Corridor, by County, 2012-2014

County	Dir.	All Crashes	Non-Deer Crashes	Inj. Crashes (KABC)	Fatal Crashes	Winter Crashes (Dec-Feb)	Truck/Bus Crashes	5+ Pileup Crashes
Berrien	Both	91.05	80.96	14.20	0.35	39.83	18.31	0.69
Van Buren	Both	122.89	111.52	19.54	0.33	68.68	25.62	2.32
Kalamazoo	Both	94.02	85.09	17.06	0.34	39.40	14.28	1.96
Calhoun	Both	104.26	88.35	15.11	0.29	43.02	15.76	1.30
Jackson	Both	109.60	87.65	15.69	0.25	35.43	16.18	1.23
All Counties	Both	101.12	88.43	15.95	0.32	43.81	17.61	1.39
Berrien	EB	103.82	92.83	15.74	0.20	45.62	21.57	0.99
Van Buren	EB	138.46	125.65	21.20	0.66	75.08	27.60	3.31
Kalamazoo	EB	93.41	84.75	17.87	0.27	35.88	14.08	1.90
Calhoun	EB	106.43	89.22	13.88	0.29	40.06	14.89	1.01
Jackson	EB	119.65	94.39	15.20	0.00	38.25	16.67	1.47
All Counties	EB	108.73	94.95	16.51	0.27	45.40	18.72	1.57
Berrien	WB	79.67	70.37	11.98	0.49	32.07	13.16	0.40
Van Buren	WB	105.11	95.18	16.56	0.00	57.86	20.10	1.32
Kalamazoo	WB	93.96	85.02	15.57	0.41	41.70	12.86	2.03
Calhoun	WB	104.84	88.64	15.33	0.29	43.81	14.60	1.59
Jackson	WB	95.13	78.95	14.22	0.49	28.44	12.99	0.98
All Counties	WB	93.52	81.92	14.39	0.36	39.76	14.33	1.21

Several important findings are observed in Table 9. First, it is interesting to note that crashes tended to occur more frequently in the eastbound direction compared to westbound, as the total eastbound crash rate for the corridor was 16.3 percent greater than the westbound rate. The greatest eastbound to westbound disparity was occurred during the winter season within Van Buren, Berrien, and Jackson Counties, where eastbound crashes outpaced westbound crashes by roughly 30 to 40 percent. These directional differences may be attributed to differing geometric conditions between the two directions, particularly near interchanges. Van Buren County possessed the highest crash rates per 100 million vehicle miles traveled for each of the following crash categories between 2012 and 2014:

- All Crashes,
- Non-Deer Crashes,
- Injury Crashes (KABC),
- Winter Crashes (Dec-Feb),
- Truck/Bus-Involved Crashes, and
- 5+ Pileup Crashes.

Overall, crashes on I-94 in Van Buren County occurred at a rate that was 21.5 percent (26.5 percent when excluding deer crashes) greater than the corridor average. Berrien, Kalamazoo, Calhoun, and Jackson counties possessed non-deer crash rates that were not substantially different from each other. Van Buren County displayed an even greater overrepresentation of winter crashes, particularly in the eastbound direction, which outpaced the eastbound corridor average by greater than 65 percent. Berrien, Calhoun, and Kalamazoo Counties showed winter crash rates that were similar to each other, while Jackson showed a slightly lower winter rate. Specifically, the winter crash rate for Van Buren County was nearly double that of Jackson County, which is very likely at least somewhat due differences in annual snowfall totals, as will be shown in the following section. Additionally, crashes in Van Buren County also tended to be more severe compared to the rest of the corridor, as injury crashes occurred at a rate that was 22.5 percent greater than the overall corridor average, while pileup crashes involving five or more vehicles occurred at a rate that was nearly 67 percent greater than the corridor average. Finally, truck or bus involved crashes occurred at a 45.5 percent greater rate in Van Buren County compared to the overall corridor average.

3.3 Statistical Analysis of Corridor Crash Occurrence

In addition to assessment of the county-by-county crash rates, it is also important to identify the effect of specific characteristics (geometry, snowfall, surrounding land-cover, ramp presence, etc.) on crash occurrence within in the study corridor, without regard to county boundaries. The identification of such relationships will assist with identification of engineering countermeasures to address the safety-related concerns within the study corridor. To identify the crash effects associated with respect to the roadway and other factors, negative binomial regression models were estimated and presented in Tables 10 (all crashes) and 11 (winter crashes). Only the statistically significant factors are displayed in the tables. Other factors were included in preliminary models, but were not found to significantly influence crashes and were excluded from the final models.

Table 10. Study Corridor Negative Binomial Model Results by Factor, All Crashes, 2012-2014

Variable	Parameter Estimate	Standard Error	t-statistic	p-value
Intercept	-6.814	0.927	54.060	< 0.0001
Ln (Segment Length)	0.794	0.031	642.825	< 0.0001
Ln (Annual Average Daily Traffic)	0.837	0.087	93.224	< 0.0001
Exit or Entrance Ramps Present	0.261	0.052	24.917	< 0.0001
Tree-lined ROW	-0.221	0.074	8.898	0.003
Proportion of Segment with Horizontal Curvature of Design Speed < 85 MPH	0.860	0.218	15.596	< 0.0001
Ln (Average Stopping Sight Distance)	-0.105	0.040	6.848	0.009
Ln (Average Annual Snowfall)	0.362	0.044	67.617	< 0.0001
Three Lanes	-0.308	0.050	37.555	< 0.0001

Table 11. Study Corridor Negative Binomial Model Results by Factor, Winter Crashes, 2012-2014

Variable	Parameter Estimate	Standard Error	t-statistic	p-value
Intercept	-7.395	1.408	27.575	< 0.0001
Ln (Segment Length)	0.804	0.046	299.747	< 0.0001
Ln (Annual Average Daily Traffic)	0.723	0.131	30.339	< 0.0001
Exit or Entrance Ramps Present	0.162	0.077	4.420	0.036
Tree-lined ROW	-0.130	0.110	1.386	0.239
Proportion of Segment with Hor. Curvature of Design Speed < 85 MPH	0.944	0.330	8.208	0.004
Ln (Average Stopping Sight Distance)	-0.119	0.060	3.858	0.050
Ln (Average Annual Snowfall)	0.621	0.068	84.431	< 0.0001
Three Lanes	-0.349	0.076	21.241	< 0.0001

The all-season model results displayed in Table 10 presents several interesting findings. Not surprisingly, the presence of any entrance or exit ramps within a segment was associated with an increase in the number of traffic crashes. As the proportion of segments with horizontal curves with design speeds below 85 mph increased, crash occurrence also increased. Similarly, the stopping sight distance along the corridor also had a significant impact on overall safety performance. Segments with greater average stopping sight distances were associated with significantly lower traffic crash totals. Segments which included three lanes had significantly lower rates of crash occurrence than those segments which included two lanes. While these findings are intuitive, they underscore the critical impact of geometric design on the study corridor.

Considering the winter crash model results in Table 11, similar to the total crash model, the presence of any exit or entrance ramps along the segment was associated with an increase in winter crashes (although this effect was diminished as compared to the all-season crash model). Greater stopping sight distance was also similarly associated with lower winter crash occurrence. Further, similar to the total crash model, as the proportion of horizontal curvature with design speeds less than 85 mph increases, crashes also tended to increase. Again, the segments which included three traffic lanes had lower winter crash occurrence (after controlling for the effect of traffic volumes). Finally, perhaps the most important conclusion that can be drawn from this analysis is the very strong correlation between average annual snowfall and crashes. Interpretation of the parameter estimate suggests that a doubling (i.e., 100 percent increase) in average annual snowfall relates to a 62.1 percent increase in crashes. This also helps explain the extreme overrepresentation of winter crashes in Van Buren County, which experiences the greatest snowfall totals along the study corridor. It is worth noting that approximately 65 percent of the 2,893 winter season crashes involved at a vehicle noted in the UD-10 report as driving “too fast for conditions”, compared to only 38 percent of all-season crashes. This suggests that speed plays a greater role in winter-season crashes compared to other seasons.

4.0 SITE REVIEWS

While the aforementioned corridor safety analysis provided general insight towards factors related to crash occurrence along the study corridor, a detailed investigation was warranted to help identify specific areas of high crash occurrence and develop recommendations to address the associated safety issues. This was accomplished through a series of site reviews along the study corridor. The following tasks were associated with these reviews, which are described in greater detail in the following sections:

- Identify areas of the study corridor where crashes most frequently occur;
- Perform field reviews of these areas to identify existing safety issues and potential countermeasures; and
- For the primary high-crash areas, review UD-10 crash reports to further identify specific safety issues, trends, and patterns, and develop potential safety countermeasures and recommendations.

4.1 Identification of High Crash Locations

In preparation for the field reviews, a series of crash concentration maps were generated for the study corridor. These maps provided a graphical display of areas with high crash concentrations, which assisted the study team with determination of field review locations. The first step was to obtain the x,y coordinates for all crashes occurring along the mainline portion of the corridor between the years of 2012 and 2014. ArcGIS was then used to generate a series of crash concentration maps for the entire study corridor for a variety of crash categories and locations. These maps, which were generated both overall and separately by direction, used color gradation to depict the relatively density of crashes at all areas along the corridor, from the highest (red/orange) to lowest (blue/white) occurrence. The maps represent crash frequencies, as it was not possible to adjust the crash data during the mapping process to account for the variations in traffic volumes along the corridor.

All maps developed as a part of this evaluation included only mainline crashes that did not involve deer. Although not included in the maps, ramp crashes were included in subsequent UD-10 reviews, where appropriate, and ramps were also investigated during the field reviews of interchange areas. Both corridor and county-level maps were presented to the study team members at the beginning of each field review meeting to provide direction towards selection of the sites to visit during the field review, which immediately followed. Each map reflects relative mainline crash occurrence along the study corridor between 2012 and 2014 and included following crash categories:

- All crashes (excluding deer-related crashes)
- Interchange-related crashes
- Non-interchange-related crashes

- Winter season crashes (December-February)
- Non-winter season crashes (March-November)
- Injury crashes (including fatal)
- Truck/Bus-related crashes
- Interchange truck/bus-related crashes
- Non-interchange truck/bus-related crashes
- Winter season truck/bus-related crashes
- Winter season interchange crashes
- Winter season non-interchange crashes
- Crashes by time of day (non-interchange)
- Crashes involving 5 or more vehicles

In addition to the crash concentration maps, several supplementary maps were generated for the corridor to provide additional supporting information during the field reviews, including:

- MDOT's incident log (for the years 2008-2014)
- Location of significant horizontal curves
- Elevation profile and stopping sight distance
- Annual average snowfall
- MDOT friction data
- Surrounding land cover

While the complete library of corridor crash concentration maps and supplementary spatial analyses can be found in Appendix B (supplemental maps) and Appendix C (crash maps), select corridor-level maps are displayed and discussed as follows. Again, please note that all crash-related maps exclude deer crashes and ramp crashes.

4.1.1 Total Crashes

Figure 10 displays the concentration of total crashes, exclusive of deer-involved, along the corridor for the three-year period between 2012 and 2014. These data are displayed both overall (10A) and independently by direction (10B and 10C). The corridor directional crash rates are also provided for the in Figure 11.

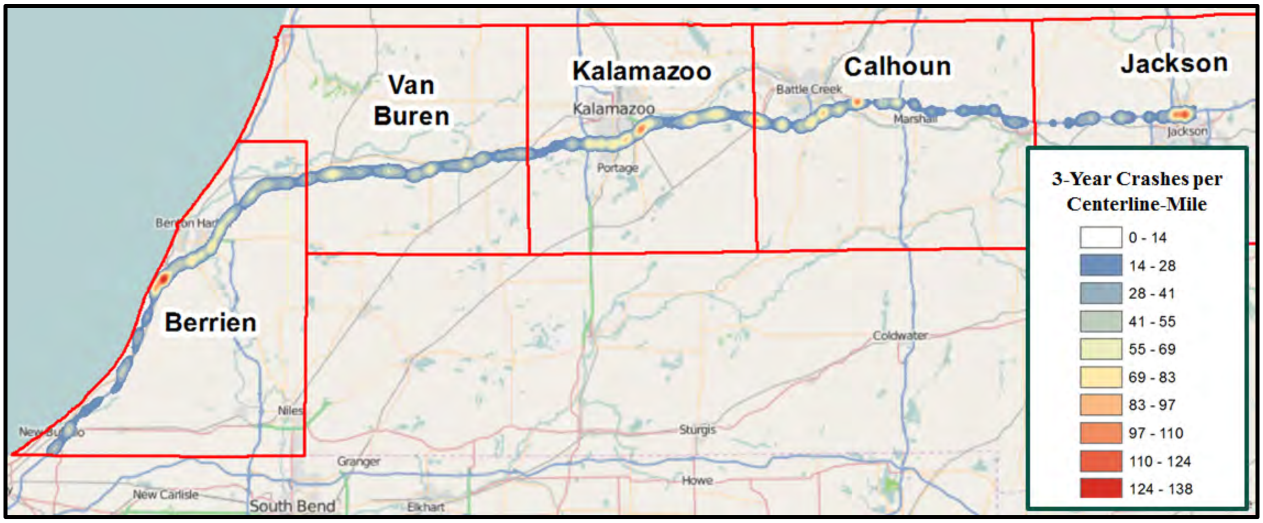


Figure 10(A). I-94 Total Crash Concentration Map, 2012-2014

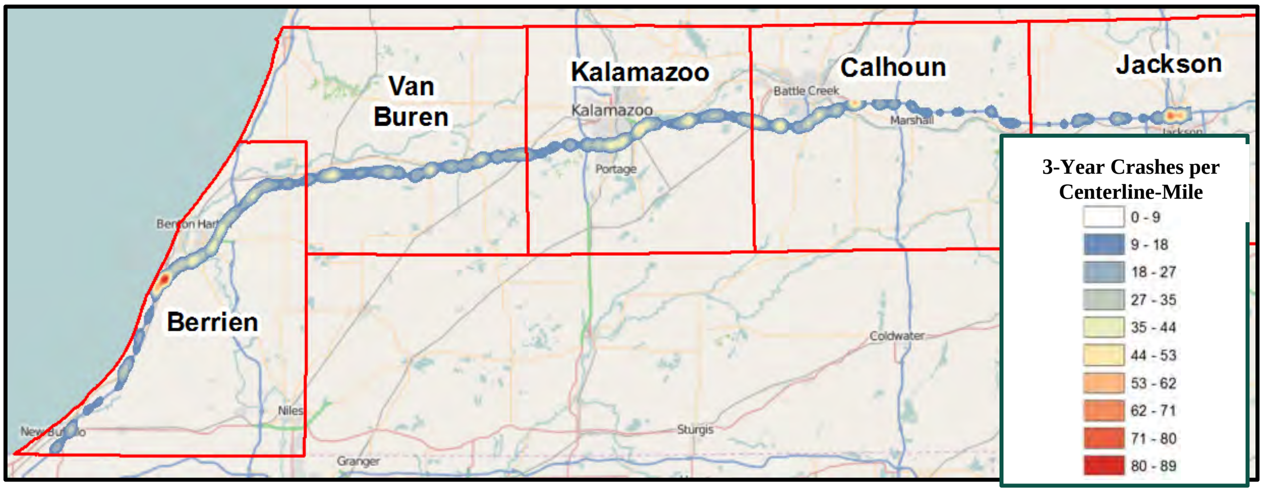


Figure 10(B). I-94 Eastbound Total Crash Concentration Map, 2012-2014

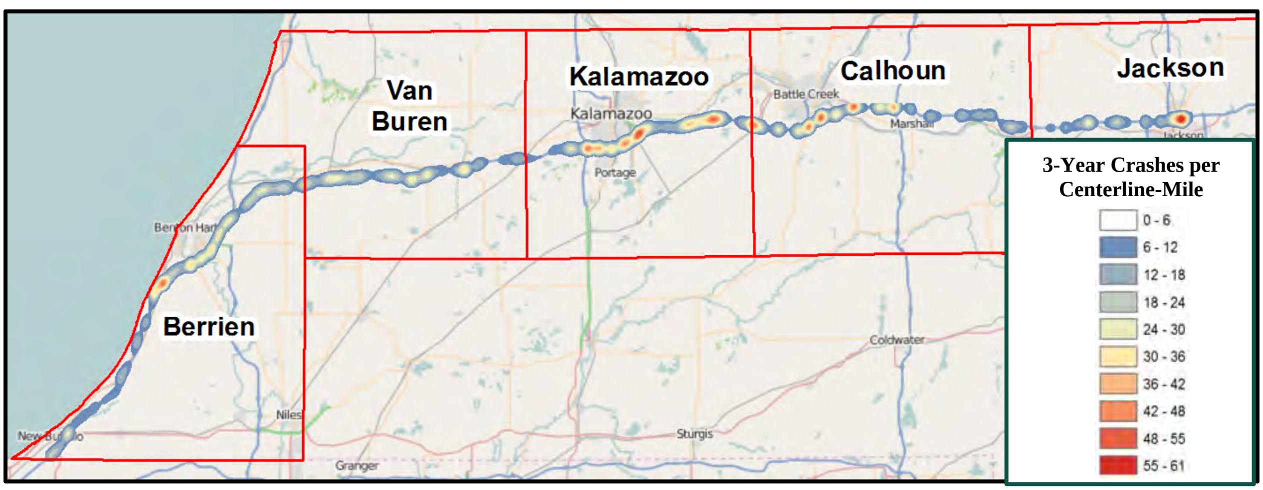


Figure 10(C). I-94 Westbound Total Crash Concentration Map, 2012-2014

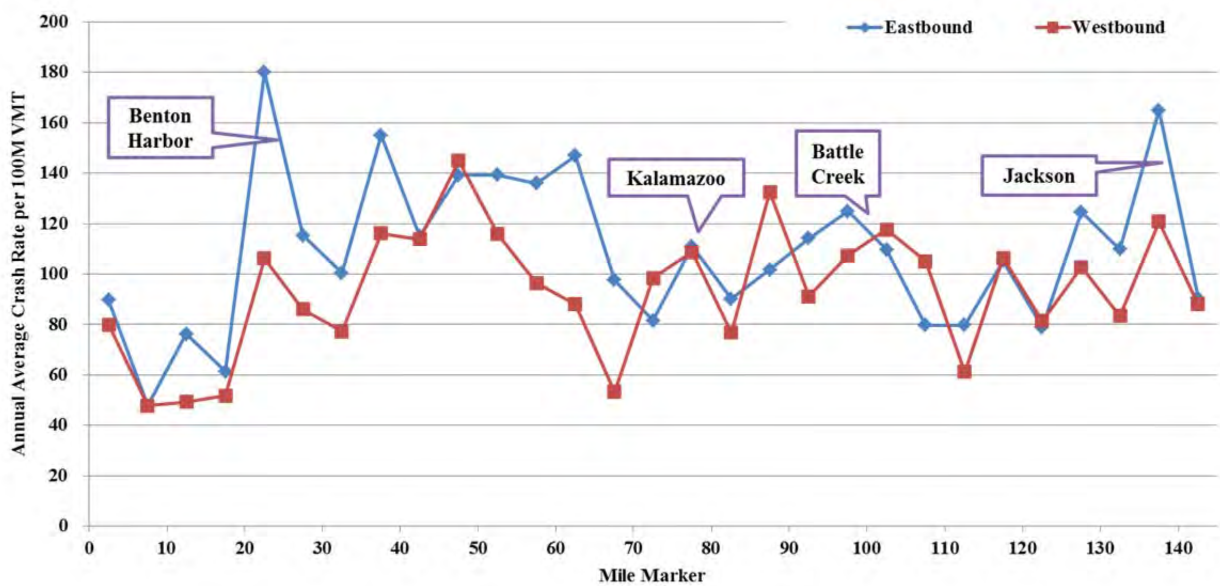


Figure 11. I-94 Study Corridor Crash Rates by Mile Marker, 2012-2014

Examination of the areas in Figure 10 that display a high concentration of crashes (red and orange areas), reveals relatively high crash occurrence in the areas adjacent to Benton Harbor, Kalamazoo, Battle Creek, and Jackson. This result was expected due to the increased interchange densities and subsequent traffic volume and interchange densities in these locations, thereby increasing the exposure for traffic crashes. Eastbound crashes appear to be most problematic near the Red Arrow Highway Interchange in Berrien County (mile marker 22-23), in Jackson County between US-127N and Elm (mile marker 140-142), and Calhoun County near the Michigan Avenue Interchange (mile marker 104). Westbound crashes were more evenly dispersed throughout the corridor, with high concentrations located near primary interchanges within the major urban areas, particularly Kalamazoo and Battle Creek, in addition to the previously mentioned eastbound areas of high crash concentration. Westbound crashes were also highly concentrated at certain interchanges between Kalamazoo and Battle Creek (Exits 85, 88 and 92) and near the I-69 interchange.

4.1.2 Injury Crashes

In addition to total crashes, it was also necessary to investigate injury crashes. Figure 12(A) and (B) displays the relative corridor crash occurrence for injury crashes (inclusive of fatal crashes) for the three-year period between 2012 and 2014.

