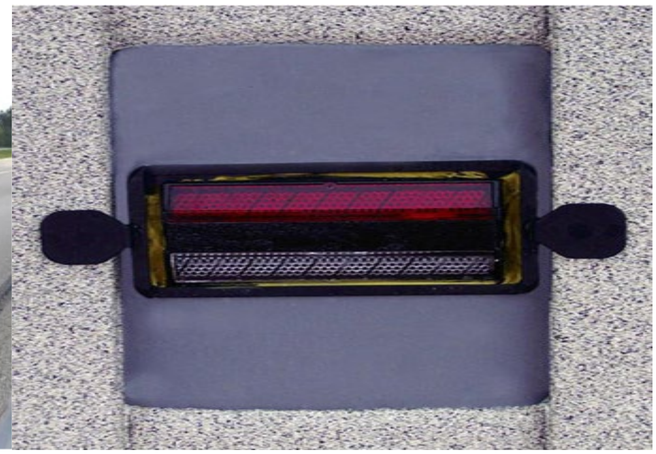
Inlaid Pavement Marker Evaluation

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16. Abstract

The objectives of this study were to assess inlaid pavement marker (IPM) performance and estimate their safety effectiveness. IPM performance was evaluated through a count of marker presence and a feedback survey from participants who viewed dry and wet night videos of IPM sections in the St Louis area. The safety effectiveness of IPMs was evaluated using a rigorous state-of-the-art empirical Bayes (EB) before-after crash analysis. The marker presence assessment, unfortunately, didn't provide any conclusive trends in IPM performance. Newer IPM sections had higher percentages of missing markers than older sections, and there were too many unknown variables to determine the source of the unexpected differences. The unanimous conclusion of the nighttime video visibility survey was that drivers and passengers traveling on a wet night feel that IPMs are very important to the visibility of the roadway's lane lines. For the EB analysis, installation and reference site data were used to examine the effects for specific crash types, including total, fatal and injury, wet pavement, nighttime, nighttime wet pavement, lane departure, wet pavement lane departure, nighttime lane departure, and fatal and injury lane departure. Based on the aggregate results, IPMs, when installed with pavement resurfacing, significantly reduce all crash types examined.

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Executive Summary

OBJECTIVES

The Missouri Department of Transportation (MoDOT) desires to provide and improve optimum lane delineation, particularly during wet nighttime conditions. Previous evaluations culminated in the current use of ASTM Type III glass beads on pavement markings. Snowplowable retroreflective pavement markers (SRPMs) and raised retroreflective pavement markers (RRPMs) are not extensively used by MoDOT. However, several experimental sections of inlaid pavement markers (IPMs) have been installed on roadways in the St. Louis area.

The first objective of this evaluation was to assess IPM performance through a count of marker presence (markers that are still bonded to the pavement surface) and through a feedback survey from participants who viewed dry and wet night videos of the St Louis area IPM sections. A further objective was to estimate the safety effectiveness of IPMs using a rigorous state-of-the-art empirical Bayes (EB) before-after analysis approach. The expected result of this study was supportive data that MoDOT needs to determine a statewide direction for the use of IPMs.

FINDINGS AND CONCLUSIONS

The IPM presence assessment was accomplished with the use of a vehicle mounted mobile retroreflectometer unit that can count reflective pavement markers. Unfortunately, the results of the marker presence assessment were inconclusive. The IPMs' performance did not exhibit an expected trend of increased missing marker percentages with time. The sections with the highest percentage of missing markers were only one year old, and most of the sections with the lowest percentage missing markers were two and three years old. Evaluating the same markers annually over a period of years would provide a trend of increased markers missing over the period of the study, but unfortunately evaluating different markers at different locations and of different ages at just one point in time didn't provide a performance trend. An unknown number of variables could have contributed to the varied performance of the different IPM sections.

The nighttime video visibility survey, however, had more useful and expected results, and the data from the marker presence assessment allowed for additional comparisons to be made in the visibility survey. The survey participants unanimously agree that the IPMs are more visible on wet nights than markings, and the IPMs' ability to provide guidance on lane delineation has much higher importance on a wet night than a dry night. The participants, all of whom had no knowledge of which routes had the higher marker presence versus lower marker presence, consistently rated the visibility higher for the routes with the higher marker percentage. Also, of the four participants, the three oldest would prefer to see a minimum of three to four consecutive IPMs on a wet night, and the youngest participant would prefer to see a minimum of two consecutive IPMs on a wet night. In summary, drivers and passengers traveling on a wet night feel that IPMs are important to the visibility of the roadway's lane lines.

The IPM safety effectiveness study used data from installation sites as well as nearby reference sites for a state-of-the-art EB before-after study. The data were used to examine the effects for specific crash types, including total, fatal and injury, wet pavement, nighttime, nighttime wet pavement, lane departure, wet pavement lane departure, nighttime lane departure, and fatal and injury lane departure. Based on the aggregate results, IPMs, when installed with pavement resurfacing, significantly reduce all crash types examined.

A disaggregate analysis of the results investigated additional factors associated with the safety performance of IPMs. The results suggested that IPMs may be more effective on segments with AADT greater than 70,000 vehicles per day, three-directional lanes (compared to four directional lanes), and more expected crashes before treatment. The disaggregate analysis also sought to identify if IPMs were more effective initially with reduced effects over time, but there was no evidence supporting this.

The resulting CMFs from this effort are directly applicable to IPM installations done in coordination with pavement resurfacing and are likely to be most applicable in these cases. Additionally, the results are applicable for urban and suburban freeways with three and four directional lanes. It is unclear if the CMFs hold up for longer than three years (the limit of this analysis) so caution should be exercised in extending the analysis results beyond this time period.

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CHAPTER 1: OVERVIEW

1.1 BACKGROUND

The Missouri Department of Transportation (MoDOT) desires to provide and improve optimum lane delineation, particularly during wet nighttime conditions. Previous evaluations culminated in the current use of ASTM Type III glass beads on pavement markings. Snowplowable retroreflective pavement markers (SRPMs) and raised retroreflective pavement markers (RRPMs) are not extensively used by MoDOT. However, several experimental sections of inlaid pavement markers (IPMs) have been installed on roadways in the St. Louis area.

An IPM is a polycarbonate plastic marker that is completely recessed in a long, shallow groove. The cast design of the marker is a rectangular cradle that holds the reflective lens just below the pavement surface, and there is a leveling tab on each side of the cradle. The length of the groove is approximately 9 ft, and typically two markers are placed in the middle of the groove about 2 ft. apart. An epoxy adhesive is used to bond the markers to the pavement, but most of the groove remains open (unfilled) so the reflective lens can be seen. Figure 1 contains a photo of an IPM and a drawing depicting the groove dimensions. In some of the St. Louis area IPM sections, the “marker” is simply a reflective lens, with no cradle, bonded directly to the pavement inside the same or similar groove.

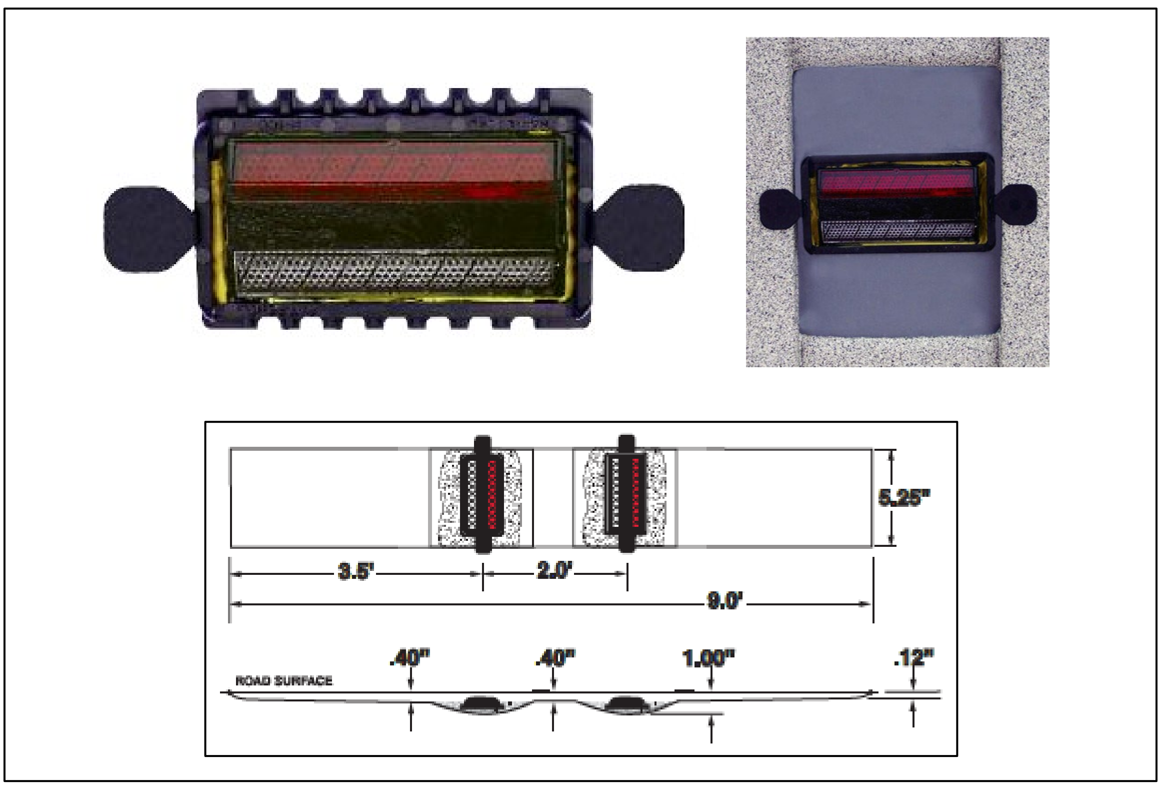

Figure 1. Inlaid Pavement Marker and Groove Dimensions

To date, a complete evaluation of the St Louis area IPMs’ performance and safety effectiveness has not been performed. Additionally, current national crash modification factors (CMFs) for similar enhanced delineation strategies may not apply to Missouri roadways if they were established from roadways with standard pavement markings or standard pavement markers, such as RRPMs or SRPMs.

The first objective of this evaluation is to assess IPM performance through a count of marker presence and a feedback survey from participants who viewed dry and wet night videos of the St Louis area IPM sections. A further objective is to estimate the safety effectiveness of IPMs using a rigorous state-of-the-art empirical Bayes (EB) before-after analysis approach. The expected result of this evaluation will be supportive data that MoDOT needs to determine a statewide direction for the use of IPMs.

1.2 INLAID PAVEMENT MARKER SECTIONS

At the beginning of the study the exact number and locations of the IPM sections in the St Louis area were unknown. The research team worked with staff from the St Louis District to identify how many sections have been installed, the end points of each section, the date of installation, the pavement surface type, the number of lanes in each direction, and whether there were single or dual markers in each groove. Twelve sections were identified.

Next, the sections were selected for the performance assessment, the crash study, or both. The sections for the performance assessment needed to be recorded by a drive-through video during both a dry night and a wet night. Therefore, the older sections that no longer exist could not be included. Ten of the 12 sections still exist and were selected to be video recorded. The sections for the crash study needed to be three years old so that there was sufficient crash data after the installation of the IPMs to perform the before-after analysis. Six of the 12 sections were selected for the crash study. Table 1 summarizes the details of the 12 IPM sections and identifies which were selected to be video recorded and which were selected for the crash study.

Table 1. IPM Section Details and Study Component Selection

IPM Section Number	Route	IPM Study Component	Installation Year	Dir	Lanes	Section Begin	Section End	Marker Type	Pavement Type
01	I-44	Video/Crash Study	2017	EB	3	MO 109	MO 141	Dual	AC
				WB	3	MO 141	MO 109	Dual	AC
02	I-44	Video	2018	EB	3	MO 141	I-270	Dual	AC
				EB	4	I-270	Shrewsbury	Dual	AC
				WB	4	Shrewsbury	I-270	Dual	AC
				WB	3	I-270	MO 141	Dual	AC
03	I-270	Video	2018	NB	4	I-55	MO 364	Single	AC
				SB	4	MO 364	I-55	Single	AC
04	I-64	Video/Crash Study	2017	EB	3	MO River	MO 340	Dual	AC
				WB	3	MO 340	MO River	Dual	AC
05	I-64	Video/Crash Study	2016	EB	3	Chest. Pkwy E	Maryville Cnt.	Single	AC
				EB	4	Maryville Cnt.	Ballas	Single	AC
				WB	4	Ballas	Chest. Pkwy E	Single	AC
06	US 61	Video	2018	NB	2	North of Piene	Lincoln Co line	Dual	AC
				SB	2	Lincoln Co line	North of Piene	Dual	AC
07	MO 370	Video	2018	EB	3	Premier Prkwy	Truman	Dual	PCC
				WB	3	Truman	I-70	Dual	PCC
08	I-70	Video	2018	EB	3	Lake St Louis Blvd	MM 215.2	Dual	AC
09	MO 364	Video	2018	EB	4	MO 94	Muegge ramp	Dual	PCC
				WB	3	Muegge ramp	MO 94	Dual	PCC
10	I-44	Video/Crash Study	2016	EB	4	River Des Peres	Macklind	Dual	AC
				WB	4	Macklind	River Des Peres	Dual	AC
11	I-70	Crash Study	2010	EB	3	I-170	West Florisant Ave	Dual	AC
			2011	EB	3	West Florisant Ave	St. Louis Ave	Dual	AC
			2010	WB	3	St. Louis Ave	Adeliade Ave	Dual	AC
			2010	WB	3	W/O West Florisant	I-170	Dual	AC
12	I-44	Crash Study	2011	EB	2	I-55	I-270	Dual	AC
				WB	2	I-270	I-55	Dual	AC

1.3 MARKER PERFORMANCE ASSESSMENT METHODS

Two methods were used to assess the performance of the IPMs. The first method was a count of the markers to determine the markers' percent presence over time. This metric was intended to evaluate the markers' durability or longevity. The second method was a survey of participants who viewed nighttime videos of the sections recorded during both dry and wet conditions to gather feedback on the markers' visibility. The purpose of the survey was to evaluate the IPMs' potential ability to enhance nighttime roadway safety, particularly during rain events.

