Evaluating the Performance and Making Best Use of Passing Relief Lanes

Michigan Department of Transportation

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RESEARCH REPORT:

Evaluating the Performance and Making Best Use of Passing Relief Lanes

FINAL REPORT

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16. Abstract

This report documents the evaluation of the performance and safety effectiveness of passing relief lanes within the State of Michigan. The study began with the identification of passing relief lanes within Michigan. This was followed by collecting historical volume data, implementation dates and crash history for each of the 10 study sites as well as for the 100 reference sites and 231 passing lanes in the State. The analysis of the passing relief lanes within Michigan included a literature review, a best practices review and summary, an evaluation of the crash data via a naïve Empirical Bayes (EB) analysis and site visits to a select group of 10 passing relief lane study sites as determined by the study team. The site visits included speed data collection at a total of 50 locations; 5 locations for each passing relief lane study site. The analysis also found that the equivalent uniform annual benefit (EUAB) was less than 1.0; a cost analysis could not be conducted as no construction costs were available for the passing relief lanes. Based upon the results of the EB analysis, Crash Modification Factors (CMFs) were established to reflect the passing lanes in Michigan.

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Executive Summary

This report evaluated the performance and safety effectiveness of the passing relief lanes within Michigan. Crash data, historical traffic volumes, installation dates, and some geometric information were collected for analysis. In addition to collecting data on the 231 passing relief lanes found throughout Michigan, site visits were conducted at ten study sites in order to determine the safety benefits, if any, of passing relief lanes.

Speed data collected at five points along each of the study site passing relief lanes was used to determine the level of service (LOS) for each study site passing lane to evaluate how the passing relief lanes were operating. The results of this analysis are as follows:

Passing Relief Lane	County	Highway	Length (miles)	Level Of Service
178	Mackinac	US-2	2.9	A
179	Mackinac	US-2	1.0	A
73	Emmet	US-31	1.4	A
75	Emmet	US-31	1.1	A
102	Iosco	M-65	1.6	A
129	Isabella	M-20	1.3	A
145	Kalkaska	M-72	1.3	A
146	Kalkaska	M-72	2.1	A
226	Osceola	M-115	1.6	A
252	Wexford	M-55	2.1	A

The crash data was analyzed utilizing both a simple before-after analysis and the Empirical Bayes (EB) methodology. The purpose of the simple before and after methodology was to analyze the data from a high level, providing trends and an overview of the data. The EB analysis was used to conduct a more in depth before-after analysis that was utilized to evaluate the effect that the passing relief lane installation had on the highway segment.

The EB analysis was utilized to develop Crash Modification Factors (CMFs). The results of the EB analysis can be seen on the following page:

Crash Type	CMF
Non-animal Non-intersection Total crashes/mile-year	0.67
Non-animal Non-intersection Injury crashes/mile-year	0.71[1]
Non-animal Non-intersection Target crashes/mile-year	0.53
Non-animal Non-intersection Day crashes/mile-year	0.60
Non-animal Non-intersection Night crashes/mile-year	0.91[1]
Non-animal Non-intersection Wet crashes/mile-year	0.81[1]
Non-animal Non-intersection Dry crashes/mile-year	0.53
Non-animal Non-intersection Peak crashes/mile-year	0.54
Non-animal Non-intersection Off-Peak crashes/mile-year	0.72[1]

Note: CMF has a low confidence level.

1.0 Introduction

1.1 BACKGROUND INFORMATION

Though the volume of traffic on many of Michigan's rural trunkline roads is decreasing, there are increased concerns associated with travel time delay and driver frustration. These factors contribute to drivers taking unnecessary risks while overtaking other vehicles. Increased risk taking often results in increased crashes (e.g. head-on and overtaking). Limited sight distance, increasing traffic volumes, and restricted passing opportunities on many rural two lane roadways may compound these problems. All of these issues increase the need for more passing relief lanes. The modern Passing Relief Lane can help to alleviate many of these issues.

1.2 SCOPE AND STUDY OBJECTIVES

The objectives of this study were to determine the safety and operational impacts of passing relief lanes on state trunklines in Michigan. A secondary objective was to apply the results to provide guidance to the Michigan Department of Transportation (MDOT) and their Office of Research and Best Practices (ORBP) to make informed decisions for effective future deployments of passing relief lanes. Elaboration of our understanding of each objective follows.

Objective 1: Evaluate the safety performance of designs and operations of passing relief lanes in Michigan

Meeting this objective would require undertaking a statistically rigorous observational before-after study that placed some special requirements on the data collection and analysis tasks. These requirements were:

- The need to acquire a large enough sample size to detect, with statistical significance, what may be small changes in safety for some geometric configuration and site characteristic subsets.
- The need to properly account for traffic volume changes that will result directly from this treatment and from natural temporal fluctuations.
- The need to properly account for other factors affecting crash frequencies not associated with passing relief lane construction, such as weather and other road safety programs.
- The need to properly account for the possible effects of regression to the mean (RTM) that may result from sites with high collision frequencies being directly or indirectly selected for installation of passing relief lanes. (Improving sites with high collision frequencies is sound engineering practice, but research has conclusively shown that RTM effects are non-trivial and, if not accounted for, can cause treatment effects to be significantly overestimated.)

Objective 2: Assess the effectiveness of current designs to reduce delays

Utilizing the Road Safety Audit (RSA) methodology and the Highway Capacity Manual, our team will conduct a multi-disciplinary evaluation of the current geometric designs of passing lanes in Michigan. This will include collecting human factors data as well as surrogate data including speeds and lane position.

Objective 3: Use modeling to determine the before-after impacts of passing relief lanes on traffic characteristics

Per our contract with the Michigan Department of Transportation, we intended to employ the Interactive Highway Safety Design Model's (IHSDM) traffic analysis module to determine the impacts of passing relief lanes on traffic characteristics. Unfortunately, after further review, we were unable to evaluate the study sites using the IHSDM module. The IHSDM Module, TWOPAS, is the microscopic traffic simulation model used to develop the two-lane highway chapter of the Transportation Research Board's (TRB) *Highway Capacity Manual* (HCM). For the purposes of this analysis, TWOPAS could not be utilized. As an alternative, we have determined the level of service of each passing relief lane study site using the Highway Capacity Manual methodology[1].

Objective 4 (Implied): Develop guidelines for future deployments

The results from this study will be evaluated for inclusion in future projects.

1.3 METHODOLOGY

To accomplish the objectives of the study, six phases were developed. The six phases are presented in the following sections.

Phase 1 – Literature Review

Task 1.1: Conduct Initial Meeting

In this task the project team, along with relevant MDOT and Federal Highway Administration (FHWA) staff, held an initial meeting in order to discuss contractual obligations, work plan, deliverables, project milestones, schedules and appropriate procedures and policies.

Task 1.2: Literature Review

The project team conducted a literature review related to the implementation of passing relief lanes. Industry-standard reference guides, recent conference proceedings, journal publications, the internet, libraries, and discussions with various road agency staff were included in the

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[1] *Highway Capacity Manual*. Transportation Research Board, Washington, D.C.. 2010. ISBN 0-309-06681-6

search. The project team attempted to find out why there was a need for the implementation of each passing relief lane, as well as when, where and how it was successfully applied.

Task 1.3: Best Practices Review

The project team also investigated best practices related to passing relief lanes (including indirectly related issues, such as operations, geometric design, maintenance, guidelines, and/or strategies). The best practices were reviewed for other state departments of transportation as well as county and municipal road agencies which the project team has relationships with and those agencies have the reputation for being "progressive" in the area of implementing passing relief lanes. The project team compared the guidelines and best practices that are documented during Task 1.2 and Task 1.3 to existing MDOT practices.

Phase 2 – Field Test Design and Site Selection

Task 2.1: Identify Segments

During this task, the project team prepared the criteria and rationale for the identification of segments to evaluate. The project team contacted MDOT Region and various Transportation Service Center (TSC) traffic engineers to determine if any passing relief lanes have been completed in their regions. Additionally, various cities and country road commissions around the state were contacted to determine if any passing relief lanes have been applied on their roadways. All of the information collected was verified using web aerial photographs from agencies such as Metropolitan Planning Organizations (MPOs) and Regional Planning Organizations (RPOs). This information was used to prepare the final list of segments that were evaluated as part of this project.

Task 2.2: Data Requirements

In this task the project team prepared a list of data requirements. The following data requirements were used in the evaluation:

- Crash data at target segment, before/after implementation
- Crash data as a group of similar non-target segments, before/after implementation
- Traffic volume at the target segments, before/after implementation
- Traffic volume at a group of similar non-target segments, before/after implementation
- Geometric and operational characteristics of the target segments.
- Geometric and operational characteristics of similar non-target segments
- Implementation dates
- Photos of locations, before/after implementation

Target segments included those areas with passing relief lanes in addition to sections of roadway within the influence area one mile upstream and downstream. These additional locations were analyzed to look for possible crash mitigation or spillover effects at adjacent locations.

Task 2.3: Safety Analysis Data Collection – Target Segments

The project team worked with the MDOT Regions and TSCs to collect crash and traffic information as well as information on geometry and speeds. Traffic volume data was collected from online resources. Speed studies to determine 85th percentile speeds along the approaching roadways were also conducted for a limited number of locations for which detailed site visits were conducted.

Task 2.4: Safety Analysis Data Collection – Reference Group

The project team collected data for 100 unrelated reference sites for use in the development of safety performance functions (SPFs) required for the Empirical Bayes (EB) evaluation. Crash data was assembled from the Michigan State Police crash database and all other traffic count data was collected from various online resources.

Task 2.5: Data Collection - Operational

The project team was unable to use the proposed TWOPAS microscopic computer model due to limitations in its functionality. The Highway Capacity Manual was used as an alternative means of determining the Level of Service (LOS).

Phase 3 –Testing

Task 3.1: Site Observations

The study team, including a senior road safety expert, visited each of the detailed site visit sites during some or all of the peak traffic periods. The team performed drive-through evaluations and collected notes for each site. Human factors analyses were conducted to assess road users' needs for navigating the study sites as well as to assess the probable causes of collisions, which were then reviewed against the actual collision trends. While on site the team reviewed driver behavior and noted the current operations.

The raw speed study data can be found in the appedicies of this report.

The team collected the following data at each of the 10 study sites:

- 85th percentile speeds at five locations:
    - 1 mile upstream of the start of the passing relief lane
    - At the start of the passing relief lane
    - Midway through the passing relief lane
    - At the end of the passing relief lane
    - 1 mile downstream from the end of the passing relief lane

- Lane Occupancy (How many vehicles, by which were, are using each lane.)
- Traffic conflicts at the merge points.

Phase 4 – Analysis and Recommendations

Task 4.1: Development of Safety Performance Functions for Sites with and without Passing Relief Lanes

Fundamental to the state of the art EB approach, SPFs were applied to represent the conditions before passing relief lane construction. These SPFs related crashes of different types and severities to traffic flow and other relevant factors, with appropriate adjustments for temporal effects. This enabled the simultaneous accounting for temporal and possible regression-to-mean effects, as well as those related to changes in traffic volume. Generalized Linear Modeling was used to estimate these functions. This approach allowed for the specification of a negative binomial error structure, known to be more appropriate for crash modeling than the normal distribution assumed in conventional regression analysis. In addition, the negative binomial dispersion parameter calibrated in the process is fundamental to the EB methodology.

There were few sites eligible for the before after analysis because the passing lane conversion dates were unknown or occurred prior to the study period. Because of this fact a cross-sectional analysis was undertaken. In this analysis data for with and without passing lane sites were combined and a factor modeled to indicate what impact the presence of a passing lane has on expected crash frequencies.

Task 4.2: Empirical Bayes Analysis to Develop Crash Modification Factors

The EB methodology was used to conduct the before-after study. In the EB evaluation of the effect of a treatment, the change in safety for a given crash type at a treated location is given by:

Equation 1: Change in Safety

$$B-A$$

Where B is the expected number of crashes that would have occurred in the “after” period without the treatment and A is the number of reported crashes in the after period.

Because of changes in safety that may result from changes in traffic volume, from regression-to-the-mean, and from trends in crash reporting and other factors, the count of crashes before a treatment by itself is not a good estimate of B – a reality that has now gained common acceptance. Instead, B is estimated from an EB procedure in which a safety performance function (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 a treatment site being analyzed. The sum of these annual SPF estimates (P) is then combined with the count of crashes (*x*) in the before period at the treatment site to obtain an estimate of the expected number of crashes (*m*) before the treatment. This estimate of m is:

Equation 2: Expected Number of Crashes

$m=wP+(1-w)x$

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

The weight *w* is estimated as:

Equation 3: Weight Estimate

$w=1/(1+kP)$

Where

$$w_{1,2} = \frac{1}{1 + kP}$$

such that; k is the over-dispersion parameter of the negative binomial distribution that is assumed for the crash counts used in estimating the SPF. The value of k is estimated from the SPF calibration process with the use of a maximum likelihood procedure.

A factor was then applied to *m* from Equation 2 to account for the length of the after period and differences in traffic volumes between the before and after periods. This factor 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 *B*. The procedure also produces an estimate of the variance of *B*, the expected number of crashes that would have occurred in the after period without the treatment.

The estimate of B was then summed over all sites in a treatment group of interest (all treatment sites, or subsets disaggregated by traffic volume or other variables of interest) (to obtain B_{sum}) and compared with the count of crashes during the after period in that group (A_{sum}). The variance of *B* is also summed over all sections in the group of interest. The index of safety effectiveness (θ) is estimated as:

Equation 4: Index of Safety Effectiveness

$\theta = (A_{sum}/B_{sum}) / \{1 + [Var(B_{sum})/B_{sum}^2]\}$

$$\theta = \frac{\frac{A_{sum}}{B_{sum}}}{1 + \frac{Var(B_{sum})}{{B_{sum}}^2}}$$

The standard deviation of θ is given by:

Equation 5: Standard Deviation

$$Stddev(\theta) = [\theta^2\{[Var(A_{sum})/A_{sum}{}^2] + [Var(B_{sum})/B_{sum}{}^2]\} / [1 + Var(B_{sum})/B_{sum}{}^2]^2]^{0.5}$$

$$Stdev(\theta) = \sqrt{\theta^2 * \frac{\frac{Var(A_{sum})}{A_{sum}{}^2} + \frac{Var(B_{sum})}{B_{sum}{}^2}}{\left(1 + \frac{Var(B_{sum})}{B_{sum}{}^2}\right)^2}}$$

The percent change in crashes is in fact $100(1 - \theta)$; thus a value of $\theta = 0.7$ with a standard deviation of 0.12 indicates a 30 percent reduction in crashes with a standard deviation of 12%.