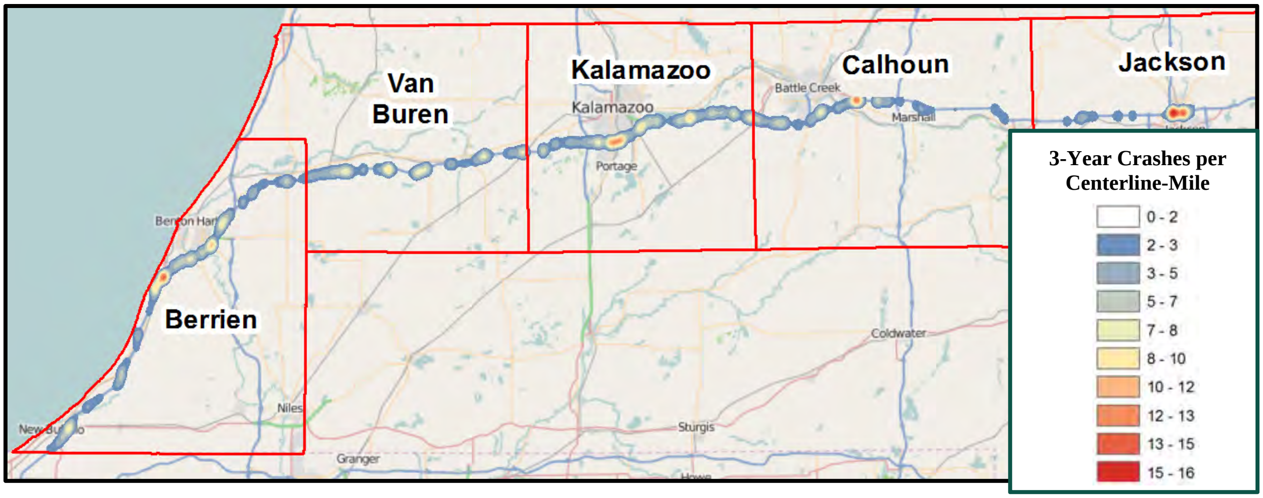


Figure 12(A). I-94 Eastbound Injury Crash Concentration Map, 2012-2014

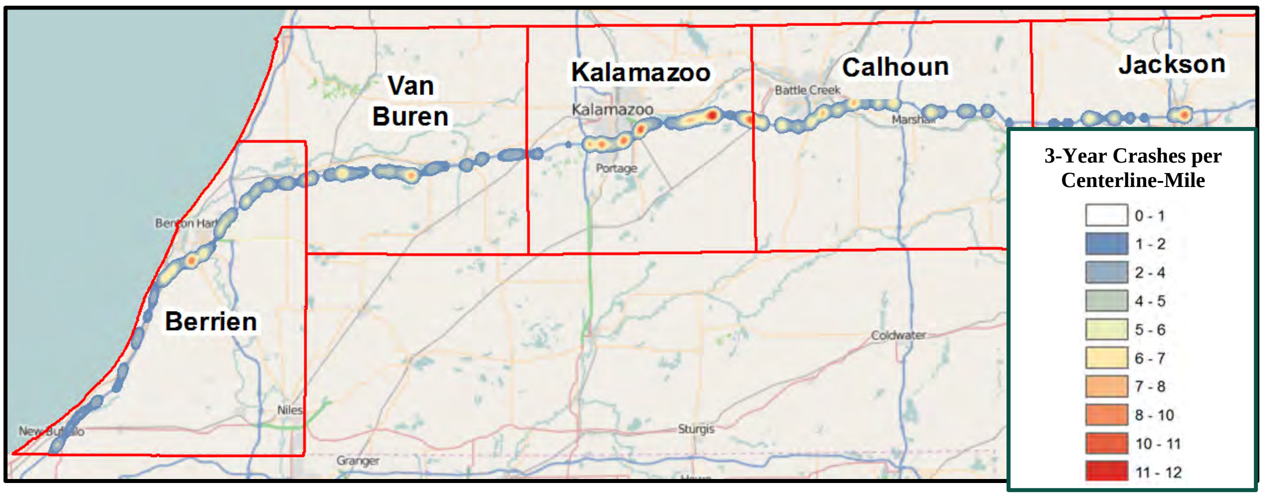


Figure 12(B). I-94 Westbound Injury Crash Concentration Map, 2012-2014

Examination of the high crash concentration areas in Figure 12 suggests that injury crashes are concentrated in relatively similar areas as observed for total crashes.

4.1.3 Non-Interchange (Segment) Crashes

While the previously described spatial analysis of total mainline crashes provided some insight into the safety performance of the corridor as a whole, the highest crashes crash concentrations were almost exclusive found near primary interchanges along the corridor. This was not an unexpected result, as interchanges tend to include greater traffic volumes, variable performance characteristics (speeds, acceleration/deceleration, weaving), and other operational differences compared to non-interchange areas. Consequently, crashes that occur outside of interchange locations (e.g., segment crashes) often have very different causal attributes compared to crashes that occur within the interchange area. Thus, it was important to isolate segment crashes that occur outside of the interchange termini and create subsequent maps for use during the field reviews. For purposes of this study, non-interchange (e.g., segment) crashes were identified as mainline crashes that occurred outside of the interchange ramp termini, based on exclusion of crashes coded as interchange for the area-type code on the UD-10 crash report form. Non-interchange crash concentration maps are displayed in Figure 13(A) and (B).

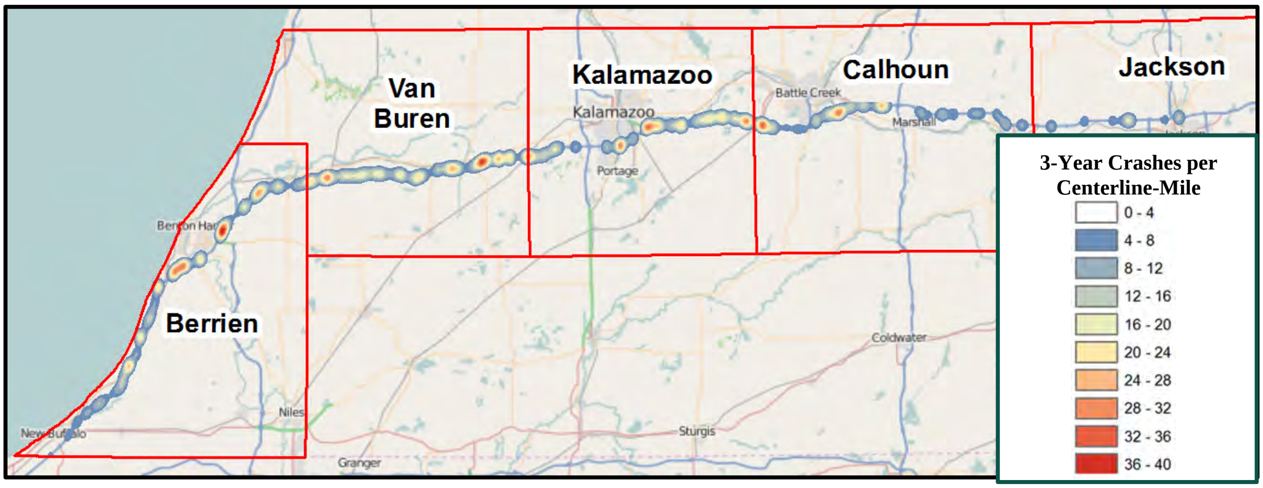


Figure 13(A). I-94 Eastbound Non-Interchange Crash Concentration Map 2012-2014

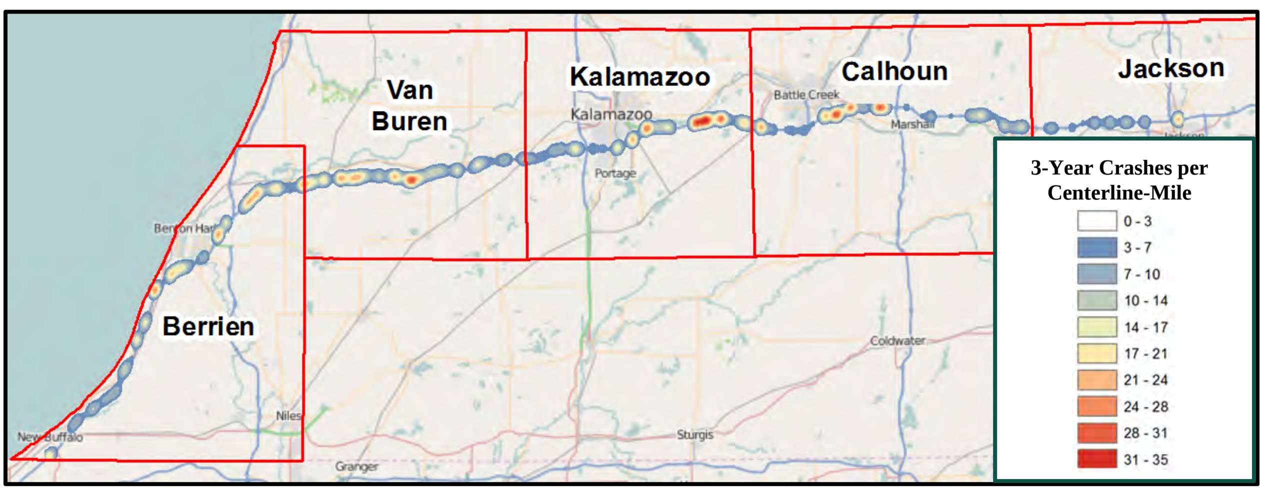


Figure 13(B). I-94 Westbound Non-Interchange Crash Concentration Map, 2012-2014

Examination of the areas of high crash concentration in Figure 13(A) and (B) reveals much different areas of high crash concentration than for total crashes. In the eastbound direction, relatively high crash non-interchange crash occurrence was observed in the northern portion of Berrien County, eastern Van Buren County, and between Kalamazoo and Battle Creek. The westbound direction showed some differences in the areas of high non-interchange crash concentration. While northern Berrien and eastern Kalamazoo counties remained as high crash concentration areas for westbound non-interchange crashes, western Van Buren County and central Calhoun County between Battle Creek and I-69 also displayed high concentrations of westbound crashes. Non-interchange crashes were not as highly concentrated between I-69 and US-127N, although the non-interchange areas between US-127N and US-127S did show relatively high crash concentration westbound.

4.1.4 Winter Non-Interchange Crashes

As stated previously, Van Buren County was found to have the highest winter crash rate along the study corridor, particularly in the eastbound direction. Consequently, it was of particular importance to provide a detailed crash concentration map depicting winter crashes, particularly for those occurring on non-interchange segments. Figures 14(A) and (B) present the non-interchange crashes occurring from 2012 – 2014 during the winter season, which was defined by the months of December, January, and February.

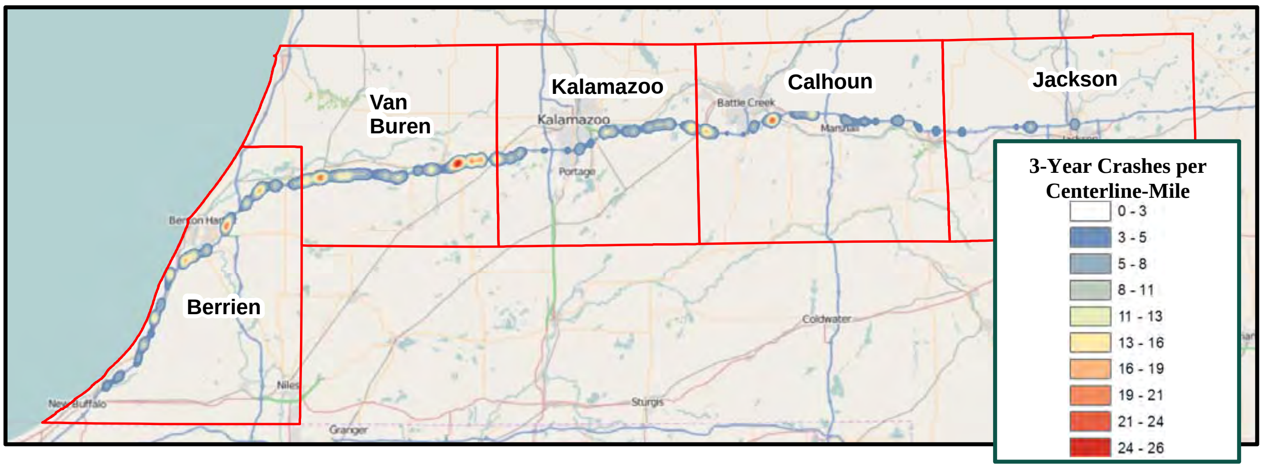


Figure 14(A). I-94 Eastbound Non-Interchange Winter Crash Concentration Map, 2012-2014

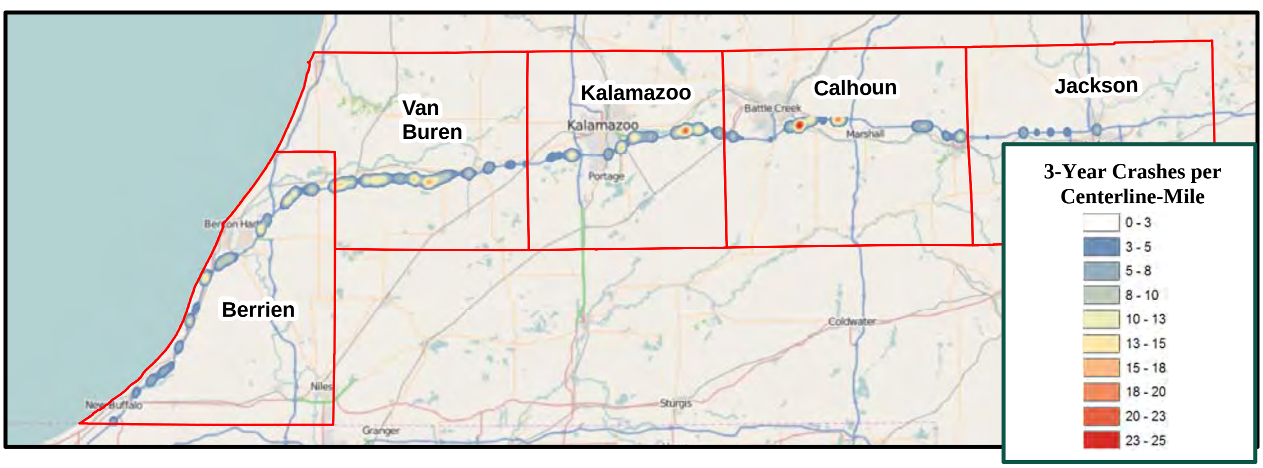


Figure 14(B). I-94 Westbound Non-Interchange Winter Crash Concentration Map, 2012-2014

Examination of the areas in Figure 14(A) and (B) displaying a high concentration of winter non-interchange crashes reveals several interesting findings. In the eastbound direction, relatively high winter non-interchange crash occurrence was observed in the northern portion of Berrien County, Van Buren County, and western Calhoun County. The westbound direction showed some differences in the areas of high non-interchange winter crash concentration, with areas between Battle Creek and I-69, the Galesburg area, and western Van Buren County displaying the greatest crash concentrations. Following similar trends for overall non-interchange crashes, winter non-interchange crashes were not highly concentrated east of I-69.

4.1.5 Truck/Bus Involved Crashes

Due to the heavy commercial vehicle volumes along the corridor, it was also deemed necessary to review areas with high concentrations of truck/bus involved crashes. Figure 15(A) and (B) present the truck or bus involved crashes occurring between 2012 and 2014.

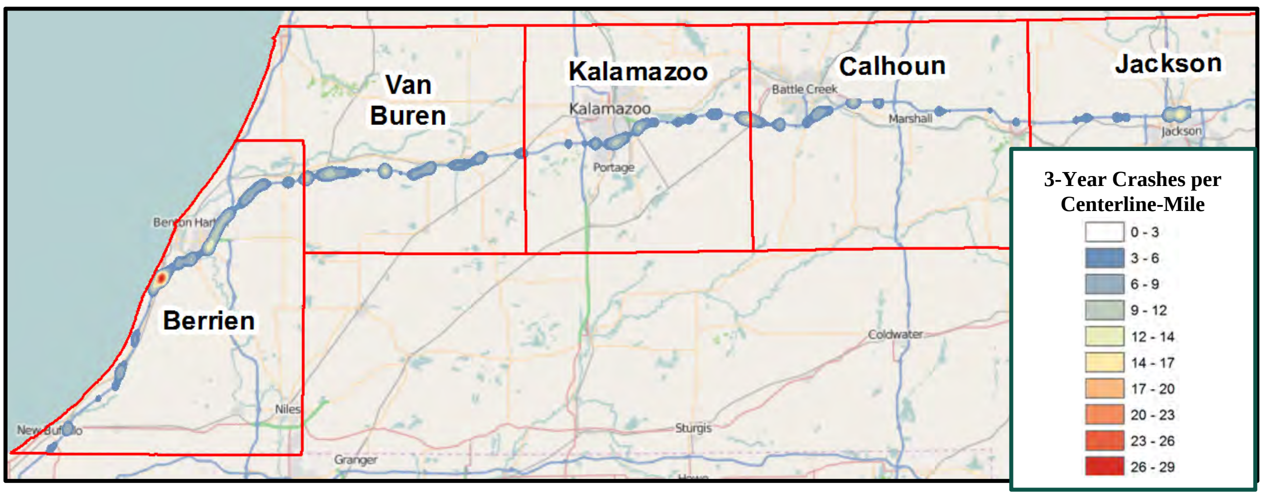


Figure 15(A). I-94 Eastbound Truck/Bus Involved Crash Concentration Map, 2012-2014

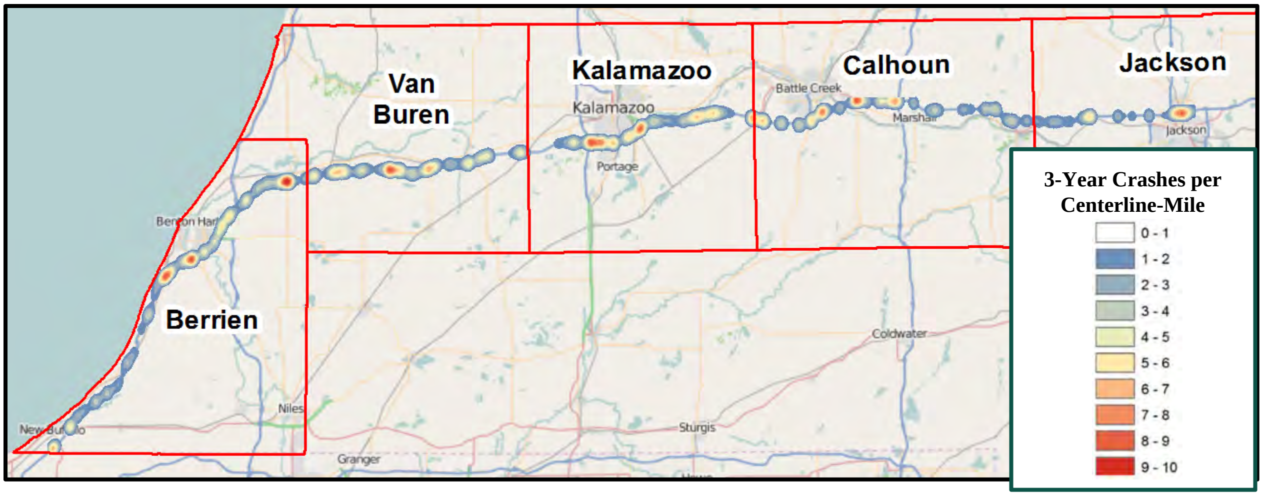


Figure 15(B). I-94 Westbound Truck/Bus Involved Crash Concentration Map, 2012-2014

Examination of the winter non-interchange crash concentration areas observed in Figure 15(A) revealed an excessive overrepresentation of truck/bus crashes in the eastbound direction near the Red Arrow Highway interchange in Berrien County (mile marker 23). This location had, by far, the highest concentration of truck/bus crashes anywhere along the corridor. Truck/bus crashes were also overrepresented in the westbound direction in northern Berrien County, Van Buren County, in the Kalamazoo metro area, between Battle Creek and I-69, and between US-127N and Elm in Jackson.

4.2 County-Level Reviews

Field reviews were performed on a county-by-county basis and were scheduled as follows:

- Berrien County, May 15, 2015;
- Van Buren County, April 20, 2015;
- Kalamazoo County, May 21, 2015; and
- Jackson/Calhoun Counties on May 28, 2015.

The field reviews were attended by the core members of the project team, in addition to local/regional MDOT and MSP staff familiar with the corridor. The field reviews typically began with an in-office presentation of the crash concentration maps to help stimulate discussion of the primary areas for further review and possible causal factors. Anecdotal comments received prior to the meetings from local MSP and MDOT staff familiar with the corridor were also reviewed for additional insight. After identification of specific areas for further field inspection, the team then traveled the corridor and performed the on-site field reviews. Following the field reviews, the team then returned to the office for follow-up discussion to develop conclusions and possible crash countermeasures. These post-review wrap-up sessions provided substantial direction towards subsequent review of UD-10 crash reports for the primary areas of high crash concentration along corridor, which is described in the paragraphs that follow. Figure 16 provides and overview of the site review locations on the study corridor.