1.3.1 Marker Presence

To assess the longevity performance of the IPM's remaining bonded to the pavement surface, the research team performed a count of the markers at each section with the use of a mobile retroreflectometer unit (MRU). The MRU used for the study was a Laserlux G7 (LLG7). The primary function of an MRU is to measure the retroreflectivity (nighttime visibility) of pavement markings, but the LLG7 also has the ability to count pavement markers. This is possible because the reflective lenses of the markers return a much higher reflectivity reading than the reflective media of pavement markings. An MRU, however, does not use the specific geometry required by ASTM for the measurement of pavement marker retroreflectivity. Figure 2 provides a photo of the LLG7 MRU attached to a survey vehicle.

Figure 2. Laserlux G7 Attached to a Survey Vehicle

The LLG7 was used to collect marker counts from every skip-line within the ten existing IPM sections (IPM Section Numbers 01 – 10 in Table 1), including both directions. The LLG7 marker count output file is a table in which each row of the table indicates the location where a marker was identified. The number of rows is summed to determine the total number of markers present. To calculate the marker presence (the percentage of the original total still present), the number of markers originally installed needed to be calculated. The spacing between the center of each IPM groove is 80 feet. Therefore, to determine the original number of IPMs for sections with a single marker in each groove, the total length of the section was divided by 80. To determine the original total IPMs for sections with dual markers in each groove the total section length was divided by 80 and then multiplied by two. Also, MoDOT does not place markers on bridge decks, which would cause a decrease in the original number of markers. To account for this, the research team identified the location and length of every bridge within each IPM section and then subtracted the bridge lengths from the total length of the section before calculating the total number of original markers.

1.3.2 Nighttime Video Visibility Survey

The videos for the nighttime visibility survey were collected by a Go-Pro camera mounted on the inside of the front windshield of a survey vehicle. The camera was attached beneath the rearview mirror. With a view from the center of lane, IPMs in lane lines on either side of the vehicle can be viewed at the same time. Therefore, for 6-lane divided routes, video was recorded in the middle lane only for both directions. For 8-lane divided routes, video was recorded from both of the middle two lanes in both directions, and video for 4-lane divided routes was recorded in the right lane of each direction. An ARA team member recorded all of the dry nighttime videos, and a St Louis-based company, Horner and Shifrin, which could respond quickly for rain events, recorded all of the wet nighttime videos.

The primary objective of the video survey was to gather feedback on comparisons of dry night vs. wet night visibility of the IPMs, as well as comparisons between the IPMs and pavement markings. Also, analysis of the marker presence assessment was completed before the survey was conducted so the survey included a comparison of a route with high marker presence to a route with low marker presence. Four ARA employees were selected to be the survey participants. They were selected based on age to gather feedback from a distribution of younger to older views. The participant demographics are shown in Table 2.

Table 2. Demographics of IPM Visibility Survey Participants

Participant	Age	Gender
A	22	Male
B	37	Male
C	55	Female
D	64	Male

A copy of the 4-page survey is provided in the Appendix, and the questions are summarized here:

1. **High IPM Presence vs. Low IPM Presence on a Dry Night**: Participants viewed a dry nighttime video of two different routes. The first route had a high IPM presence, and the second had a low IPM presence. Participants had no knowledge of the differences in marker presence. After viewing each video, the participants were asked to rate the visibility of the IPMs on a scale of 1 to 5, with 5 being “high visibility” and 1 being “low visibility”.

2. **Dry Night vs. Wet Night for a Route with High IPM Presence**: Participants viewed the dry nighttime and wet nighttime video of the same lane, segment, and direction of an IPM section

with high marker presence. After viewing each video, the participants were asked to rate the visibility of the IPMs and the visibility of the skip dash pavement markings on a scale of 1 to 5, with 5 being “high visibility” and 1 being “low visibility”.

3. **Dry Night vs. Wet Night for a Route with Low IPM Presence**: Participants viewed the dry nighttime and wet nighttime video of the same lane, segment, and direction of an IPM section with low marker presence. After viewing each video, the participants were asked to rate the visibility of the IPMs and the visibility of the skip dash pavement markings on a scale of 1 to 5, with 5 being “high visibility” and 1 being “low visibility”.

4. **Minimum Number of Consecutive IPMs on Dry Night vs. Wet Night**: Participants viewed another pair of dry and wet night videos of the same IPM section. After viewing the videos, the participants were asked to select the minimum number of consecutive IPMs they’d prefer to see on a dry night and on a wet night. The selection options for the participants was 2, 3, and 4. At the current marker spacing, no more than 4 consecutive markers can be visible at one time.

5. **Importance of IPMs on a Dry Night**: From the dry night videos previously viewed, the participants were asked to rate the importance of IPMs on a dry night on a scale of 1 to 5, with 5 being “very important” and 1 being “not important”.

6. **Importance of IPMs on a Wet Night**: From the wet night videos previously viewed, the participants were asked to rate the importance of IPMs on a wet night on a scale of 1 to 5, with 5 being “very important” and 1 being “not important”.

No comparison questions for single marker versus dual marker sections were created because no pair of single and dual sections had the same percent missing. An ideal comparison would be made when both a single and a dual marker section still had 100 percent of the original markers present.

1.4 CRASH MODIFICATION FACTOR DEVELOPMENT METHOD

1.4.1 Approach

To develop a CMF or set of CMFs for quantifying the safety effect from IPM use in Missouri, ARA teamed with VHB. A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. A CMF is a point estimate, but a single point may or may not be appropriate. Instead, it may be more appropriate to represent the CMF as a function, allowing the value of the CMF to change for different scenarios (e.g., changes in traffic volume or area type). This study examined the development of point estimates of CMFs based on an analysis of the aggregate data. This study also explored more disaggregate analyses to determine the need for a function or, perhaps, a set of point estimates to reflect differential effects of IPMs under different conditions.

CMF development was separated into two phases. In Phase I, the research team used a naïve before-after approach with adjustment for changes in annual average daily traffic (AADT) to develop a CMF. The naïve approach provided an opportunity to quickly determine if the national CMFs for RRPMs appear to represent a similar effectiveness to the IPM installations in Missouri. The IPM installations all coincided with pavement resurfacing and installation of new pavement markings, so it was difficult to separate the effect of IPMs from the effect of resurfacing.

In Phase II, the research team used the state-of-the-art EB before-after approach to develop a CMF and separate the effects of IPMs from the effects of resurfacing. The EB approach is currently recognized as a more reliable method for estimating the effectiveness of treatments while accounting for potential biases, such as regression-to-the-mean (RTM) and changes in traffic volume. Since all installations were combined with pavement resurfacing, the reference group was selected to include sites with pavement resurfacing but without the installation of IPMs. All treatment and reference sites were in Urban and Suburban areas in the St. Louis vicinity, had three or four directional lanes, and were in areas likely to have some level of ambient lighting.

The objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. Target crash types included the following:

- Total crashes (all types and severities combined). These were identified as all crashes, without exclusion.
- Injury crashes (K, A, B, and C injuries on KABCO scale). Crashes coded as fatal, disabling injury, and minor injury were included.
- Wet pavement crashes (all severities combined). Crashes with a roadway surface condition of wet were included.
- Nighttime crashes (all severities combined). Crashes with a light condition with anything other than daylight were included.
- Nighttime wet pavement crashes (all severities combined).
- Lane departure crashes (all severities combined). Target lane departure crashes were defined by the crash variables "MHTD_ACC_CLS_NAME" and "MHTD_ACC_TYPE_NAME". Crashes coded as cross median, head on, other (with accident type coded as any ran off road category, other object, other non-collision), out of control (with accident type coded as any ran off road category), parking or parked car, passing, and sideswipe. The research team considered the analysis with and without passing. While many crashes were coded as passing, inclusion or

exclusion made little difference on the outcome, therefore passing was retained in the definition.
- Lane departure wet pavement crashes (all severities combined).
- Lane departure nighttime crashes (all severities combined).
- Lane departure injury crashes (K, A, B, and C injuries on the KABCO scale).

A further objective was to address questions of interest, such as:
- Do effects vary by traffic volume (i.e., AADT)?
- Do effects vary by number of directional through lanes?
- Do effects vary by expected crash frequency prior to installation?
- Are the effects short-lived?

The Phase I evaluation did not consider 2019 data, nor did it consider potential RTM bias or the effects of annual trends. Using the EB before-after methodology in Phase II, the research team conducted further disaggregate analysis to determine where IPMs are more or less effective.

Special requirements were placed on the data collection and analysis tasks to meet the objectives, including the need to:
- Select a large enough sample size to detect, with statistical significance, possible small changes in safety for some crash types.
- Identify appropriate untreated reference sites (i.e., no IPMs) along with years each site had pavement resurfacing.
- Properly account for changes in safety due to changes in traffic volume and other nontreatment factors.
- Pool data from multiple facilities to improve reliability of results and facilitate broader applicability of the products of the research.

1.4.2 Literature Review

In order to compare the results of the naïve before-after evaluation to national CMFs, the research team conducted a brief review of the literature for safety evaluations of RRPMs. The literature review focused on study results included in FHWA's CMF Clearinghouse and focused on snowplowable raised pavement markers. The studies included in this section will be used for comparative purposes with the CMFs developed as part of this research.

Bahar et al. (2004) examined the safety effects of snowplowable raised pavement markers (SRPMs) in six states along two-lane roadways, four-lane expressways, and four-lane freeways using an EB before-after safety evaluation methodology. SPFs were developed for total, fatal and injury, nighttime, nighttime fatal and injury, daytime, daytime fatal and injury, wet weather, dry weather, and guidance related crashes. The disaggregate analyses showed that:

- Nonselective implementation of SRPMs on two-lane roadways does not have a significant association with total or nighttime crashes.
- For locations where SRPMs were implemented based on selective policies (e.g., crash history), significant positive effects were found in some instances (decreases in total, nighttime, wet weather, and wet weather nighttime crashes). Additionally, SRPMs that were installed based on nighttime crashes were found to be associated with a significant increase

in crashes on curves for AADT between 5,000 and 15,000 with a degree of curvature greater than 3.5.

- Nonselective implementation of SRPMs on four-lane freeways showed no safety effect for total or nighttime crashes. Significant reductions were found for wet weather crashes at non-interchange locations, and results showed that SRPMs were effective in reducing nighttime crashes where the AADT exceeds 20,000.
- The safety effect of SRPMs was not explored for four-lane expressways due to data constraints.

Smiley et al. (2004) found that RRPMs can be used as a treatment for locations with a history of above average wet weather nighttime crash frequencies. They found a decrease in total crashes, nighttime crashes, and wet weather crashes when the RRPMs were installed at locations with high numbers of wet weather nighttime crashes. The benefit of RRPMs was not as clear at locations selected based on total crashes or without any selection criteria. Total, dry weather, and wet weather crashes increased in frequency after the application of RRPMs, showing that selective implementation may prove effective and nonselective implementation ineffective.

Wright et al. (1982) estimated a 22 percent reduction in nighttime crashes compared with daytime crashes. Sites installed in 1976 and 1977 had reductions of 33 percent and 32 percent, respectively. Sites installed in 1978 observed a 53 percent increase in nighttime crashes. Single-vehicle crashes were estimated to have been reduced by 12 percent more than other nighttime crash types. These reductions were found to be independent of average daily traffic (ADT) and curvature (although all curves were 6 degrees or greater).

Kugle et al. (1984) collected two years of data before-and-after installation for PRPMs installed on two-, three-, four-, five-, and six-lane roadways from 1977 to 1979 in Texas. The results indicated a 15 percent to 31 percent increase in nighttime crashes and an insignificant 1 percent to 1.4 percent decrease in wet weather crashes. The authors noted that about 10 percent of the sites showed very large increases in total crashes, which may have unfairly skewed the overall results.