In addition to the EB before-after analysis a naïve before-after analysis was performed as a was requested by MDOT. In a naïve analysis there is no correction for regression-to-the-mean or time trends in crash counts.

Task 4.3: Determine Migration and Spillover Effect

The methodology described above was applied to adjacent non-treated sites one mile upstream and downstream of the passing relief lane segment to examine the possible migration or spillover effect.

Task 4.4: Economic Analysis

The change in safety for each site may be estimated by Equation 1 and then applied to estimate crash cost benefits in an economic analysis of the passing relief lane installation to assess the cost-effectiveness of the program to date. First these crash changes are summed over all sites and an annual value calculated by dividing this sum by the total number of after period site years in the data. FHWA unit comprehensive crash costs are then applied to estimate an annual dollar benefit that can be compared to an annual program cost that includes the capital costs converted to an annual value using estimated service life and discount rate derived from consultation with MDOT. In this procedure, crashes were disaggregated by crash type and severity to the extent possible, and unit crash costs for those types and severities applied before aggregating to obtain an overall crash cost savings. Operational data, such as the reduction in delay, is also included in the economic analysis.

Task 4.5: Operational Impacts of Passing Relief Lanes

Operational impacts of the passing relief lane sites were determined using the Highway Capacity Manual (HCM) to determine the Level of Service (LOS) of each study site. If traffic volume or geometric data was unavailable for the before period, the project team compared the treatment segments to nearby control sites.

Task 4.6: Develop Guidance for Future Application

Based on the information outlined in the earlier tasks, guidelines have been developed for potential Passing Lane Relief projects. Sites that meet these criteria are expected to be most successful in terms of ease of implementation, maintaining corridor function and improving safety.

2.0 Literature Review

2.1 BACKGROUND INFORMATION

The purpose of a passing relief lane on a two-lane rural highway is to reduce traffic delays, improve the overall performance of traffic operations, to reduce driver frustration and to improve the safety by providing assured passing opportunities.

2.2 STUDY OBJECTIVES

The purpose of this literature review was to analyze existing research and best practices used by various road agencies in the field of passing relief lane effectiveness in the various aspects of transportation. This review analyzed the effect of passing relief lanes with respect to:

- Safety impacts;
- Operational impacts;
- Speeds;
- Pedestrian, bicyclist and driver behavior;
- Traffic control devices; and
- Access management.

A literature review was conducted to assess documented benefits of passing relief lanes and to determine the state-of-the-art of their design, location, and signing.

2.3 SAFETY

Previous studies have shown that passing relief lanes can improve both the Level-of-Service (LOS) and safety of two-lane highways (Emoto and May 1988; Harwood and St. John 1985; Morall and Blight 1984; Staba et al. 1991; Taylor and Jain 1991).

The effect of passing relief lanes on safety can be measured by before-and-after comparison of crash history, in a comparison with similar sections without passing relief lanes, or a combination of these two methods.

2.3.1 Crash History

A comparison study of the crash histories of Germany and Canada published by the TRB found that, compared to a two-lane highway, the crash rate and the crash severity distribution for both fatal and injury related crashes were less for two-lane highways with passing relief lanes (Frost and Morall 1998).

A study performed by the Midwest Research Institute found that the non-intersection crash frequency per mile per year within passing relief lane sections on two-lane highways ranges from 12 to 24 percent lower than for conventional two-lane highway sections (Potts and Harwood). The range is dependent on the level of ADT with larger differences in crash rate at increasing levels of ADT.

2.3.2 Traffic Conflicts

Providing a passing relief lane on a two-lane highway creates two distinct conflict points, 1) at the lane-addition and 2) at the lane-drop. The presence of these two conflict points may reduce the overall safety of the passing relief lane section.

Research performed by Harwood and St. John found no indication in the crash data of a safety problem in the lane addition or lane drop transition areas of passing relief lanes. Additionally, in-field studies of traffic conflicts and evasive maneuvers at the lane add/drop points of ten separate passing relief lane sites were found to operate smoothly. They found that 1.3 percent of the vehicles passing through the lane drop area created a conflict while the rate of evasive maneuvers were 0.4 and 0.3 percent for centerline and shoulder encroachments, respectively. The traffic conflict and encroachment rates observed at lane add/drop locations in passing relief lanes were significantly smaller than the rates found at other locations (without passing relief lanes), such as work zones.

2.4 OPERATIONAL PERFORMANCE MEASURES

Several studies have evaluated the effectiveness of passing lanes using percent time spent following, speed, and passing rates as major measures of effectiveness (Potts and Harwood). Percent time spent following, speed and capacity utilization are used by the Highway Capacity Manual (HCM) (TRB 2010) to define Level-of-Service (LOS) for a rural two-lane highway. Other measures of effectiveness may include but are not limited to;

- Percent vehicles in a platoon;
- User opinion;
- Lane utilization, and;
- Time headway.

The effectiveness of passing relief lanes may be evaluated in two ways: 1) an evaluation to compare the effectiveness of the passing relief lane to a standard two-lane highway, and 2) an evaluation to measure the effect of different passing relief lane elements (geometry, signing, and marking).

2.4.1 Passing Rates

The primary objective of a passing relief lane is to increase the opportunity for a vehicle to pass a slower, moving vehicle. The HCM (TRB 2010) uses percent time delay as a primary criterion when evaluating the Level-of-Service on two-lane highways. The percent time delay depends on the availability of passing opportunities in both directions. Passing demands in one direction of travel depends on traffic characteristics in that direction.

A before/after study performed by the Missouri Department of Transportation showed that for two of the three highways evaluated, the level of service improved when passing relief lanes were installed. Table 2-1 illustrates their findings.

Table 2-1 Missouri Department of Transportation Findings

Highway	LOS **WITHOUT** Passing Relief Lane	LOS **WITH** Passing Relief Lane
US-54	LOS B	LOS B
MO-13	LOS D	LOS B
US-60	LOS C	LOS A

Shoulder Use

Roadway sections with wide, paved shoulders may be used as informal passing relief lanes when slower drivers pull to the shoulder allowing faster vehicles to pass them. In their Canadian study, Morrall and Blight (1984) noted that some slower drivers will pull to a shoulder (10 feet, paved) to let a faster vehicles pass them. However, they noticed that this gesture was usually limited to low volume conditions. At higher volumes, drivers may be reluctant to pull to the shoulders due to the difficulty of reentering the main stream.

2.4.2 Speed

Speed and capacity utilization are used as secondary measures in defining LOS for a two-lane rural highway in the HCM procedures (TRB 2010). Percent time delay is used as a primary measure. The speed used is the average travel speed, which may also be called the “space mean speed”. This speed is calculated by taking the length of the highway segment under consideration and dividing by the travel time of all vehicles traversing the segment in both directions.

Harwood and St. John (1985) showed that the mean speeds upstream, within, and downstream of a passing relief lane were only slightly affected by the presence of a passing relief lane. The difference in mean speed (downstream location speed minus upstream location speed) varied between a high of +8.3 mph or as low as -6.7 mph. The researchers concluded that spot speed was more influenced by the local geometry at upstream and downstream sites than by the presence of a passing relief lane.

2.4.3 Percent Time Delay and Percent of Vehicles in Platoons

The HCM (TRB 2010) defines percent time delay as the average percent of time that all vehicles traveling in platoons are delayed due to the inability to pass. In determining the LOS of a two-lane highway by HCM procedures, percent time delay is used as a primary measure.

An evaluation of three existing passing relief lane sites on Missouri NHS routes found that those passing relief lanes improve percent time spent following on those roads by 10 to 31 percent in comparison to a conventional two-lane highway without passing relief lanes (Potts and Harwood).

2.4.4 Lane Utilization

In segments where a passing relief lane is provided, the outer lane (right lane) is supposed to be used by slow-moving vehicles, leaving the inner lane (left lane) for passing vehicles. The volume of vehicles in the left lane may reflect the passing activity within the section. Thus, lane utilization may be considered an indirect measure of passing rates. This assumes that motorists both understand and follow the desired method of lane use.

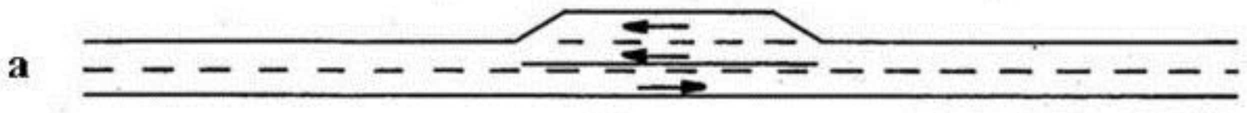
Fong and Rooney (1990), who conducted an extensive study of 20 passing relief lanes in California, found that lane proper lane utilization is highly dependent on the type of passing relief lane and the pavement markings.

2.5 GEOMETRIC FEATURES OF A PASSING RELIEF LANE

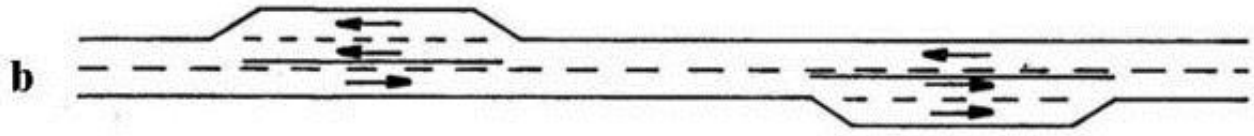
There exist a number of ways to configure passing relief lane segments, many of which can be found in:

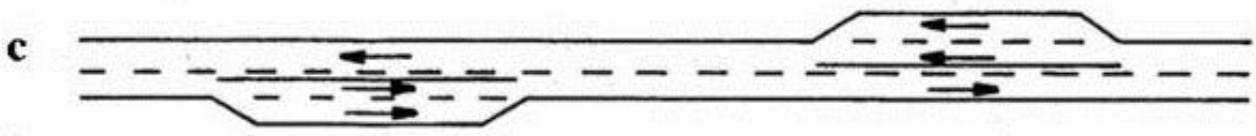
Table 2-2 Possible Passing Relief Lane Configurations

Isolated Passing Relief Lane

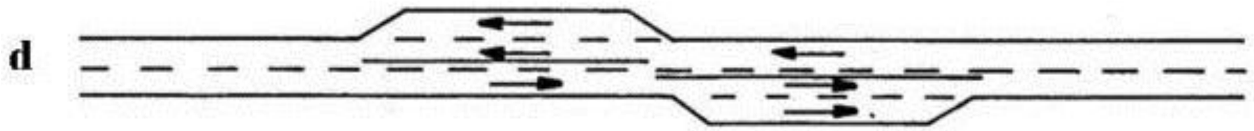


Intermittent Passing Relief Lanes, Separated



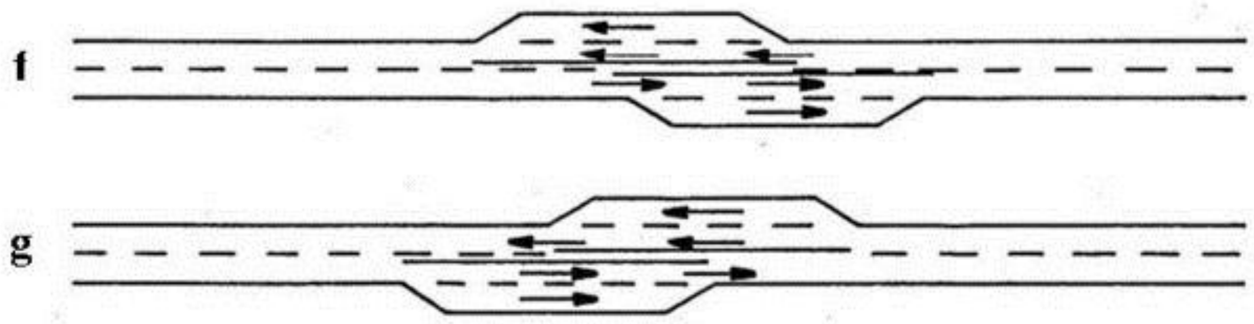


Intermittent Passing Relief Lanes, Joined Tail to Tail

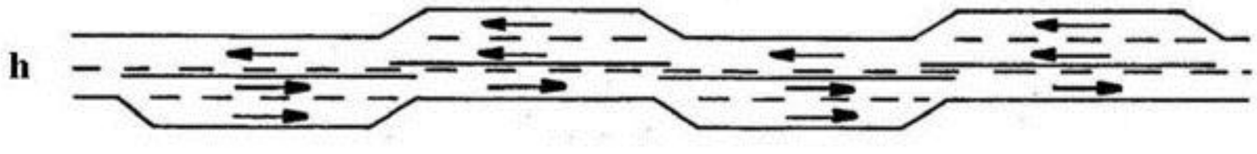


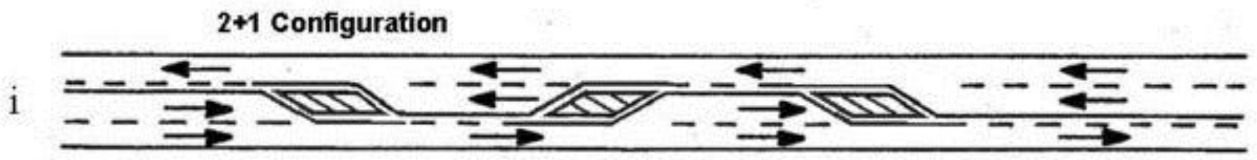
Intermittent Passing Relief Lanes, Joined Head to Head

Intermittent Passing Relief Lanes, Overlapping



Continuous Passing Relief Lanes





Short Four Lane Section

Source: Missouri DOT Engineering Policy Guide

Passing relief lane geometric features are comprised of horizontal alignment, vertical alignment, lane and taper lengths, cross-section and shoulder width.

2.5.1 Location

The Michigan Department of Transportation Geometric Design Unit's guidelines Traffic and *Safety Note 606B* suggests that a passing relief lane be installed in the following areas:

1. An area that can accommodate four lanes (passing relief lanes for each direction of traffic) so that the amount of three-lane sections in minimized.