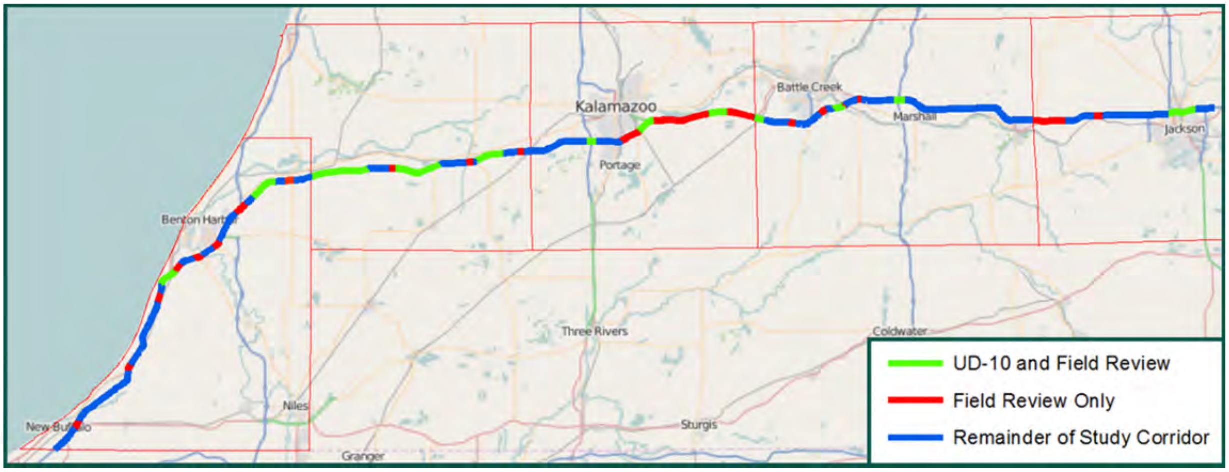


Figure 16. Overview of Safety Review Locations

A subsequent review of more than 2,000 UD-10 crash report forms was performed for selected areas along the study corridor that were identified during the field reviews as areas warranting further investigation. The UD-10 reviews were intended to identify specific crash trends and recommend appropriate countermeasures. Ten freeway segments and two interchanges were selected for this detailed evaluation. Deer crashes were excluded from this review. The selected interchanges and segments for the UD-10 crash report review are summarized in Table 12 and displayed in Figure 16.

Table 12. Summary of Locations Included in UD-10 Crash Report Review

Type	Location	Direction	County	Average AADT*	Crashes*	Crash Rate (per 100MVMT)*
Segment	MM 22-24	Both	Berrien	42.400	202	218.0
Segment	MM 36-39	Both	Berrien	34,614	197	176.0
Segment	MM 43-49	Both	Van Buren	31,972	293	134.0
Segment	MM 52-57	Both	Van Buren	33,006	246	135.0
Segment	MM 61-64	Eastbound	Van Buren	36,550	91	83.0
Interchange	US-131 (Exit 74)	Both	Kalamazoo	55,400	160	N/A
Segment	MM 79-81	Both	Kalamazoo	46,300	169	175.4
Segment	MM 87-89	Westbound	Kalamazoo	50,834	88	175.1
Segment	MM 92-93	Both	Calhoun	48,270	96	181.6
Segment	MM 101-102	Both	Calhoun	50,096	63	114.9
Interchange	I-69 (Exit 108)	Both	Calhoun	33,028	120	N/A
Segment	MM 138-141	Both	Jackson	56,456	304	130.8

*2012 – 2014 data

All non-deer-involved Michigan UD-10 crash report forms were obtained for the years 2012, 2013, and 2014 for each site listed in Table 12. These report forms were reviewed by MDOT staff to identify crash patterns and potential highway improvements or other agency actions to treat the safety issues. These recommended improvements were classified as short, medium, or long term based on cost and other factors. The following considerations were given to each location during the review and subsequent recommendation of potential improvements:

- Count of mainline and ramp traffic crash frequency;
- Crash rate per 100M VMT;
- Trends or patterns based on the analyzed crash report forms;
- Geometric characteristics of the study location;
- Presence of interchanges within the study location;
- Study locations inclusion on the annual MDOT high-crash/transparency list; and
- Current or planned future actions for the study location.

The findings and recommendations resulting from the UD-10 crash report and field reviews for each location listed in Table 12 are provided in full detail in Appendix D. The following sections provide a county-by-county summary of the findings and recommendations resulting from the field reviews and UD-10 reviews. Please note that all street-level images were obtained from Google StreetView. The following countermeasures were considered during development of the site-specific recommendations:

- Winter Weather Treatments
  - Environmental sensor station (Figure 26a)
  - Variable speed limits (Figure 26b)
  - ITS devices providing weather-related messages (Figure 26c,26d)
  - Advanced de-icing strategies
  - Living snow fence (strategic planting of roadside vegetation)
- Pavement Surface Treatments
  - Resurfacing
  - High friction course
- Visibility Enhancements
  - Signing
  - Marking
  - Delineation
  - Lighting
- Geometric Improvements
  - Cable barrier relocation
  - Ramp extension or realignment
  - Shoulder widening
  - Increased superelevation
- Congestion Management
  - Crash investigation pull-off site
  - Courtesy patrol
  - Incident management improvements
  - ITS devices providing queue warning messages (Figure 26c,26d)
  - Add third lane

4.2.1 Berrien County

Figure 17 presents a map of the reviewed locations within Berrien County.

Figure 17. Safety Review Locations – Berrien County

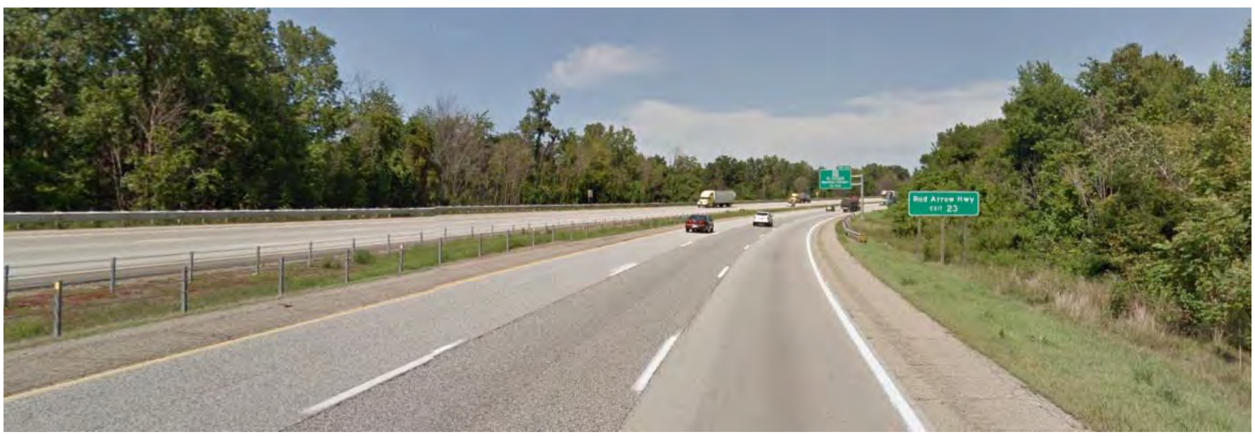
Brief summaries of the findings from the Berrien County field and UD-10 reviews, including identified issues and potential recommendations, are listed as follows (underlined sections indicates that UD-10 crash forms were reviewed in addition to the field review):

- **Exit 4 (US-12):** The entrance ramp from Westbound US-12 to Eastbound I-94 is difficult for trucks to negotiate due to the sharp horizontal curvature with a steep incline, which may contribute to truck overturns. Additionally, the ramp enters the freeway from the left, and the merge is abrupt due to the bridge immediately beyond the ramp gore area. The safety issues are exacerbated by the heavy ramp truck volumes. The truck weigh station located one mile in advance of the interchange may also contribute to merging issues. Optical speed bars may be a suitable treatment on the loop ramp to help control speeds and alleviate overturns. Extension of the acceleration lane or ramp reconfiguration may also be a potential safety countermeasure.

Eastbound I-94 at Entrance Ramp from Westbound US-12 (Exit 4)

- **Exit 12 (Sawyer Road):** Substantial horizontal and vertical curvature exists on I-94 at this interchange. Heavy truck traffic exists on the ramps due to the busy truck stops along Sawyer Road. MDOT has previously implemented optical speed bars on the loop ramps to help control speeds of exiting vehicles.
- **Mile Marker 20:** A downgrade exists in the westbound direction towards the Cook Road overpass. A narrow shoulder is present on the median side. No additional issues were observed.
- **Mile Marker 22-24 (including Puetz Road curve and Red Arrow Highway Interchange [Exit 23]):**
  - Issues Identified: This area, particularly near the Red Arrow Highway interchange, contains the highest concentration of crashes along the entire study corridor. This is especially the case in the eastbound direction near the entrance ramp from Red Arrow Highway, where truck-involved crashes are greatly overrepresented compared to all other locations along the study corridor. Crashes were found to frequently occur downstream of the eastbound entrance ramp, possibly due to truck acceleration issues and/or sight distance issues caused by the crest vertical curve prior to the entrance ramp. The interchange issues are compounded by the nearby horizontal curve at Puetz Road, which possesses the lowest design speed (between 70 mph and 75 mph) of any horizontal curve on the study corridor. The UD-10 review of this area found approximately half of the crashes to have occurred during wintry road surface conditions.
  - Potential Countermeasures: MDOT has resurfacing projects programmed for 2016 (westbound) and 2017 (eastbound) that will include the Puetz Road curve. In addition to the resurfacing, which should improve pavement surface friction, these projects will also include superelevation improvements to increase the curve design speed and shoulder widening to improve the recovery

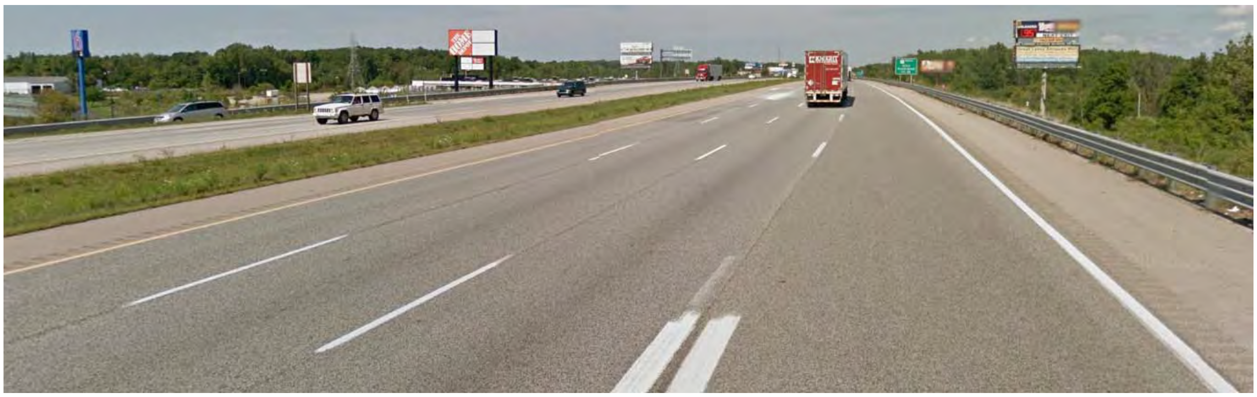
area for vehicles. The recently installed median cable barrier will help prevent the often severe cross-median type crashes that had previously occurred in the area. Property damage crashes may also be reduced if the cable median barrier is relocated away from the eastbound shoulder through the Puetz Road curve. However, cable barrier relocation may not be possible in the interchange area due to the reduced median width. To combat winter weather safety issues, this section may benefit from installation of an environmental sensor station and corresponding ITS signs/devices to alert motorists when poor weather and/or surface conditions are predicted. Additionally, a “living snow fence” consisting of dense installation of trees and other vegetation, similar to that proposed between Exits 46 and 56, may help reduce the occurrence of blowing and drifting of snow across open sections of the freeway. Advanced salting techniques, including brine or other chemicals or methods, may help improve winter road conditions along this section. Although a long-term implementation strategy, improvements to the freeway lighting, particularly at the interchange, may provide additional safety benefits.



Eastbound I-94 at Puetz Road Curve

Eastbound I-94 Entrance Ramp from Red Arrow Highway (Exit 23)

- **Mile Marker 25:** Crashes continue to persist well downstream of the eastbound entrance ramp from Red Arrow Highway, possibly due to truck acceleration issues to the vertical upgrade and the horizontal curve near mile marker 25. Anecdotal observations also suggested that there may potential concrete pavement icing issues in this area.
- **Exit 27 (M-63):** New development has caused increased traffic volume at this interchange. There is also a concrete to asphalt transition here in the eastbound direction. Winter crash issues are present here, particularly westbound and especially for trucks.
- **Exit 29 (Pipestone Road):** The eastbound entrance ramp involves both a vertical upgrade and horizontal curve with an abrupt merge taper. These collectively create acceleration issues, particularly for trucks. The eastbound auxiliary lane extension to the next interchange (Napier Road) is a possible medium to long term improvement.



Eastbound I-94 Entrance Ramp from Pipestone Road (Exit 29)

- **Exit 34 (I-196):** Westbound I-94 to Northbound I-196 ramp has substantial curvature for a system interchange, but this location was not identified as a major crash problem area. An environmental sensor station will be installed near this interchange in 2016.
- **<u>Mile Marker 36-39 (including Friday Road Interchange [Exit 39] and adjacent curve):</u>**
  - <u>Issues Identified</u>: This is an area of relatively high crash concentration, both eastbound and westbound, particularly for winter crashes and overnight crashes. The UD-10 review revealed that nearly one-half of crashes occurred under wintry or wet pavement surface conditions. Blowing snow is known to frequently occur between mile markers 36 and 38. Geometric issues also persist along this portion of the study corridor. The Friday Road curve leads into eastbound exit ramp, which includes a very short tapered deceleration lane just beyond the Friday Road overpass and in advance of a sharply curved loop ramp. Although this ramp meets the minimum geometric standards, run-off-the-road crashes still occur along the curved portion of this ramp. Advance ramp speed signs were previously placed in order to warn traffic of the approaching

curvature of this exit ramp. Similar to the Puetz Road curve, many property damage crashes occur in the Friday Road curve, including many collisions with the cable median barrier.

- <u>Potential Countermeasures:</u> An environmental sensor station is proposed for installation nearby at the I-196 interchange in 2016. This station will provide real-time weather data, along with pavement condition and forecasting data for the area, which should help improve winter maintenance and other safety and operational aspects along this segment. The environmental sensor data may also be used in conjunction with variable speed limit signs or other ITS signs/devices to better alert motorists of changing weather and/or pavement conditions. Additionally, a "living snow fence" consisting of dense installation of trees and other vegetation (similar to that proposed between Exits 46 and 56), may help reduce the occurrence of blowing and drifting of snow across open sections of the freeway. Targeted high friction surface treatments are recommended to treat area of low pavement friction within this segment. Advanced salting techniques, including brine or other chemicals or methods, may help improve winter road conditions along this section. Lengthening the acceleration and deceleration lanes at the Friday Road interchange is also recommended to help control crashes associated with the freeway/ramp transition. Although a long-term implementation strategy, improvements to the freeway lighting, particularly at the interchange, may provide additional safety benefits. Relocating the cable median barrier away from the eastbound shoulder through the Friday Road curve should reduce the occurrence of median barrier collisions, while still inhibiting cross-median crashes.

Envir. Sensor Station

Flashing Warning Sign

Eastbound I-94 Exit Ramp at Exit 39 (Friday Road)

- **Mile Marker 40 (Hennesy Hill):** This area includes a steep upgrade/downgrade eastbound/westbound between Exits 39 and 41. Icing has been noted as an issue, particularly for the westbound concrete pavement on the steep downgrade. This may be a good candidate for a high friction treatment in the westbound direction. The steep vertical upgrade in the eastbound direction may also present potential climbing issues for trucks entering from Friday Road.

Westbound I-94 Downgrade at Mile Marker 40 (Hennesy Hill)

4.2.2 Van Buren County

Figure 18 presents a map of the reviewed locations within Van Buren County.

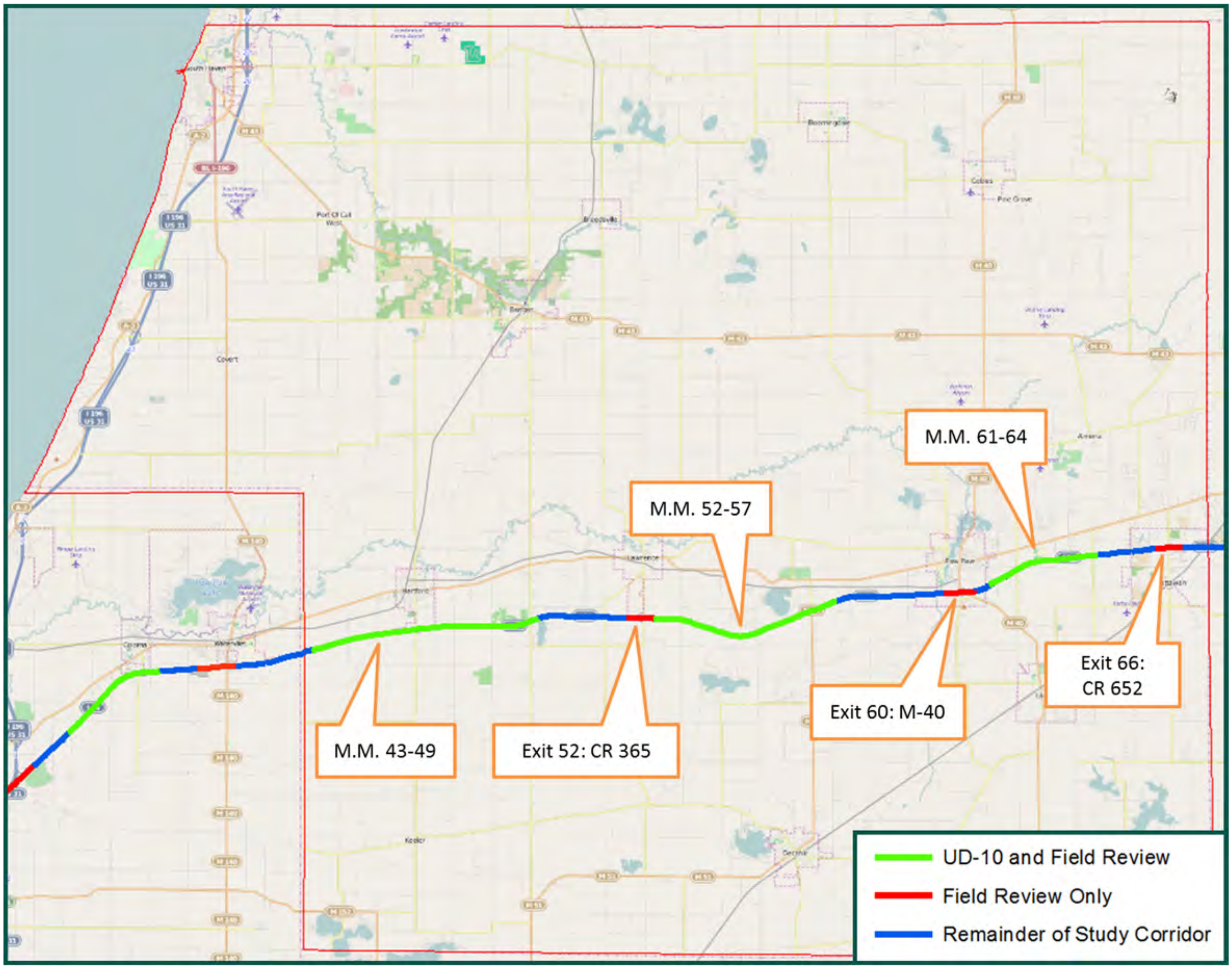


Figure 18. Safety Review Locations – Van Buren County

Brief summaries of the findings from the Van Buren County field and UD-10 reviews, including identified issues and potential recommendations, are listed as follows (underlined sections indicates that UD-10 crash forms were reviewed in addition to the field review):

- **<u>Mile Marker 43-49 (including CR 687 Interchange [Exit 46]):</u>**
    - <u>Issues Identified</u>: As with many portions of the corridor in Van Buren County, this section of I-94 experiences an overrepresentation of winter crashes, including some of the highest winter season crash rates along the entire study corridor. Approximately 75 percent of all crashes in this area were noted in the UD-10 reports as occurring during wintry road surface conditions. The highest concentration of winter crashes within this section occurs near mile marker 45, just west of the CR 687 interchange. The field review at this location revealed a

potential issue with the westbound entrance ramp acceleration lane, which includes a narrow shoulder and limited shy line for entering traffic due to the Pine Creek Bridge near the end of the ramp. While the western portion of this segment contains relatively straight alignment, the eastern portion near mile marker 49 contains significant vertical and horizontal curvature. In particular, the westbound direction at mile marker 49 includes a vertical downgrade leading into a horizontal curve. It was noted during the field review that westbound vehicles tend run-off into the median while approaching the curve at this location, often striking the cable median guardrail, which is positioned on the inside of the curve. Queue spillback is a particular concern at this location due to the limited sight distance over the hill crest near mile marker 50.

- Potential Countermeasures: An environmental sensor station is proposed at the County Road 687 interchange (Exit 46) in 2016, which should help improve winter maintenance and subsequent safety and operational impacts. This data may also be used in conjunction with variable speed limit signs or other ITS signs/devices to better alert motorists of changing weather and/or pavement conditions. Additionally, a large tree installation project ("living snow fence") to reduce blowing and drifting of snow across the freeway is proposed to occur in 2019 between Exits 46 and 56. Advanced salting techniques, including brine or other chemicals or methods, may help improve winter road conditions along this section. Relocating the cable median guardrail away from the westbound shoulder through the curve may limit incidental contact with the barrier and reduce subsequent residual crashes that often occur at the back of the queue that forms after the initial barrier strike during incident response. The crest vertical curve near mile marker 50 may be a suitable location for installation of an ITS sign or queue spillback alert sign in advance of the hill crest. Lengthening the acceleration and deceleration lanes at the CR 687 interchange is also recommended to help control crashes associated with the freeway/ramp transition. Targeted high friction surface treatments are also recommended to treat area of low pavement friction within this segment.