Mak et al. (1987) reevaluated Kugle’s data, screening those sites that underwent major modifications other than SRPM installation, using a statistical procedure based on the cross-product ratio. The results showed that four locations experienced a significant decrease in nighttime crashes relative to daytime crashes, 9 showed significant increases, and 74 showed no significant change.

Griffin (1990) reevaluated the Mak sites by calculating a weighed log odds ratio. The results indicated an expected 16.8 percent increase in nighttime crashes, which is statistically significant at the 95 percent confidence level.

New York State Department of Transportation (DOT) (1989) analyzed the effect of SRPMs on unlit suburban and rural roadways with proportionally high numbers of nighttime and nighttime wet weather crashes using a naive before-after methodology. The DOT found a 7 percent decrease in total crashes, 26 percent decrease in nighttime crashes, 33 percent decrease in nighttime wet weather-related crashes, 23 percent reduction in all guidance-related crashes, and a 39 percent reduction in nighttime guidance-related crashes. A second analysis of 60 long sections of highway found an 8.6 percent reduction in nighttime crashes, 7.5 percent reduction in total crashes, and a 7.4 percent increase in nighttime wet weather crashes. They concluded that SRPMs should be installed only at locations with high frequencies of wet weather, nighttime, and guidance-related crashes.

Orth-Rodgers and Associates, Inc. (1998) used the odds-ratio to evaluate the effects of raised and recessed pavement markers on nighttime crashes on rural Interstate highway locations in Pennsylvania. Results indicated a 12.3 percent increase in nighttime crashes, a 1.2 percent decrease for locations with raised pavement markers, and a 20.1 percent increase for locations with recessed pavement markers. Nighttime wet condition crashes showed increases from 30 to 47 percent, and nighttime wet road sideswipe and fixed-object crashes increased 56.2 percent. However, the odds ratio methodology required the researchers to drop sites with zero crashes in any period. Since the after period was shorter than the before period, a bias is created toward the underestimation of effects if a zero crash after period is associated with the SRPM installation.

Das et al. (2013) examined the safety impact of RPMs along with pavement striping on Louisiana freeways using annual condition inspection ratings. This study included nine years of data for each site, where each site experienced several cycles of good to poor ratings for RPMs or striping. The authors found that RPMs have a significant effect in reducing crashes, particularly nighttime crashes, at all AADT levels. The analysis results also indicated that RPMs do not have any safety benefits on urban freeways. The analysis was conducted as a t-test for equality of means for crash rates between segments with good RPM ratings and poor RPM ratings.

Pendleton (1996) used classical and EB before and after methods to evaluate the effect of SRPM nighttime crashes on undivided and divided arterials in Michigan. He found an increase in nighttime crashes for undivided roadways and a decrease in nighttime crashes for divided roadways. Daytime crashes as comparison sites yielded larger reductions (or smaller increases) in crashes than when nighttime crashes at untreated sites were used as a comparison group. However, no results were statistically significant at the 95 percent confidence level.

Bahar et al. (2006) performed a time-series safety analysis of pavement markings and markers on multilane freeways, multilane highways, and two-lane highways in California. National Testing Product Evaluation Program data were used to develop retroreflectivity models as a function of age, color, material type or marker type, climate region, and amount of snow removal. The authors found that the difference in safety for markings or markers between time periods with high retroreflectivity and low retroreflectivity is approximately zero. The authors surmised that it is important that markings are present and visible but level of retroreflectivity is less important.

Dwyer and Himes (2019) evaluated the safety effects of SRPMs on suburban and urban six and eight lane freeways on the Illinois Tollway. The authors used an EB before-after analysis approach for sites that had a moratorium after a reconstruction effort. The before-after analysis indicated no changes (significant at the 95 percent confidence level) in any crash type when accounting for changes in traffic volumes and time trends based on reference sites (sites that had SRPMs for the entire study period).

1.4.3 Phase I Methodology

Phase I included a naïve before-after with traffic volume adjustment study design to develop the initial CMFs. This methodology assumes a linear relationship between traffic volume and crash frequency and does not include safety performance functions (SPFs). Additionally, this methodology does not account for RTM bias but reduces analytical complexity by forgoing the need for reference sites. Additionally, the methodology does not account for the effects of time trends (e.g., changes in weather, vehicle fleet, or crash reporting). Using this approach, the CMF was calculated as follows:

$$CMF = \frac{\frac{\sum N_A}{\sum N_E}}{1 + \frac{\sum var(N_E)}{\sum N_E^2}}$$

where:

N_A = Observed number of crashes in the after period with IPMs.

N_E = Expected number of crashes in the after period without IPMs.

The number of expected crashes in the after period (N_E) is calculated as follows:

$$N_E = N_B \times r_{time} \times r_{AADT}$$

where:

N_B = Observed number of crashes in the before period without IPMs.

r_{time} = Ratio of years after to years before (0.33, 0.67, or 1.0 in this case).

r_{AADT} = Ratio of AADT after to AADT before (0.89 to 1.28 in this case).

Finally, the variance of the CMF is calculated as follows:

$$var(CMF) = CMF^2 \times \frac{\frac{1}{\sum N_A} + \frac{\sum var(N_E)}{\sum N_E^2}}{(\frac{\sum var(N_E)}{\sum N_E^2})^2}$$

The standard error of the CMF is the square root of the CMF variance.

For the Phase I installation sites, the average time ratio was 0.711 and the average AADT ratio was 1.00. The average combined ratio was 0.709, indicating an expected reduction in crash frequency of 29 percent due to the change in AADT and differences in time periods.

1.4.4 Phase II Methodology

Phase II employed the EB before-after study design to develop final CMFs. The naïve before-after methodology employed in Phase I provided an indication of the effectiveness of IPMs but suffers from potential biases. Specifically, it does not account for RTM, does not consider annual trends in crashes, and does not account for pavement resurfacing and restriping activities conducted in conjunction with the IPM installation. CMFs estimated in Phase I were a function of only number of years and changes in traffic volume; however, the relationship between traffic volume and crash frequency was assumed to be linear. Phase II focused on the safety effectiveness of IPMs while accounting for potential RTM and changes in traffic volumes using the study design methodology outlined in this section.

The general methodology for Phase II is the EB before-after study design. This method is based on the observational before-after study design, but benefits from significant advances, which culminated in a landmark book by Hauer (1997). That book, which was used as a resource for this research, also provided guidance on study design elements such as sample size and selection criteria for treatment and reference groups. These are crucial elements to conducting a safety effectiveness study.

The methodologies documented by Hauer (1997) range from naive before-after comparisons to the more powerful EB before-after methodology. The research team implemented the latter approach to overcome the difficulties associated with conventional before-after comparisons. Specifically, the proposed analysis:

- Properly accounts for RTM bias.
- Overcomes the difficulties of using crash rates in normalizing for traffic volume differences between the before and after periods.
- Reduces the level of uncertainty in the estimates of safety effect.
- Provides a foundation for developing guidelines for estimating the likely safety consequences of contemplated installations.

In the EB approach, the change in safety (Δ) for a given crash type at a site is given in the following:

$$\Delta Safety = \lambda - \pi$$

where:

λ = expected number of crashes that would have occurred in the after period without the strategy.

π = number of reported crashes in the after period.

In estimating λ, the effects of RTM and changes in traffic volume were explicitly accounted for using SPFs, relating crashes of different types to traffic flow and other relevant factors based on reference sites. Annual SPF multipliers were calibrated to account for temporal effects on safety (e.g., variation in weather, demography, and crash reporting).

In the EB procedure, the SPF is used to first estimate the number of crashes that would be expected in each year of the before period at locations with traffic volumes and other characteristics similar to the one analyzed (i.e., reference sites). The sum of these annual SPF estimates (*P*) is then combined with the count of crashes (*x*) in the before period at an installation site to obtain an estimate of the expected number of crashes (*m*) before installation, as shown as:

$$m = w(P) + (1 - w)(x),$$

where *w* is estimated from the mean and variance of the SPF estimate, shown as:

$$w = \frac{1}{1 + kP},$$

where *k* is the constant for a given model and is estimated from the SPF calibration process with the use of a maximum likelihood procedure. In that process, a negative binomial distributed error structure is assumed with *k* being the overdispersion parameter of this distribution.

A factor (C) is then applied to *m* to account for the length of the after period and differences in traffic volumes between the before and after periods, shown as:

$$\lambda = Cm$$

where C is the sum of the annual SPF predictions for the after period divided by *P*, the sum of these predictions for the before period. The result, after applying this factor, is an estimate of λ. The procedure also produces an estimate of the variance of λ.

The estimate of λ is then summed over all installation sites in a group of interest (to obtain λ_{sum}) and compared with the count of crashes observed during the after period in that group (π_{sum}). The variance of λ is also summed over all sites in the strategy group.

The Index of Effectiveness (θ) is estimated as:

$$\theta = \frac{\pi_{sum} / \lambda_{sum}}{1 + \left(Var(\lambda_{sum}) / \lambda_{sum}^2 \right)},$$

The standard deviation of θ is given as:

$$StDev(\theta) = \sqrt{\frac{\theta^2 \left(\frac{Var(\pi_{sum})}{\pi_{sum}^2} + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)}{\left(1 + \frac{Var(\lambda_{sum})}{\lambda_{sum}^2} \right)^2}},$$

The percent change in crashes is calculated as 100(1–θ); thus, a value of θ = 0.7 with a standard deviation of 0.12 indicates a 30% reduction in crashes with a standard deviation of 12%.

CHAPTER 2: DATA COLLECTION AND ANALYSIS

2.1 MARKER PERFORMANCE

2.1.1 Marker Presence

The results of the marker presence assessment are summarized in Table 3. To make comparisons easier the current number and original number of IPMs for all lane lines were grouped by direction. The marker presence is reported as both percent missing and percent present. As shown the marker performance varied considerably. Sections that were a little over one year old had missing IPM percentages ranging from 5.7 to 84.5. Sections that were a little over two years old had missing IPM percentages ranging from 9.0 to 15.3, and sections that were a little over three years old had missing IPM percentages ranging from 10.8 to 11.9. The two sections of markers that were three years old had the most consistent performance and the lowest average percentage of missing markers.

The MO 370 section, which was only one year old, had the highest percentage of missing markers in both directions, with 84.5% missing east bound and 79.5% missing west bound. US 61, which was also only one year old, had the next highest percentage of missing markers, with 29.9% missing north bound and 47.2% missing south bound. Both of these sites, particularly MO 370, likely had an issue with the installation of the IPMs.

Table 3. Results of Marker Presence Assessment by Route and Direction

IPM Section	Route	Direction	Surface Type	Age	Current Number of IPMs	Original Number of IPMs	Percent Missing (%)	Percent Present (%)
01	I-44	EB	AC	2.2	1558	1831	14.9	85.1
01	I-44	WB	AC	2.2	1536	1814	15.3	84.7
02	I-44	EB	AC	1.4	2646	3538	25.2	74.8
02	I-44	WB	AC	1.4	2619	3272	20.0	80.0
03	I-270	NB	AC	1.4	3006	3188	5.7	94.3
03	I-270	SB	AC	1.4	2982	3213	7.2	92.8
04	I-64	EB	AC	2.2	1368	1544	11.4	88.6
04	I-64	WB	AC	2.2	1413	1552	9.0	91.0
05	I-64	EB	AC	3.1	916	1040	11.9	88.1
05	I-64	WB	AC	3.1	1127	1263	10.8	89.2
06	US 61	NB	AC	1.3	295	421	29.9	70.1
06	US 61	SB	AC	1.3	226	428	47.2	52.8
07	MO 370	EB	PCC	1.1	78	503	84.5	15.5
07	MO 370	WB	PCC	1.1	124	604	79.5	20.5
08	I-70	EB	AC	1.3	385	493	21.8	78.2
09	MO 364	EB	PCC	1.3	287	350	18.0	82.0
09	MO 364	WB	PCC	1.3	209	277	24.6	75.4
10	I-44	EB	AC	3.7	577	654	11.8	88.2
10	I-44	WB	AC	3.7	889	1000	11.1	88.9

Table 4 presents the results of the marker presence assessment by route only.

Table 4. Results of Marker Presence Assessment by Route

IPM Section	Route	Surface Type	Age	Current Number of IPMs	Original Number of IPMs	Percent Missing (%)	Percent Present (%)
01	I-44	AC	2.2	3094	3644	15.1	84.9
02	I-44	AC	1.4	5265	6810	22.7	77.3
03	I-270	AC	1.4	5988	6401	6.5	93.5
04	I-64	AC	2.2	2781	3096	10.2	89.8
05	I-64	AC	3.1	2043	2303	11.3	88.7
06	US 61	AC	1.3	521	849	38.6	61.4
07	MO 370	PCC	1.1	202	1107	81.8	18.2
08	I-70	AC	1.3	385	493	21.8	78.2
09	MO 364	PCC	1.3	496	627	20.9	79.1
10	I-44	AC	3.7	1466	1654	11.4	88.6

The two concrete surfaced routes, MO 370 and MO 364, were among the top five sections with the highest percentage of missing markers. With the other three of the top five being asphalt surfaced routes, no conclusions can be made from these St Louis area sections that the pavement surface type has an effect on the marker's ability to remain bonded to the pavement. However, the research team completed a pavement marker study in 2019 for the Illinois Department of Transportation (IDOT) in which the R-100 IPM was evaluated on both asphalt and concrete surfaced roads, and by the third (final) year of the study over half of the IPMs were missing from the three concrete surfaced roads. Figure 3 is a graph of the IPM performance results provided in the IDOT study's final report.