2. With rolling terrain where vertical grades (even though not considered “critical grades”) are present to enhance:
    a. Visibility to readily perceive both a lane addition and a lane-drop.
    b. Differential in speed between slow and fast traffic. This occurs on upgrade location and produces increased passing opportunities.
3. Relatively free of commercial and/or residential development (driveways) and away from major intersections.
4. Where horizontal curvature does not exceed three degrees. (Metric: Where the radius, R, of the horizontal curve is greater than or equal to 580m.)
5. With no restrictions in width resulting from bridges or major culverts unless structure widening is done in conjunction with the passing relief lane construction.
6. That are farther than 705 feet (230 m) from a railroad crossing.
7. Where directional spacing of approximately five miles (8 km) can be maintained.

These guidelines are intended to provide safe opportunities to pass slower vehicles.

2.5.2 Length

The study conducted by Harwood and Hoban (1987) offered that the optimum length (excluding the tapers) of a passing relief lane is between 0.5 and 1.0 miles. The researchers stated that lengths of more than 1.0 mile are usually not cost effective, and that lengths shorter than .5 miles do not create enough passing opportunities.

A study from Arkansas showed that fewer drivers would attempt to use shorter passing relief lanes (lanes no longer than .47 miles). It was suggested that this may be a result of the drivers’ perception of inadequate distance to complete the passing maneuver (Gattis et. al. 1997).

2.5.3 Lane-Addition/Reduction

The lane-drop may be the most critical element of a passing relief lane segment from both operational and safety standpoints. The lane-drop is the section where the two lanes in one direction converge into one lane. In regard to traffic operations, a lane-drop may act like a bottleneck. The traffic stream, which was a two lane section, is forced to merge into one lane. Merging is likely to the left, where slower vehicles in the outer lane being terminated merge to the inside lane. With regard to safety, the mode of terminating the right lane, a slower merging vehicle has to estimate and choose a suitable gap in the adjacent stream to merge safely. This maneuver has the potential to produce a “race track” phenomenon wherein the merging slower vehicle increases its speed to merge with faster passing vehicles, while the passing vehicle increases its speed to avoid ending up behind the slower vehicle after the passing relief lane section.

If a lane-addition is not properly designed, marked, and signed, the result may degrade operation and safety of the passing relief lane. Most design guidelines recommend that taper lengths for lane-additions be shorter than those for lane-drop.

2.6 SIGNING AND MARKINGS

Signing is intended to enhance the drivers understanding of the intended use of the roadway. Choosing a signing system that accomplishes this goal enhances the operation of a passing relief lane by informing the driver of the intended use of the passing relief lane and the upcoming opportunities to pass. Signing associated with passing relief lanes is usually provided in six distinct places within a passing relief lane system: 1) in advance of the passing relief lane, 2) at the lane addition 3,) in advance of the lane-drop, 4) at the lane-drop, 5) the end of a passing relief lane, and; 6) in the opposing direction of the passing relief lane. Figure 2-1 illustrates the suggested signing locations.

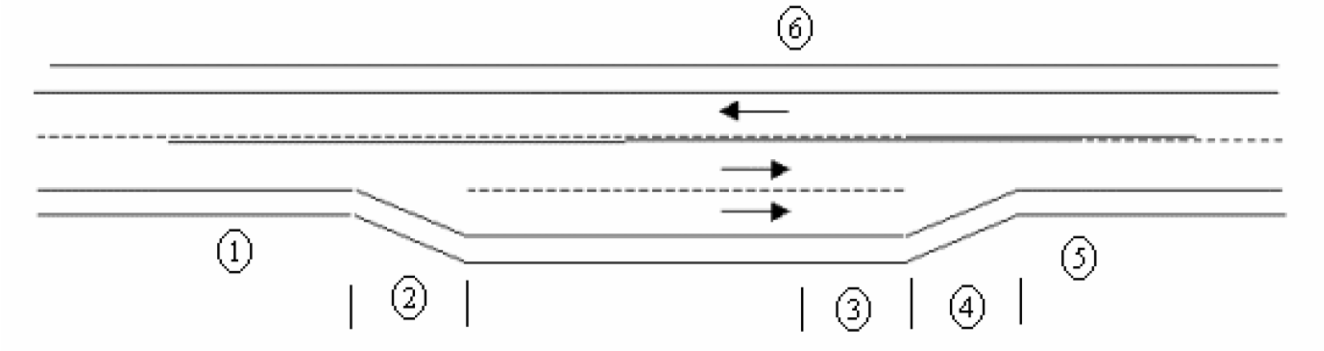


Figure 2-1 Passing Relief Lane Signing Locations[2]

2.6.1 Advance Signing

A passing relief lane is most effective in dispersing platoons if it is located at the downstream of a low passing-opportunity section. However, drivers being delayed in platoons for a considerable time due to their inability to pass may become frustrated and perform risky passing maneuvers in front of opposing traffic. Informing such drivers of the presence of an upcoming passing relief lane may reduce such incidents. Signs informing motorists of the distance to the beginning of the passing relief lane serves this purpose. These signs should be located where they will remind motorists of a passing relief lane ahead, thereby possibly reduce risk-taking, passing behavior.

2.6.2 Lane-Addition Signing and Marking

At the beginning of the passing relief lane, drivers are normally reminded of the lane assignments; e.g., slower drivers should use the outside lane. Some agencies remind motorists with the **SLOWER TRAFFIC KEEP RIGHT** (R4-3) sign, while other agencies may use a **KEEP RIGHT EXCEPT TO PASS** sign (R4-16). Channeling traffic to the outer lane is highly recommended because slower vehicles tend to flow naturally to the outer lane. Pavement markings and signs indicate to slower drivers to keep right to allow for faster moving vehicles to pass them on the left. At the end of the passing lane, pavement markings at the taper indicated to drivers that they should merge back into the normal roadway cross section.

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[2] http://tti.tamu.edu/documents/4064-1.pdf

Per the 2009 MUTCD (Section 2B.30, Guidance), the **SLOWER TRAFFIC KEEP RIGHT** sign should be installed just beyond the beginning of a multi-lane pavement, if used. Section 2B.31, Guidance, notes that "if an extra lane has been provided for trucks and other slow-moving traffic, a **SLOWER TRAFFIC KEEP RIGHT** (R4-3) sign, **TRUCKS USE RIGHT LANE** (R4-5) sign, or other appropriate sign should be installed at the beginning of the lane.

Fong and Rooney (1990), found in an evaluation of ten passing relief lanes without channelization, that 36 percent of the total vehicles, including 6.4 percent of platoon leaders, and 57.7 percent of the followers were in the inner lane. For those sites with channelization, 22 percent, 4.9 percent, and 47 percent, respectively; and as such, more vehicles were "channeled" to the outer lane, creating greater passing opportunities.

2.6.3 Lane-Drop Signing and Marking

Where the lane is dropped at the end of a passing relief lane section, some agencies use only one sign to alert motorists to this, while other agencies use a combination of signs. (Morall et. al. 1984). Those who use one sign, use a symbolic lane reduction, transition sign (W4-2) as defined in MUTCD (FHWA 2009) near or at the beginning of the lane-drop taper. For those who prefer two signs, the first, with wording such as **RIGHT LANE ENDS** (W9-1) serves as an advance notification sign upstream from the merging area, while the second, symbolic sign (W4-2) serves to inform motorists of the location where the lane-drop taper begins. This is consistent with the guidance provided in Section 2C.42 of the MUTCD.

2.6.4 Opposing Lane Signing and Marking

Within the length of the passing relief lane section, passing in the opposing direction can be allowed or restricted. Signing and marking for traffic approaching from the opposite direction has to reflect the restriction or permission. It is recommended that where passing is allowed, signing must clearly show the priority of the opposing, passing relief lane for traffic in the passing lane direction.

Examples of appropriate passing relief lane signing and pavement markings from the Michigan Department of Transportation Traffic Signs Unit can be seen in Figures 2.2 and 2.3.

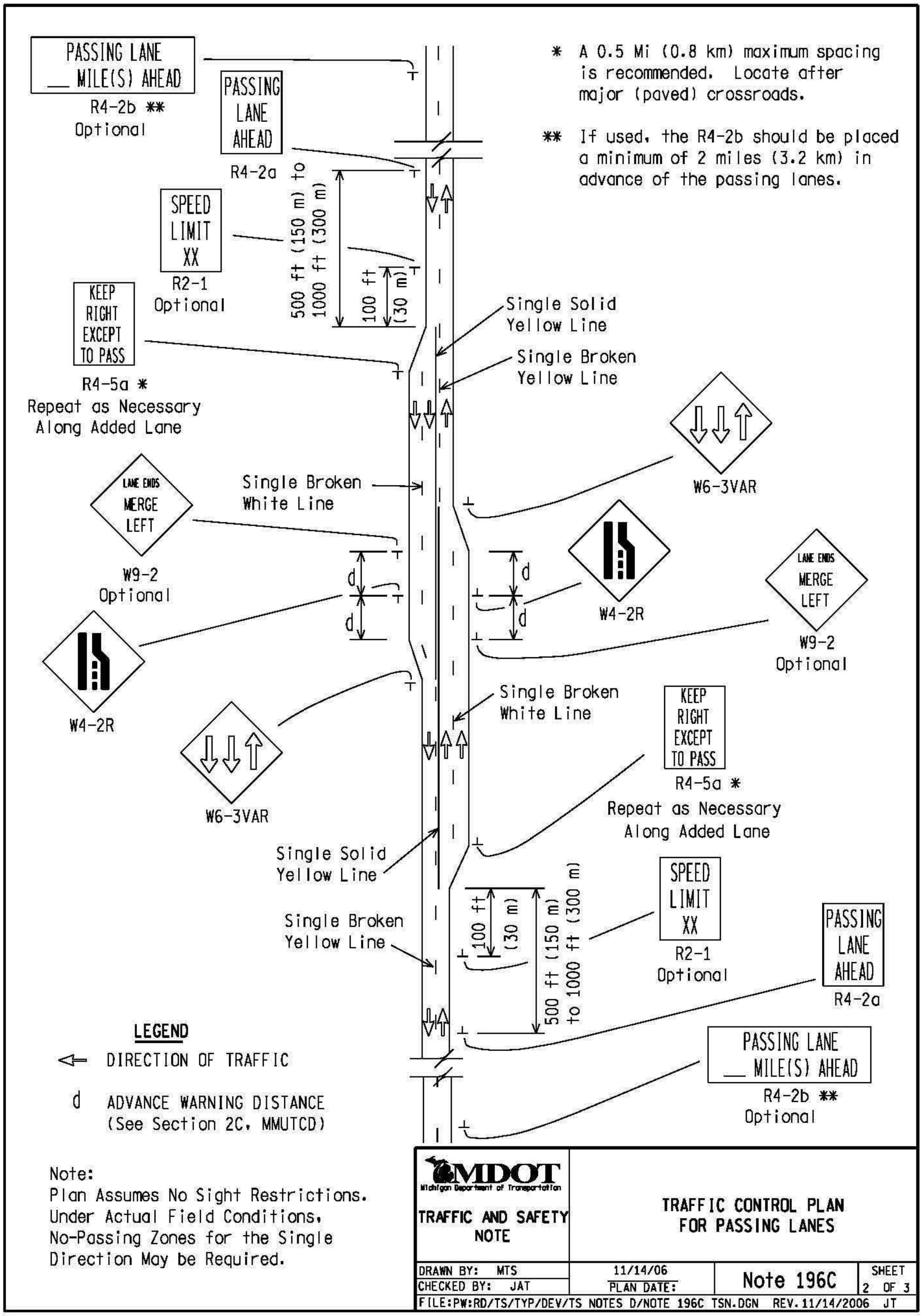


Figure 2-2 Passing Relief Lane Signing Example 1

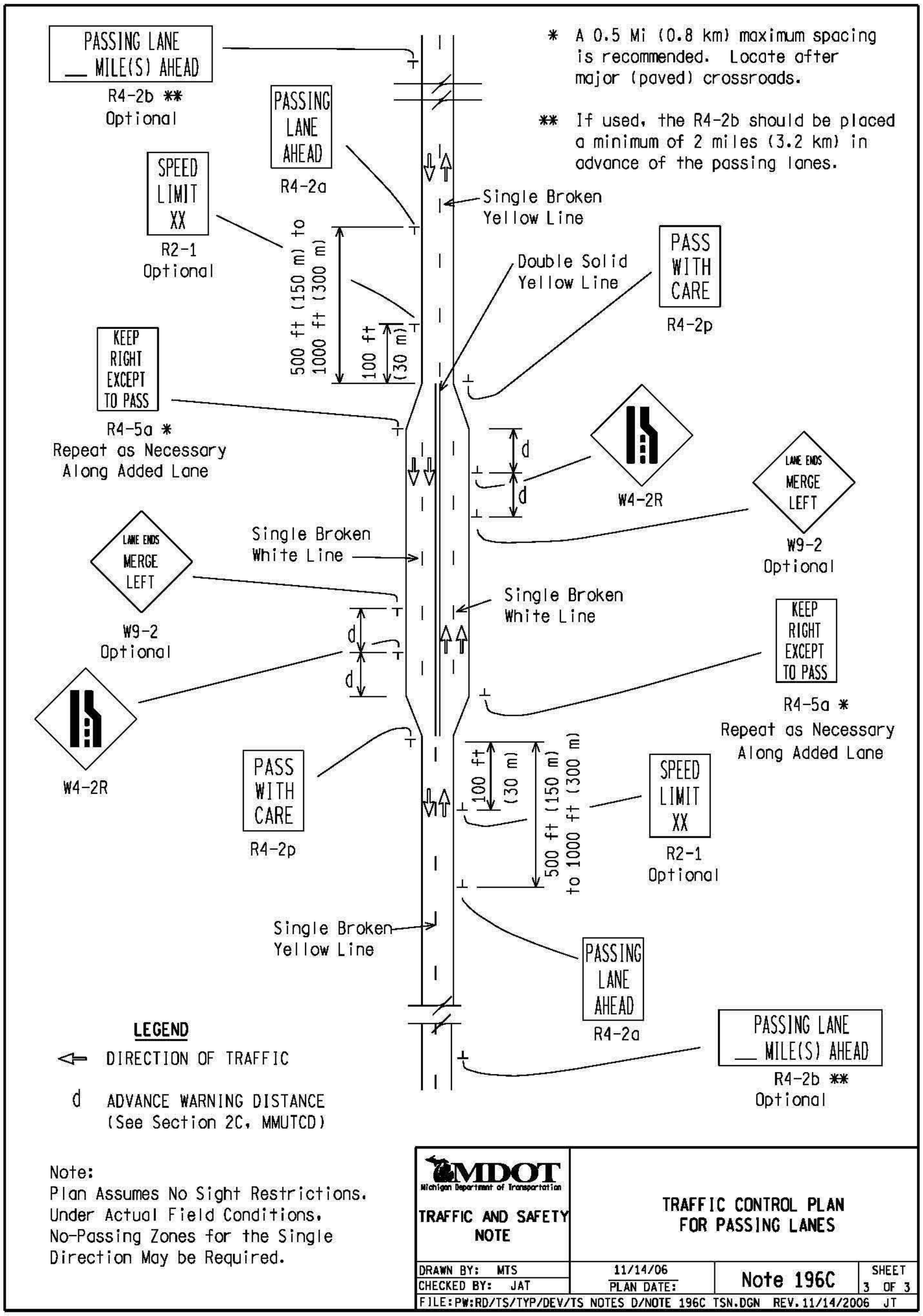


Figure 2-3 Passing Relief Lane Signing Example 2

3.0 Literature Review Summary

Current MDOT guidance related to passing relief lanes is primarily included in MDOT's *Road Design Manual* as well as in their *Standards and Special Details*. As passing relief lanes have been in use for a significant amount of time, few new developments have been made related to best practices in passing relief lane development or use. As part of the MDOT Passing Relief Lane Study, numerous guides, reports, scholarly research articles, and studies were reviewed to identify best practices being used by FHWA, other State Highway Agencies, and municipalities. The presence of the following best practices should be verified in applicable MDOT guidance and policies. The practices noted below are described in general terms and do not include specific details.