Var. Speed Limit

Entrance Ramp to Westbound I-94 from Exit 46 Approaching Pine Creek Bridge

Westbound I-94 near Mile Marker 49

- **Exit 52 (CR 365):** Eastbound I-94 includes substantial vertical downgrade near the entrance ramp leading into a bridge underpass. This may be a suitable location for high friction surface, which is particularly effective during winter road conditions.

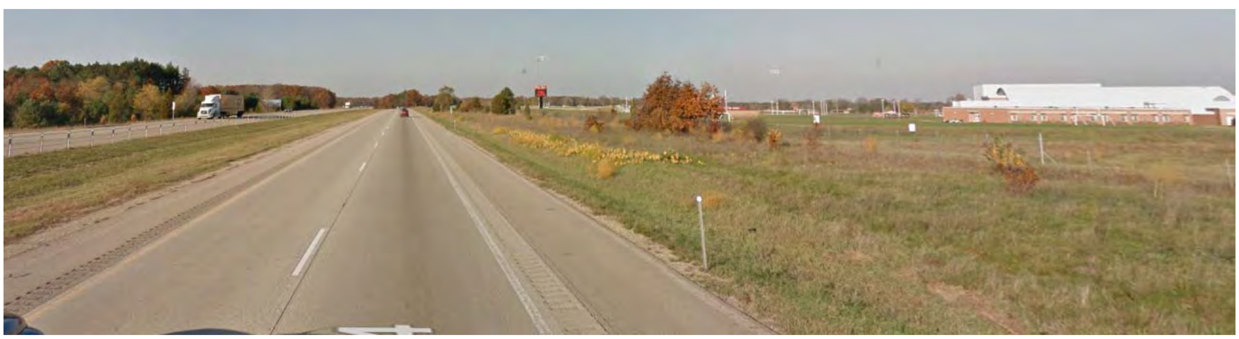
Entrance Ramp to Eastbound I-94 at Exit 52 (CR 365)

- **<u>Mile Marker 52-57 (including M-51 Interchange [Exit 56]):</u>**
  - <u>Issues Identified:</u> This section includes several horizontal and vertical curves and 70 percent of the crashes were noted as having a wintry road surface. One-third of the crashes involved contact with the cable median barrier or beam guardrail, which may be reduced by relocating the barrier further away from the shoulder. Trucks entering at the eastbound entry ramp often face challenges entering the freeway due to the abrupt merge caused by the relatively short tapered acceleration lane.
  - <u>Potential Countermeasures:</u> This area will fall between two proposed environmental sensor stations proposed at Exits 46 and 60, which should help improve winter maintenance and subsequent safety and operational impacts, particularly if this data is used along with ITS signs/devices to alert motorists of changing weather and/or pavement conditions. Additionally, a large tree installation project ("living snow fence") to reduce blowing and drifting of snow across the freeway is proposed to occur in 2019 between Exits 46 and 56. Advanced salting techniques, including brine or other chemicals or methods, may help improve winter road conditions along this section. Resurfacing in the westbound direction in 2015 and eastbound direction in 2017 in the eastern portion of this section will correct issues with low pavement friction in this area. Pavement friction may be improved in other areas by using localized high friction surface treatments. The eastbound reconstruction will also include shoulder widening and superelevation adjustment. The M-51 interchange may also benefit from lengthening of the acceleration and deceleration lanes to help control crashes associated with the freeway/ramp transition.

Dynamic Message Sign (Small)

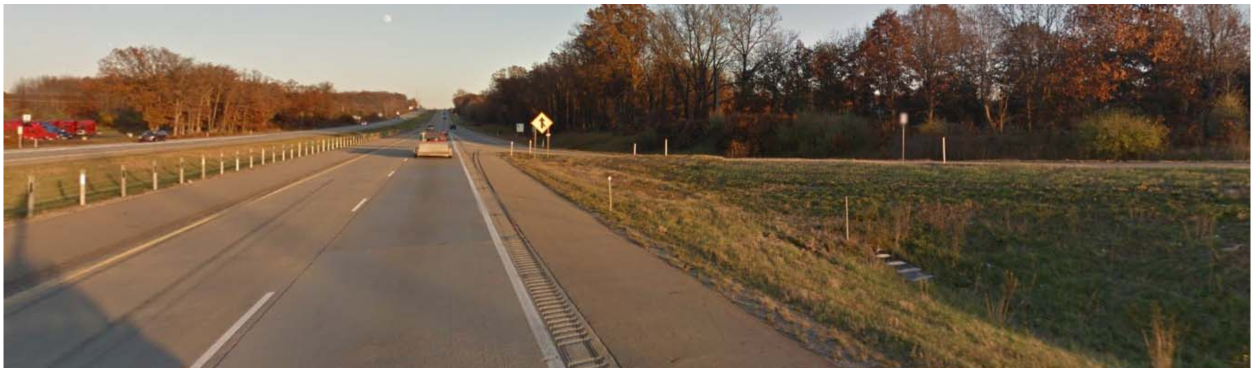
Eastbound I-94 Entrance Ramp from Exit 56 (M-51)

- **Exit 60 (M-40):** The westbound ramp merge area was investigated during the field review and no apparent issues were discovered. An environmental sensor station will be installed along I-94 near Exit 60 in 2016.
- **<u>Mile Marker 61-64 (Eastbound only):</u>**
    - o <u>Issues Identified:</u> Similar to other locations within Van Buren County, 75 percent of the reviewed crashes were noted has having wintry road surface conditions. The north side of the freeway is generally open with little tree cover at the Paw Paw High School property between mile markers 62.5 and 63, allowing for blowing snow across the freeway. Forty percent of the crashes involved contact with the cable median barrier.
    - o <u>Potential Countermeasures:</u> The nearby environmental sensor station proposed for installation near Exit 60 in 2016 will help improve prediction of winter weather and pavement surface conditions and alleviate associated safety and operational issues, particularly if this data is used along with ITS devices to alert motorists of changing weather and/or pavement conditions. Advanced salting techniques, including brine or other chemicals or methods, may help improve winter road conditions along this section. The area near Paw Paw High School may be another suitable location for a living wind barrier, which would include trees and other vegetation planted adjacent to the corridor to block blowing snow. Incidental collisions with the cable median barrier may be reduced by relocating the barrier further away from the shoulder in the areas where crashes frequently occur.



Westbound I-94 and Adjacent Roadside near Paw Paw High School (Mile Marker 63)

- **Exit 66 (CR 652):** Safety issues were noted for truck entering the freeway at the eastbound entry ramp, due to the abrupt merge caused by the relatively short tapered acceleration lane. Lengthening the acceleration lane may help control merging-related crashes. Several median barrier strikes, possibly caused by merging vehicles, were noted in the area immediately beyond the ramp terminus. Collisions with the cable median barrier may be reduced by relocating the barrier further away from the shoulder. Trucks frequently park along the eastbound entrance ramp, which may further contribute to these safety issues.



Eastbound I-94 Entrance Ramp from Exit 66 (CR 652)

4.2.3 Kalamazoo County

Figure 19 presents a map of the reviewed locations within Kalamazoo County.

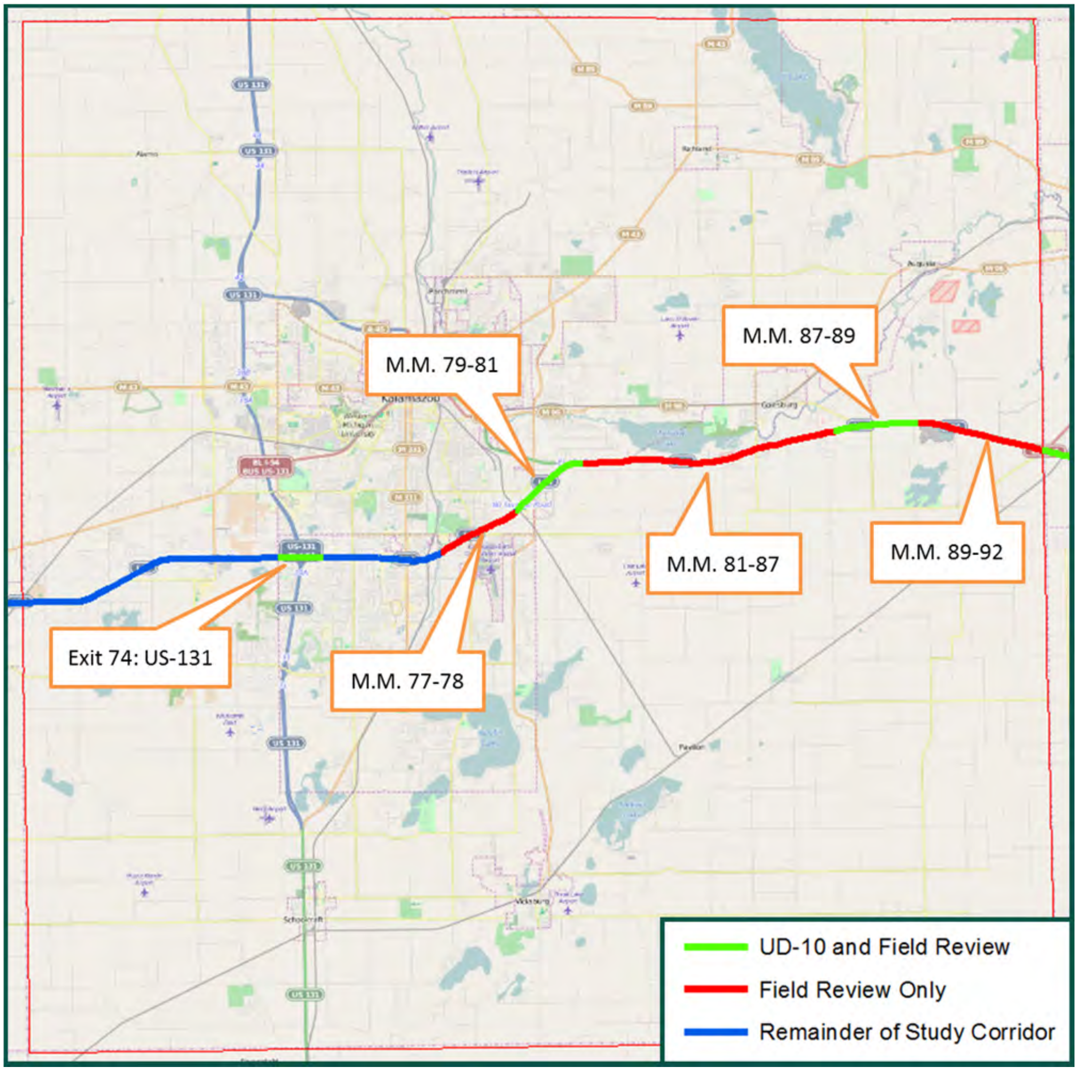


Figure 19. Safety Review Locations – Kalamazoo County

Brief summaries of the findings from the Kalamazoo County field and UD-10 reviews, including identified issues and potential recommendations, are listed as follows (underlined sections indicates that UD-10 crash forms were reviewed in addition to the field review):

- **<u>US-131 Interchange (Exit 74)</u>:**
    - <u>Issues Identified</u>: Although recently reconstructed, the Southbound US-131 ramp to Eastbound I-94 includes significant horizontal curvature. A disproportionate number of crashes occurring on this ramp involved overturning vehicles, which indicates speeding issues on the ramp. Furthermore, a majority of the overturning crashes on the southbound ramp occurred at the transition point where the southbound ramp splits into separate ramps for eastbound and westbound I-94. Most of the overturning collisions occurred due to vehicles making erratic overcorrection maneuvers in an attempt to exit in the eastbound direction. Throughout the entire interchange, 55 percent of the crashes took place under adverse road weather conditions such as icy, snowy or wet roadway conditions. The simultaneous loop ramps along westbound I-94 contribute to additional weaving in the interchange. When coupled with the simultaneous lane-drops on both the left and right side just beyond the Southbound US-131 entrance ramp terminus, this may contribute to the disproportionate number of rear end and side-swipe crashes that occur in the westbound direction compared to eastbound. Weaving-related crashes may also be an issue between the westbound entrance ramp from Oakland and the westbound exit ramp to northbound US-131, particularly with the relatively short uphill acceleration lane. Dark crashes were also overrepresented in the westbound direction.
    - <u>Potential Countermeasures:</u> To help control ramp speeds, MDOT recently installed advisory speed and curve warning signs for Southbound US-131 to Eastbound and Westbound I-94 ramp traffic, including lane assignment arrows overlays, speed advisory warning to guide signs, chevrons, and reflective post sheeting. However, additional signing and delineation through this curve is recommended to help further control speeds. Enhanced roadside delineation will be provided throughout the interchange as a part of corridor signing upgrades in Kalamazoo County in 2016. It may eventually be necessary to provide lighting at this interchange to help reduce nighttime crashes. In addition, a high friction surface project, which includes the Southbound US-131 to I-94 ramp, is scheduled for 2016. This interchange may also benefit from an environmental sensor station, which would help improve winter maintenance and subsequent safety and operational impacts, particularly if this data is used along with ITS devices to alert motorists of changing weather and/or pavement conditions. Advanced salting techniques, including brine or other chemicals or

methods, may also help improve winter road conditions along this section. Courtesy patrols or other incident management activities may also help improve operations and reduce secondary collisions after the incident has occurred.

Southbound US-131 Ramp to Eastbound I-94

Westbound I-94 beyond Southbound US-131 Ramp Terminus

- **Mile Marker 77-78 (including Portage Road Interchange [Exit 78]):** Safety issues may exist due to the unusual condition where the I-94 eastbound right lane becomes the Portage Road exit ramp. MDOT has installed "Exit Only" pavement markings and will be installing a large cantilever sign to inform drivers of the pending exit ramp and subsequent lane drop. Also, the low friction on the new concrete pavement between Oakland and Lovers should be reviewed. The eastbound entrance ramp from Southbound Portage Road has a relatively short acceleration lane. It is recommended that MDOT review the current design to determine if the lane can be lengthened into the northbound Portage Road entrance ramp.

Eastbound Approaching Exit 78 (Portage Road)

Eastbound Entrance Ramp from Southbound Portage Road

- **<u>Mile Marker 79-81 (including Sprinkle Road Interchange [Exit 80] and I-94BL Interchange [Exit 81]])</u>:**
    - <u>Issues Identified</u>: Single vehicle and rear-end crashes collectively accounted for 80 percent of the crashes within this section of the corridor. Between 40 and 50 percent of the crashes occurred during dark periods. The majority of the single vehicle crashes were collision with the concrete median barrier, while the remainder were run-off-the-road to the right. Median barrier crashes were most frequent between mile markers 80 and 81, near the curve west of the I-94BL interchange. The median side-shoulder is very narrow along the concrete median barrier section, which not only increases the likelihood of barrier collisions, but also creates difficulties with clearing crashes from the travel lanes leading to residual queuing and associated secondary collisions. These safety and operational issues are exacerbated by the horizontal curve just west of the I-94BL interchange, which possesses a design speed between 80 and 85 mph. Winter pavement conditions further contribute to these safety issues, particularly in the westbound direction. Rear-end collisions were most frequent between mile markers 79 and 80, likely related to ramp traffic from the Sprinkle Road interchange or residual collisions associated with queuing from prior collisions. The area near the Sprinkle Road interchange had several westbound crashes involving an overturned vehicle. Numerous side-swipe collisions also occurred in the westbound direction near the Sprinkle Road entrance ramp. The eastbound I-94BL entrance ramp is somewhat obstructed by the horizontal curve and contains a relatively short acceleration lane.
    - <u>Potential Countermeasures:</u> Several improvements are either currently being implemented or planned for implementation in the near future. The Sprinkle Road interchange was under reconstruction at the time of this study. This reconstruction will include new ramp geometry, with improved acceleration and deceleration lanes. These ramp improvements are expected to reduce the crashes resulting from the merging and lane changing around the interchange, especially side-swipe, single vehicle overturning, and fixed object crashes. Crash

investigation sites are also planned to be constructed near mile marker 83 for eastbound I-94 and between mile marker 81 and 82 for westbound I-94. The crash investigation sites will allow for more efficient clearance of crashes along the mainline, which is difficult due to the restricted area along the median barrier wall. These sites are expected to reduce congestion and secondary crashes, particularly rear-end crashes, resulting from slowed traffic due to an upstream crash. ITS devices, including variable speed limit signs and/or queue detection/notification systems may also improve safety and operations in this area. Further safety and operational enhancements would result from the addition of an environmental sensor station linked with ITS warning devices. Advanced salting techniques, including brine or other chemicals or methods, may also help improve winter road conditions along this section. More efficient clearance of crashes and other incidents may be enhanced by implementing freeway courtesy patrols, which have been successful in Metro Region. Enhanced roadside delineation, particularly along the barriers, will be provided as part of the 2016 I-94 signing upgrades scheduled for Kalamazoo County. The eastbound I-94BL entrance ramp may benefit from delineation enhancements, such as Quick Kurb, near the ramp merge point. Eastbound shoulder widening and westbound resurfacing are also scheduled from Miller to 40th in 2018. This resurfacing should correct the low friction measured on westbound I-94 at the I-94BL overpass. The addition of a third lane is a potential long-term solution that should enhance operations and safety along this section.

I-94 Eastbound Entrance Ramp from I-94BL

- **Mile Marker 81-87 (including 35th Street Interchange [Exit 85]):** Similar to mile marker 79-81, the concrete median barrier and limited shoulder creates queuing after a median-side collision occurs, contributing to secondary crashes at the back-of-queue. Emergency post-crash pull-off sites are planned for mile marker 82 westbound and mile marker 83 eastbound to help improve the efficiency of crash clearance and alleviate the residual operational and safety issues. Horizontal and vertical curvature is present near Exit 85, which likely contribute to the safety issues. However, there is little opportunity for geometric improvements through the horizontal curve (i.e., increase superelevation) without raising 35th Street bridge, which has a posted 14’5” underclearance.

I-94 Westbound Approaching 35th Street Bridge

- **<u>Mile Marker 87-89 (Westbound only; including 40th Street Interchange [Exit 88]):</u>**
  - o <u>Issues Identified:</u> One-half of the crashes along this segment were single vehicle crashes, the majority of which were fixed object crashes. Winter weather was noted for nearly 60 percent of the fixed object crashes. The remainder of the crashes in this section were rear-end or side-swipe. The majority of the rear-end crashes took place under dry pavement conditions, primarily from vehicles colliding with slowed or stopped traffic, often caused by an earlier crash downstream. A pattern of rear-end and sideswipe crashes was observed near the merge point of westbound I-94 entrance ramp. A formal road safety audit was conducted at the 40th Street interchange in 2012, including all ramps. The interchange was noted as having insufficient acceleration/deceleration lane lengths combined with heavy truck movements and limited vertical and horizontal sight distance for the westbound I-94 entrance ramp and eastbound I-94 exit ramp. Insufficient vertical profile of I-94 was also identified as a potential contributor to rear-end crashes, which can be worsened by adverse weather.
  - o <u>Potential Countermeasures:</u> Based on the recommendations resulting from the 2012 road safety audit, the 40th Street interchange will be reconstructed in 2016. This will include full reconfiguration of the interchange, vertical profile changes to I-94, and improvement to the acceleration and deceleration lengths of the ramps. These improvements are expected to reduce driver confusion and the pattern of crashes currently being observed along this segment of I-94. The new pavement surface should also improve pavement friction at this location, which may be further enhanced during winter weather conditions by the use of advanced salting techniques. Furthermore, an environmental sensor station will built nearby at the Galesburg Rest Area (mile marker 84.4) in 2016. The sensor station data will help improve prediction of winter weather and pavement surface conditions and alleviate associated safety and operational issues, particularly if this data is used along with ITS devices to alert motorists of changing weather and/or pavement conditions. Roadside delineation will also be improved as part of the 2016 Kalamazoo County signing upgrades.

- **Mile Marker 89–92:** Although this area was not identified as an area of high crash concentration from 2012 through 2014, it was the location of the January 9, 2015 crash, and was thus reviewed in the field. During the field review, it was noted that some areas are confined by cable median barrier and outside guardrail. Relocating the cable median barrier away from the median-side shoulder should reduce the occurrence of median barrier collisions, while still inhibiting cross-median crashes. This should also help prevent residual traffic back-ups resulting from collisions with the median barrier. Some crest vertical curves were present in this section. Ample tree coverage exists on the north side (Fort Custer) to inhibit blowing snow across the freeway.

4.2.4 Calhoun County

Figure 20 presents a map of the reviewed locations within Calhoun County.