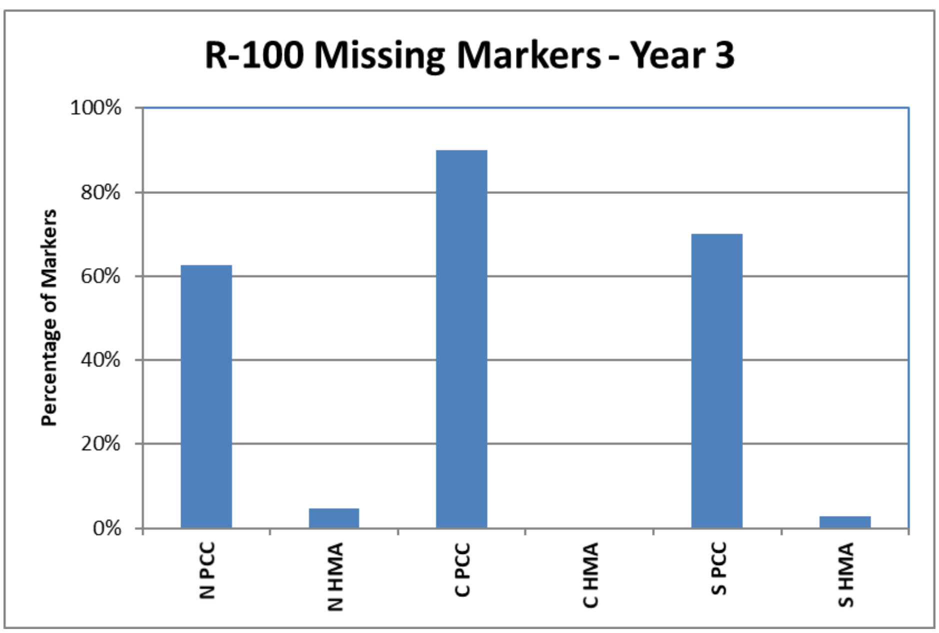

Figure 3. IL DOT Marker Study – IPM Performance after 3 Years at 6 Test Sites (Dwyer and Himes)

Typically, degradation in performance would increase over time. However, Figure 4 shows that the greatest loss of IPMs occurred with sections that are only one year old, and the older sections have some of the lowest percentage of missing IPMs. Therefore, the data doesn't provide any trends to indicate a rate at which IPMs become missing with age. If there had been a trend, there could have been an additional evaluation to assess a threshold percentage of missing markers to trigger maintenance, marker replacement.

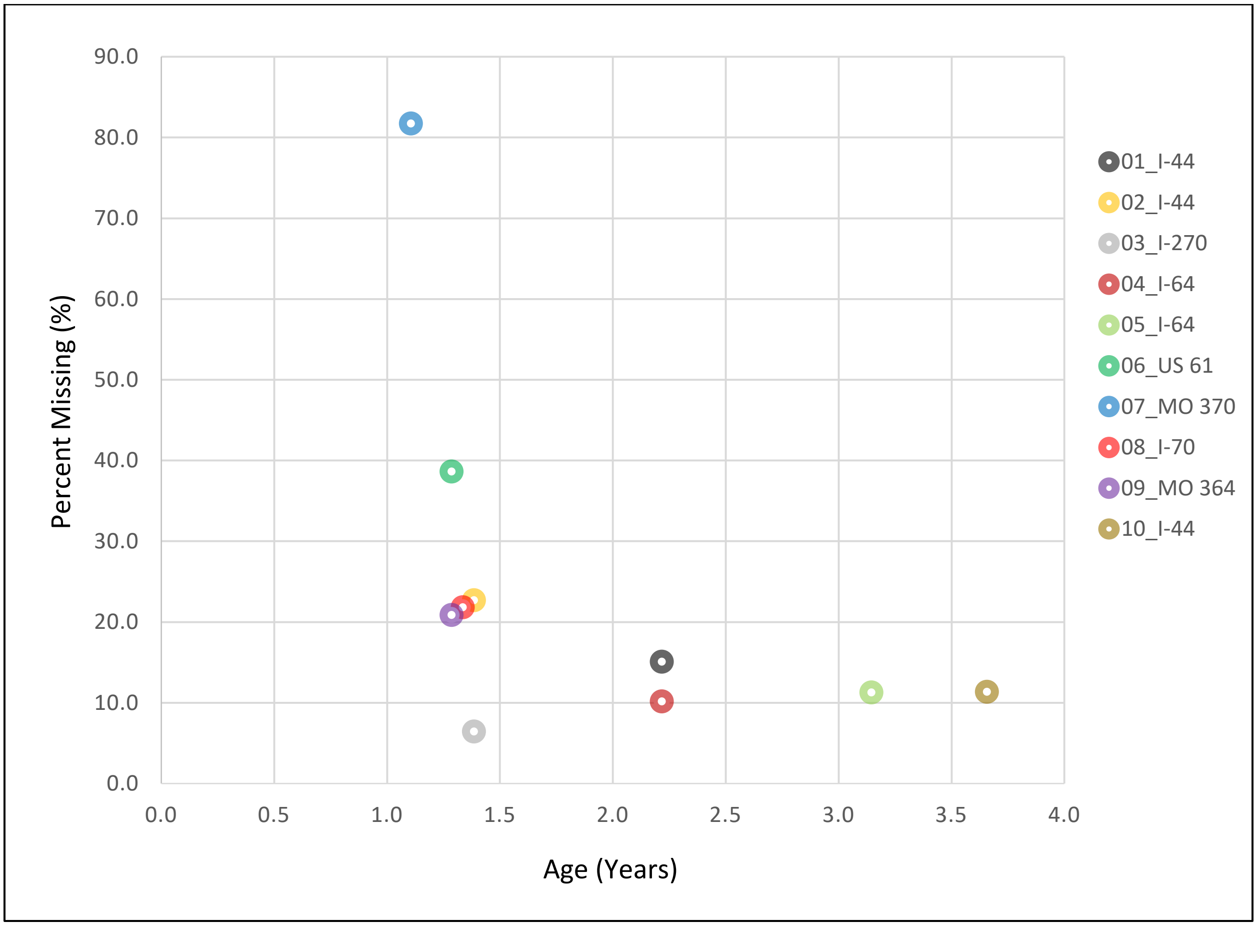

Figure 4. IPM Percent Missing vs Age

2.1.2 Nighttime Video Visibility Survey

The findings of the nighttime video survey are summarized in Figure 5 through Figure 9. For the high IPM presence versus low IPM presence, I-270, with a 93.5% presence, was compared to US 61, with 61.4% presence. Figure 5 shows that all participants rated the visibility of the I-270 IPMs higher than the US 61 IPMs. The I-270 section uses a single marker per groove, and US 61 has dual markers per groove. Therefore, the higher presence clearly has an impact on the IPM visibility.

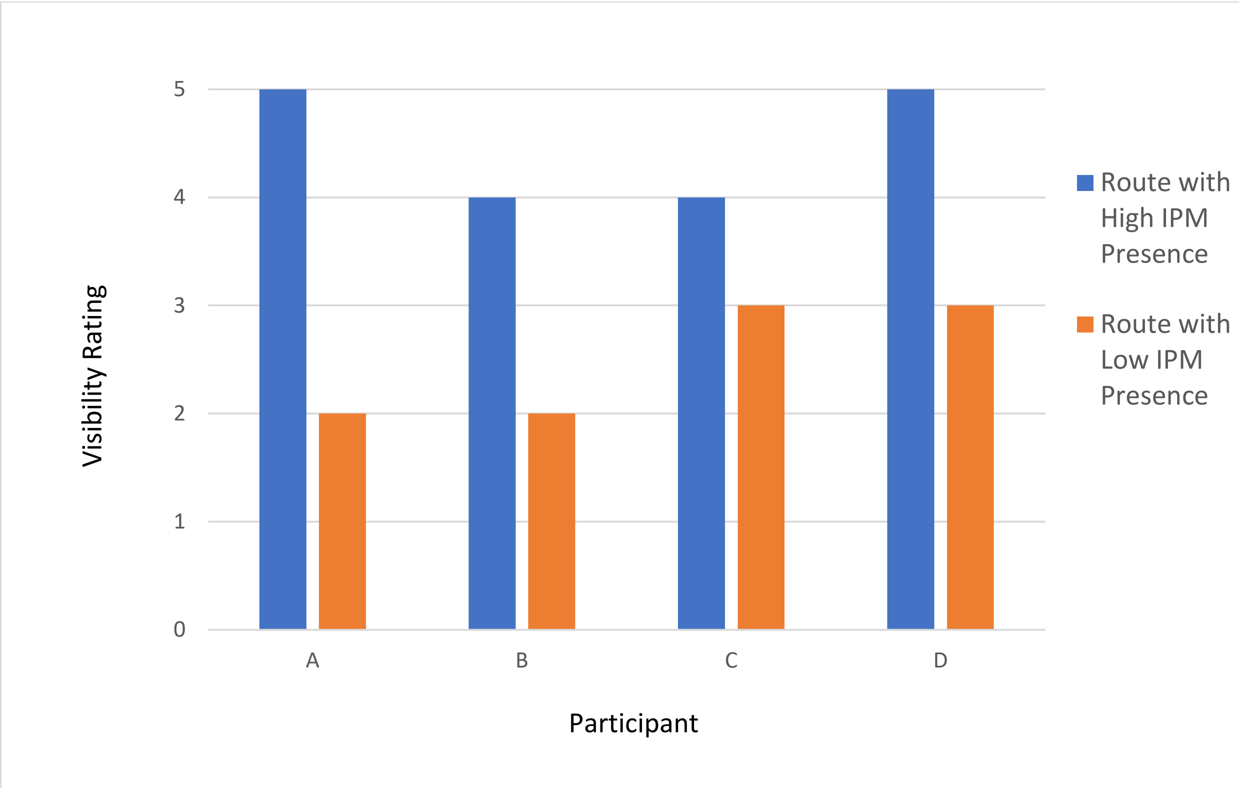

Figure 5. IPM Visibility Rating of Routes with High IPM Presence vs Low IPM Presence

Figure 6 presents the results of the IPM and skip dash marking ratings on dry versus wet nights for a route with high IPM presence. The exact same section of I-270 on a dry night and a wet night was used for this comparison. Three of the four participants gave both the IPMs and the markings a rating of five on the dry night, and the fourth participant rated the IPMs just one point less than the markings. Therefore, both the IPMs and markings have high visibility on a dry night. However, on the wet night comparison every participant rated the IPMs' visibility higher than the markings, and three of the four rated the IPMs two points higher than the markings.

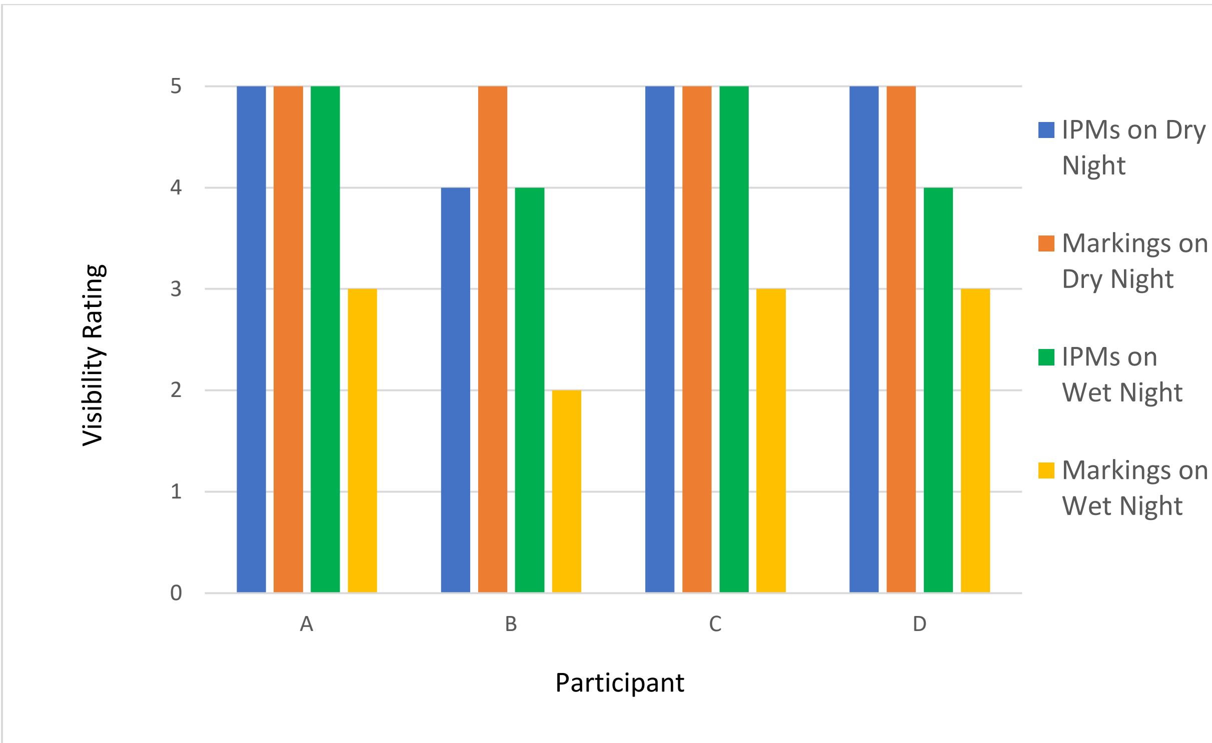

Figure 6. IPM and Marking Visibility Ratings on Dry vs Wet Night for Route with High IPM Presence

Figure 7 presents the results of the IPM and skip dash marking ratings on dry versus wet nights for a route with low IPM presence. The exact same section of US 61 on a dry night and a wet night was used for this comparison. Every participant rated the markings' visibility higher than the IPMs', which reflects the lower percentage of markers present, and all IPM dry night ratings were two points lower than the same ratings in Figure 6. Although the marker presence was low on US 61, three of the four participants still rated the IPM visibility higher than the markings', and the fourth participant rated them the same.