1. Verify that the policies and guidance found in the Michigan Department of Transportation's *Road Design Manual* is consistent with the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD). It is recommended that a thorough evaluation be conducted to ascertain all areas where updates are needed.

2. Verify the existence of standard typical drawings for common passing relief lane design configurations. This will help standardize certain design elements and encourage consistency in plan sets where appropriate.

3. Require MDOT's Local Agency Program projects to follow all aspects of FHWA and MDOT policies and guidance.

4. Require uniform data recording and reporting in passing relief lane installation to be provided to MDOT. Useful information could be used in future modeling and analyses. This information could include:

    - Standard location reporting in the form of coordinates;
    - Installation dates;
    - Cost;
    - Geometric design details; and,
    - Traffic volume data.

4.0 Field Data Collection

This section discusses how the passing relief lanes were identified and the data collected during the site visits. The data collected included speed, geometric, and operational data.

4.1 IDENTIFY PASSING RELIEF LANES

At the onset of the project, the project team worked with the Research Advisory Panel (RAP) to develop a list of passing relief lanes to be evaluated. The project team contacted MDOT Region and TSC traffic engineers to determine if any passing relief lanes have been completed in their regions. A total of 237 passing relief lanes were identified within Michigan.

Of the 237 passing relief lanes ten were selected to be included in the field data collection and empirical Bayes before-after study. The remaining 227 passing lanes were evaluated as part of the cross-sectional analysis presented in Section Six of this report.

Table 4-1 summarizes the ten passing relief lanes that were selected for the final analysis along with information about the county they are in, type, and the surrounding environment. The LRS ID is a unique identifier provided by MDOT.

Table 4-1: Passing Relief Lanes Selected for Final Analysis

LRS ID	County	Highway	Length (miles)	Type
178	Mackinac	US-2	2.9	Partial Overlap
179	Mackinac	US-2	1.0	Partial Overlap
73	Emmet	US-31	1.4	4-lane section (both the same size)
75	Emmet	US-31	1.1	Partial Overlap
102	Iosco	M-65	1.6	4-lane section (both the same size)
129	Isabella	M-20	1.3	4-lane section (both the same size)
145	Kalkaska	M-72	1.3	No Overlap
146	Kalkaska	M-72	2.1	Partial Overlap
226	Osceola	M-115	1.6	Partial Overlap
252	Wexford	M-55	2.1	Partial Overlap

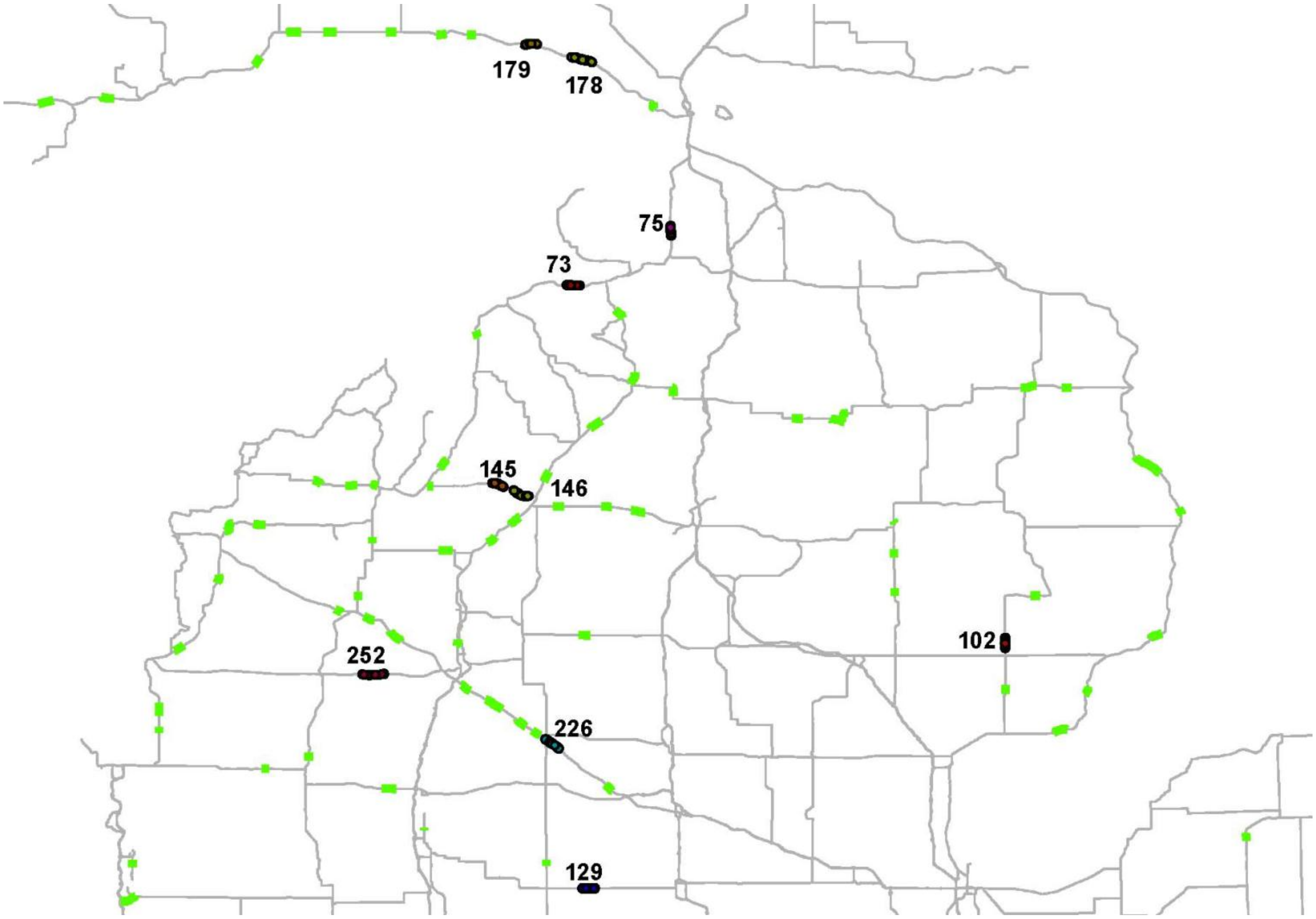


Figure 4-1 Map of Passing Relief Lane Study Sites

4.2 SITE VISITS

The site visits were conducted to gain firsthand knowledge of the physical and operational conditions of the various types of passing relief lanes. Each of the ten sites listed in Table 4-1 were visited. The site visits were also used as an opportunity to observe factors that may increase the collision risk for vehicles. No site visits were conducted during holiday peak days. The site visits included the following actions or considerations:

- Drive through;
- Review of geometric design;
- Observe operations of the passing relief lane;
- Consider a wide range of road user abilities;
- Consider the visibility of road users at night;
- Review signing and markings; and,
- Examine the treatment and transition of non-motorized facilities.

The results of the site visits are detailed on the following pages:

US-2, Mackinac County (2.9 Miles)

- The westernmost of the two passing relief lane sites in Mackinac County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly residential and agricultural;
- very low traffic volumes were observed during the site visit date;
- the shoulders are two-feet paved shoulders and the lanes are approximately 12 feet wide;
- the weather on the day of the site visit was sunny and clear with a high temperature in the mid 60's;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-1.

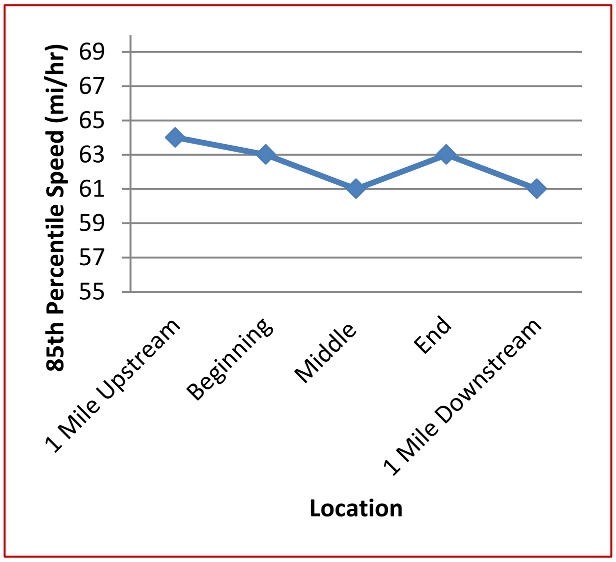


Figure 4-2 85th Percentile Speed Profile for US-2 (West)

US-2 Mackinac County (1.0 Miles)

- The easternmost of the two passing relief lane sites in Mackinac County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly residential and agricultural;
- very low traffic volumes were observed during the site visit;
- the shoulders are two-feet paved shoulders and the lanes are approximately 12 feet wide;
- some heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was sunny and clear with a high temperature in the mid 70's;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-3.

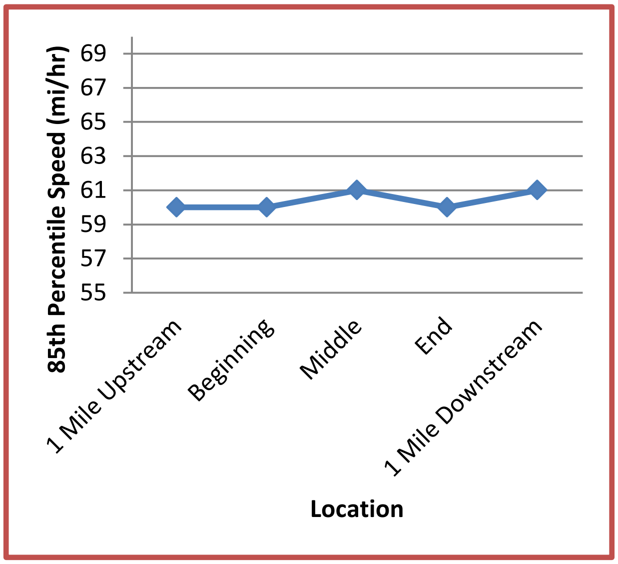


Figure 4-3 85th Percentile Speed Profile for US-2 (East)

US-31, Emmet County (1.4 Miles)

- The westernmost of the two passing relief lane sites in Emmet County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly residential and commercial;
- notable traffic generators in this area are a golf course and a subdivision located close to the passing relief lane segment;
- moderate traffic volumes were observed during the site visit;
- the shoulders are six-foot paved shoulders and the lanes are approximately 12 feet wide;
- some heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was cloudy with rain with a high temperature in the mid 70's;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-4.

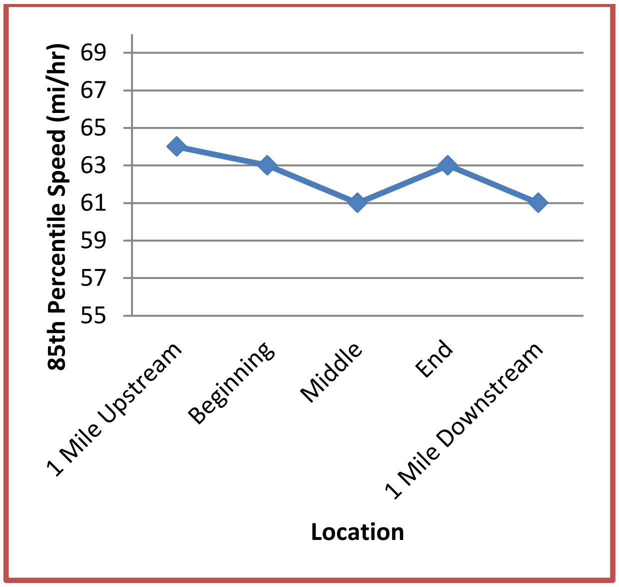


Figure 4-4 85th Percentile Speed Profile for US-31 (West)

US-31, Emmet County (1.1 Miles)

- The easternmost of the two passing relief lane sites in Emmet County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly residential;
- moderate traffic volumes were observed during the site visit;
- the shoulders are six-foot paved shoulders and the lanes are approximately 12 feet wide;
- some heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was clear and sunny with a high temperature in the mid 70's;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-5.