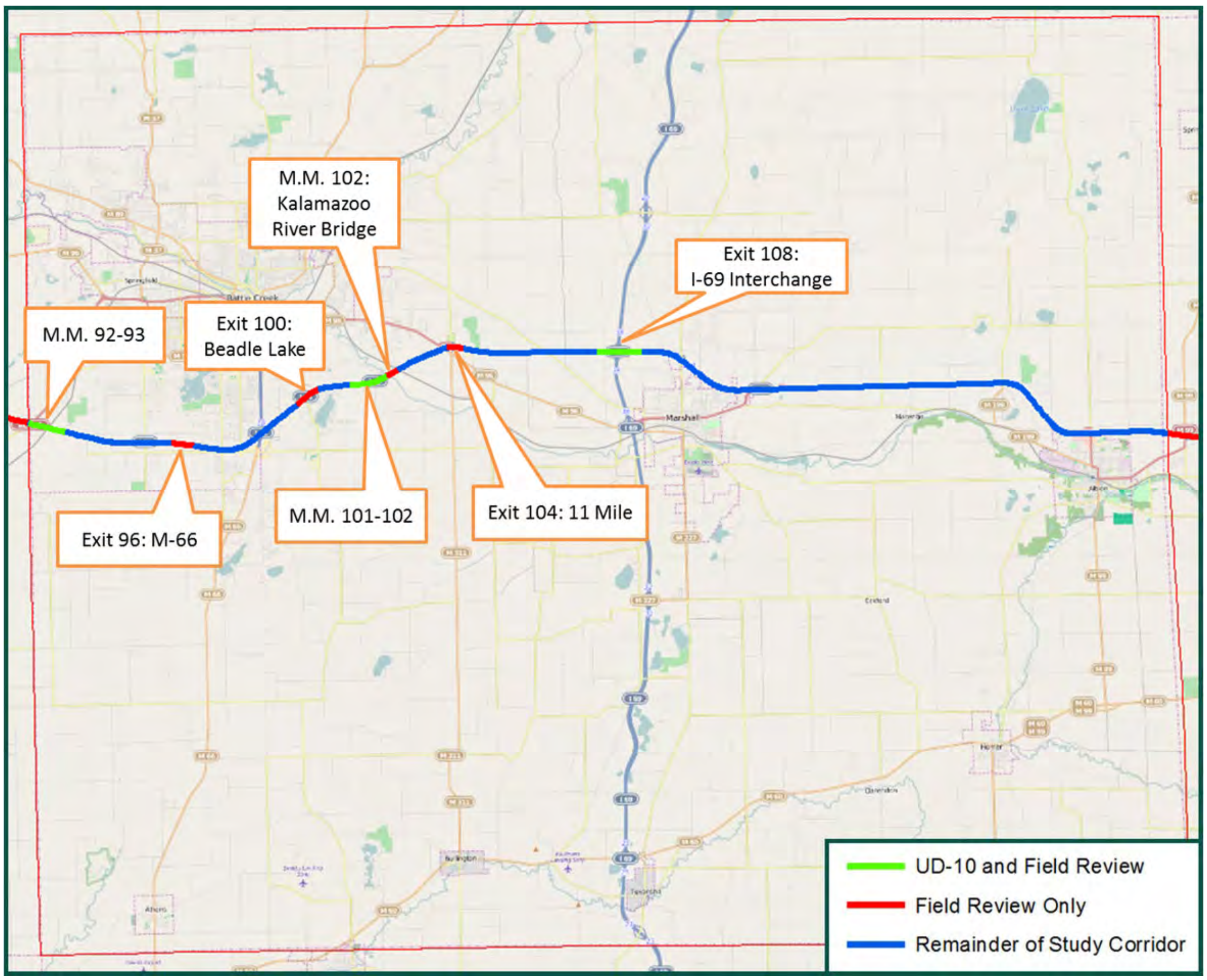


Figure 20. Safety Review Locations – Calhoun County

Brief summaries of the findings from the Calhoun County field and UD-10 reviews, including identified issues and potential recommendations, are listed as follows (underlined sections indicates that UD-10 crash forms were reviewed in addition to the field review):

- **<u>Mile Marker 92-93 (including Columbia Avenue Interchange [Exit 92]):</u>**
    - <u>Issues Identified:</u> Greater than one-half of the crashes along this section occurred during wintry or wet pavement conditions and greater than one-third occurred at night. Nearly 40 percent of the crashes were fixed object crashes, nearly all of which occurred during wintry or wet roadway conditions. Many slide-off roadway crashes occur near the railroad and Renton Road overpasses during winter weather conditions. Three-quarter of the fixed object crashes were collision with the cable barrier or guardrail. Rear-end collisions were also an issue here, accounting for nearly one-third of the crashes, the majority of which were collisions with slowed or queued traffic. This location has significant vertical curvature east of Exit 92, which may contribute to sight distance issues and associated crashes with slowed or queued traffic.
    - <u>Potential Countermeasures:</u> Current improvements at the Columbia Avenue interchange will lengthen the acceleration and deceleration lanes for the ramps. Enhanced roadside delineation will be provided through this section as a part of the I-94 signing upgrades in Calhoun County. A high friction surface project is also scheduled for the I-94 mainline at Exit 92 in 2016. Advanced salting techniques, including brine or other chemicals or methods, may also help improve pavement surface conditions during winter weather events along this section. Slope regrading and restriping ramp gore areas are additional recommended improvements. The installation of ITS devices, particularly those linked with an environmental sensor station, may further enhance safety and operations at this location.
- **Exit 96 (M-66):** The full cloverleaf interchange creates inherent issues with weaving and merging. Improved delineation and or signing should be investigated here. Commercial vehicle rollovers are a problem on the loop ramps.
- **Exit 100 (Beadle Lake Road):** This interchange contains unfavorable geometry near the exit and entry ramps. The eastbound entrance ramp has a substantial horizontal curve near the merge taper. The westbound exit ramp has sight distance issues due to the ramp crest vertical curve at the ramp. In both cases, special delineation should be utilized to better inform drivers of impending hazards.

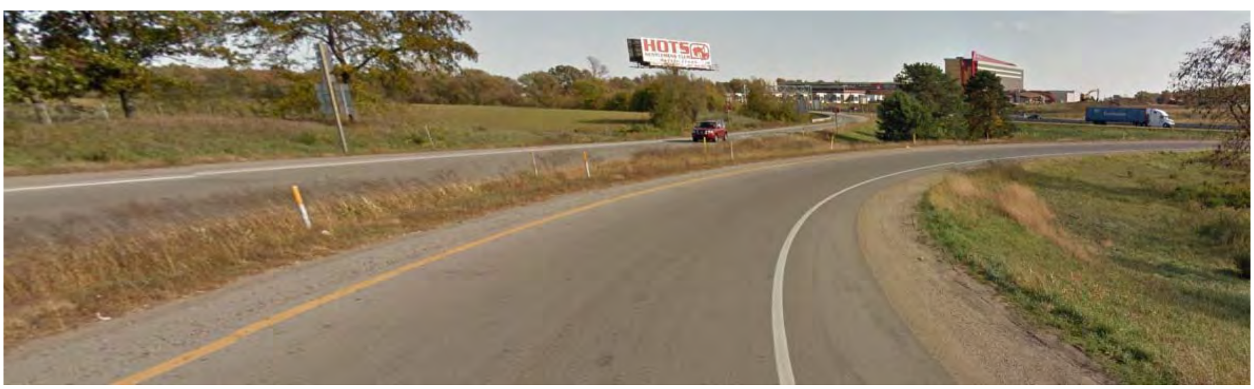
I-94 Westbound Approaching Exit Ramp to Beadle Lake Road

I-94 Eastbound Approaching Beadle Lake Road Entrance Ramp

- **<u>Mile Marker 101-102 (including Kalamazoo River Bridge):</u>**
  - <u>Issues Identified</u>: Weather-related crashes are a problem along this section, as 70 percent of the crashes were noted as occurring during wintry or wet pavement conditions. It should be noted that 2014 friction measurements did not show evidence of poor pavement surface friction here. Greater than 60 percent of the crashes were with fixed objects, nearly all of which occurred during wintry or wet weather conditions. Greater than 75 percent of the fixed object crashes were collision with the cable barrier or guardrail. The eastbound direction has a steep downgrade towards the Kalamazoo River, with narrow shoulders on the bridge.
  - <u>Potential Countermeasures</u>: Enhanced roadside delineation will be implemented as a part of the 2016 I-94 Calhoun County signing upgrades. A resurfacing project is scheduled in 2021 on I-94 from 6 ½ Mile Road to 11 Mile Road. Advanced salting techniques, including brine or other chemicals or methods, may further enhance pavement surface conditions during winter weather events along this section. Although not currently planned, installation of an environmental sensor station in this area would help improve prediction of winter weather and pavement surface conditions and alleviate associated safety and operational issues, particularly if this data is used along with ITS devices to alert motorists of changing weather and/or pavement conditions.

- **Exit 104 (M-96/11 Mile Road):** Both the eastbound and westbound exit ramps to 11 Mile Road have recently been extended to account for the increased traffic associated with the casino. Two truck stops also exist on the north side of the interchange. The eastbound loop ramp has tight horizontal radii and is particularly susceptible to backups. Truck rollover crashes is a major issue on the westbound entrance ramp. However, the bridge will require replacement in the event of westbound entrance ramp realignment. Cross-hatching or other delineation treatments should be implemented in the gore area. Safety improvement projects are scheduled for this interchange in 2020 to correct the superelevation difference with the mainline.

I-94 Eastbound Approaching 11 Mile Road Exit Ramp



Curve on 11 Mile Road Entrance Ramp to I-94 Westbound

- **<u>I-69 Interchange (Exit 108):</u>**
  - <u>Issues Identified:</u> A review of the crash reports did not reveal an overrepresentation of any particular crash type or pattern. Nearly 40 percent of the crashes occurred during wintry or wet pavement conditions. Approximately 40 percent of the crashes were speed related, with citations issued for nearly 25 percent of all crashes. Greater than one-third of the crashes were with fixed objects, the majority of occurred during wintry or wet weather and/or with the cable barrier or guardrail. Greater than one-third of the crashes occur at night. Blowing

snow is a known problem across the open areas west of the interchange. This is particularly problematic for accelerating westbound truck traffic that has just entered from I-69.

- Potential Countermeasures: A living snow fence should be considered to inhibit blowing snow. I-69 SB to I-94 Westbound presents a particularly precarious merge area between the ramp and the collector-distributor road, with the 15 Mile Road bridge abutment at the end of the merge taper, which contributes to a relatively high occurrence of side-swipe collisions. A potential long-term solution is to improve the merging area at this location, which would require reconstruction of the 15-mile Road Bridge. Furthermore, the eastbound I-94 crash attenuator at the I-69 exit ramp is struck several times each year. Delineation improvements have recently been installed within the eastbound exit gore area. Speed-related truck rollover crashes have been a longstanding problem on the loop ramps at this interchange. A subsequent signing/delineation project in late 2012 was performed to help correct this issue. This project included the addition of advisory speed signs, chevrons with reflective sheeting on posts, and truck rollover signs to all ramps. Increasing the superelevation of the loop ramps is a possible countermeasure to increase the ramp design speed. Additional enhancements to roadside delineation throughout the mainline and interchange will be performed as part of the 2016 I-94 Calhoun County signing upgrade project. An environmental sensor station is proposed to be built within the I-69 interchange in 2016, which will provide real time pavement condition data as well as support roadway condition forecasting with atmospheric sensors. This should improve winter maintenance and help alleviate weather related safety and operational issues, particularly if this data is used along with ITS devices to alert motorists of changing weather and/or pavement conditions. Advanced salting techniques, including brine or other chemicals or methods, may also help improve winter road conditions along this section. Although a long-term implementation strategy, improvements to the freeway lighting may provide additional safety benefits.

Westbound I-69 Entrance Ramp to Westbound I-94 Collector-Distributor Road

4.2.5 Jackson County

Figure 21 presents a map of the reviewed locations within Jackson County.

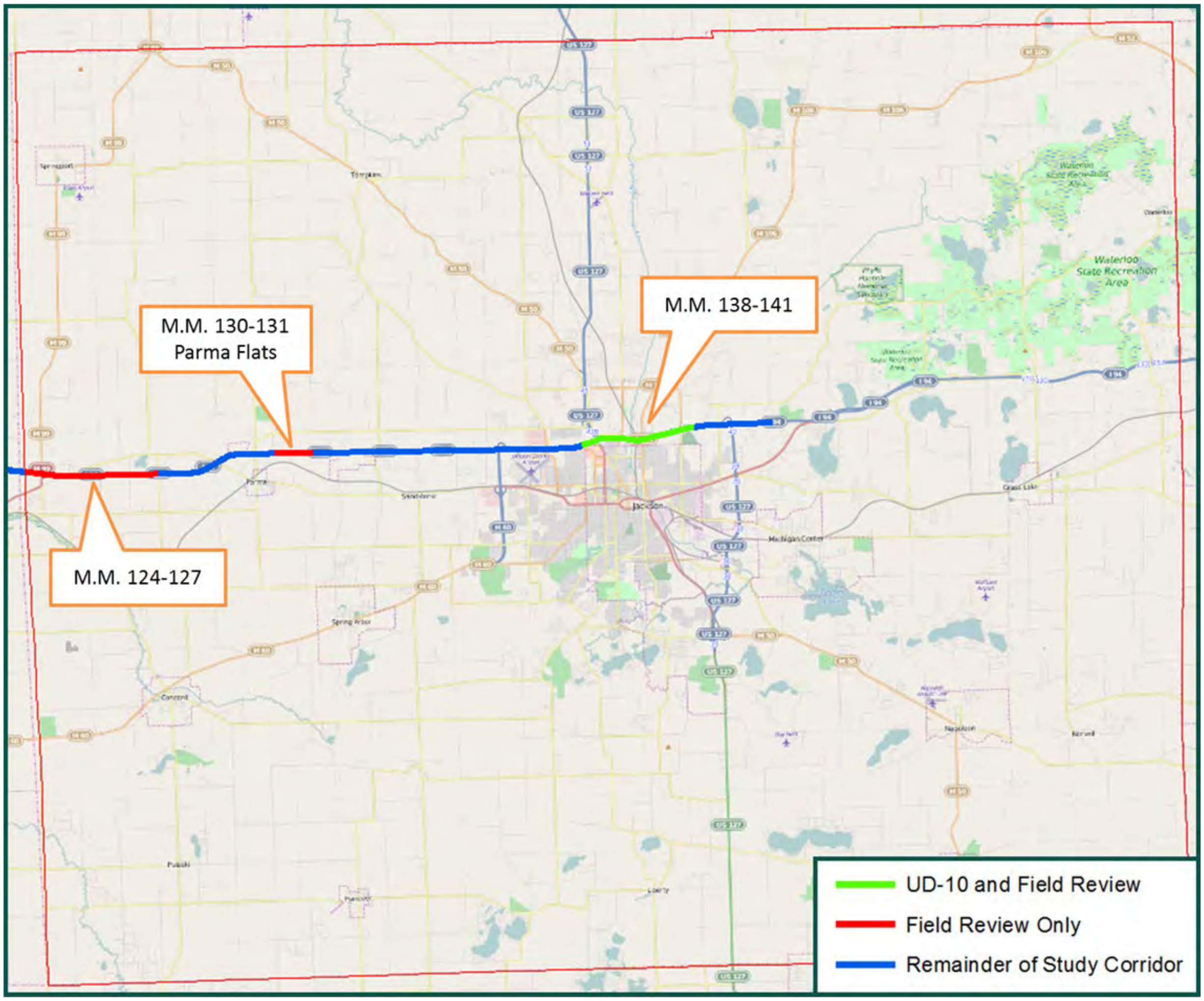


Figure 21. Safety Review Locations – Jackson County

Brief summaries of the findings from the Jackson County field and UD-10 reviews, including identified issues and potential recommendations, are listed as follows (underlined sections indicates that UD-10 crash forms were reviewed in addition to the field review):

- **Mile Marker 124-127 (M-99 to Concord Road):** Although not a major area of high crash concentration when considering the entire study corridor, this area was noted as having relatively high winter crash occurrence compared to the rest of the corridor in western Jackson County.
- **Mile Marker 130-131 (Parma Flats):** This area experiences similar issues as mile marker 124-127. The wide open adjacent land does not inhibit blowing snow. The crash issues are more prevalent in the westbound direction, especially for trucks. A living snow fence may help prevent

blowing/drifting snow at this location. The recent closure of the truck stop may help alleviate any interchange related crashes near Exit 130.

- **<u>Mile Marker 138 to Mile Marker 141 (including US-127N Interchange [Exit 138], Cooper Street Interchange [Exit 139], and Elm Avenue Interchange [Exit 141]):</u>**
  - <u>Issues Identified:</u> By far the greatest crash problem area within the Jackson County section of the study corridor is the area between US-127N and US-127S, which contains challenging geometry throughout. The median is extremely narrow throughout the corridor with a concrete barrier and 2 ft. left shoulders. The right side is also somewhat constrained with 10 ft. right shoulders and guardrail in most areas. The narrow shoulders and proximity of the barriers to the travel lanes not only increases the potential for barrier collisions, but also creates difficulties with clearing crashes or incidents from the travel lanes leading to residual queuing and associated secondary collisions. Winter and wet pavement conditions further contribute to these safety issues, particularly in the westbound direction. The review of the crash report forms showed confirmed these issues, as numerous fixed object and rear end collisions occurred in this area between 2012 and 2014. Geometric alignment issues are particularly problematic between Lansing and Elm areas. Sight distance is limited in this area by the horizontal and vertical alignment in this area (mostly on westbound), which limits sight distance and creates issues with secondary crashes occurring due to queueing that occurs when median barrier crashes occur. Furthermore, the entrance ramps at the US-127N and Cooper Street interchanges include short tapered acceleration lanes, which contribute to side-swipe collisions with vehicles and/or barriers in the ramp merge areas. There is also evidence of drainage issues in the left lane eastbound lane of I-94 east of Elm Avenue, as multiple crashes in this area were caused by water on the road, likely from drainage structures clogged by large debris. Maintenance crews clear the debris, but issues persist.
  - <u>Potential Countermeasures:</u> To correct many of the geometric issues, MDOT has programmed an extensive widening project planned for this section of the study corridor between 2018 and 2020. The most constrained section (Lansing Road to Elm) will be fully reconstructed and realigned to address many of the geometric issues that persist. The reconstruction work will include shifting the current I-94 alignment to the north, replacing the Grand River and Cooper Street bridge structures, adding a merge weave lane, and reconstructing the Cooper Street interchange. This project will also include rehabilitation work from M-60 to Lansing Avenue and Elm Avenue to Sargent Road and will include extending the ramp acceleration and deceleration lanes, widening shoulders,

and resurfacing the roadway. Over the past few years, the Jackson TSC staff has developed working relationships with area first responders. The TSC maintenance coordinator is on site for most incidents that occur on I-94, assisting with traffic control to keep traffic moving as safety and efficiently as possible to help reduce the occurrence of secondary crashes. This section of corridor has also experienced improved winter maintenance initiatives, including advanced deicing techniques. Freeway lighting and ITS initiatives have also been discussed for long term implementation along this section of the corridor.

I-94 Westbound Exit Ramp to Cooper Street

5.0 OPERATIONAL INITIATIVES

5.1 User Delay Performance Metrics

The MDOT Southwest Region implemented performance metrics along I-94 in 2011 as a result of work zone congestion to improve overall operations along the freeway. The MDOT University Region has also implemented similar performance metrics. The desired outcome is to limit delays, expressed in terms of dollars of lost time and efficiency, to the road users and provide better travel time reliability so motorists can arrive at their destination routinely in the time expected. Since its establishment, every delay experienced along I-94 has been recorded and converted to a monetary value. One of the benefits of the tracking is to allow smarter decisions to be made on the activities that influence delay.

Region staff implemented Four Disciplines of Execution (4DX) as model to follow for monitoring and improving freeway operations. The 4DX process itself is a performance metric and requires an overall measurable goal, tracks efforts of what influences that goal, uses a scoreboard tracking progress, and necessitates routine discussion of the goal. In addition to the overall reliability goal, measures were created toward specific causes of congestion: work zone delays, incident management response, and winter weather impacts. The focus was on these causes of non-recurring congestion since they are more likely to be influenced in the short-term compared to high cost construction projects taking years to implement. Southwest Region weekly user delay costs for 2014 are shown in Figure 22.

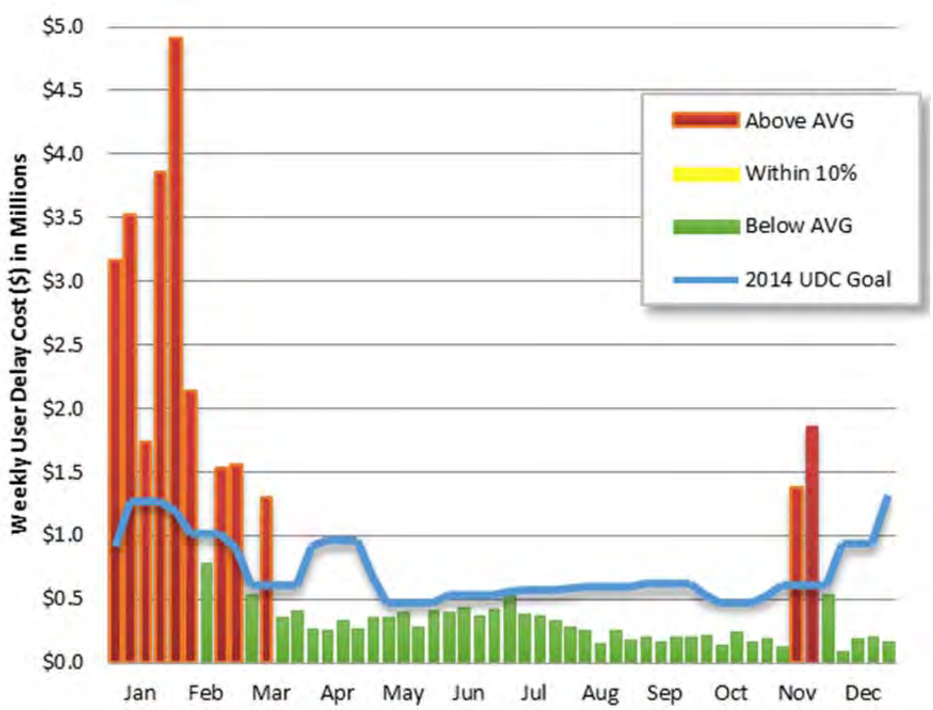


Figure 22. 2014 Southwest Region Weekly User Delay Cost

The process has evolved over the years from counting instances of slow traffic from screen captures on the MDOT real-time travel information site Mi-Drive (www.michigan.gov/drive), to running delay reports directly from the speed data used on Mi-Drive. Originally, delays were monitored on I-94 but have expanded to I-196, I-69, and US-131 as well. Each year, the region sets a goal for user delay cost based on the annual averages over the prior three years. The weekly results from last year are shown in the chart. The winter of of 2013-2014 played a major factor in the region's ability to achieve its reliability goals. Goals for the causes of non-recurring congestion are also data driven, which is described, as follows:

- **Work zones** are monitored and delay in minutes through a work zone is calculated using RITIS. Work zones have a goal to limit delays to a maximum of 10 minutes each day 90 percent of the time for each day a work zone is in place. Construction schemes are developed through the design process to achieve this as best and cost effectively as possible. Additionally, weekly meetings are held to discuss upcoming work zones and messaging efforts to notify road users.
- **Incident** success is measured by the amount of time it takes to open all lanes to traffic. The goal on the four freeways monitored is to reduce the number of incidents blocking lanes over two hours to 45 for the year, a reduction of five percent over the prior three-year average. Post-incident reviews are held to discuss what went well and what could be improved to safely reduce incident response.
- **Winter weather** impacts are measured by the amount of time it takes to clear the routes and traffic is able to return to normal speeds during peak hours. The regions efforts to improve this roadway recovery time by doing pre-storm planning across various areas, discussing what the expected storm will bring as well as the planned response. Another effort measured is the percent of time spent applying salt at slower speeds which is expected to improve its effectiveness of staying on the pavement.