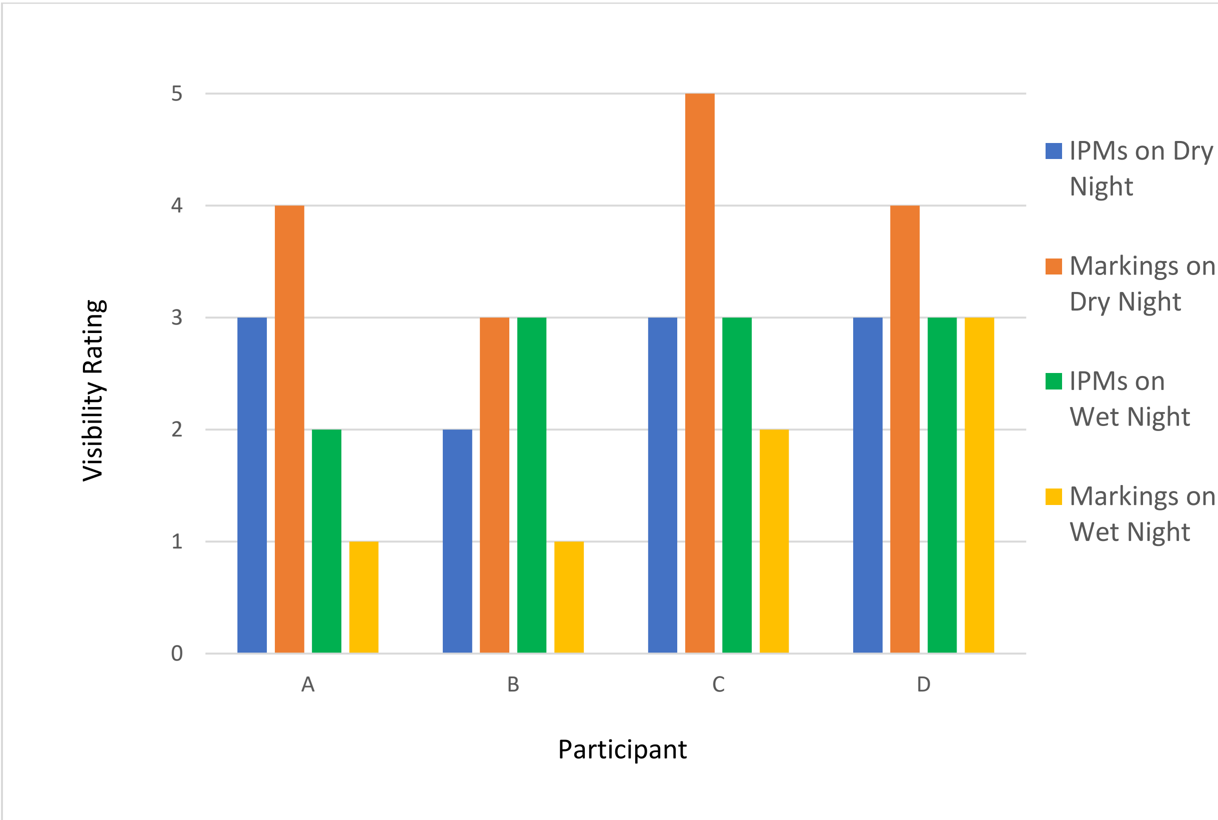

Figure 7. IPM and Marking Visibility Rating on Dry vs Wet Night for Route with Low IPM Presence

Figure 8 presents the participants' preferred minimum number of consecutively visible IPMs on a dry night versus a wet night. The exact same section of MO 364 on a dry night and a wet night was used for this comparison. The youngest participant, Participant A, would prefer a minimum of two consecutive IPMs on either a dry or wet night. Participant C could also get by with a minimum of two IPMs on a dry night, but all other three participants prefer three or four consecutively visible IPMs on a wet night. Participants A and D prefer the same number of consecutively visible markers whether the night is clear or rainy, but Participants B and C prefer to see more consecutive markers on a rainy night.

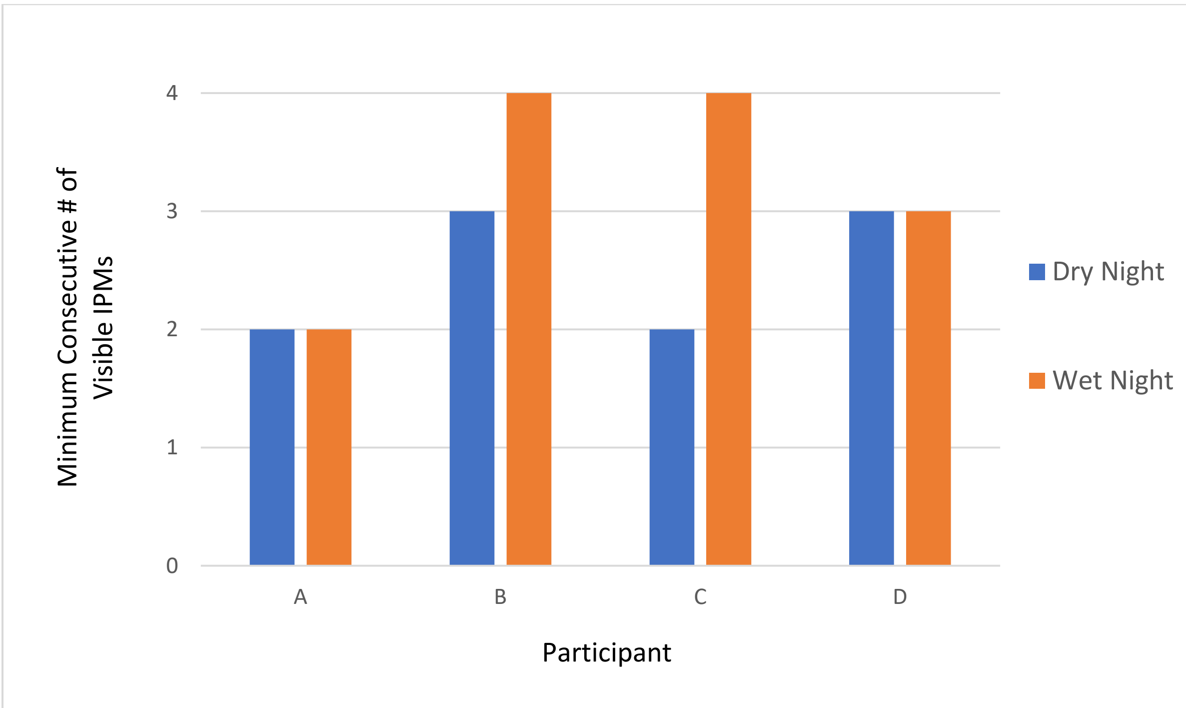

Figure 8. Preferred Minimum Consecutive Number of Visible IPMs on Dry vs Wet Night

Figure 9 presents the participants' rating of the IPMs' importance on a dry night versus wet night. As shown, every participant rated the IPMs importance higher during a wet night. Three of the participants rated the markers two points higher during a rain event, and the oldest participant, Participant D, rated the markers three points higher during a rain event.

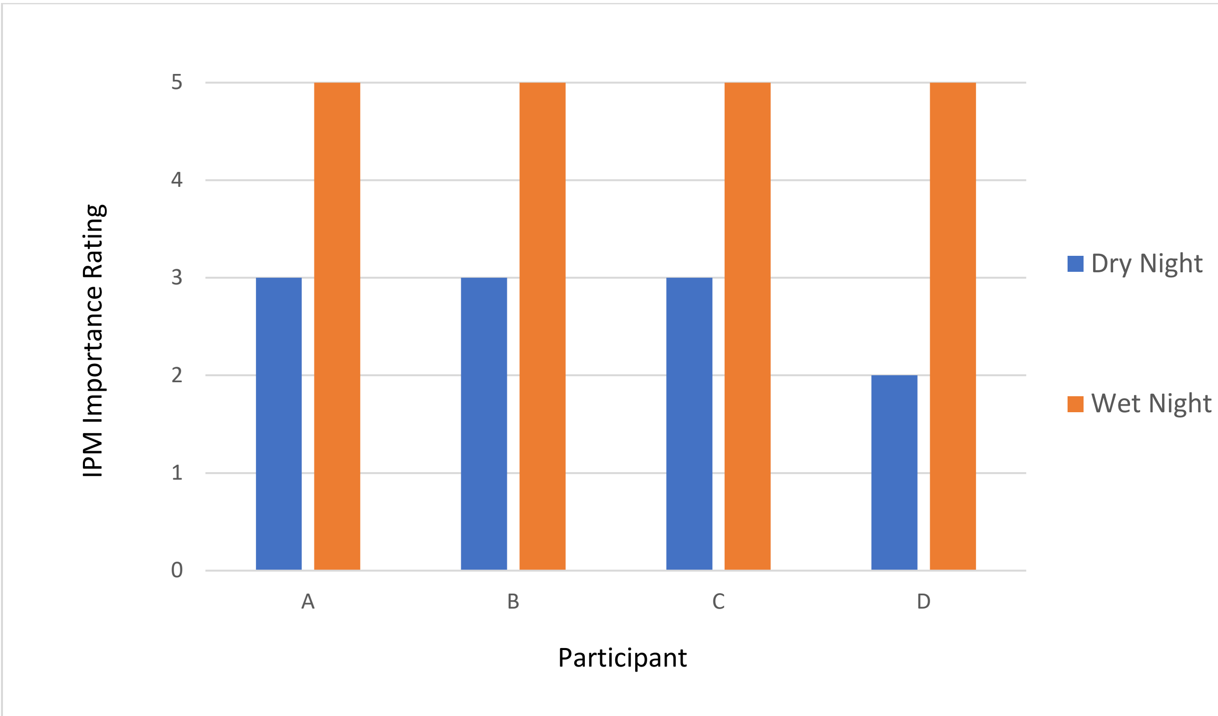

Figure 9. IPM Importance Rating on Dry vs Wet Night

2.2 CRASH MODIFICATION FACTOR DEVELOPMENT

2.2.1 Phase I Data Collection

The six IPM sections identified in Table 1 for the crash study were separated into 15 sites based on direction and segment changes. Table 5 provides an overview of the study segments, including facility, direction, extents, number of directional lanes, installation year, and marker type. It should be noted that some sections of I-44 received the treatment in both 2011 and 2017. For the Phase I analysis, all sections were included in the analysis.

Table 5. Initial List of Crash Study Installation Sites

Site	Route	Begin	End	Lanes	Year	Type
1	I-44 EB	MO 109	MO 141	3	2017	Dual
2	I-44 WB	MO 141	MO 109	3	2017	Dual
3	I-64 EB	MO River	MO 340	3	2017	Dual
4	I-64 WB	MO 340	MO River	3	2017	Dual
5	I-64 EB	Chest. Pkwy E	Maryville Cnt.	3	2016	Single
6	I-64 EB	Maryville Cnt.	Ballas	4	2016	Single
7	I-64 WB	Ballas	Chest. Pkwy E	4	2016	Single
8	I-44 EB	River Des Peres	Macklind	4	2016	Dual
9	I-44 WB	Macklind	River Des Peres	4	2016	Dual
10	I-70 EB	I-170	W Florissant	3	2010	Dual
11	I-70 EB	W Florissant	St. Louis Ave	3	2011	Dual
12	I-70 WB	St. Louis Ave	Adelaide Ave	3	2011	Dual
13	I-70 WB	W Florissant	I-170	3	2010	Dual
14	I-44 EB	I-55	I-270	4	2011	Dual
15	I-44 WB	I-270	I-55	4	2011	Dual

MoDOT provided traffic volumes and crash data by year for each section for three years before and three years after installation through 2018 (the latest data available during Phase I). The corridors were provided as shown in Table 5 and average traffic volumes for the corridors were provided; however, it should be noted that traffic volumes within corridors are highly variable.