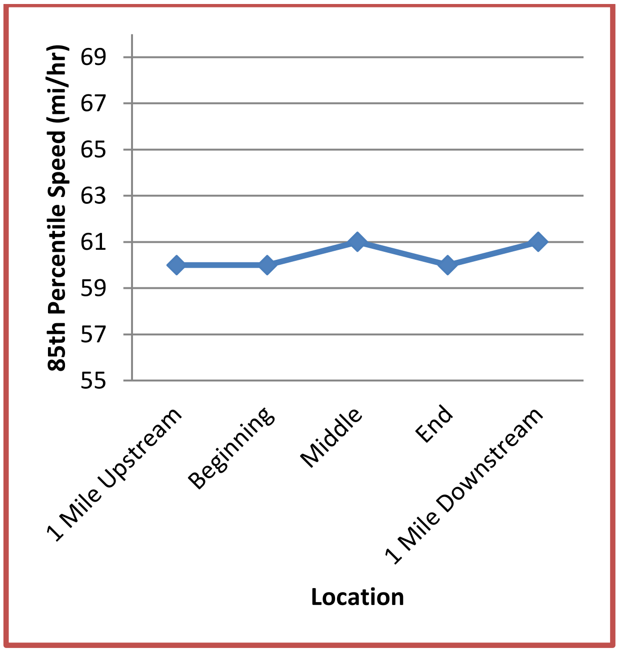


Figure 4-5 85th Percentile Speed Profile for US-31 (East)

M-65, Iosco County (1.6 Miles)

- The only passing relief lane study site evaluated in Iosco County;
- terrain in this area is gently rolling and the alignment is straight;
- land use in this area is predominantly residential and agricultural;
- some agricultural equipment was observed on M-65 during the site visit;
- very low traffic volumes were observed during the site visit;
- Michigan State Police were observed patrolling the area;
- the shoulders are two-feet paved shoulders with additional aggregate shoulder in varying widths;
- the lanes are approximately 12 feet wide;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was cloudy with rain and sleet towards the end of the site visit;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-6.

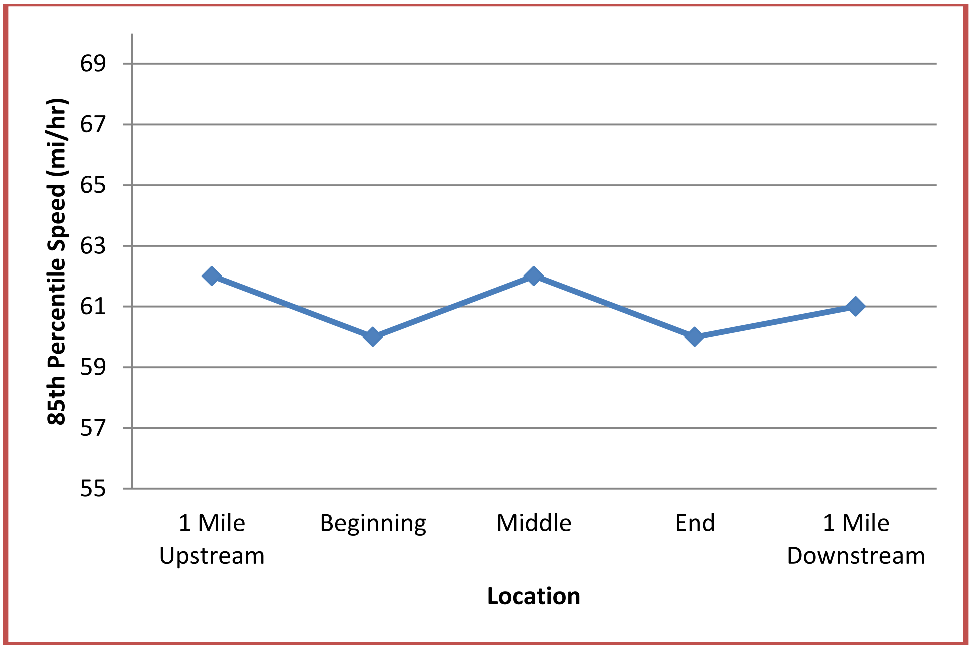


Figure 4-6 85th Percentile Speed Profile for M-65

M-20, Isabella County (1.3 Miles)

- The only passing relief lane study site evaluated in Isabella County;
- terrain in this area is gently rolling and the alignment is straight;
- land use in this area is predominantly residential and agricultural;
- some agricultural equipment was observed on M-20 during the site visit;
- moderate traffic volumes were observed during the site visit;
- the shoulders are two-feet paved shoulders with additional aggregate shoulder in varying widths;
- the lanes are approximately 12 feet wide;
- a number of personal driveways access this state trunkline in the vicinity of the passing relief lane segment;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was clear and sunny with high temperatures in the high 60's;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-7.

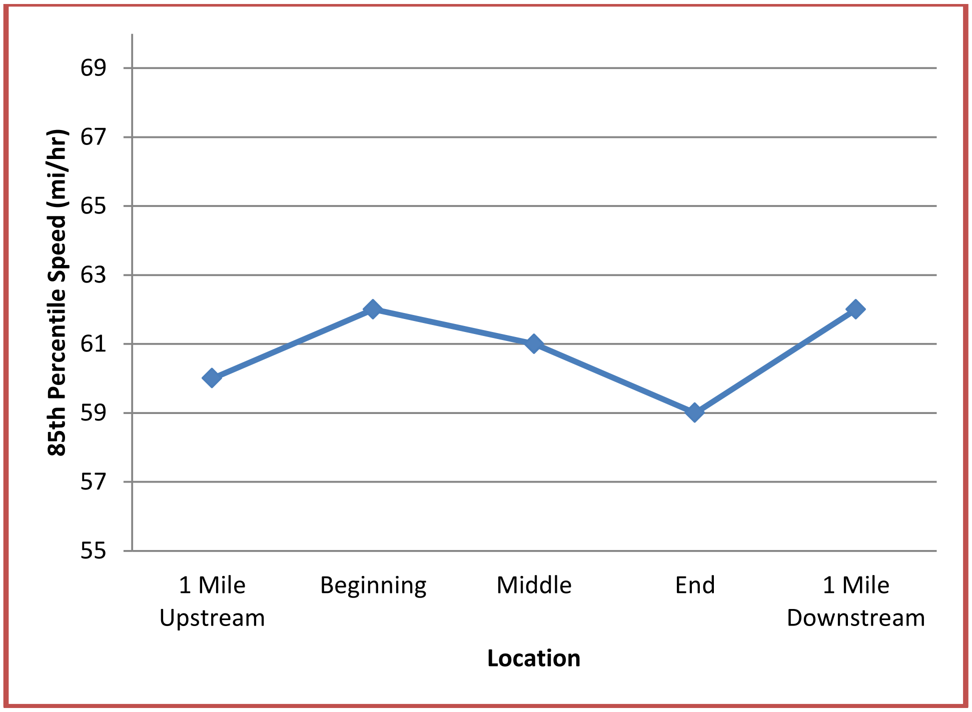
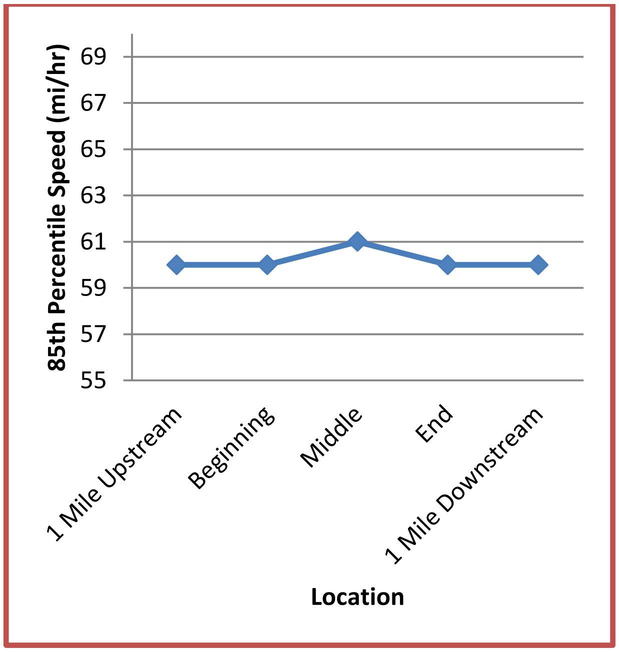


Figure 4-7 85th Percentile Speed Profile for M-20

M-72, Kalkaska County (1.3 Miles)

- The westernmost passing relief lane site in Kalkaska County;
- terrain in this area is level and the alignment has a gentle horizontal curve on the western end of the segment;
- land use in this area is predominantly residential and agricultural;
- some motorcyclists were observed during the site visit;
- low traffic volumes were observed during the site visit;
- the shoulders are six-feet paved shoulders;
- the lanes are approximately 12 feet wide;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was cool and cloudy;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-8.



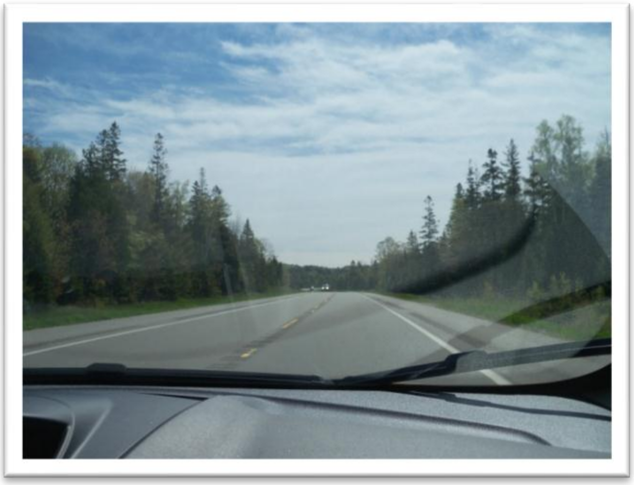


Figure 4-8 85th Percentile Speed Profile for M-72 (West)

M-72, Kalkaska County (2.1 Miles)

- The easternmost of the two passing relief lane sites evaluated in Kalkaska County;
- terrain in this area is gently rolling and the segment has two gradual horizontal curves, at either end;
- land use in this area is predominantly residential and agricultural;
- moderate traffic volumes were observed during the site visit;
- motorcyclists were observed during the site visit;
- the shoulders are six-feet paved;
- the lanes are approximately 12 feet wide;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was cool and cloudy;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-9.

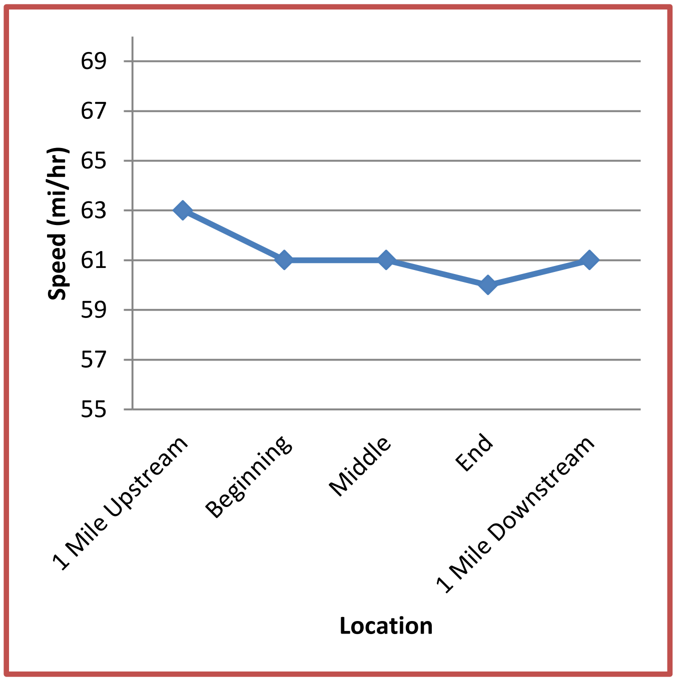


Figure 4-9 85th Percentile Speed Profile for M-72 (East)

M-115, Osceola County (1.6 Miles)

- The only passing relief lane study site evaluated in Osceola County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly agricultural;
- very low traffic volumes were observed during the site visit;
- the shoulders are six-feet paved;
- the lanes are approximately 12 feet wide;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was sunny and warm;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-10.

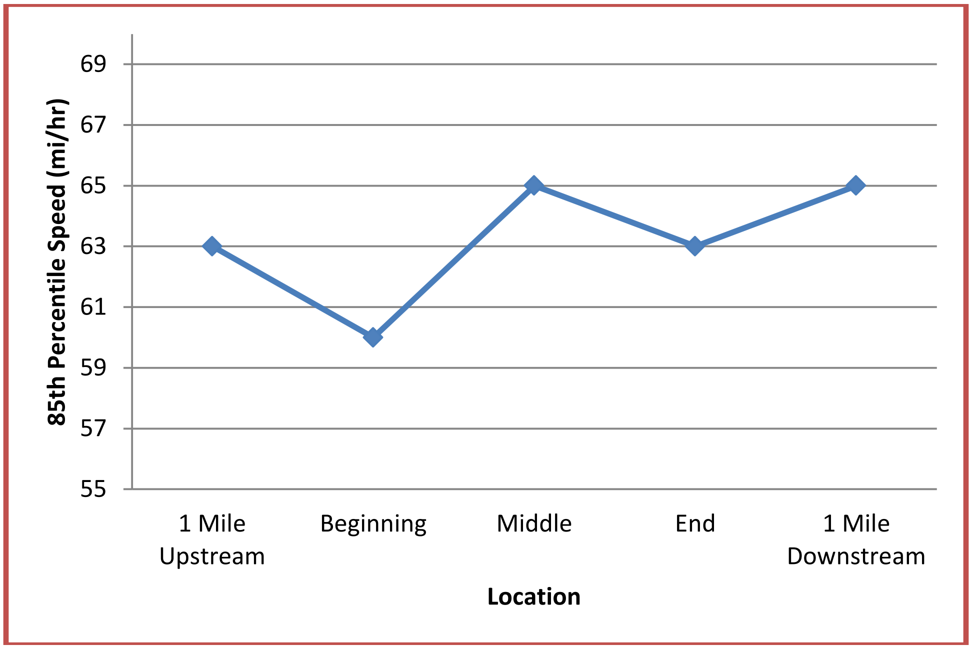


Figure 4-10 85th Percentile Speed Profile for M-115

M-55, Wexford County (2.1 Miles)

- The only passing relief lane site evaluated in Wexford County;
- terrain in this area is level and the alignment is straight;
- land use in this area is predominantly agricultural;
- low traffic volumes were observed during the site visit;
- the shoulders are six-feet paved shoulders;
- the lanes are approximately 12 feet wide;
- heavy vehicles were observed during the site visit;
- the weather on the day of the site visit was clear and sunny;
- relatively consistent speeds were observed; and,
- the 85th percentile speeds at this segment can be seen in Figure 4-11.