Weekly reporting sessions have been held to discuss the causes of delays from the prior week as well as planned activities over the upcoming week that could play a part in improving travel time reliability. The sessions are also when updates on the various metrics are presented and discussed. In the same way, best practices are also shared and used to improve mobility and travel time reliability.

5.2 Intelligent Transportation Systems

5.2.1 Past Five Years

The first Intelligent Transportation System (ITS) infrastructure deployment along the I-94 corridor between the state line and US-127 was completed in November 2012. The project consisted of ten closed circuit television (CCTV) cameras, four dynamic message signs (DMS) and five microwave vehicle detection systems (MVDS). Three of the CCTV cameras are located in Calhoun County along I-94 and seven of the CCTV cameras are located in Kalamazoo County along I-94. All four of the DMS are located in Calhoun County; two along Westbound I-94, one along Northbound I-69 and one along Southbound I-69. All five MVDS are located along I-94, one being in Kalamazoo County with the remaining in Calhoun County. All of these devices are operated by the Statewide Transportation Operations Center (STOC) located in Lansing.

The second ITS infrastructure deployment in the Southwest Region was completed a year later in November 2013. The project constructed and integrated four DMS and four MVDS in Berrien County. Two of the DMS serve Eastbound I-94, one serves Westbound I-94 and one serves Southbound I-196. All four MVDS are co-located with the four DMS in which case three MVDS collect traffic data for I-94 and one collects traffic data for I-196. All of these devices are also operated by the STOC located in Lansing.

The next ITS project to be completed in the Southwest Region was the Truck Parking Information and Management System (TPIMS). The TPIMS project was funded by a FHWA grant MDOT was award in 2011. The grant was specific to the Truck Parking Facilities Program and allowed MDOT to implement the TPIMS along the I-94 corridor from 1.5 miles south of the Indiana border through mile marker 128, just west of Parma. The project outfitted five public rest areas and ten private truck stops with real-time truck parking availability sensors. The information is disseminated to drivers in several fashions. The most public facing dissemination method are the five dynamic truck parking availability signs. These signs are strategically placed along I-94 each with three parking destinations per sign. One destination is a rest area, and the other two are alternate private truck stops. Along with the destinations, there are three dynamic LED panels that display the current number of available parking spaces at each facility. The real-time truck parking availability is also made available through the Mi-Drive traveler information website and mobile applications as well as the Truck Smart Parking mobile application. Lastly the real-time truck parking availability can be supplied to drivers through a connected vehicle application using dedicated short range communication (DSRC) radios located along the I-94 corridor. It has yet to be formally documented if the system is reducing the amount of illegal and dangerous truck parking along the I-94 corridor. However, the University of Michigan Transportation Research Institute is under contract to evaluate the accuracy of the technology, level of manual calibration needed, and overall effectiveness of the data dissemination in decision-making. The MDOT ITS Program Office anticipates the results from this work to be available soon.

The most recent ITS project to be complete along the I-94 corridor in the Southwest Region consisted of nine DMS, three CCTV cameras and eleven MVDS. The project came online in July of 2014. Six of the DMS are located in Kalamazoo County; two severing Northbound US-131, one serving Southbound US-131, two serving Eastbound I-94 and one serving Westbound I-94. The other three DMS are located in Calhoun County on I-94; two serving westbound traffic and one serving eastbound traffic. All three CCTV cameras are in Kalamazoo County along US-131. Two are just north of I-94 and one is just south of I-94. The eleven MVDS are collocated at each DMS and CCTV location. All of these devices are operated by the STOC located in Lansing.

In addition to the four ITS infrastructure deployment projects that have been completed in the Southwest Region, there have also been a couple software advancements which have had an effect on the way MDOT operates the ITS infrastructure. When the TPIMS project was designed, there had to be a mechanism for calculating truck parking availability. This was done by counting the number of trucks entering a parking lot and the number of trucks exiting a lot. In order to accomplish this, MDOTs Advanced Traffic Management System software was modified in such a way that one to one relationships could be made with sensors in the field, if-then type logic. This has given MDOT the ability to code such logic between any sensors deployed in the field. This can be applied to environmental sensors and vehicle detection systems and when certain pre-defined criteria are met correlated messages can be sent automatically to select DMS. For example:

IF:

Air Temperature < 32°F; AND
Pavement Temperature < 32°F; AND
Pavement Condition = Snow Covered; AND
Wind Speed = 30mph; AND
Vehicle Speed = 40mph.

THEN:

Post message to DMS:

"Snow Covered Roads
And Blowing Snow
Ahead"

"Current Speeds
40 MPH"

Another software related project that enhanced the way MDOT operates from a control room perspective was the Weather Response Traffic Information System (WxTINFO). WxTINFO is a software related process that ingests weather data from MDOTs Environmental Sensor Stations (ESS), the National

Weather Service (NWS) stations, NWS radar and NWS Warnings. It also ingests mobile data from MDOTs fleet vehicles equipped with road surface condition sensors. All of these data can then be analyzed and location specific weather events can be identified. Once a weather event is identified, the affected area is sent to MDOT's ATMS software along with a suggested message to be displayed on DMS. Once the affected area is accepted by the ATMS an area weather event is created with a subsequent polygon outlining the affected area. Then the ATMS identifies DMS in that area and operators are automatically prompted to post the suggested message from WxTINFO to the selected DMS. This information is also transferred to MDOTs traveler information website, Mi-Drive to notify the public.

5.2.2 Next Five Years

There is one ITS infrastructure project under construction in the Southwest Region at this time. The project is constructing 18 CCTV cameras along the I-94 corridor with the first device being near the state line and the last device being installed just east of I-194. Twelve of the CCTV cameras will be in Berrien County, two of the CCTV cameras will be in Van Buren County, two will be in Kalamazoo County and the remaining two CCTV cameras will be in Calhoun County. Most of the camera sites will also have a MVDS installed. All of these devices will be controlled by the STOC located in Lansing. The project is expected to be completed and operational before the winter of 2015.

Currently being designed in the Southwest Region is an Environmental Sensor Station (ESS) project. The project will be let this year with anticipated construction in the spring 2016. The project consists of 15 ESS locations that will each contain a different array of atmospheric sensors (visibility, air temperature, humidity, wind speed/direction, barometric pressure and precipitation), pavement sensors (temperature, condition, salinity) and subsurface temperature probes. Most ESS locations will also include additional CCTV cameras and possibly infrared illuminators for night time camera viewing. Eight of the ESS locations are along I-94 with the remaining being designed at locations on US-12, US-131BR, I-69, M-179, US-131, US-31 and I-196. All of the data from these 15 ESS locations will be collected by MDOTs Road Weather Information System (RWIS) and then made available to ATMS, Mi-Drive, MDSS, WxTINFO and the NWS. One additional ITS project is scheduled to begin design in the next few months and includes seven DMS on I-94, I-196 and US-31. The project will tentatively be built in fiscal year 2017. There was previously another ITS design scheduled for the Southwest Region in fiscal year 2018 with construction in fiscal year 2019. However, this project was deferred due to budget constraints in the ITS program template.

5.2.3 Transportation Operations Centers (TOCs)

The Michigan Department of Transportation owns and manages four Transportation Operations Centers (TOCs) which provide active operations coverage of all state roadways. The MDOT TOCs are displayed in Figure 23. Note that I-94 from the Indiana state line to the Washtenaw/Wayne County line fall under the coverage area of the Statewide Transportation Operations Center (STOC).

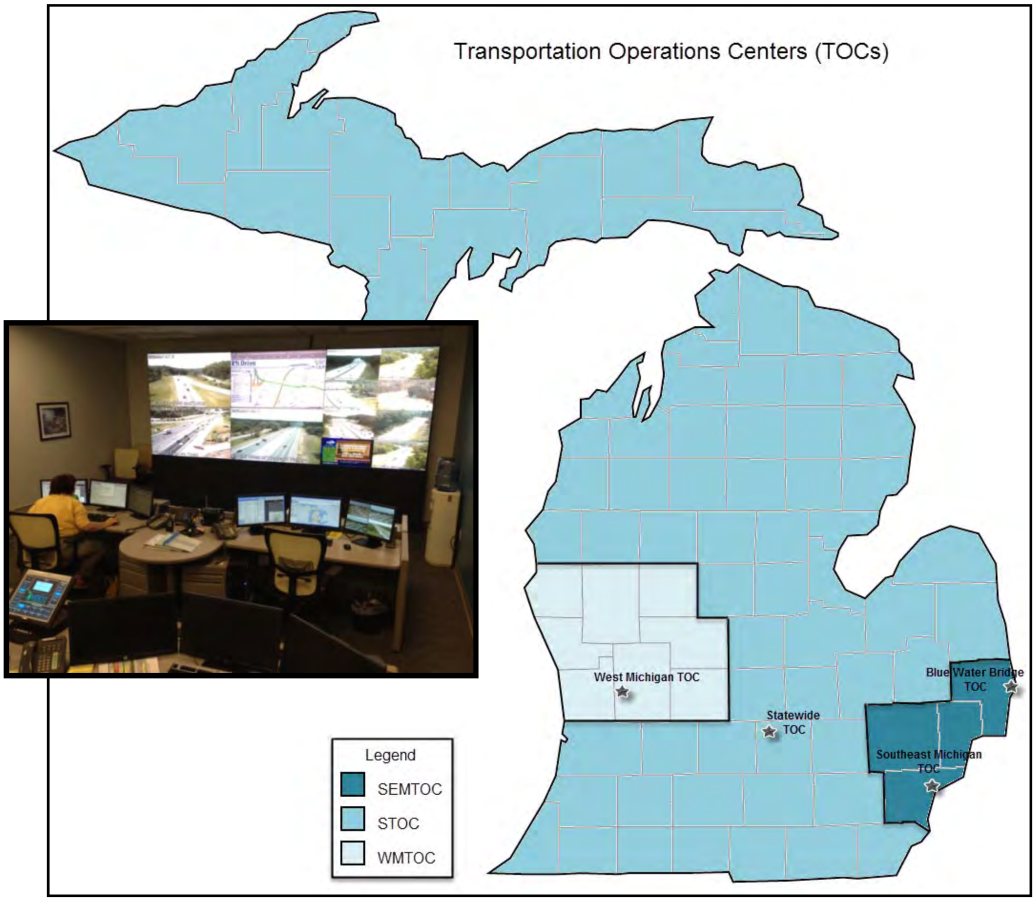


Figure 23. MDOT Transportation Operations Centers

The STOC is a 24/7 operations center in downtown Lansing with eight full time Control Room Operators (CROs). The number of CROs working in the control room at any time can vary from one to four, depending on the time of day and day of week. The TOCs are tasked with being aware of and conveying information as appropriate for any activity that is affecting or has the potential to affect the operation of a state highway. This could be construction, maintenance activities, a traffic incident, a police incident, a house or vehicle fire, severe weather, etc. Once the CRO becomes aware of an incident that is affecting, or has the potential to affect, the safety and efficiency of our roadway system, they are responsible for conveying the information to all appropriate parties. This means they are frequently in contact with local dispatch centers and MDOT first responders to gather and share information associated with incidents, and other unplanned events closing lanes or roadways. They implement messaging plans associated with construction and maintenance activities and maintain direct communication with the field staff to update construction messaging as the project progresses. They closely monitor weather and work with MDOT region staff to determine whether weather or other safety messaging is appropriate to convey to the traveling public.

From the STOC the CROs can pan/tilt/zoom the CCTV cameras to get visual information and confirmation of ongoing activities on the roadway. Any additional information ascertained by the camera images is conveyed back to local dispatch and MDOT first responders to help expedite response to the activity. While the STOC is responsible for operating all devices within the I-94 study area, the other TOCs can also operate the devices in an emergency where the STOC is evacuated or loses power. The web-based software used to operate the devices enables all TOCs to operate all devices statewide if needed. Therefore all devices are operated 24/7, even in an emergency.

In order to keep the traveling public aware of upcoming and real-time traffic conditions, there are multiple methods of communication that the CROs use on a regular basis. First, dynamic message signs (DMS) out on the roadways are used to provide information to vehicles already on the roadway and headed toward an affected area. The CRO in the STOC uses web-based software to change the DMS message.

Another method for communicating with the public is the Mi-Drive website and associated mobile app. All lane closures and road closures on state trunkline roadways are posted to Mi-Drive. Closures associated with construction and maintenance projects are typically entered into the system in advance by the local project office or garage. The information is updated in real-time as appropriate. Closures associated with unplanned incidents are entered into the system by the CROs in the TOC and are also updated in real-time as appropriate.

From both the Mi-Drive website and the Mi-Drive app, users can access information regarding lane closures and road closures associated with: upcoming construction projects, ongoing construction projects, current incidents, recently cleared incidents, and special events. Mi-Drive also shows the average speed of traffic currently traveling on most MDOT freeways and many MDOT non-freeways. Mi-Drive can also be used to get information on location of airports, park and rides, rest areas and roadside parks. Users can view camera images from MDOT CCTV cameras and see what message is currently displayed on any DMS throughout the state. Weather data from environmental sensor stations can be viewed and the I-94 corridor truck parking information is posted on Mi-Drive as well.

A third communication tool used to convey real-time information to our users is e-mail. E-mail is used to get information out to internal stakeholders for high impact incidents. There are also GovDelivery contact lists which allow anyone to sign up to receive an e-mail for incidents within certain urban areas or counties. The STOC CRO sends e-mails to internal stakeholders and to the GovDelivery lists based on geographic area and county wide contact lists.

In addition to DMS, Mi-Drive, and e-mail, the STOC also uses Twitter to keep the public updated on incidents that could affect their travels.

Issuing work orders and tracking routine maintenance for ITS devices on the I-94 corridor is also the responsibility of the STOC. The STOC works with the local MDOT office and the maintenance contractor to prioritize and schedule the work.

5.3 Maintenance Initiatives

5.3.1 Maintenance Services and Innovation

As our economy develops and transportation technologies advance, maintaining state roadways must also be an evolving and ongoing effort. Responding to the impacts of weather, roadway failures, and emergency response requires a nimble workforce equipped with the necessary tools and technology to provide the best customer service to the Michigan road user. MDOT maintenance is a critical component of the MDOT mission to provide the highest quality integrated transportation services by achieving value in its efforts, quality in the results, and innovation in the process.

5.3.2 Technology

This section highlights some of the recent technologies MDOT has employed to continue delivering quality work with resulting value to the State of Michigan. To achieve quality results during winter maintenance operations, weather prediction and information collection technology such as the Maintenance Decision Support System (MDSS) and the Automated Vehicle Location (AVL) system provide valuable data for taking action. The information from these systems allows MDOT to track incoming winter events, prepare materials and equipment, and ensure proper staffing levels. These tools have allowed MDOT to provide a better level of service during tough Michigan winters.

In addition, the department is using the MDSS and AVL data to identify the areas with the most severe winter weather through the means of a Winter Severity Index (WSI). This index is being used to measure winter operational efficiency and to identify areas of success and areas of improvement. The use of the WSI along with measured User Delay Cost (UDC) is another benchmark for level of service used by the department for the purpose of ensuring a quick recovery of the loss of time a driver experiences during a commute due to inclement weather.

5.3.3 Materials and Equipment

To perform quality work, MDOT consistently explores potential innovations involving the materials and equipment. By expanding the tools available for use, MDOT is able to effectively treat winter conditions with greater success and greater value. The following section highlights the recent materials and equipment MDOT has used to increase the value of maintenance efforts.

- **<u>Materials:</u>** The winter season in Michigan brings storms with fluctuating variables: temperature and wind, location and duration, as well as varying conditions before and after a storm. Each of these variables impact the effectiveness of the operation. With the wide variety of storm types, it is important to have options that can compete with the different circumstances. For example, pre-wetting salt allows it to remain effective at lower temperatures when compared to rock salt alone. The salt starts working immediately once placed, and stays were it is placed as opposed to scattering. Another example is the practice of anti-icing. This technique requires the placement of liquid calcium chloride directly on the roadbed to prevent snow and ice from forming on the pavement. This increases maintenance effectiveness if used prior to the storm.
- **<u>Equipment:</u>** The use of tow plows at MDOT is a relatively new practice, where the benefits are still being studied. The ability to clear more of the road and place de-icing material with less direct force provides a greater value to snow clearing efforts. Zero velocity spreaders are another piece of equipment that have added value to winter maintenance activities. Zero velocity spreaders have the ability to output salt at higher vehicle speeds. They offer flexibility in where the salt can be placed on the road which in turn generates less waste and a more effective use of less material.

5.3.4 Workforce

Much of the innovation that makes MDOT maintenance so effective is on the part of the Transportation Maintenance Workers. Having the appropriate number of employees who work effective shifts to cover the roads is an important asset to achieve value in our maintenance efforts.

- **<u>Quad Shifts:</u>** Quad shifts were developed in 2008 and implemented to maximize maintenance coverage around the clock. If a snow storm is formed outside of standard work hours along I-94, there is a quicker response available to begin winter maintenance. The faster response creates the opportunity for the motoring public to experience less delay and road conditions that are clearer than what would otherwise be available. The implementation of quad shifts also shares the burden of monitoring bad weather among more people. The responsibility of monitoring weather during non-work hours falls on the garage supervisor and the lead workers. With quad shifts, weather monitoring responsibilities are shared by staff around the clock.

- **Temp vs Perm TMWs**: The amount of maintenance actions required during the winter season is typically higher than that of the rest of the year. In response to this, the Southwest Region employs temporary workers during the winter season. The ratio is seventy percent permanent employees and thirty percent temporary employees. The total number of employees in a garage, both permanent and temporary, is determined by the number of snow routes in which the garage has jurisdiction. There are two employees for each snow route in a garage. By organizing in this manner, MDOT guarantees that there will be enough employees to perform the necessary winter maintenance and also gains the most value by assigning employees at the time and place where they can be most effective.

5.3.5 Routes

Snow routes are being made more effective by improving existing, utilizing better equipment. Larger trucks, better spreaders, and strategic route planning, enables the operators to reduce the amount of dead-head time. Another innovation includes the existing partnership with the Kalamazoo County Road Commission (KCRC). Salt shed sharing with the KCRC means that an operator does not need to return to the MDOT garage before finishing the route. This is a valuable way of performing winter operations because more time is spent clearing roads resulting in higher quality for the maintenance effort.

5.3.6 Partnering

Another best practice, recently utilized by MDOT partners, is the rolling escort. This practice has been used in situations when the winter weather is so severe that the operators clearing the roadway may not be able to maintain reasonable and safe driving conditions. In lieu of shutting down the road, a patrol car leads the vehicles along the roadway at a slow speed, allowing the highway to remain open until weather conditions improved.

5.4 Traffic Incident Management

Six injury crashes occur approximately every hour in Michigan, putting first responders potentially in harm’s way every day. Congestion from these incidents often generates secondary crashes, further increasing traveler delay and frustration. The longer incident responders remain at the scene, the greater the safety risk the traveling public and first responders, face. Minimizing the time and allocating appropriate resources required for incident clearance is essential to meeting the goals for safety and reliability of our transportation system.

Traffic Incident Management (TIM) has a significant effect on the road user experience. MDOT’s responsibility is to return the road to its intended operating condition as quickly and as safely as possible. Communication and preparation are the best tools for these situations. Building partnerships with the communities and emergency services are beneficial in reducing user delay and increasing the safety of incident responders.

The I-94 corridor has had a long history of utilizing traffic incident management practices. First responder TIM trainings started in early 2000's teaching techniques on how best to manage traffic, and keeping everyone safe. These trainings were delivered in special training sessions and at the Winter Operations Weather (WOW) Workshops done in the fall before winter weather started.

Another first responder learning tool that has been deployed along the I-94 corridor is the use of tabletop exercise. These table top exercises bring together first responders and stakeholders to pre-plan responses. By practicing traffic incident scenarios MDOT and its incident management partners prepare for different situations by improving on current practices or by exposure to situations that have not yet occurred. Table Top exercises give good direction when it comes to the best response and steps needed to resolve traffic incidents. Winter workshops and chiefs' meetings offer the opportunity to build working relationships and help to establish MDOT as a resource. Post-incident response meetings are a good practice following an incident to examine successful maintenance actions and what actions could have been performed better or differently. These are a tremendous tool to learn the capabilities of different agencies response and capacity. A large tabletop exercise was done on October 30th 2013. This table exercise gave the scenario of a smoking propane tanker, hanging off the side of a bridge at major freeway to freeway interchange. Attendees had to develop a response and mitigation plan. This tabletop exercise aided in the response of the incident on January 7, 2015 with 193 vehicles affected.