2.2.2 Phase I Results

Table 6 provides the Phase I, naïve before-after estimates of expected crashes in the after period without installation, the observed crashes in the after period, and the estimated CMF and its standard error for all crash types considered. The analysis indicates statistically significant decreases for installing IPMs across all crash types and severities based on a 95 percent confidence interval.

Table 6. Phase I Aggregate CMFs for IPMs by Crash Type

Crash Type	Empirical Bayes estimate of crashes expected in the after period without strategy	Count of crashes observed in the after period	Estimate of CMF	Standard Error of CMF
Total	4,258	2,682	0.63	0.02
FI	1,231	800	0.65	0.03
N	1,415	857	0.61	0.03
W	1,387	517	0.37	0.02
WN	511	192	0.38	0.03
LD	1,437	838	0.58	0.02
N LD	611	339	0.55	0.04
W LD	631	253	0.40	0.03
FI LD	476	315	0.66	0.05

*Crash rates are presented as crashes/mile/year; FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure

The results of the analysis indicate a significant 37 percent reduction in total crashes, 39 percent reduction in nighttime crashes, 63 percent reduction in wet pavement crashes, and 62 percent reduction wet pavement nighttime crashes. The results also indicate a 42 percent reduction in lane departure crashes.

As further indicated in Table 6, target crash types (falling under the lane departure category) do not generally see improvements relative to their subsets of total crashes (nighttime, wet pavement, and fatal and injury). These results indicate that the safety benefit from IPMs are not larger for target crash types than non-target crash types (mostly characterized by rear-end crashes) for all crashes, wet pavement crashes, and nighttime crashes. Further, the CMFs for all crashes are slightly smaller (but not significantly smaller at the 95 percent level) than the CMFs for fatal and injury crashes. Additionally, the results indicate that IPMs may be more effective for property-damage-only crashes than for fatal and injury crashes.

These results are consistent with the IPMs being installed in conjunction with asphalt pavement resurfacing. It is likely that that the increased friction from the newer asphalt is responsible for the larger decrease in wet-pavement crashes as well as non-target (lower-speed) rear-end crashes. Additionally, comparing to the results found in other studies (summarized in the literature review), these results indicate much larger reductions than found in other studies, particularly for six- and eight-lane urban and suburban freeways.

The results of the Phase I analysis informed the EB before-after analysis conducted in Phase II. While selecting reference sites, emphasis was placed on identifying sites with one or more pavement resurfacings during the study period. The purpose was to further identify the safety effectiveness of IPMs when accounting for the effects of pavement resurfacing. Ideally, the analysis would have included sites installed with IPMs without resurfacing for comparison; however, no sites were installed without pavement resurfacing.

Since the Phase I analysis was done using a naïve approach, the Phase I results should not be used as CMFs. The results of the Phase II analysis provide more reliable results for use in decision-making.

2.2.3 Phase II Data Collection

As described in Section 2.2.1, MoDOT provided information on when and where segments of the St. Louis area freeway network received IPM installation. Additionally, MoDOT provided information on all other similar sections of freeway (i.e., three and four directional lanes) in the St. Louis vicinity. The research team identified reference sites that did not receive the treatment, but had similar traffic volumes, the same number of lanes, were on the same freeway (or adjacent) corridors and had at least one pavement resurfacing during the study duration. The following sections provide insights on the data collected for segments with IPMs installed (i.e., treatment sites) and for reference sites.

2.2.3.1 Installation Data

The research team worked with MoDOT to identify locations and extents where IPMs had been installed for inclusion in the crash-based study. For the location to be included in the study, there needed to be at least one full year of after data available, limiting the sample to those installed in 2017 or earlier. Initially the research team was not sure if 2019 crash data would be available in time for the study. For each site, three years of before data were included, and a maximum of three years of after data were included. Three years was selected for two purposes:

1. This limited the site to years where it was most likely that IPMs would not have become damaged or dislodged. Since maintenance history was unavailable, MoDOT and the research team felt comfortable that the IPMs remained in place for at least three years.
2. This limited the potential influence of any one site in the overall analysis. Since several sites were treated more recently and only had two years of after data, it was possible that the sites installed in 2010 and 2011 would influence the overall CMF development if all years of the after period were included.

MoDOT provided information on the sections where IPMs had been installed in 2017 or earlier along with information on the beginning and ending locations of the segments. The segments were directional in nature, meaning that opposite directions on the same highway section were included and analyzed separately. Table 5 (section 2.2.2) provides an overview of the study segments, including the facility, direction, extents, number of directional lanes, installation year, and marker type. It should be noted that all facilities were Interstate freeways and all sections had recently undergone asphalt resurfacing just prior to IPM installation. It is difficult to note from Table 1, but some sites installed in 2010/2011 were actually reinstalled in 2016/2017. For those segments that were first installed in 2010 or 2011, the years after the re-installation date were removed (since IPMs existed in the before period).

Table 7 provides an overview of the final study corridors included as treatment sites in the analysis. Note that some segments within several corridors were not included in the analysis dataset (because they had more than four directional lanes); therefore, the total mileage included for each section does not match with the beginning and ending mileposts in those cases. Additionally, the research team verified installation year through use of MoDOT’s Datazone Traffic Application. The application provided a directional video-log for each segment along with the AADT for each year of the study period.

Table 7. Final List of Crash Study Installation Sites

Site	Route	Begin	End	Mileage	Install Year
1	I-44 EB	265.102	272.393	6.591	2017
2	I-44 EB	276.303	289.660	13.357	2010
3	I-44 WB	3.251	17.195	13.944	2010
4	I-44 WB	20.728	27.860	13.124	2017
5	I-64 EB	19.840	27.745	6.825	2016
6	I-64 WB	13.982	20.974	6.718	2016
7	I-64 WB	20.974	26.96	5.986	2017
8	I-70 EB	238.755	245.020	6.265	2010
9	I-70 EB	245.020	246.629	1.609	2011
10	I-70 EB	246.629	249.278	2.649	2010
11	I-70 WB	1.236	3.381	2.145	2010
12	I-70 WB	3.381	4.405	0.882	2011
13	I-70 WB	4.405	11.123	6.717	2010
Total				86.812	

2.2.3.2 Roadway Data

MoDOT provided roadway inventory data including directional route information, beginning and endpoints of segments, as well as the number of directional lanes. The research team initially considered capturing additional data elements from MoDOT's Datazone application (such as shoulder widths, lane widths, and posted speed limit), but initial data collection indicated little variability in these data elements.

For each treatment and reference segment, the research team included the following data attributes:

- Segment beginning milepost, ending milepost, and segment length.
- Route and direction.
- Number of lanes.
- Presence of construction within a given year.
- Indicators for year before pavement resurfacing, year of pavement resurfacing, and the first two-years after pavement resurfacing. The purpose of these indicator variables was to determine if pavement surface and marking condition played an additional role in the safety effects being captured by the IPMs in the naïve before-after analysis.

The MoDOT facilities were divided into directional segments to better quantify the effects of IPMs at the individual segment level. Additionally, volume data was provided directionally, allowing for a directional analysis of safety performance. Each directional segment across all facilities had at least three travel lanes per direction and were generally suburban in nature, likely having some ambient light at night. However, the data collection process could not capture the magnitude of ambient light.

2.2.3.3 Traffic Data

The research team captured AADTs from 2007 through 2019 for each study segment (both treatment and reference sites). In general, segments ran from one interchange cross-street to the next interchange cross-street (where there was likely to be a change in traffic volume). The research team used MoDOT's Datazone application to capture AADT information for each year. While collecting AADT information, the research team confirmed installations and presence of IPMs each year as well as pavement resurfacing and other construction activities at each site.

2.2.3.4 Crash Data

MoDOT provided crash data from 2007 through 2019 for all freeway sections with three or four directional lanes in the St. Louis vicinity. The crash data provided details on crash location, crash direction, lighting condition, pavement condition, and crash type. From these details, the research team developed counts of the total number of crashes by type and severity for each directional segment (by route, direction, and milepost). The crash types developed included the following:

- Total crashes.
- Fatal and injury (FI) crashes.
- Wet pavement (W) crashes.
- Nighttime (N) crashes.
- Nighttime wet pavement (NW) crashes.
- Lane departure (LD) crashes.
- Lane departure wet pavement (LD W) crashes.
- Lane departure nighttime (LD N) crashes.
- Lane departure fatal and injury crashes (LD FI) crashes.

The definitions of each crash type are provided in the Data Characteristics and Summary section.

2.2.3.5 Reference Sites

The research team identified adjacent segments (when possible) to serve as a reference group. Typically, the reference group would consist of nearby sites that could have been treated, but were not, for the entire period. In this way, the reference sites help to account for potential RTM bias and to account for unobserved factors over time (e.g., weather conditions that may have influenced annual crash trends for the region). In this case, RTM bias is not suspected since the treatment sites were not selected for improvement due to crash history but were done in conjunction with resurfacing projects.

Table 8 provides an overview of the reference sites collected by the research team. Note that the overall mileage is similar to the treatment sites. The research team selected reference sites with three- and four-directional lanes and had similar AADTs to treatment sites. Reference sites were available on Interstate 44 and Interstate 70 and were adjacent to treatment sites. Other reference sites were on nearby corridors that have not had IPMs installed as of 2019.

Table 8. Final List of Reference Sites

Site	Route	Begin	End	Mileage
1	I-170 EB	1.373	6.792	4.788
2	I-170 WB	4.334	9.780	4.597
3	I-270 EB	1.820	4.273	1.282
4	I-270 EB	22.027	33.854	11.827
5	I-270 WB	1.902	13.008	10.466
6	I-270 WB	31.538	32.105	0.567
7	I-44 EB	258.191	262.188	3.997
8	I-44 WB	31.415	34.914	3.499
9	I-55 NB	197.518	207.836	9.792
10	I-55 SB	2.034	12.318	10.284
11	I-70 EB	217.503	229.361	9.147
12	I-70 EB	234.199	238.755	4.556
13	I-70 WB	11.224	15.855	4.631
14	I-70 WB	20.660	32.261	11.538
Total				90.971

The research team used a test of suitability to determine if the time-based effects of the reference group were similar to the treatment sites. The test of suitability compares the annual trends of the before period data from the treatment sites to the data from the same time period for comparison sites. Since installations took place over a period of 7 years, the before period for treatment sites were only included until the year prior to installation. To account for the change in sites, total crashes are normalized by mileage. Therefore, the research team compared crash rates (i.e., crashes/mile) from year to year in the test of suitability. Total crashes, fatal and injury crashes, and lane departure crashes were the focus for the test of suitability due to sample sizes and expected development of SPFs.

Figure 10 provides a graphical representation of total crash rate per year for treatment and reference sites (from 2007 to 2015). The graphics for fatal and injury and lane departure crashes are similar to total crashes. From Figure 10, it appears as though the reference sites adequately mimic the trends in the treatment sites prior to installation. Further, the test of suitability provides a reliable, scientifically rigorous method for determining if the reference sites are sufficient. The test of suitability computes odds-ratios from year to year for treatment and reference sites and determines if the odds ratios are significantly different from 1.0. If 1.0 is within the 95 percent confidence interval, then the null hypothesis cannot be rejected (the null hypothesis is that the two groups have the same trends). Based on the test of suitability, the 95% confidence interval for total crashes was 0.82 to 1.22 for total crashes (with a mean of 1.02), 0.62 to 1.37 for fatal and injury crashes (with a mean of 1.00), and 0.74 to 1.48 for lane departure crashes (with a mean of 1.11). Therefore, there is sufficient evidence to suggest that the reference group is suitable for identifying annual trends.