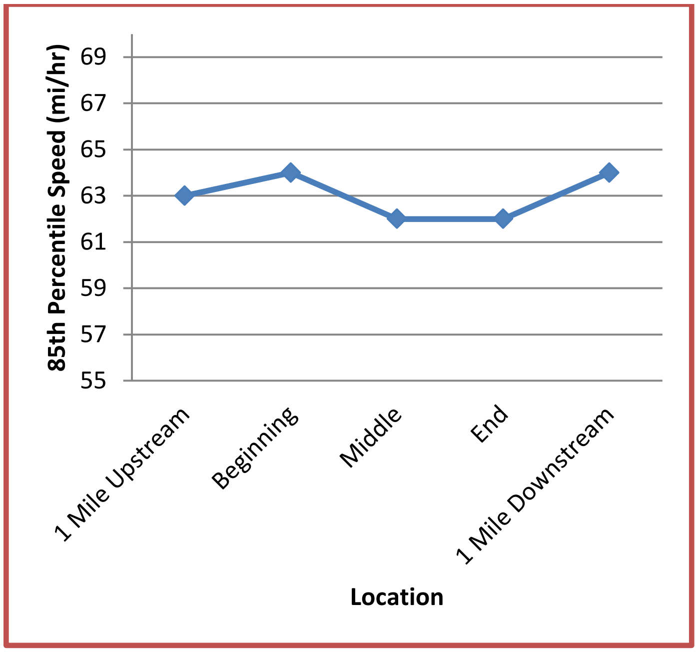


Figure 4-11 85th Percentile Speed Profile for M-55

A summary of the data collected at all 10 study sites can be seen graphically in Figure 4-12, below.

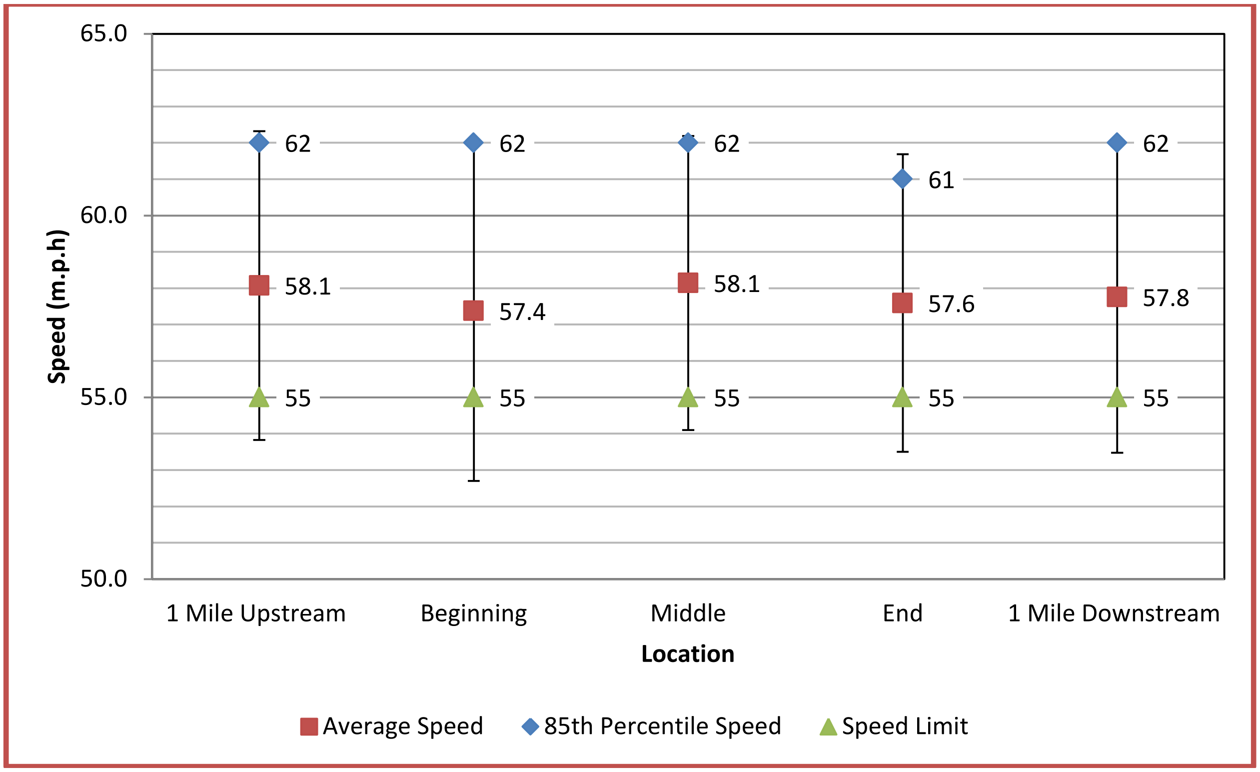


Figure 4-12 Average Data for 10 Passing Relief Lane Study Sites

In tabular form, this information can be found in the following table;

Table 4-2 Average Data for 10 Passing Relief Lane Study Sites

Location	Average Speed	85th Percentile Speed	Standard Deviation	Speed Limit
1 Mile Upstream	58.1	62	4.2	55
Beginning	57.4	62	4.7	55
Middle	58.1	62	4.0	55
End	57.6	61	4.1	55
1 Mile Downstream	57.8	62	4.3	55

The highest average speed, 58.1 m.p.h, is 3.1 m.p.h. over the regulatory speed limit and was the average speed both one mile upstream of the passing lane, as well as in the center of the passing lane. The lowest average speed, found at the beginning of the passing lane, was 57.4 m.p.h. The total difference between the highest average speed and the lowest average speed is 0.7 m.p.h. The 85th percentile speed was calculated at 62 m.p.h at all locations excluding the end of the passing lane where the 85th percentile speed was 61.

5.0 Additional Data Collection

This section discusses the data required to conduct the operational analysis, as well as the results of the safety analysis for the study intersections and reference intersections.

5.1 DATA REQUIREMENTS

The project team, in agreement with MDOT and the Research Advisory Panel (RAP), prepared a list of data requirements that were used in the passing relief lane evaluation:

- Crash data at study sites, before and after implementation
- Crash data at a group of similar reference sites
- Traffic volume at the treatment sites, before and after implementation
- Traffic volume at a group of similar reference sites, before and after implementation
- Geometric and operational characteristics of the treatment sites
- Geometric and operational characteristics of the reference sites

for both before and after implementation, along with the crash data for the reference sites was obtained from the Michigan State Police Traffic Crash Reporting System (TCRS). Traffic volume data was collected from partner agencies and from online resources, while other information (geometric characteristics, operational characteristics, implementation dates, and construction costs) were obtained from plans, field visits, project reports, and aerial photographs.

6.0 Operational Analysis

6.1 DATA COLLECTION

The data necessary for conducting the operational analysis was collected during site visits to each of the 10 study sites. The “Directional Two-Lane Highway Segment with Passing Lane Worksheet” from the Highway Capacity Manual, which can be seen in Figure 5-1, was used collect data at each study site. A radar gun was used to capture speed data at 5 different locations for each passing relief lane segment. Speed studies were taken 1 mile upstream of the passing relief lane, at the entrance of the passing relief lane, midway through the passing relief lane, at the end of the passing relief lane, and 1 mile downstream of the passing relief lane. Speed data was collected in 1 hour increments, 1 hour at each of the 5 locations, or; when data had been recorded for 100 vehicles. During each of the speed studies the operations of each site were observed and any trends or apparent safety issued were noted.

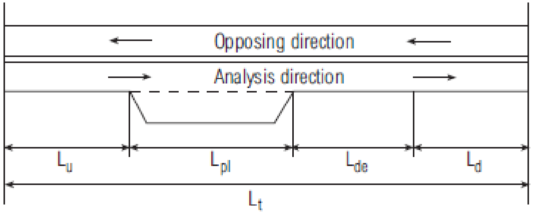
DIRECTIONAL TWO-LANE HIGHWAY SEGMENT WITH PASSING LANE WORKSHEET

General Information	***Site Information***
Analyst ________________________	Highway/Direction of Travel ________________________
Agency or Company ________________________	From/To ________________________
Date Performed ________________________	Jurisdiction ________________________
Analysis Time Period ________________________	Analysis Year ________________________

☐ Operational (LOS) ☐ Design (v_p) ☐ Planning (LOS) ☐ Planning (v_p)

Input Data

☐ Class I highway ☐ Class II highway



Total length of analysis segment, L_t (mi)	
Length of two-lane highway upstream of the passing lane, L_u (mi)	
Length of passing lane including tapers, L_{pl} (mi)	
Average travel speed, ATS_d (from Directional Two-Lane Highway Segment Worksheet)	
Percent time-spent-following, $PTSF_d$ (from Directional Two-Lane Highway Segment Worksheet)	
Level of service,[1] LOS_d (from Directional Two-Lane Highway Segment Worksheet)	
Average Travel Speed	
Downstream length of two-lane highway within effective length of passing lane for average travel speed, L_{de} (mi) (Exhibit 20-23)	
Length of two-lane highway downstream of effective length of the passing lane for average travel speed, L_d (mi) $L_d = L_t - (L_u + L_{pl} + L_{de})$	
Adj. factor for the effect of passing lane on average speed, f_{pl} (Exhibit 20-24)	
Average travel speed including passing lane,[2] ATS_{pl} $ATS_{pl} = \dfrac{ATS_d * L_t}{L_u + L_d + \dfrac{L_{pl}}{f_{pl}} + \dfrac{2L_{de}}{1+f_{pl}}}$	
Percent Time-Spent-Following	
Downstream length of two-lane highway within effective length of passing lane for percent time-spent-following, L_{de} (mi) (Exhibit 20-23)	
Length of two-lane highway downstream of effective length of the passing lane for percent time-spent-following, L_d (mi) $L_d = L_t - (L_u + L_{pl} + L_{de})$	
Adj. factor for the effect of passing lane on percent time-spent-following, f_{pl} (Exhibit 20-24)	
Percent time-spent-following including passing lane,[3] $PTSF_{pl}$ (%) $PTSF_{pl} = \dfrac{PTSF_d\left[L_u + L_d + f_{pl}L_{pl} + \left(\dfrac{1+f_{pl}}{2}\right)L_{de}\right]}{L_t}$	
Level of Service and Other Performance Measures [4]	
Level of service including passing lane, LOS_{pl} (Exhibits 20-3 or 20-4)	
Peak 15-min total travel time, TT_{15} (veh-h) $TT_{15} = \dfrac{VMT_{15}}{ATS_{pl}}$	

Notes

1. If LOS_d = F, passing lane analysis cannot be performed.
2. If $L_d < 0$, use alternative Equation 20-22.
3. If $L_d < 0$, use alternative Equation 20-20.
4. v/c, VMT_{15}, and VMT_{60} are calculated on Directional Two-Lane Highway Segment Worksheet.

Figure 5-6-1 Directional Two-Lane Highway Segment with Passing Relief Lane Worksheet

6.2 OPERATIONAL ANALYSIS RESULTS

The LOS is the criteria by which each passing relief lane segment operations are evaluated. The level of service is measure used to determine the effectiveness of elements of transportation infrastructure. LOS is most frequently used to analyze highways by categorizing traffic flow with corresponding safe driving conditions.

All of the 10 study sites are operating at a level of service “A”. Having a level of service “A” indicates free-flow operations. Traffic flows at or above the posted speed limit and all motorists have complete mobility between lanes. The average spacing between vehicles is about 550 ft or 27 car lengths. Motorists have a high level of both physical and psychological comfort. The Highway Capacity Manual uses the “percent-time-spent-following” as the criteria for determining different levels of service. Percent-time-spent-following is the average percent of total travel time that vehicles must travel in platoons behind slower vehicles due to inability to pass on a two-lane highway. A summary of the level of service criteria can be seen in Table 5-2, below.

Table 5-6-1 Level Of Service Parameters

Level of Service (LOS)	Percent-Time-Spent-Following (PTSF, %)
A	≤ 40
B	> 40-55
C	> 55-70
D	> 70-85
E	> 85

During the site visits there were no traffic conflicts observed. The passing relief lanes appeared to be functioning as intended, though given the low traffic volumes observed determining whether the passing relief lanes were preventing conflict from occurring was unable to be determined. Few actual passing maneuvers were observed with the passing relief lane segments. It may be important to note that none of the site visits were performed during the summer months or over holidays. A summary of the safety analysis can be seen in Table 5-1 below;

Table 5-6-2 Summary of Passing Relief Lane Study Sites

Passing Relief Lane	County	Highway	Length (miles)	Level Of Service
178	Mackinac	US-2	2.9	A
179	Mackinac	US-2	1.0	A
73	Emmet	US-31	1.4	A
75	Emmet	US-31	1.1	A
102	Iosco	M-65	1.6	A
129	Isabella	M-20	1.3	A
145	Kalkaska	M-72	1.3	A
146	Kalkaska	M-72	2.1	A
226	Osceola	M-115	1.6	A
252	Wexford	M-55	2.1	A

As corroborated by the level of service analysis, no conflict issues were identified for these 10 passing relief lane study sites.

7.0 Safety Analyses

The purpose of the safety analysis is to evaluate the safety impacts of passing relief lanes on state trunklines in Michigan. An additional, implied objective is to apply the results to provide guidance to MDOT to make informed decisions for effective future deployments of passing lanes.

Two complementary analyses are undertaken: an observational before-after crash study of passing lane installation sites in Michigan; and a cross-sectional analysis, using generalized linear modeling, to estimate the difference in safety performance of segments with and without passing lanes.

The outputs of the analysis includes Crash Modification Factors (CMFs). A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. The CMF is multiplied by the expected crash frequency without treatment to estimate the safety benefits of contemplated implementation. A CMF greater than 1.0 indicates an expected increase in crashes, while a value less than 1.0 indicates an expected reduction in crashes after implementation of a given countermeasure. For example, a CMF of 0.8 indicates an expected safety benefit; specifically, a 20 percent expected reduction in crashes. A CMF of 1.2 indicates an expected degradation in safety; specifically, a 20 percent expected increase in crashes.