Post-incident reviews (PIRs) are also a tool used to capture items or practices that went well during the incident and areas of improvement for future incidents. These PIRs have become an integral part of TIM on the I-94 corridor. Items that have resulted in positive change due to PIRs have been better contacts for resources, improved emergency routes, proposed safety projects, improved response times and more.

A new coordinated, multi-disciplinary training program developed through the Strategic Highway Research Program (SHRP2) has been deployed in Michigan and is available for all first responders supporting Traffic Incident Management operations. The training puts firefighters, police, state and local departments of transportation, towing, medical personnel and other incident responders on the same page, leading to a safer, faster, integrated responder team. In Michigan the program is known as Mi-TIME – Michigan Traffic Incident Management Effort.

The Mi-TIME training can be taught in many different ways; participants can attend a 10-hour intensive course, a four-hour modified version and single-lesson modules. Most training is completed via the 4 hours modified session. The program has now been accepted in all 50 states, the District of Columbia and

Puerto Rico. The national program has had Michigan-specific items added, including Michigan laws and proper placement of barricades for a lane closure. Michigan has had three train-the-trainer sessions in 2014 with over 2,000 first responders already trained in the MI-TIME program. Another train-the-trainer session has been scheduled in August 2015.

In 2010, legislation for the Steer It, Clear It law passed (Public Act 10 of 2010). This law requires drivers to move their vehicle from the main traveled portion of the roadway if they have been in a crash where the vehicle can be moved and there are no apparent injuries. Vehicles should be moved to locations such as the shoulder, emergency lane, or median, and then call the law enforcement. Failure to obey this law can result in a civil penalty. When crashes are not moved off the roadway in a timely manner, traffic congestion and possible secondary crashes can result. A small public safety education campaign has been started to inform motorist of this law. This law changes what many people were taught in driver education to call for law enforcement and leave the vehicle in place till law enforcement arrives.

Another law passed that aids in TIM is the Hold Harmless legislation (Public Act 303 of 2014). This law went into effect January 7, 2015 and protects authorized personnel from liability for any damages that may occur while removing vehicle(s) or cargo from the main travel lanes of the roadway in order to maintain the safety of the traveling public. The owner and carrier, if any, of the vehicle, cargo or personal property removed or disposed of under the authority of this section shall reimburse the Law Enforcement Agency, Department of Transportation, Fire Department, Emergency Management and other local public safety agencies for all documented costs incurred in the removal and subsequent disposition of such property. This law aids in quicker removal of incidents.

Emergency crossovers in the median are another consideration in traffic incident management and quick response for first responders. Crossovers on limited access divided highways are used by maintenance, police, and emergency vehicles. It is illegal for the public to use them. With the installation of median cable barriers unofficial crossovers were closed for emergency first responders. Listening to the first responder community the department reexamined the policy for spacing of official crossovers to improve response. MDOT changed the Road Design Manual to reflect the change in spacing.

Lastly, considerable effort has been made along freeway routes to design and install emergency route signing for use in the event of a traffic incident resulting in a closure. Working with the local communities to identify alternative routes, MDOT installed signs that show the motorist where to go to return to the highway network.

5.5 Work Zones and Mobility

MDOT has focused on work zone safety and mobility, in 2008 when the federal regulation for the Work Zone Final Rule was issued MDOT raised awareness with policy changes and improvements. Projects with significant delay are required to go through a statewide peer review to assess if mitigation techniques are applied to projects appropriately. In 2010, MDOT applied a corridor approach for work zone delays to the I-94 corridor. Once this occurred a culture change took place looking at a user delay cost and operations focus. Many teams were formed to focus on Customers and Efficiency & Effectiveness on I-94 work zones.

Some of the items that resulted from these teams were bi-weekly construction coordination meetings for the entire I-94 corridor. A new typical was developed to always close the left lane at the beginning of a work zone. The concept of this technique is to always close the left lane and shift traffic over, even if the work is occurring in the right lane. The benefits of this on the I-94 corridor are improved driver expectations and improved traffic flow. The improved traffic flow is from allowing the high volume of truck traffic to remain in the right lane and have passenger vehicle merge to the right lane. Since the majority of truck traffic is already traveling in the right lane, this merge improves the traffic flow into and through the work zone.

The other tool that is being used is the stopped/slowed traffic advisory system which alerts motorist of stopping or slowing traffic. This has been used in the Jackson area on two separate projects and is now being used on a large segment that covers multiple paving projects. The system alerts motorists of upcoming slowdowns in real-time by changing the message on the portable changeable message signs (PCMS). MDOT has also used the practice of placing temporary rumble strips and PCMS on both sides of the roadway to make this system as effective as possible. This system is valuable due to the fact that this system address rear-end crashes which account for 50% of the total work zone crashes in the state of Michigan.

Multiple levels of work zone reviews are conducted when the project is being constructed. Projects are reviewed at the MDOT Transportation Service Center (TSC) and MDOT Region on regular intervals. Projects are also reviewed by the Traffic Incident & Work Zone Management Unit for statewide alignment. Examples of items reviewed include but are not limited to; temporary traffic control, work zone delay, contractor interaction with traffic, and personal protect equipment.

Delineation in a work zone is key to safely traveling through the work zone. Many work zones have the motorist traveling through traffic shifts and/ or not on the original alignment of the road when the project is being built. Pavement markings are one of the key temporary traffic control items that are important to delineate where the motorist is to travel. MDOT has recently revised specifications for temporary pavement markings to be wet reflective. This aids the motorist in seeing the pavement markings better at night in a work zone and when it is raining or the road is wet. In addition to wet reflective pavement markings MDOT has also adopted guidance for tools to increase visibility when a project has a narrow shoulder in a work zone on freeways with major work. Guidance details the use of delineators for guardrail and open ditches, improved material specifications for constructing a temporary shoulder, and the use of safety edge. Safety edge is a construction method that tapers the edge of the pavement to allow for easier recovery by driver that has veered off of the roadway.

MDOT has also created a process to review any projects that have a narrow shoulder on a major freeway project to make sure that the design is appropriate for the project location. This process is called a Work Zone Narrow Shoulder Variance and must be completed for major freeway projects that will have a lane width of less than 11 feet and/or a shoulder that is next to an open ditch and less than 2 feet paved, 1 foot aggregate to hinge point.

5.7 Toward Zero Deaths Initiatives

The Michigan Department of Transportation has adopted the Toward Zero Deaths (TZD) National Strategy as a statewide. TZD is a relatively new statewide safety campaign based on the national strategy on highway safety intended to positively enhance road users' behavior and improve safety. With more than 35,000 fatalities occurring on U.S. highways each year, roadway safety remains one of the most challenging issues facing Michigan, and the nation. More than 875 people were unable to return home in Michigan in 2014 due to traffic crashes. The TZD strategy involves enhancing driver education, emergency response, enforcement, engineering, policy, communications and other efforts that will move Michigan closer to zero fatalities. By incorporating safety into all facets of transportation, Michigan will achieve this vision. MDOT is involved in various safety efforts with its federal, state and local partners. Without these partnerships, this vision will not be a reality.

The first step to improving the nation's traffic safety culture is to establish a TZD vision with key stakeholders. Michigan, through the Governor's Traffic Safety Advisory Commission, has done that through the Strategic Highway Safety Plan (SHSP). While the SHSP goal is to reduce traffic fatalities from 889 in 2011 to 750 in 2016 our ultimate vision is Toward Zero Deaths on Michigan's roadways. Now it is time to market TZD through the various stakeholders. MDOT is asking its partners, organizations companies and the public to be a champion in supporting TZD by incorporating the official logo for the National Strategy on Highway Safety TZD program on websites, ads, brochures, posters and other communications.

Communication is a key aspect of implementing TZD and in addition to the action plans, MDOT has developed a number of tools and resources. A sample of the TZD-focused resources include a website, rest area posters, internal and external newsletter articles, crash statistics postcard, safety fact sheet with actionable items for pedestrians, bicyclists, motorcyclists and drivers and a safety programs brochure. MDOT also communicates the year-to-date fatalities across a number of different media including a weekly email listserv, messaging on our digital messaging signs and social media outlets. Each Wednesday from February through November, Dynamic Message Signs (DMS) on various I, M and US routes display the number of traffic fatalities on Michigan roadways year-to-date. If there is a higher-priority message to display, the sign will be switched. Higher priority messages include incident messages, lane closures, shoulder closures and work zone messages. MDOT also will share this information on Facebook and Twitter. This effort has let to numerous related news stories by media outlets across the state. Posting fatality messages on DMS is another simple and inexpensive way MDOT can contribute to educating motorists on the scope of the fatal crash issue.

5.8 Enforcement Initiatives

- **Niles/Bridgman Post:** In the Niles and Bridgeman Posts a car was assigned Monday through Friday from 3:00 to 6:00 pm to address aggressive driving from May through September 2014.
- **Paw Paw Post:** In summer 2014, the Paw Paw Post worked an aggressive driving initiative during the months of July and August on I-94 in Kalamazoo County. During this initiative, the focus was on speeding, following too closely, safety belt violations and aggressive lane changes. The post is currently working a distracted driving initiative in the same area (I-94 in Kalamazoo County). This includes patrols in an unmarked vehicle to identify texting violations. These drivers are then videotaped and the vehicles are followed until a marked unit makes the stop. This initiative has been implemented since June 1, 2015 and has been relatively successful. Plans are being prepared to contact local news media to increase public awareness to this problem.
- **Coldwater Post:** Apart from OHSP Traffic Initiatives, the Coldwater Post has independently run the following directed patrol/traffic initiatives on I-94.
    - Crash Reduction: 4/26 – 8/29/2015
    - Distracted Driving: 9/25 – 9/26/2014
    - Crash Reduction: 1/1 – 1/31/2014
    - Aggressive Driving: 6/1 – 8/31/2014

    - Speed, Thanksgiving weekend: 11/27 – 12/1/2013
    - OUIL/OUID: 10/26 – 10/28/2013
    - Construction Zone: 9/7/2013
    - Seatbelt: 9/5 – 9/16/2013
    - Speed/Aggressive Driving: 8/31 – 9/17/2013
    - Speed/Aggressive Driving: 7/28 – 8/31/2013

- **Jackson Post**:
    - Distracted driving on I-94 with marked and unmarked cars.
    - Speed enforcement
    - OUIL
    - Aggressive driving (Motor Carrier Enforcement detail).

- **Other Traffic Safety Initiatives:**
    - Operation CARE (Combined Accident Reduction Effort)
    - State Trooper Project
    - I-94 Challenge
    - Click it or ticket-safety belt enforcement

6.0 MDOT SAFETY PROGRAM PROJECTS AND POTENTIAL CORRIDOR-WIDE IMPROVEMENTS

6.1 MDOT Five Year Safety Project Program

The recent and future MDOT roadway safety improvement projects are provided in the tables that follow.

Table 13. 2011 – 2015 MDOT Safety Program Projects

Year	Job ID	Location	Work Description	Safety Improvement
2011	103239	21 1/2 Mile Road to 29 Mile Road	Cable Median Barrier	Cable Median Barrier
2011	106483	Park Road to Hennesey	Two Course HMA Overlay	Superelevation correction, outside shoulder widening
2011	110571	Eastbound ML Avenue east to 40th Street	Cold Mill and Resurface	Improved Surface Friction
2011	86970	21 1/2 Mile Road to 29 Mile Road	Multiple Course HMA overlay	Improved Surface Friction
2012	109093	M-63 over I-94	Shallow Overlay	outside bridge shoulder widening
2012	79871	Sawyer (Exit 12) to Red Arrow Hwy (Exit 16)	Mill and Two Course HMAOverlay	Superelevation correction, freeway bridge & road shoulder widening,
2012	108715	M-311 (11 Mile Road) Interchange (exit 104)	Ramp extenstion	Lengthened Acceleration lane
2012	113831	Kalamazoo County Line east to 12th Street	Mill and Resurface	Improved Surface Friction
2012	109707	Indiana State Line to Exit 46	Dymanic Message Signs	Additional 2 message signs to provide motorist information
2012	116706	Various interchanges	Wrong Way Movement Improvements	Address freeway wrong way movements at 8 interchanges
2012	113787	at the Oshtemo Truck Parking Area	Improved Asphalt Pad and PITWS	Safe Enforcement Site
2013	110779	EB and WB over Hickory Creek	Bridge Replacement	Freeway bridge & approach shoulder widening,
2013	118848	I-94 from 6 1/2 Mile Road to 11 Mile Road	CPRs and diamond grinding outside lanes	Improved Surface Friction
2013	117293	under 35th Street, 4 miles east of I-94 BL	Railing Replacement, Epoxy Overlay	Increased shoulder width on 35th Street and improved sight distance for ramp terminals with different railing
2013	119876	under 35th Street	Bridge approach work and maintenance of traffic	Widened outside shoulders of 35th Street
2013	109963	Various locations	Dymanic Message Signs	Additional 7 message signs to provide motorist information
2013	113689	Corridor wide	Truck Parking and Info Management System	Provide real time parking information to truckers
2014	115986	Berrien County	Overhead Signing Upgrade	Improved sign readability, enhanced mile markers
2014	113461	Puetz Road to I-196	Median Cable Barrier	Cable Median Barrier
2014	114269	I-94 EB over Pine Creek, Hartford, Van Buren Co.	Shallow overlay, Widening, Beam repair, Railing	Freeway bridge & approach shoulder widening,
2014	117756	Watervliet Rest Area	Expand truck parking area	Additional spaces for truckers to park safely
2014	107965	Regionwide	CCTV and Detectors	Provide real time information to Traffic Operations Center
2014	122511	At Sargent Road	Dual Overhead Head Flashing Beaon	Overhead traffic control
2015	124114	I-94 BL (Michigan Ave) to I-94 BL (11 Mile Road)	Cold mill and HMA overlay with concrete pavt reprs	Improved Surface Friction
2015	110581	under Cork Street in Kalamazoo area	Bridge Removal	Removal of fixed objects (bridge piers) near roaday
2015	110524	under Sprinkle Road in Kalamazoo	Interchange Reconstruction	Improved Capacity will reduce congestion related crashes, install guardrail in I-94 median where there was a gap, bring all geometrics up to current standards
2015	126332	0.7 miles east of CR 687 to 0.8 miles west of M-51	Clearing and Tree Removal	Removal of fixed objects in right-of-way
2015	118259	I-94 EB & WB over East Branch of Paw Paw River	Superstructure Repl, Widening, Scour Protection	Shoulder widening at bridge
2015	124021	Mile Marker 58 to 61	Diamond Grinding	Superelevation correction
2015	123306	0.7 miles east of CR 687 to 0.8 miles west of M-51	Multiple Course HMA Overlay	Superelevation correction, outside shoulder widening
2015	107966	Regionwide	Enviormental Sensor Stations	Provide real time weather information form 10 stations

Table 14. 2016 – 2020 MDOT Safety Program Projects

Year	Job ID	Location	Work Description	Safety Improvement
2016	115839	Kalamazoo County	Freeway Signing and delineation	Upgrade to signs and enhanced delineation
2016	115841	Calhoun County	Freeway Signing and delineation	Upgrade to signs and enhanced delineation
2016	113585	Red Arrow Highway (Exit 16) to I-94 BL (Exit 23)	Mill Existing and Multiple Course HMA Overlay	Freeway shoulder widening, superelevation adjustment
2016	118994	over East Michigan Avenue (40th Street)	Bridge Replacement	New bridge will meet all current standards
2016	122066	Westbound I-94 from ML Ave E to Michigan Ave E	Cold Milling & Bituminous Overlay	Improved Roadway Surface Friction
2016	112614	at E Michigan Avenue (40th Street)	Interchange reconfiguration	Improved geometry will reduce driver confusion and correct any geometric deficiencies
2016	88117	over Puetz Road	Deep Overlay, Widening, Substructure Repair	Bridge shoulder widening, cross slope correction
2016	128536	Four interchange ramps along I-94 and US-131.	High Friction Surface	Improve roadway surface friction at Southbound US-131 to I-94 and I-94 Mainline at Exit 92
2017	116716	Various Locations in Calhoun and Kalamazoo County	Ramp Modifications	Wrong way crash prevention improvements at various locations
2017	119672	From Red Arrow Hwy (exit 16) to I-94BL (exit 23)	Mill and Mult-Course HMA Overlay	Freeway shoulder widening, superelevation adjustment
2017	110138	17 1/2 to 21 1/2 Mile Road	Multiple Course HMA Overlay	Improve Roadway Surface Friction
2017	113682	17 1/2 Mile Road to 21 1/2 Mile Road	Cable Median Barrier	Cable Median barrier
2017	107969	Regionwide	Dynamic Message Signs	Additional message signs to provide motorist information
2017	127121	W. of Lawrence (CR 365) easterly for 3.39 miles	Multiple Course HMA Overlay	Freeway shoulder widening, superelevation adjustment
2018	120543	EB I-94 from Miller Road to 40th Street	widen outside shoulder	Increase outside shoulder width
2019	126888	under Glenlord Road and Cleveland Avenue over I-94	Deep Overlay, Substructure Repair, Beam Repair,	Railing replacement
2019	124035	I-94 WB from Exit 46 to Exit 56	Install Trees	Reduce drifting snow across pavement
2020	51268	Watervliet Township	New facility	Additional safe parking for cars and trucks
2020	127501	EB at MM 83 and WB at MM 82	Construct Emergency/Crash Investigation Sites	Removing disabled vehicles from shoulder will reduce secondary crashes and also provide safe enforcement site
2020	105885	East of Lovers Lane to east of Portage Road	Road Reconstruction and Widen	Bring geometrics up to current, increase capacity to reduce congestion related incidents
2020	105886	Portage Road to Sprinkle Road	Road and Bridge Reconstruction	Increase capacity will reduce congestion related incidents
2020	127639	I-94 WB entrance ramp from I-94 BL / M-311	Reconstruction of the loop entrance ramp	Improved cross slope to prevent truck roll overs
2021	125865	6 1/2 to 11 Mile Roads	HMA overlay, partial reconst, drainage & ramp impr	Improve Roadway Surface Friction

6.2 Potential Corridor-wide Improvements

Roadway departure is one of the more severe types of crashes, compared with other crash types. Roadway departure occurs when a vehicle departs from the roadway by either crossing an edge line or a centerline. The latter may result in a head-on collision. According to the FHWA and as reported in the Fatality Analysis Reporting System (FARS) database, approximately 57 percent of motor vehicle traffic fatalities that have occurred annually in the United States in recent years are due to roadway departure.

The reasons for roadway-departure events are varied but do include the driver attempting to avoid a vehicle, an object, or an animal in the travel lane; inattentive driving due to distraction, fatigue, medical conditions, or the use of alcohol or drugs; wet or slippery pavement conditions; driver inexperience; or traveling too fast through curves or downhill. In difficult situations, many drivers do not have the knowledge or the skills to maintain or regain control of the vehicle in a safe manner.

To effectively address roadway-departure crashes, it is critical to select the appropriate set of roadway safety features and install them correctly in the locations with the greatest potential to prevent or reduce the severity of crashes. One example of a low-cost infrastructure treatment is shoulder rumble strips. The vibration and noise caused by these grooves in the pavement can greatly influence drivers' reactions to crossing the edge by prompting a corrective action when alerted that they are leaving the roadway. The vibration and noise can also awaken a drowsy driver. Additionally, rumble strips can serve as an effective guide, alerting drivers as to the location of the travel lane when fog, snow, driving rain, or darkness obscures pavement markings. The results of an evaluation of shoulder rumble strips, which included more than 200 sites in 19 states, indicate a reduction in single-vehicle roadway-departure collisions of 11 percent to 18 percent for urban and rural freeways. Since the late 1990s, MDOT has been systematically installing rumble strips on freeway shoulders, to the benefit of Michigan motorists

Although many roadway departure crashes are single-vehicle run-off-the-road crashes, they also include vehicles that leave their lane and cross over into oncoming traffic. During periods of reduced visibility, including at night and during inclement weather, drivers require additional assistance in identifying and maintaining their travel lane to drive confidently and safely. Effective pavement markings and delineation can significantly assist the driver in making important driving decisions, which contributes significantly to roadway safety for all motorists. Wide pavement markings are effective in improving safety. In Michigan, 6 inch wide edge line markings were found to reduce injury and fatal crashes by 24.6 percent, nighttime crashes by 39.5 percent and wet pavement nighttime crashes by 33.2 percent. MDOT has utilized 6 inch wide edge line markings since 2004.

Beyond wide pavement markings MDOT is evaluating improved delineation along freeway corridors and interchange ramps. The department has been piloting with various materials and delineation placement that goes beyond existing standards and practices in order to provide efficient and effective motorist guidance at night and during inclement weather. In 2016, the delineation pilot will be expanded to I-94 in Kalamazoo and Calhoun Counties as part of two planned traffic signing upgrade projects. The traditional roadside delineator will be replaced by a 3 in by 6 in highly reflective sign panel. All concrete barriers and guardrail will receive upgraded delineation treatments. All ramps in both the US-131 and I-69 interchanges with I-94 will provide with enhanced delineation to aid the motorist's movements from one freeway to another. In addition, all curve and chevron warning signs along the corridor in both counties will be replaced with highly reflective fluorescent yellow sign panels and reflective strips on the sign post. Current research being conducted by Western Michigan University indicates a reduction in crashes for freeways utilizing fluorescent yellow warning signs, in particular for drivers aged 65 and older. Fluorescent yellow became the standard in 2004 for MDOT on all its warning signs. Reflective strips on curve warning sign posts became the standard in 2012.