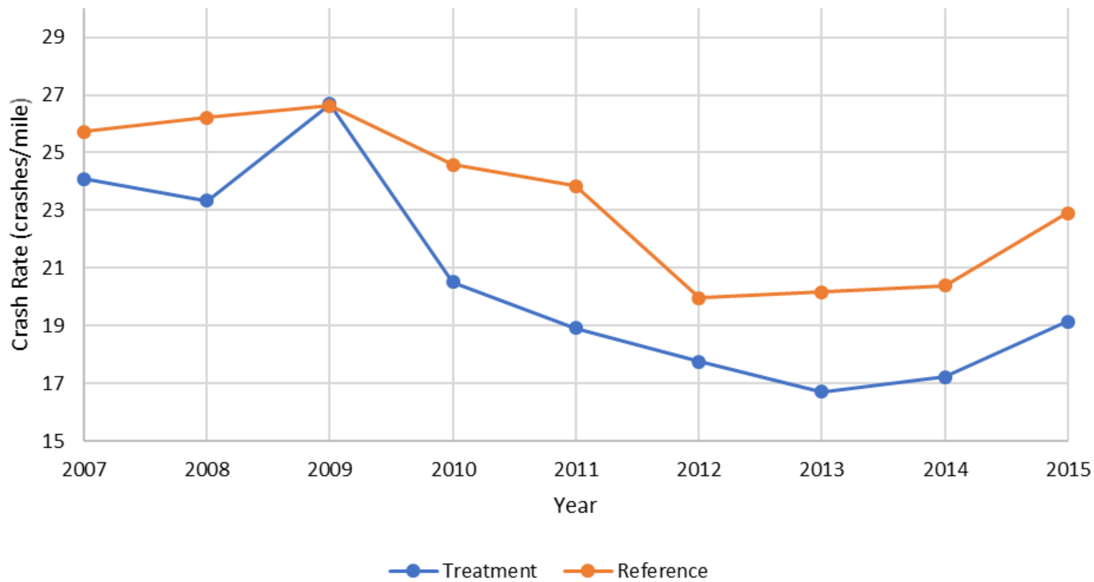

Figure 10. Annual Crash Rates for Treatment and Reference Groups

2.2.3.6 Data Characteristics and Summary

Table 9 provides summary information for the data collected for the installation sites. The information in Table 9 should not be used to make naive before-after comparisons of crashes per site year, since it does not account for factors, other than the strategy, that may cause a change in safety between the before and after periods. Such comparisons are properly done with the EB analysis as presented in section 2.2.4 Aggregate Analysis. Table 10 provides summary information for the reference site data.

Table 9. Data Summary for Installation Sites

Interstate	44	64	70	Total
Segment years before	138	60	135	333
Segment years after	127	54	135	316
Mile years before	123.07	76.56	60.80	260.44
Mile years after	109.35	64.59	60.80	234.74
Total crashes before*	18.83	22.70	48.49	26.89
Total crashes after*	13.87	16.44	26.02	17.72
FI crashes before*	4.66	6.60	14.51	7.53
FI crashes after*	3.42	4.47	8.59	5.05
W crashes before*	5.18	4.39	18.06	7.96
W crashes after*	3.36	2.57	5.51	3.70
N crashes before*	5.86	3.83	19.28	8.39
N crashes after*	4.56	4.04	9.56	5.71
WN crashes before*	1.63	0.82	7.68	2.81
WN crashes after*	1.35	0.82	2.07	1.39
LD crashes before*	9.22	5.75	26.46	12.23
LD crashes after*	6.77	4.94	14.42	8.25
LD W crashes before*	2.72	1.18	10.26	4.03
LD W crashes after*	1.85	1.00	3.55	2.04
LD N crashes before*	3.65	1.59	11.99	4.99
LD N crashes after*	2.66	1.70	5.79	3.21
LD FI crashes before*	2.27	1.46	7.83	3.33
LD FI crashes after*	1.87	1.21	4.64	2.41
AADT before	Avg: 51,364 Min: 32,766 Max: 72,096	Avg: 68,246 Min: 42,203 Max: 91,884	Avg: 61,002 Min: 42,539 Max: 82,356	Avg: 58,577 Min: 32,766 Max: 91,884
AADT after	Avg: 50,506 Min: 34,306 Max: 79,889	Avg: 68,995 Min: 45,975 Max: 92,283	Avg: 57,782 Min: 40,248 Max: 76,381	Avg: 57,478 Min: 34,306 Max: 92,283

*Crash rates are presented as crashes/mile/year; FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure

Table 10. Data Summary for Reference Sites

Interstate	170	270	44	55	70	Total
Segment years	260	533	65	364	546	1,768
Mile years	122.01	313.85	97.49	260.99	388.34	1,182.62
Total crashes*	21.56	29.04	5.40	19.29	26.75	23.42
FI crashes*	4.88	8.11	1.19	5.43	5.66	5.81
W crashes*	4.10	6.14	1.62	5.44	6.65	5.57
N crashes*	5.87	7.50	1.77	6.46	6.91	6.44
WN crashes*	1.40	1.91	0.51	2.07	2.01	1.81
LD crashes*	9.09	10.46	3.44	10.23	11.03	9.88
LD W crashes*	2.12	2.64	1.23	3.42	3.31	2.86
LD N crashes*	3.18	3.45	1.16	4.23	3.84	3.54
LD FI crashes*	2.16	3.09	0.77	3.08	2.45	2.59
AADT	Avg: 55,442 Min: 41,679 Max: 68,611	Avg: 65,326 Min: 30,761 Max: 98,852	Avg: 27,687 Min: 23,587 Max: 32,220	Avg: 53,170 Min: 37,227 Max: 71,057	Avg: 64,562 Min: 36,855 Max: 97,276	Avg: 59,750 Min: 23,587 Max: 98,852

*Crash rates are presented as crashes/mile/year; FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure

2.2.4 Phase II Analysis and Results

2.2.4.1 Development of Safety Performance Functions

This section presents the SPFs developed for each crash type and severity, which are subsequently used in the EB methodology. Generalized linear modeling was used to estimate model coefficients assuming a negative binomial error distribution, which is consistent with the research in developing these models. In specifying a negative binomial error structure, the dispersion parameter, *k*, was estimated iteratively from the model and the data. For a given data set, smaller values of *k* indicate relatively better models.

Since IPM installations were completed along with pavement resurfacings, rather than targeted for safety improvements directly, RTM is not suspected. However, to account for potential RTM and annual fluctuations due to unobserved trends (e.g., annual weather patterns), reference sites were used for SPF development.

The form of the SPFs for all crash types is given as:

$$\frac{crashes}{year} = L^b \times AADT^c \times e^{(a+d\times fourlane+e\times prepave+f\times repave+g\times afterpave)}$$

where:

L = Segment length (miles)

AADT = Directional annual average daily traffic volume for freeway segment.

fourlane = Segment has four directional lanes.

prepave = Indicator for year before resurfacing activities on segment.

repave = Indicator for year of resurfacing activities on segment.

afterpave = Indicator for period within 2 years after resurfacing activities on segment.

a – g = Regression parameters estimated as part of the modeling process.

Additionally, the following parameter is provided for each SPF:

k = overdispersion parameter of the model.

Table 11 provides SPFs estimated from freeway segment reference sites. Table 11 provides the parameter estimates for each variable included in the final specification along with the standard error (in parentheses). Separate SPFs were estimated for each crash type, and Table 11 includes the overdispersion parameter for each model. Note that the effects of pavement resurfacing/restriping appear to be largest on wet-pavement crashes.

Table 11. Pretreatment Freeway Segment SPFs

Crash Type	Parameter Estimates (Standard Error)							
	a	***b***	***c***	***d***	***e***	***f***	***g***	***k***
Total	-9.44 (0.70)	0.67 (0.02)	1.16 (0.06)	-0.17 (0.03)	0.09 (0.05)	N/A	N/A	0.26
FI	-9.90 (0.93)	071 (0.03)	1.07 (0.08)	-0.11 (0.04)	0.10 (0.07)	N/A	N/A	0.28
W	-8.24 (1.05)	0.66 (0.03)	0.92 (0.10)	-0.20 (0.04)	0.15 (0.08)	-0.21 (0.09)	-0.19 (0.06)	0.46
N	-5.39 (0.83)	0.73 (0.02)	0.66 (0.08)	-0.10 (0.03)	0.15 (0.06)	N/A	N/A	0.22
WN	-4.95 (1.43)	0.69 (0.04)	0.52 (0.13)	-0.15 (0.06)	0.20 (0.11)	-0.17 (0.12)	N/A	0.54
LD	-4.21 (0.75)	0.73 (0.02)	0.60 (0.07)	-0.15 (0.03)	0.11 (0.06)	N/A	N/A	0.23
LD W	-2.64 (1.30)	0.70 (0.04)	0.35 (0.12)	-0.18 (0.05)	0.16 (0.10)	-0.21 (0.11)	-0.16 (0.08)	0.64
LD N	-2.65 (0.99)	0.72 (0.03)	0.36 (0.09)	-0.06 (0.04)	0.12 (0.08)	N/A	N/A	0.26
LD FI	-5.35 (1.10)	0.70 (0.03)	0.59 (0.10)	-0.09 (0.05)	N/A	N/A	-0.12 (0.06)	0.27

Note: FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure

The reference site data were also used to develop annual factors to account for unobserved trends over time. Table 12 provides the annual factors used in the safety effectiveness evaluation. The annual factors were estimated as part of the SPFs for each crash type, accounting for the other factors considered in the model. The annual factors are used to adjust the prediction by year to account for unobserved time-based trends (e.g., impacts of weather). Annual factors are interpreted as multipliers. For example, a factor of 0.90 indicates 10 percent fewer crashes to occur based on unobserved trends, relative to the base year. For all models, 2007 serves as the base year, which is why all multipliers for 2007 are 1.00.

Table 12. Annual Adjustment Factors Based on Reference Sites

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Total	1.00	0.99	1.04	0.98	1.03	0.81	0.82	0.76	0.93	0.89	0.87	0.96	0.85
FI	1.00	0.98	1.03	0.93	1.04	0.68	0.70	0.69	0.92	0.92	0.89	0.98	0.85
W	1.00	1.13	1.37	1.01	1.06	0.64	0.82	0.67	0.84	0.68	0.62	1.04	0.78
N	1.00	1.11	1.01	0.90	0.99	0.77	0.84	0.76	1.05	0.94	1.06	1.09	1.00
WN	1.00	1.14	1.31	1.02	0.97	0.71	0.80	0.67	0.90	0.58	0.64	1.16	0.94
LD	1.00	1.06	1.11	0.94	0.95	0.84	0.84	0.87	1.04	1.00	0.98	1.08	0.99
LD W	1.00	1.12	1.42	0.99	0.96	0.65	0.77	0.74	0.89	0.64	0.76	1.06	0.82
LD N	1.00	1.15	0.96	0.88	0.94	0.80	0.85	0.83	1.13	0.96	1.06	1.18	1.03
LD FI	1.00	1.02	1.04	0.96	0.96	0.69	0.72	0.67	0.91	0.96	1.02	1.02	0.86

Note: FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure

2.2.4.2 Aggregate Analysis

Table 13 provides the estimates of expected crashes in the after period without installation, the observed crashes in the after period, and the estimated CMF and its standard error for all crash types considered. The results of a naïve before-after analysis are provided in the final column for comparative purposes. The EB analysis results incorporate the effects of changes in traffic volume through SPFs, the effects of pavement resurfacing, and associated pavement markings done in tandem with installation, and the effects of unobserved factors from year to year. The results of the EB analysis should be used since this methodology is more statistically rigorous and, therefore, more reliable than the naïve before-after method. The EB results indicate statistically significant reductions at the 95 percent confidence level for all crash types except for lane departure fatal and injury crashes.

Not all results in Table 13 are intuitive relative to each other; however, the naïve before-after estimates are. Since IPM installations were done in combination with pavement resurfacing, it is possible that the improvements in safety observed were masked by the new pavement surface and associated pavement markings. While pavement resurfacing was accounted for in the SPFs, there is overlap in the crash types targeted by both resurfacing (and associated markings) and IPMs. If resurfacing is responsible for large reductions in wet pavement crashes, then it will mask the possible effects of IPMs if resurfacing and restriping had not been done in combination. It is possible that IPMs may have slightly different impacts than those estimated here when installed without pavement resurfacing. However, it should be noted that the confidence intervals for all CMFs overlap with each other, which means it is not appropriate to conclude that IPMs are more effective for one crash type than another. It is possible to discern from Table 13 that IPMs are associated with a statistically significant reduction in all crash types evaluated at the 95 percent confidence level.

Note that when comparing the naïve before-after CMF to the EM before-after CMF, the largest changes were for wet pavement, nighttime, and all subsets of lane departure crashes, which are those that are targeted specifically by the treatment. The changes from naïve analysis to EB analysis indicate that new pavement surfaces and associated markings likely also had some impact on those crash types, as discussed in the previous paragraph. Future studies should examine the effectiveness of IPM installations on all crash types when not installed as part of a pavement resurfacing project, unless the

DOT intends only to apply this countermeasure as part of pavement resurfacing projects (when the pavement condition is least susceptible to issues from milling operations).

Table 13. Aggregate CMFs for IPMs by Crash Type

Crash Type	EB estimate of crashes expected in the after period without strategy	Count of crashes observed in the after period	Estimate of CMF	Standard Error of CMF	Naïve Before-After CMF
Total	5,798	4,161	**0.72**	0.01	**0.62 (0.01)**
FI	1,510	1,185	**0.78**	0.03	**0.62 (0.02)**
W	1,209	868	**0.72**	0.03	**0.43 (0.02)**
N	1,341	1,052	**0.82**	0.03	**0.63 (0.02)**
WN	327	238	**0.72**	0.05	**0.46 (0.03)**
LD	2,419	1,936	**0.80**	0.02	**0.63 (0.01)**
LD W	577	480	**0.83**	0.05	**0.47 (0.02)**
LD N	920	753	**0.82**	0.04	**0.60 (0.02)**
LD FI	566	565	1.00	0.05	**0.67 (0.03)**

Note: FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure; **Bold** indicates statistically significant difference at 95 percent level.