An additional objective was to develop Safety Performance Functions (SPFs) for road segments with and without passing lanes. An SPF is a mathematical model that predicts the mean crash frequency for similar locations with the same traffic volume and other characteristics that define the model. Such an SPF may be used when evaluating the safety performance of a location by comparing the frequency of observed to predict crashes or estimating the likely safety effects of a passing lane. These SPFs can also be used to estimate the likely safety effects of a future passing lane deployment. How to do so is documented within this report.

7.1 DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

This section presents the safety performance functions (SPFs) applied in the EB before-after methodology to estimate the safety effectiveness. The reference site data were used to estimate the required SPF coefficients, assuming a negative binomial error distribution, which is consistent with the state of research in developing these models. Separate models were sought for each crash type analyzed. The SPFs developed are provided in Table 7-1. The parameter k, which is the over dispersion parameter of the negative binomial distribution for the models, is estimated during the development of the SPFs. This parameter is used in the EB methodology.

The model form for all models is: $Crashes/mile/year = \exp^{(\alpha)}(AADT)^{\mathrm{B1}}$

Table 7-1: Reference Site SPFs for Before-After Study

Crash Type	**α (s.e.)**	**β (s.e.)**	**k (s.e.)**
Total crashes/mile-year	-4.5331 (1.5638)	0.7140 (0.1863)	1.5001 (0.2206)
Injury crashes/mile-year	-5.9362 (1.3858)	0.6492 (0.1644)	1.1269 (0.1973)
Non-intersection crashes/mile-year	-5.0145 (1.5270)	0.7264 (0.1819)	1.3951 (0.2093)
Intersection-related crashes/mile-year	-5.5112 (1.4197)	0.6924 (0.1689)	1.1981 (0.1904)
Non-intersection injury crashes/mile-year	-6.4517 (1.4202)	0.6437 (0.1679)	1.0798 (0.2168)
Intersection-related injury crashes/mile-year	-7.1619 (1.5419)	0.6941 (0.1821)	1.0542 (0.2285)
Non-animal Total crashes/mile-year	-4.5433 (1.4772)	0.6253 (1.4231)	1.4231 (0.2145)
Non-animal Injury crashes/mile-year	-5.9073 (1.4076)	0.6357 (0.1670)	1.1471 (0.2039)
Non-animal Non-intersection crashes/mile-year	-5.2360 (1.4403)	0.6329 (0.1713)	1.2739 (0.2014)
Non-animal Intersection-related crashes/mile-year	-5.3084 (1.4207)	0.6256 (0.1689)	1.2550 (0.2042)
Non-animal Non-intersection injury crashes/mile-year	-6.3763 (1.4648)	0.6200 (0.1732)	1.1201 (0.2304)
Non-animal Intersection-related injury crashes/mile-year	-7.1822 (1.5496)	0.6923 (0.1830)	1.0572 (0.2328)

To account for time trends in the EB procedure it is desired that the SPFs be also recalibrated for each year of data. In doing so these SPFs are now re-applied to the reference site data but now predicting for one year of data at a time. The sum of observed crashes is divided by the sum of predictions to derive a yearly multiplier to be applied to the model. Because of low numbers of crashes for specific crash types the yearly multipliers for the total and total non-animal related crash SPFs were applied to all specific crash type SPFs.

As an illustration of the recalibration, consider the following example. The SPF for total non-animal crashes is recalibrated for the years 2001, 2002 and 2003. For each site, the SPF is applied using the AADT for the respective year. The number of observed and predicted crashes for each year is then summed over all sites.

Site	AADT 2001	AADT 2002	AADT 2003	Observed 2001	Observed 2002	Observed 2003	Predicted 2001	Predicted 2002	Predicted 2003
1	2548	2568	3139	3	0	0	1.43	1.44	1.63
2	1594	1588	1909	0	1	4	1.07	1.07	1.20
.									
.									
.									
n	14300	15024	15279	6	2	3	4.22	4.35	4.40
sum				280	244	263	255.5	260.0	264.5

The recalibration factor, F_y, for each year is then calculated.

$F_{2001} = 280/255.5 = 1.10$
$F_{2002} = 244/260.0 = 0.94$
$F_{2003} = 263/264.5 = 0.99$

To apply the SPF to individual years, the recalibration factor is added as a multiplicative factor to the original SPF: $Crashes/mile_y = F_y \exp^{(a)}(AADT)^{B1}$

Table 7-2: Yearly Multipliers for Before-After Study SPFs

Model	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total Crashes	1.131	1.131	1.085	1.162	1.121	1.054	0.950	0.932	1.116	0.886
Total Non-Animal Crashes	1.322	1.322	1.004	1.272	1.164	1.081	0.844	0.995	1.009	0.873

7.2 EMPIRICAL BAYES ANALYSIS TO DEVELOP CRASH MODIFICATION FACTORS

The results from the empirical Bayes (EB) and naïve before-after analyses are shown in Table 6-3 through Table 6-8, separately for passing lane sites, adjacent up/downstream sites and the combination of passing lane and adjacent sites. As noted earlier, these results are based on a treatment sample that was much less than desirable for this sort of evaluation. In addition, disaggregating the already small sample by crash type meant that some results, whether statistically significant or not, are based on very small crash counts and cannot be deemed to be robust.

The EB results do suggest generally that the passing lanes were safety effective. In particular, there are statistically significant reductions generally for injury crashes overall and for all severities for non-animal crashes at the passing lane sites. More modest and generally non-statistically significant benefits in these crash types are evidenced for the adjacent up/downstream sites.

The main reason for differences between the naïve results and EB results is that the significant time trend indicated by state-wide crash statistics is not accounted for in the naïve study. Nevertheless, considering this key difference between the two studies, the general indication is that the naïve results are consistent with, and do corroborate the EB results.

Table 7-3: EB Results for Passing Lanes

Collision Type	Collisions recorded in after period	EB estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	161	166.14	-3.9	0.961 (0.116)
Injury crashes	13	25.77	-51.3	0.487 (0.158)
Non-intersection crashes	142	130.03	+7.9	1.079 (0.147)
Intersection-related crashes	19	40.80	-54.7	0.453 (0.125)
Non-intersection injury crashes	10	13.99	-33.1	0.669 (0.257)
Intersection-related injury crashes	3	14.74	-80.7	0.193 (0.114)
Non-animal Total crashes	38	54.47	-31.3	0.687 (0.137)
Non-animal Injury crashes	11	22.21	-52.2	0.478 (0.165)
Non-animal Non-intersection crashes	29	31.52	-10.2	0.898 (0.213)
Non-animal Intersection-related crashes	9	27.71	-68.6	0.314 (0.116)
Non-animal Non-intersection injury crashes	8	12.08	-38.1	0.619 (0.255)
Non-animal Intersection-related injury crashes	3	12.79	-77.8	0.222 (0.131)

Table 7-4: Naïve Results for Passing Lanes

Collision Type	Collisions recorded in after period	Naïve estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	161	187.75	-15.0	0.850 (0.103)
Injury crashes	13	24.10	-47.7	0.523 (0.167)
Non-intersection crashes	142	146.56	-4.3	0.957 (0.131)
Intersection-related crashes	19	41.19	-55.1	0.449 (0.123)
Non-intersection injury crashes	10	10.86	-13.9	0.861 (0.332)
Intersection-related injury crashes	3	13.24	-78.5	0.215 (0.127)
Non-animal Total crashes	38	65.51	-42.8	0.572 (0.113)
Non-animal Injury crashes	11	23.50	-54.6	0.454 (0.154)
Non-animal Non-intersection crashes	29	34.88	-18.5	0.815 (0.187)
Non-animal Intersection-related crashes	9	30.63	-71.7	0.283 (0.105)
Non-animal Non-intersection injury crashes	8	10.86	-31.2	0.688 (0.284)
Non-animal Intersection-related injury crashes	3	12.64	-77.6	0.224 (0.133)

Table 7-5: EB Results for Up/downstream Sites

Collision Type	Collisions recorded in after period	EB estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	149	141.25	+4.4	1.044 (0.134)
Injury crashes	21	28.75	-31.0	0.690 (0.213)
Non-intersection crashes	105	101.21	+2.3	1.023 (0.156)
Intersection-related crashes	44	45.26	-5.7	0.943 (0.212)
Non-intersection injury crashes	9	15.22	-45.6	0.544 (0.223)
Intersection-related injury crashes	12	12.42	-10.7	0.893 (0.336)
Non-animal Total crashes	51	57.37	-13.0	0.870 (0.174)
Non-animal Injury crashes	19	19.57	-8.3	0.917 (0.289)
Non-animal Non-intersection crashes	25	30.78	-21.9	0.781 (0.213)
Non-animal Intersection-related crashes	26	31.3	-19.8	0.802 (0.218)
Non-animal Non-intersection injury crashes	7	11.79	-46.1	0.539 (0.242)
Non-animal Intersection-related injury crashes	12	11.04	+0.4	1.004 (0.378)

Table 7-6: Naïve Results for Up/downstream Sites

	Collisions recorded in after period	Naïve estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	149	158.49	-6.9	0.931 (0.119)
Injury crashes	21	22.42	-12.0	0.880 (0.277)
Non-intersection crashes	105	112.51	-8.0	0.920 (0.140)
Intersection-related crashes	44	45.98	-7.4	0.926 (0.213)
Non-intersection injury crashes	9	13.19	-40.0	0.599 (0.263)
Intersection-related injury crashes	12	9.23	+18.3	1.183 (0.459)
Non-animal Total crashes	51	69.90	-28.7	0.713 (0.145)
Non-animal Injury crashes	19	20.09	-11.9	0.881 (0.291)
Non-animal Non-intersection crashes	25	34.80	-31.3	0.687 (0.192)
Non-animal Intersection-related crashes	26	35.10	-29.4	0.706 (0.199)
Non-animal Non-intersection injury crashes	7	10.86	-45.4	0.546 (0.263)
Non-animal Intersection-related injury crashes	12	9.23	+18.3	1.183 (0.459)

Table 7-7: EB Results for Combined Passing Lane and Up/downstream Sites

Collision Type	Collisions recorded in after period	EB estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	310	307.39	+0.4	1.004 (0.089)
Injury crashes	34	54.52	-39.1	0.609 (0.138)
Non-intersection crashes	247	231.24	+6.1	1.061 (0.108)
Intersection-related crashes	63	86.06	-27.9	0.721 (0.124)
Non-intersection injury crashes	19	29.21	-37.4	0.626 (0.183)
Intersection-related injury crashes	15	27.16	-46.6	0.534 (0.027)
Non-animal Total crashes	89	111.84	-21.2	0.788 (0.112)
Non-animal Injury crashes	30	41.77	-29.8	0.702 (0.163)
Non-animal Non-intersection crashes	54	62.29	-14.7	0.853 (0.156)
Non-animal Intersection-related crashes	35	58.84	-41.7	0.583 (0.125)
Non-animal Non-intersection injury crashes	15	23.87	-39.7	0.603 (0.191)
Non-animal Intersection-related injury crashes	15	23.83	-39.1	0.609 (0.187)

Table 7-8: Naive Results for Combined Passing Lane and Up/downstream Sites

Collision Type	Collisions recorded in after period	Naïve estimate of collisions expected after without passing lanes	Point estimate of the % change in collisions	Index of Effectiveness θ (and standard error)
Total crashes	310	346.24	-10.9	0.891 (0.079)
Injury crashes	34	46.52	-28.6	0.714 (0.160)
Non-intersection crashes	247	259.08	-5.3	0.947 (0.097)
Intersection-related crashes	63	87.17	-28.8	0.712 (0.124)
Non-intersection injury crashes	19	24.05	-25.2	0.748 (0.233)
Intersection-related injury crashes	15	22.48	-35.6	0.644 (0.199)
Non-animal Total crashes	89	135.41	-34.9	0.651 (0.093)
Non-animal Injury crashes	30	43.59	-32.9	0.671 (0.158)
Non-animal Non-intersection crashes	54	69.68	-23.8	0.762 (0.140)
Non-animal Intersection-related crashes	35	65.73	-47.9	0.521 (0.115)
Non-animal Non-intersection injury crashes	15	21.72	-35.0	0.650 (0.220)
Non-animal Intersection-related injury crashes	15	21.88	-33.9	0.661 (0.205)

7.2.1 Cross-Sectional Study to Develop CMF's

Due to the low number of sites eligible for the before-after study, a cross-sectional analysis was undertaken to develop CMFs for passing lanes. Generalized linear regression modeling was used to estimate the model coefficients assuming a negative binomial error distribution, all consistent with the state of the art research in developing these models. In developing the recommended SPFs, low values of the dispersion parameter and statistical significance of the estimated variable coefficients were considered.

In this analysis only non-animal related, non-intersection related crashes are considered as these are the most relevant when considering passing lanes. These crash types were defined as follows:

- Crash type <u>not</u> equal to 18 (animal)
- Area type equal to 3 (Non-intersection and non-interchange area.)

In addition to total and fatal+injury crashes, certain sub-categories of crashes of interest were considered:

<u>'Target' Crashes</u>
- Run-Off-Road
    - Harmful Event #1, Unit 1 equal to 3 (run off road left) or 4 (run off road right)
- Head-on
    - Crash Type equal to 31
- Rear-end straight
    - Crash Type equal to 24
- Sideswipe same direction
    - Crash Type equal to 32
- Sideswipe opposite direction
    - Crash Type equal to 33

<u>Day vs Night</u>
- Day where Lighting = 1 (daylight), 2 (dawn), 3 (dusk)
- Night where Lighting = 4 (dark, lighted), 5 (dark, unlighted)

<u>Wet vs Dry</u>
Wet where Roadway Surface Condition = 2 (wet), 3 (icy), 4 (snowy), 5 (muddy), 6 (slushy)
Dry where Roadway Surface Condition =1 (dry), 7(debris), 8 (other)

<u>Seasonal</u>
- Summer where Month of Crash = 6 (June), 7(July), 8 (August)
- Non-summer all other months

In calibrating the models the data for passing lane segments, up/downstream segments, and reference sites were pooled and the model intercept term calibrated for each type of site as follows:

Type1 = passing lane
Type2 = 1 mile upstream + 1 mile downstream
Type3 = reference site

The CMF for the change in safety from a Type 3 to a Type 1 or Type 2 site is then estimated from the difference in the intercept terms. The estimated models are shown in the table below along with the implied CMFs. The value k in the table is the over-dispersion parameter of the model. The models are of the form:

Crashes/year = $\exp^{(\alpha+\beta 3)}\text{AADT}^{\beta 1}(\text{Segment Length})^{\beta 2}$

Note that other variables are not significant in the models and even including them does not materially change the "type" parameter estimates.