Skid-resistant roadway surfaces help a vehicle's tires maintain contact with the road through horizontal curves and in curves at inappropriately high speeds. High-friction surface (HFS) treatments can also help prevent the vehicle from departing the roadway. HFS is a thin layer of durable aggregates (typically calcined bauxite) that is highly resistant to "polishing" or wear. The aggregate is bonded to the asphalt, concrete, or other pavement surfaces using polymer, epoxy or other binders. When this treatment was applied to 75 Kentucky locations in 2010, roadway-departure crashes decreased by 91 percent in wet weather and 78 percent in dry weather conditions. In response to the Field and UD-10 Crash Report Reviews four interchange ramps along I-94 and US-131 have been identified for HFS treatments in 2016. The two locations on I-94 are Southbound US-131 to I-94 and I-94 Mainline at Exit 92.

The safety modeling presented previously found Van Buren County to have very high winter crash overrepresentation compared to all other portion of the study corridor. Between Exit 46 and Exit 56 there is an effort in 2019 to install trees to reduce drifting of snow across the pavement. Beyond minimizing drifting with roadside improvements MDOT has employed weather prediction and information collection technology such as the Maintenance Decision Support System (MDSS) and the Automated Vehicle Location (AVL) system provide valuable data for taking action. The information from these systems allow MDOT to track incoming winter events, prepare materials and equipment, and ensure proper staffing levels. In addition, the department is using the MDSS and AVL data to identify the areas with the most severe winter weather through the means of a Winter Severity Index (WSI). This index is being used to measure winter operational efficiency and to identify areas of success and areas of improvement.

The winter season brings storms with fluctuating variables: temperature and wind, location and duration, as well as varying conditions before and after a storm. Each of these variables impacts the effectiveness of the operation. With the wide variety of storm types, it is important to have options that can compete with the different circumstances. For example, pre-wetting salt allows it to remain effective at lower temperatures when compared to rock salt alone. The salt starts working immediately once placed, and stays were it is placed as opposed to scattering. Another example is the practice of anti-icing. This technique requires the placement of liquid calcium chloride directly on the roadbed to prevent snow and ice from forming on the pavement. With the pertinent information the department can review its winter surface treatment techniques including routes, materials and equipment.

Providing information to the motorist is key in affecting driver behavior. Examples of this are dynamic messages signs (DMS) and variable speed limit (VSL) systems. Eleven DMS exist along the study corridor. Paired with environmental sensor stations (ESS) software logic exists to provide merging weather information to motorists with an appropriate message of how they should respond. In 2016 an ESS project with 10 locations along I-94 will be constructed. Each location will contain a different array of atmospheric sensors (visibility, air temperature, humidity, wind speed/direction, barometric pressure and precipitation), pavement sensors (temperature, condition, salinity) and subsurface temperature probes. Most ESS locations will also include additional CCTV cameras and possibly infrared illuminators for night time camera viewing. All the data collected will be made available to several analytical models and MDOT information outlets such as DMS and Mi-Drive. Key installations will be at the I-196, CR 687, M-40 and I-69 interchanges and the Galesburg Rest Area. For 2017, additional DMS are being evaluated for I-94 including Westbound I-94 approaching Van Buren County.

VSL systems are signs or other traffic control devices capable of displaying different speed limits to road users (either regulatory or recommended) that are activated by a manual or autonomous system to select an appropriate speed given the highway conditions (1). VSL systems attempt to improve driver behavior during specific conditions by adjusting the speed limit in an attempt to homogenize vehicular operating speeds along a corridor (2). VSL systems have been utilized in a variety of settings to provide effective speed management for safety and congestion purposes, speed control for inclement weather, traffic incidents, school zones, shopping strips, tunnels, bridges as well as work zones (3). However, current Michigan law only allows for school zone implementation of VSLs

Several recent national efforts have attempted to provide standardized guidance for VSL systems, warrants for the use of such devices, as well as best practices for road weather management in general. The *Best Practices for Road Weather Management* documented published by the FHWA in 2012 contains 27 case studies of systems in 22 states that improve roadway operations under adverse weather conditions (4). The ENTERPRISE Pooled Fund Study completed in 2009 developed warrants for the use of several ITS devices, including VSLs (1). The FHWA also published the *Guidelines for the Use of Variable Speed Limit Systems in Wet Weather* in 2012 (5). The report includes guidelines for the design, installation, operation, maintenance, and enforcement of VSL systems intended for wet weather conditions where operating speeds and stopping distance exceeds design values (5).

The literature generally suggests that a site selection criterion is developed which considers traffic crash history, traffic volumes, minimum speeds, congestion as well as prevailing weather conditions (6). One study recommended the use of a composite ranking system based upon factors that include the equivalent property damage only crashes, crashes involving poor roadway surface conditions, as well as critical bottleneck locations (7). Speed limit posting decisions are typically made using algorithms that utilize real-time weather and traffic data (8).

In general, VSL systems have been found to produce significant safety benefits. Compliance with speed limits was typically improved, resulting in reduced mean speeds as well as reduced speed variance (3). Further, fewer traffic crashes and shorter trip durations were experienced after the implementation of VSLs and drivers also found the roadway system to be more reliable (3). Previous research has also demonstrated that the interaction between grades and horizontal curvature with weather variables have a significant impact on traffic crashes, suggesting that specific VSL strategies should be implemented on highway segments involving significant horizontal or vertical curvature (9).

Driver behavior, specifically compliance with the posted speed limit, is an important consideration regarding VSL systems. Prior studies evaluating driver behavior relating to VSL systems have demonstrated that driver satisfaction, gender, age, road type, visibility condition, familiarity with VSLs and other human factors have a significant impact on compliance (10,11). Preliminary results from a rural VSL system deployed in 2009 in Wyoming along I-80 demonstrated that drivers reduce their speeds by 0.47 to 0.75 mph for every mile per hour in posted speed reduction (12).

After a vehicle leaves the roadway, roadway safety improvements can help prevent or reduce the severity of a collision. Several options provide the ability to enhance safety by minimizing the consequences of a driver action that causes a vehicle to depart the roadway. The probability for roadway-departure crashes to have severe outcomes depends on side slopes, fixed-object density, offset to fixed objects, and shoulder width. Collision with a fixed object is usually identified as the first harmful event in run-off-road crashes.

When installed correctly in between opposing directions of traffic, cable median barrier can redirect a vehicle back toward the intended travel lane to help prevent deadly head-on collisions. A collision still occurs between the errant vehicle and the cable barrier, but the outcome is likely to result in property damage only and not an injury or fatality as a result of a head-on collision. Also, cable median barrier can prevent a vehicle from traveling across the oncoming lanes and striking fixed objects alongside the roadway. Several state departments of transportation (including Illinois, Michigan, Minnesota, and Missouri) determined there was an elimination of cross-median crashes and a reduction in the severity of roadway-departure crashes due to the installation of cable median barrier along several of their state highways. A recently completed research project *Study of High-Tension Cable Barriers on Michigan Roadways* on Michigan's 333 miles of placed cable median barrier showed an approximate 87 percent reduction in the median cross over crash rate and was approximately 97 percent effective in controlling out of control vehicles. For the seven I-94 cable median barrier installations (86.7 miles) the recently completed research shows a decrease of both fatalities and serious injuries. In the before period these locations experienced 9.5 serious injuries (A) and 3.4 fatalities annually compared to 6 serious injuries (A) and 1.9 fatalities annually for the after period. In 2017, cable median barrier is scheduled in Calhoun County between 17 ½ Mile Road and 21 ½ Mile Road. For future installations consideration will be given on sites along curves locating the barrier on the outside of the curve.

Six injury crashes occur approximately every hour in Michigan, putting first responders potentially in harm's way every day. Congestion from these incidents often generates secondary crashes, further increasing traveler delay and frustration. The longer incident responders remain at the scene, the greater the safety risk the traveling public and first responders, face. Minimizing the time and allocating appropriate resources required for incident clearance is essential to meeting the goals for safety and reliability of our transportation system.

Traffic Incident Management (TIM) has a significant effect on the road user experience. MDOT's responsibility is to return the road to its intended operating condition as quickly and as safely as possible. The actions taken by enforcement personnel to influence the behavior of motorists, or to arrest motorists who exhibit dangerous driving behavior, can be supported with infrastructure modifications to assist that police activity. The actions of all EMS participants in assisting victims of highway crashes and in clearing up the crash site and restoring the road to open status likewise can be supported infrastructure modifications to assist that EMS and TIM activity. Such improvements include consideration of additional crossovers, construction of firm areas for crash investigation and traffic enforcement, seeking locked gate access points to the freeway from the right of way and providing staging areas within interchanges for EMS personnel. In 2020, Crash investigation sites are planned to be constructed near mile marker 83 for Eastbound I-94 and between mile marker 81 and 82 for Westbound I-94. It is anticipated that this would alleviate some of the congestion and secondary crashes such as rear-end crashes resulting from slowed traffic due to another crash ahead. The crash investigation sites would also help to clear the crashes faster from the mainline I-94 which in turn would reduce the backups and slowdowns on mainline.

When motorist are in need of emergency services they often do not know where they are at. In response the department has been placing Enhance Mile Makers which displays the route and direction the motorist is going as an aid to EMS. Currently these markers are in place every 2/10 of a mile on I-94 in Berrien and Van Buren Counties. In 2016, both Kalamazoo and Calhoun Counties will be completed with these mile markers as part of two planned traffic signing upgrade projects.

7.0 CONCLUSIONS AND RECOMMENDATIONS

This report provides details of a safety evaluation of the I-94 corridor between the Indiana border and US-127 South in Jackson County. Approximately 143 miles of I-94 in were included within this study, including all sections of the corridor in Berrien, Van Buren, Kalamazoo, Calhoun, and the western portion of Jackson County. The team, led by the Michigan Department of Transportation, included engineers, safety experts, and law enforcement officers from the Federal Highway Administration, Michigan State Police, and the Michigan Office of Highway Safety Planning, among others. The study incorporated an engineering review of extensive data, including recent crash patterns, roadway geometry, cross-sectional characteristics, barrier locations, related weather conditions, incident management, and initiatives of various agencies. A series of county-level safety reviews were performed, including field reviews of locations with high crash concentrations, in addition to detailed reviews of the crash reports at targeted areas to identify specific safety issues, trends, and patterns, and develop potential safety countermeasures and recommendations. The findings, conclusions, and recommendations (both corridor-wide and site-specific) that resulted from this study are summarized as follows.

7.1 Corridor Safety Findings

The findings of this review indicate that the I-94 study corridor, as a whole, experiences crashes at a rate that is comparable with other freeway corridors in Michigan. Like other corridors, specific influences of weather, atmospheric conditions, geometry, lighting, traffic volumes, and driver behavior combine resulting in above average crash rates in specific areas. It is worth noting that the portion of the corridor where the 193-vehicle crash occurred in January of 2015 is historically not an area with above average crash occurrence. The specific safety findings are summarized as follows:

- A total of 6,678 crashes occurred along the study corridor (mainline) between 2012 and 2014, including 5,840 (87.5 percent) that did not involve deer. The overall corridor crash rate during this period was 101.12 crashes (88.43 non-deer crashes) per 100 million vehicle miles traveled.
- From 2012 – 2014, the I-94 study corridor had an overall crash rate that was similar to the statewide average for freeways with 70 mph posted speed limits. However, during this same period, the study corridor experienced a winter season (December – February) crash rate that was 24 percent greater than the other statewide 70 mph freeways. Only I-196 and US-131 demonstrated greater winter season crash rates than the study corridor during this period.
- Crashes occurred 16.3 percent more frequently in the eastbound direction compared to westbound. Eastbound crashes were particularly overrepresented in Berrien, Van Buren, and Jackson Counties. This directional disparity may be attributed to differing geometric conditions between the two directions, particularly near interchanges.

- Considering all counties included in the study corridor, crash rates (per 100 million VMT) were greatest in Van Buren County, particularly in the eastbound direction and especially during winter months, when the eastbound crash rate is 65 percent greater than the eastbound corridor average. Overall crash rates in Berrien, Kalamazoo, Calhoun, and Jackson Counties were not significantly different from each other, although winter crash rates were significantly lower in Jackson County compared to the other counties.
- Approximately 65 percent of the winter season crashes involved a vehicle driving "too fast for conditions", compared to only 38 percent of all-season crashes. This suggests that speed plays a greater role in winter-season crashes compared to other seasons. This also supports the Michigan State Police findings from the January 9, 2015 crash, in which a total of 58 drivers were cited for driving too fast for conditions, including 30 commercial drivers.
- A statistical analysis of crashes on the I-94 study corridor was performed to determine the impacts of various roadway, geometric, weather, and roadside factors. The factors that were found to correlate to a higher rate of overall crash occurrence included:
    - Interchange presence,
    - Significant horizontal curvature,
    - Limited stopping sight distance (due to vertical curvature), and
    - Segments with only two lanes in each direction.
- Similar results were also found for winter crashes. However, in addition, a very strong correlation between average annual snowfall and crashes was also determined. This finding helps explain the extreme overrepresentation of winter crashes in Van Buren County, which typically experiences the greatest snowfall totals along the study corridor.

7.2 Corridor-wide Recommendations

Improving roadway safety takes significant efforts from all stakeholders, including the transportation agencies that own, operate, and maintain the roadways; enforcement agencies; first responders; policy makers; and ultimately the motorists traveling along the roadway. The findings of this report compliment the ongoing safety efforts of MDOT and MSP by identifying crash concentrations, contributing factors, and possible solutions. While statewide trends for serious crashes have generally improved over the past several years, opportunities for significant improvement still remain. Several corridor-wide recommendations were made as a result of the findings of this study, which are provided as follows. By incorporating these recommendations (along with the site-specific recommendations, as funding permits), the corridor review team believes continual improvements in crash and severity reductions can be made along the I-94 study corridor.

- MDOT should continue data driven crash mitigation efforts, focusing on the highest priority crash locations, and utilizing the most cost effective strategies to improve safety. Several safety related improvement projects have recently been completed along the I-94 study corridor, and several more are scheduled to occur over the next five years. As future projects become funded, incorporation of crash and crash severity reducing strategies into these projects should continue to be evaluated.
- It is also recommended that MDOT continue improving operational and roadway maintenance procedures to further enhance roadway safety. Utilizing historic crash information along with implementation of pavement condition forecasting technology can assist with maintaining historically problematic winter crash areas.
- Efforts toward improving driver behavior should also continue to occur. The frequency and severity of crashes can be reduced when drivers maintain a safe speed for the roadway conditions. Continuing campaigns by enforcement agencies is recommended. Additionally, efforts to inform motorists of adverse driving conditions should be continued, but must be timely and specific. This may include communication of roadway conditions via dynamic message signs or other technology or temporary reduction of statutory roadway speed limits via variable speed limit displays. It is recommended that specific legislation be enacted to legally accommodate the latter. At this time only a lower advisory speed could be displayed.

7.3 Site-Specific Recommendations

A series of site reviews were performed to help identify specific areas of high crash occurrence and develop recommendations to address the associated safety issues. The following countermeasures were considered:

- Winter Weather Treatments
    - Environmental sensor stations (Figure 24a)
    - Variable speed limits (Figure 24b)
    - ITS devices providing weather-related messages (Figure 24c,24d)
    - Advanced de-icing strategies
    - Living snow fence (strategic planting of roadside vegetation)
- Pavement Surface Treatments
    - Resurfacing
    - High friction course
- Visibility Enhancements
    - Signing

    - Pavement markings
    - Delineation
    - Lighting
- Geometric Improvements
    - Cable barrier relocation
    - Ramp extension or realignment
    - Shoulder widening
    - Increased superelevation
- Congestion Management
    - Crash investigation pull-off site
    - Courtesy patrol
    - Incident management improvements
    - ITS devices providing queue warning messages (Figure 26c,26d)
    - Add third lane

Environmental Sensor Station

Variable Speed Limit Sign

Severe Weather Warning Sign

Dynamic Message Sign

Figure 24. Examples of Potential Treatments

The following table presents a summary of recommended potential improvements and associated timeframes for the high-crash areas of the study corridor, along with additional projects that have been recently implemented or programmed for future implementation at each location. Summaries of all site-level reviews are provided in Section 4.2, while full details of the site-specific UD-10 crash report reviews are provided in Appendix D.

Table 15. Summary of Potential Site Improvements

Location/County	Resurface/ Friction Course	Superelevation/ Slope Improvements	Shoulder Widening	Ramp Extension/ Realignment	Signing/Marking /Delineation	Cable Barrier Relocation	Enviro. Sensor Station	ITS*	Living Snow Fence	Advanced De-icing	Lighting	Crash Investigation Site	Courtesy Patrol/ Incident Mgmt.	Add Lane
Exit 4 (US-12), Berrien				L	S									
Exit 12 (Sawyer Road), Berrien					I									
MM 22-24, Berrien	P/M	P	P			M	M	M	L	S	L			
Exit 29 (Pipestone Road), Berrien				L										
Exit 34 (I-196), Berrien							P							
MM 36-39, Berrien	S/M			M		M	P	M	L	S	L			
MM 40, Berrien	S/M													
MM 43-49, Van Buren	S/M			M/L		M	P	S/M	P	S				
Exit 52 (CR 365), Van Buren	S/M													
MM 52-57, Van Buren	I (WB) P (EB)	I (WB) P (EB)	I (WB) P (EB)	L	S		M	M	P	S				
Exit 60 (M-40), Van Buren							P							
MM 61-64 (EB),Van Buren	S/M				S	M	P	M	L	S				
Exit 66 (CR 652), Van Buren				M/L		M								
Exit 74 (US-131), Kalamazoo	P	M			I/P		M	M		S	L		S/M	
MM 77-78, Kalamazoo	S/M			M/L	P									
MM 79-81, Kalamazoo	P (WB)	I	P (EB)	I	S		M	M		S			S/M	L
MM 81-87, Kalamazoo							P					P		
MM 87-89 (WB), Kalamazoo	P	P	P	P	P		P	S/M		S				
MM 89-92, Kalamazoo						M								
MM 92-93 Calhoun	P	M		I	P/S			M		S				
Exit 96 (M-66), Calhoun					S									
Exit 100 (Beadle Lake), Calhoun					S									
MM 101-102, Calhoun	P				P		M	M		S				
Exit 104 (M-96), Calhoun				M/L	S									
Exit 108 (I-69), Calhoun		M		L	I/P		P			S	L			
MM 130-131, Jackson									L					
MM 138-141, Jackson	P	P	P	P				M		S	L		I	P

Key: Short-Term (S), Medium-Term (M), Long-Term (L); Recently Implemented (I); Programmed (P)
* May include: variable speed limits, weather or pavement surface alerts/messages from environmental sensor station, queue warning devices, etc.

REFERENCES

1. Athey Creek Consultants and Michigan Department of Transportation, *Warrants for Intelligent Transportation System (ITS) Devices*. Federal Highway Administration, Washington, D.C., 2013.

2. Borough, P. *Variable Speed Limits Reduce Crashes Significantly in the U.K*. The Urban Transportation Monitor, March 14, 1997.

3. Han, C., Pyta, V. and Lennie, S., *A Review of Variable Speed Limits Initiatives and Reported Results*. Australian Institute of Traffic Planning and Management National Conference, Perth, 2008.

4. Murphy, R., Swick, R. and Guevara, G., *Best Practices for Road Weather Management*, Version 3.0. Federal Highway Administration, Washington, D.C., 2012.

5. Katz, B., O'Donnel, C., Donoughe, K., Atkinson, J., Finley, M., Balke, K., Kuhn, B. and Warren, D., *Guidelines for the Use of Variable Speed Limit Systems in Wet Weather*. Federal Highway Administration, Washington, D.C., 2012.

6. Guebert, A.A., Chow, R., Mulyk, C., Akhnoukh, I., Sharma, S., McDonald, S. and Pinet, M., *Variable Speed Limits Framework for a Pilot Study on Alberta Highways*. Transportation Association of Canada, Fredericton New Nrunswick, CA, 2012.

7. Harrington, C.P., Knodler, M.A., Freeman, J. and Fitzpatrick, C., A Conceptual Framework for Identification of Locations for Variable Speed Limit Implementation. Transportation Research Board, 94th Annual Meeting, Washington, D.C., 2015.

8. Sabawat, V. and Young, R.K., Control Strategy for Rural Variable Speed Limit Corridor. Transportation Research Record: *Journal of the Transportation Research Board* No. 2329, pp.31-44, 2013.

9. Saha, P., Ahmed, M.M. and Young, R.K., Safety Effectiveness of Variable Speed Limit (VSL) Systems in Adverse Weather Conditions on Challenging Roadway Geometry. Transportation Research Board 94th Annual Meeting, 2015.

10. Hassan, H.M. and Abdel-Aty, M.A., Analysis of Drivers' Behavior under Reduced Visibility Conditions using a Structural Equation Modeling Approach. *Transportation Research Part F: Traffic Psychology Behavior*, Vol. 14, No. 6, 2011.

11. Hassan, H.M., Abdel-Aty, M.A., Choi, K. and Alghadi, S.A., Driver Behavior and Preferences for Changeable Message Signs and Variable Speed Limits in Reduced Visibility Conditions. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, Vol . 16, No. 3, 2012.

12. Buddemeyer, J., Young, R.K. and Dorsey-Spitz, B., Rural Variable Speed Limit System for Southeast Wyoming. Transportation Research Record: *Journal of the Transportation Research Board* No. 2189, pp.37-44, 2010.