2.2.4.3 Disaggregate Analysis

The disaggregate analysis sought to identify those conditions under which the strategy may be most effective. The disaggregate analysis focused on all crash types examined in the aggregate analysis. Several variables were available for exploration: AADT, number of lanes, and expected crash frequency before treatment. Table 14 provides the results of the disaggregate analysis. Note that in each case, bold values are provided to indicate results where the 95^{th} percentile confidence intervals do not overlap for comparative CMFs. Bold does not indicate statistically significant increases or decreases for individual CMFs.

The disaggregate analysis considered the effectiveness of IPMs under higher and lower traffic volume conditions. There was a notable break when the directional AADT was greater than or less than 70,000 vehicles per day. In general, the results indicated that IPMs were more effective under higher traffic volumes; the confidence intervals did not overlap for total and fatal and injury crashes. Regarding number of lanes, the disaggregate results indicate that IPMs may be more effective when there are three directional lanes than when there are four directional lanes. The confidence intervals for wet-night crashes did not overlap. Finally, the results indicated IPMs were more effective when the expected number of crashes before treatment are higher. The note below Table 14 indicates the cutoffs used for each crash type in the analysis. The confidence intervals did not overlap for total, fatal and injury, wet-pavement, and wet-night crashes. In all cases, 95 percent confidence intervals were considered.

Table 14. Disaggregate CMFs for IPMs by Crash Type

Factor	Total	FI	W	N	WN	LD	LD W	LD N	LD FI
AADT < 70,000	**0.753 (0.017)**	**0.862 (0.035)**	0.743 (0.033)	0.826 (0.031)	0.731 (0.052)	0.809 (0.025)	0.841 (0.050)	0.835 (0.040)	1.056 (0.059)
AADT > 70,000	**0.620 (0.025)**	**0.603 (0.045)**	0.632 (0.057)	0.793 (0.064)	0.664 (0.105)	0.757 (0.053)	0.777 (0.105)	0.728 (0.085)	0.785 (0.097)
Three Lanes	0.706 (0.018)	0.766 (0.036)	0.657 (0.034)	0.769 (0.034)	**0.592 (0.051)**	0.773 (0.029)	0.783 (0.054)	0.775 (0.045)	0.952 (0.065)
Four Lanes	0.734 (0.022)	0.809 (0.045)	0.822 (0.052)	0.898 (0.047)	**0.957 (0.095)**	0.838 (0.037)	0.911 (0.079)	0.881 (0.060)	1.056 (0.082)
Expected Low-Med*	**0.780 (0.021)**	**0.851 (0.037)**	**0.846 (0.038)**	0.858 (0.037)	**0.846 (0.062)**	0.842 (0.028)	0.894 (0.058)	0.854 (0.046)	1.045 (0.061)
Expected High*	**0.659 (0.019)**	**0.668 (0.044)**	**0.499 (0.040)**	0.769 (0.041)	**0.446 (0.062)**	0.717 (0.037)	0.704 (0.070)	0.750 (0.058)	0.872 (0.092)

Notes: FI = fatal and injury; W = wet pavement; N = nighttime; WN = wet nighttime; LD = lane departure; **Bold** indicates statistically significant difference at 95 percent level.

*The following thresholds were used to categorize sites by the expected crashes before treatment: Total (<75, 75+), Injury (<20, 20+), Wet (<25, 25+), Night (<25, 25+), Night Wet (<8, 8+), Lane Departure (<40, 40+), Lane Departure Wet (<10, 10+), Lane Departure (<15,15+), Lane Departure Injury (10, 10+).

The disaggregate analysis also considered years after installation to determine if IPM effectiveness changed over time. The research team tested the results after one year and two years to determine if IPMs were initially more effective and then less effective over time. The results indicated no pattern or drop in effectiveness over the three-year after period.

Furthermore, the research team conducted supplemental analyses based on before-after EB changes in crashes on individual segments. The research team evaluated each segment to determine if there was a significant change in crash frequency (from before to after IPM installation) for each crash type. Many of the specific segments studied observed significant reductions in some or all crash types. However, only one site observed a significant increase in crashes after pavement resurfacing and installation of IPMs: I 64 EB: MP 26.524 to MP 27.745. This site should be examined further to determine why a statistically significant increase was found during the study period.

CHAPTER 3: SUMMARY AND CONCLUSIONS

3.1 MARKER PERFORMANCE

The first objective of this research was to assess IPM performance through a count of marker presence and a feedback survey from participants who viewed dry and wet night videos of the St Louis area IPM sections. As listed in Table 4 and shown graphically in Figure 4, marker presence does not exhibit an expected trend of increased missing marker percentages with time. The sections with the highest percentage of missing markers were only one year old, and most of the sections with the lowest percentage missing markers were two and three years old. A couple of the one-year old sections had a very high percentage of missing markers, which was likely due to an issue with installation. However, even excluding those two sections, there isn't the expected degradation in performance (increased missing markers) with age.

Unfortunately, there isn't sufficient information and too many variables to explain these results. The type of epoxy used to bond the markers to the pavement could have been different. Which type of markers, the Ennis-Flint cradle, the Marker One cradle, or a simple lens in the groove, is unknown. The weather condition at the time of installation is unknown, and because the sections were all installed at different times, they experienced different winters. Also, there's not sufficient data to make conclusions that the pavement surface type has an effect on the markers' ability to remain bonded to the pavement.

Ideally, to have better results and to observe trends, all three marker types would need to be placed on two test decks, one asphalt surfaced and one concrete surfaced, and then assessed every year for a period of years. With multiple assessment values over time, each marker type would have a performance curve or trend line. With a trend line, there could be an additional evaluation to assess a threshold percentage of missing markers to trigger maintenance, marker replacement.

The nighttime video visibility survey, however, had more useful and expected results, and the data from the marker presence assessment allowed for additional comparisons to be made in the visibility survey. The survey participants responses unanimously agree that the IPMs are more visible on wet nights than markings, and the IPMs' ability to provide guidance on lane delineation has much higher importance on a wet night than a dry night. The participants, who had no knowledge of which routes had the higher marker presence versus lower marker presence, consistently rated the visibility higher on the routes with the higher marker percentage. Also, the three oldest participants would prefer to see a minimum of three to four consecutive IPMs on a wet night. In summary, drivers and passengers traveling on a wet night feel that IPMs are important to the visibility of the roadway's lane lines.

3.2 CRASH MODIFICATION FACTOR

The second objective of this research was to perform a rigorous before-after evaluation of the safety effectiveness, as measured by crash frequency, of IPMs applied on Missouri freeway segments in St. Louis. The study used data from installation sites as well as nearby reference sites for a state-of-the-art EB before-after study. The data were used to examine the effects for specific crash types, including total, fatal and injury, wet pavement, nighttime, nighttime wet pavement, lane departure, wet pavement lane departure, nighttime lane departure, and fatal and injury lane departure. Based on the aggregate results in Table 13, IPMs, when installed with pavement resurfacing, significantly reduce all crash types examined. The recommended CMFs for IPM installation are included in Table 15.

Table 15. Aggregate CMFs for IPMs by Crash Type

Crash Type	EB estimate of crashes expected in the after period without strategy	Count of crashes observed in the after period	Estimate of CMF	Standard Error of CMF
Total	5,798	4,161	**0.72**	0.01
FI	1,510	1,185	**0.78**	0.03
W	1,209	868	**0.72**	0.03
N	1,341	1,052	**0.82**	0.03
WN	327	238	**0.72**	0.05
LD	2,419	1,936	**0.80**	0.02
LD W	577	480	**0.83**	0.05
LD N	920	753	**0.82**	0.04
LD FI	566	565	1.00	0.05

A disaggregate analysis of the results investigated additional factors associated with the safety performance of IPMs. The results suggested that IPMs may be more effective on segments with AADT greater than 70,000 vehicles per day three-directional lanes (compared to four directional lanes), and more expected crashes before treatment. The disaggregate analysis also sought to identify if IPMs were more effective initially with reduced effects over time, but there was no evidence supporting this. Further, the disaggregate analysis identified one location where total crashes increased significantly: I 64 EB: MP 26.524 to MP 27.745. This section should be examined further to determine what underlying factors are present and associated with this increase.

The resulting CMFs from this effort are directly applicable to IPM installations done in coordination with pavement resurfacing and are likely to be most applicable in these cases. Additionally, the results are applicable for urban and suburban freeways with three and four directional lanes. It is unclear if the CMFs hold up for longer than three years (the limit of this analysis) so caution should be exercised in extending the analysis results beyond this time period.

As noted in the aggregate analysis section, the CMFs for the naïve before-after analysis were consistent with intuition when considering target crash types, while those for the EB analysis were not. The largest changes between naïve analysis and EB analysis were for wet pavement, nighttime, and all subsets of lane departure crashes, which are those that are targeted specifically by the treatment. The changes from naïve analysis to EB analysis indicate that new pavement surfaces and associated markings likely also had an impact on those crash types. It is likely that the effects of pavement resurfacing, while accounted for in the analysis, have an overlap with IPM installation target crashes. Future studies should examine the effectiveness of IPM installations on all crash types when not installed as part of a pavement resurfacing project, unless the DOT intends only to apply this countermeasure as part of pavement resurfacing projects (when the pavement condition is least susceptible to issues from milling operations). Additionally, IPM installation and maintenance costs were not provided as part of this study. Future efforts should include total costs to estimate the benefit-cost ratio for this treatment.

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APPENDIX: NIGHTTIME VIDEO VISIBILITY SURVEY

MoDOT Inlaid Pavement Marker Performance Survey

Participant Demographics:

1. Gender (please circle response):   M   F

2. Age: __________

Survey Instructions:

To complete this survey, you will need to view a few videos and then respond to questions about what you saw. When viewing the videos, focus on the skip line immediately to the left of the vehicle that "you are in" and if present, also focus on the skip line immediately to the right of your vehicle. The questions that you'll be answering are related to the visibility of the inlaid pavement markers (IPMs) which are installed between every other skip dash. You will also need to pay attention to the visibility of the skip dash pavement markings. The survey questions will tell you specifically which videos you need to watch. All videos should be downloaded to your computer before viewing, and all videos can be found in one of the following two network folders:

Y:\Groups\Research\MoDOT Inlaid Pavement Marking Evaluation\06 Task 3 - Collect Field Data and Perform Analysis\Videos_Recorded with GoPro Camera\01_Dry Night Videos

Y:\Groups\Research\MoDOT Inlaid Pavement Marking Evaluation\06 Task 3 - Collect Field Data and Perform Analysis\Videos_Recorded with GoPro Camera\02_Wet Night Videos

Survey Questions:

1. Download the following two videos and watch the timeframe segment shown in parentheses:

   A. I270_03_NB_2_Dry_1 (0:30 – 4:00)
   B. US61_06_SB_2_Dry (Full Video: 0:00 – 3:28)

   For Video A, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1   2   3   4   5

   For Video B, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1   2   3   4   5

2. Download the following two videos and watch the timeframe segment shown in parentheses:

   A. I270_03_SB_2_Dry_1 (6:55 – 9:25)
   B. I270_03_SB_3_Wet_1 (6:30 – 9:00)

   For Video A, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video A, rate the visibility of the skip dash markings on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video B, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video B, rate the visibility of the skip dash markings on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

3. Download the following two videos and watch the timeframe segment shown in parentheses:

   A. US61_06_SB_2_Dry (Full Video: 0:00 – 3:28) **Note:** This video was used for Question 1
   B. US61_06_SB_2_Wet (Full Video: 0:00 – 3:15)

   For Video A, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video A, rate the visibility of the skip dash markings on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video B, rate the visibility of the IPMs on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

   For Video B, rate the visibility of the skip dash markings on a scale of 1 to 5, with 5 being "high visibility" and 1 being "low visibility". Circle your response below:

   1 2 3 4 5

4. Download the following two videos and watch the timeframe segment shown in parentheses:

   A. MO364_09_EB_2_Dry (Full Video: 0:00 – 1:02)
   B. MO364_09_EB_3_Wet (Full Video: 0:00 – 0:55)

   Using these videos and the videos from Question #2, if needed, answer the following questions:

   1) What is the minimum number of consecutive IPMs that you would prefer to see on a dry night? Circle your response:

      2 3 4

   2) What is the minimum number of consecutive IPMs that you would prefer to see on a wet night? Circle your response:

      2 3 4

5. On a scale of 1 to 5 (1 = Not Important, 5 = Very Important), how important are the IPMs on dry nights? Circle your response:

   1 2 3 4 5

6. On a scale of 1 to 5 (1 = Not Important, 5 = Very Important), how important are the IPMs on wet nights? Circle your response:

   1 2 3 4 5