The implied CMFs should be used with the usual caution that applies to cross-section studies. This is because they assume that difference in safety (i.e., the intercept terms, $\exp^{(\alpha+\beta 3)}$, in this case) between two site type are due entirely to the presence or absence of a passing lane. For this particular study every effort was made to eliminate the confounding effects of other factors by selecting reference sites that were as similar as possible to the passing lane sites. However, formal confirmation of similarity, or accounting for potentially confounding effects by including the other factors in the model, was not possible because data on these other factors were unavailable.

Nevertheless, that the direction of the safety effects are confirmed by the limited before-after study, and by other research, does provide justification for confidence in using the CMFs provided in planning future passing lane deployments.

Table 6-9 provides the coefficients and standard errors of the parameters of the SPFs as well as the CMFs. All estimated coefficients were estimated to be significant at the 95% confidence limit except where noted. Where a parameter has been estimated to be statistically significant at less than the 90th percentile a note has been made. It should also be noted that while Type 2 (upstream and downstream) sites have an implied CMF smaller than the Type 1 (passing lane) sites the differences between the two are not significant.

Table 7-9: SPFs and Implied CMFs from Cross-Sectional Models

Crash Type	α (s.e.)	β1 (s.e.)	β2 (s.e.)	β3 (s.e.)	k (s.e.)	Type 1 CMF	Type 2 CMF
Non-animal Non-intersection Total crashes/mile-year	-6.4639 (1.0333)	0.7801 (0.1231)	0.7963 (0.2816)	1 -0.4005 (0.2205) 2 -0.4570 (0.2185)	1.9900 (0.1690)	0.67	0.63
Non-animal Non-intersection Injury crashes/mile-year	-6.7759 (1.0233)	0.6677 (0.1207)	0.6978 (0.2690)	1 – -0.3406 (0.2162) 2 - -0.4311 (0.2187)	1.6661 (0.1778)	0.71[1]	0.65
Non-animal Non-intersection Target crashes/mile-year	-8.7502 (1.0198)	0.9464 (0.1220)	0.8624 (0.2680)	1 – -0.6326 (0.2122) 2 - -0.7832 (0.2098)	1.5465 (0.1587)	0.53	0.46
Non-animal Non-intersection Day crashes/mile-year	-7.1058 (1.0371)	0.8228 (0.1243)	0.7287 (0.2792)	1 – -0.5097 (0.2186) 2 - -0.5400 (0.2164)	1.8922 (0.1683)	0.60	0.58
Non-animal Non-intersection Night crashes/mile-year	-7.5788 (1.0694)	0.7434 (0.1251)	0.8122 (0.2740)	1 – -0.0932 (0.2222) 2 - -0.2051 (0.2220)	1.7238 (0.1810)	0.91[1]	0.81[1]
Non-animal Non-intersection Wet crashes/mile-year	-6.7716 (1.1201)	0.7409 (0.1327)	0.8137 (0.2981)	1 – -0.2158 (0.2341) 2 - -0.3479 (0.2347)	2.1974 (0.1985)	0.81[1]	0.71[1]
Non-animal Non-intersection Dry crashes/mile-year	-7.8567 (1.0344)	0.8517 (0.1235)	0.6872 (0.2767)	1 – -0.6288 (0.2215) 2 - -0.5647 (0.2160)	1.7810 (0.1755)	0.53	0.57
Non-animal Non-intersection Peak crashes/mile-year	-7.4907 (1.2185)	0.7187 (0.1460)	0.8897 (0.3501)	1 – -0.6078 (0.2736) 2 - -0.6253 (0.2682)	2.5081 (0.2917)	0.54	0.54
Non-animal Non-intersection Off-Peak crashes/mile-year	-6.9435 (1.0860)	0.8076 (0.1289)	0.7399 (0.2846)	1 – -0.3261 (0.2255) 2 - -0.3900 (0.2242)	2.0742 (0.1799)	0.72[1]	0.68

[1] Note that the parameter estimate was estimated with significance at less than the 90th percentile so the corresponding point estimate of the CMFs should not be considered statistically significant.

7.3 ESTIMATING THE SAFETY IMPACTS OF CONTEMPLATED PASSING LANES

To estimate the expected safety impacts on crashes of a contemplated passing lane, crash prediction models for the existing condition are required. Models for the existing condition would be used, along with the site's crash history, in the empirical Bayes procedure to estimate *the expected crash frequency with the status quo in place (the EB estimate)*, which would then be compared to *the expected frequency should a passing lane be constructed* to estimate the benefits.

The expected frequency should a passing lane be constructed is estimated from an SPF for passing lane segments. If it is believed that there is no applicable passing lane SPF for the jurisdiction, an alternate approach can be used. In this Collision Modification Factors (CMFs) can be applied to *the expected collision frequency with the status quo in place* to estimate the expected benefit.

The first approach is preferred to the alternate and is most convenient because a comprehensive set of collision modification factors (which would be required for a large number of conditions, including AADT levels) is unlikely to be available.

The models included in the Appendix developed for both passing lane and non-passing lane roads may be used for this application. It is anticipated that the model for total non-animal non-intersection crashes would be of most interest in applying the procedure.

7.3.1 Overview of the Recommended Approach

Step 1

Assemble data and a crash prediction model for non-passing lane segments. It is recommended that three to five years of before data be used.

1. Obtain the count of fatal+injury and total crashes
2. For the same period obtain or estimate the average AADT.
3. Estimate the AADT that would prevail for the period immediately after the installation.
4. Assemble required crash prediction models for passing lane and non-passing lane segments for fatal+injury and total crashes. If the models cannot be assumed to be representative of the jurisdiction, a calibration multiplier must first be estimated using data (similar to data acquired in Step 1) from a sample of sites representative of that jurisdiction. At a minimum, a dataset for at least 100 miles of roadway with a minimum of 100 crashes is needed for each model. The recalibration multiplier is the sum of crashes recorded in this dataset divided by the sum of the crashes predicted by the model for this dataset. The multiplier is applied to the model selected for predicting crashes.

Step 2

Use the EB procedure with the data from Step 1 and the *non-passing lane model* to estimate the expected annual number of fatal+injury and total crashes that would occur without installation.

The EB estimate of the expected annual crash frequency, m, is calculated as:

$$m = wP + (1 - w)x$$

Where:

$$w = \frac{1}{1+knP}$$

Where:
P = the yearly crash frequency per year expected as predicted by a crash prediction model
x = the observed crash frequency per year
n = the number of years of observed crashes
k = the over dispersion parameter for a given model

Step 3

Use the appropriate passing lane model and the AADT from Step 1 to estimate the expected number of fatal+injury and total crashes that would occur per year if a passing lane were installed.

Step 4

Obtain the difference between the EB estimate from Step 2 and the passing lane model estimates from Step 3. The estimated change for PDO crashes is the difference between the change in total and fatal+injury crashes.

Step 5

Applying suitable dollar values for fatal+injury and total crashes to the estimates from Step 4, obtain the estimated net safety benefit of installing a passing lane.

Step 6

Compare the estimated net safety benefit from Step 5 against the annualized installation and maintenance costs, if any, considering other impacts if desired, and using conventional economic analysis tools. How this is done, and in fact whether it is done, is very jurisdiction-specific, and conventional methods of economic analysis can be applied after obtaining estimates of the economic values of changes in delay, fuel consumption, and other impacts. The results of the analysis above may indicate that passing lane installation is justified based on a consideration of safety benefits. This result may be considered in context with other factors, such as:

- Other improvement measures may be more cost effective.
- Other impacts (delay, fuel consumption, etc.) may need to be assessed.

7.3.2 Example Calculation

A segment of rural two-lane road is being considered for a passing lane installation. This example provides some calculations that could have been used to inform that decision. It is assumed that the models from the Appendix are applicable.

Step 1

The assembled data and models are as follows:
Years of observed data = n = 5
Length = 1 mile
Fatal+Injury collisions observed = 5
PDO crashes observed = 5
Major AADT before installation = 8,000
Major AADT after installation = 8,500

For the example, it is total non-animal non-intersection crashes that are of interest.

Applying the model for non-passing lanes from the Appendix:

Total Crashes/year = (1)exp(-5.2360)$(8,000)^{0.6329}$=1.57
The dispersion parameter is 1.2739

Fatal+Injury Crashes/year = (1)exp(-6.3763)$(8,000)^{0.6200}$=0.45
The dispersion parameter is 1.1201

Step 2

Estimate the empirical Bayes estimate of the expected crash frequency without conversion.

Next, the weights and EB estimates are calculated per the above equations. Note that the number of observed crashes is divided by the number of years since the EB estimate is per year.

$$w_{Total} = \frac{1}{1 + k_{Total} n P_{Total}} = \frac{1}{1 + 1.2739(5)(1.57)} = 0.09$$

$$m_{Total} = w_{Total} P_{Total} + (1 - w_{Total}) x_{Total} = 0.09(1.57) + (1 - 0.09) * (10/5) = 1.96$$

$$w_{F+I} = \frac{1}{1 + k_{F+I} n P_{F+I}} = \frac{1}{1 + 1.1201(5)(0.45)} = 0.28$$

$$m_{F+I} = w_{F+I} P_{F+I} + (1 - w_{F+I}) x_{F+I} = 0.28(0.45) + (1 - 0.28) * (5/5) = 0.85$$

Because volumes are expected to increase in the after period, albeit only slightly, an adjustment is made to the EB estimates to account for this change. This adjustment factor is calculated by dividing the existing condition model predictions using the after period volumes by the prediction with the present volumes:

For total crashes:
$(8{,}500)^{0.6329}/(8{,}000)^{0.6329}=1.04$

For fatal+injury crashes:
$(8{,}500)^{0.6200}/(8{,}000)^{0.6200}=1.04$

The adjusted EB estimates, using these factors are now equal to:

1.96(1.04) = 2.04 for total crashes per year
0.85(1.04) = 0.88 for fatal+injury crashes per year

The estimate for PDO crashes is 2.04-0.88 = 1.16 crashes per year

Step 3

The passing lane models are used to predict the annual number of fatal+injury and total crashes should a passing lane be installed.

Total Crashes/year = $(1)^{0.8258}\exp(-7.4667)(8{,}500)^{0.8507}=1.26$

Fatal+Injury Crashes/year = $(1)^{0.5873}\exp(-8.1097)(8{,}500)^{0.7907}=0.38$

The expected number of PDO crashes at the site if a passing lane were installed is 1.26-0.38=0.88 per year.

7.3.3 Alternate Approach

In the alternate approach, Steps 1 and 2 are followed to estimate the yearly crash frequency without conversion. In Step 3 a crash modification factor is used instead of a model to estimate the reduction in crashes due to a passing lane installation.

The CMFs for a passing lane site derived from the cross-section analysis for total and fatal+injury crashes are 0.67 and 0.71 respectively.

Using these values in the example the expected changes in crashes are equal to:

2.04(0.67)-2.04 = -0.67, a reduction of 0.67 total crashes per year
0.88(0.71)-0.88 = -0.26, a reduction of 0.26 fatal+injury crashes per year

The reduction in PDO crashes is 0.67-0.26=0.41 per year

The difference between the results using the preferred and the alternate approach is due to the fact that the preferred method gives consideration to the observed AADTs at the site, whereas the CMF approach uses a CMF that is by necessity based on an amalgamation of results from many sites with varying AADT and other conditions.

7.4 ECONOMIC ANALYSIS

Point estimates of the crash benefit for each passing lane installation, expressed in terms of crash costs per year and for the entire after periods, are provided in the last columns of Table 6.10.

These are based on unit crash costs and the estimated change in crashes per year for injury and PDO crashes. The change in PDO crashes was calculated as the change in all crashes minus the change in injury crashes. 95% confidence intervals are provided for the change in crashes; as expected these are quite wide for individual passing lane installations and must be considered in interpreting the results based on point estimates.

The unit crash costs were derived from the National Safety Council 2009 Average Economic Cost per Death, Injury, or Crash suggested by MDOT for use on RSA projects. These are available at the following link:

http://www.nsc.org/news_resources/injury_and_death_statistics/Pages/EstimatingtheCostsofUnintentionalInjuries.aspx

The basic numbers are as follows:

Death	$1,290,000
Nonfatal Disabling Injury	$68,100
Property Damage Crash (including non-disabling injuries)	$8,200

Since the death and injury costs are per victim, they needed to be first converted to cost per crash using the average number of victims per crash for Michigan in 2009 (1.081 and 1.357, respectively, for fatal and non-fatal crashes). The cost per crash so derived was $1,394,032 and $92,390, respectively, for fatal and non-fatal crashes.

Then, it was necessary to derive an aggregate cost for fatal plus non-fatal injury crashes since our analysis defined injury crashes as such. To do so, the relative numbers of fatal and non-fatal crashes in 2004, the average of the conversion years (1055 and 73118), were used as weights applied to the fatal and non-fatal injury costs estimated in the first step. The unit aggregate crash cost for a fatal plus injury crash so derived was $110,903.

			Change in PDO/Year			Change in injury/year						Point Estimate $ benefit
LRS_ ID	Install_ Year	After Period Years	Mean	Lower 95% limit	Upper 95% limit	Mean	Lower 95% limit	Upper 95% limit	PDO/year	Injury/year	ALL/year	ALL/After period
98	2002	8	-2.143	-89.613	85.326	-0.112	-4.289	4.065	$ (17,576)	$ (12,402)	$ (29,977)	$ (239,819.92)
102	2002	8	-0.017	0.231	-0.265	0.303	-4.118	4.724	$ (139)	$ 33,572	$ 33,433	$ 267,461.97
104	2004	6	0.100	-5.143	5.344	0.129	-1.126	1.384	$ 823	$ 14,291	$ 15,113	$ 90,680.02
18	2005	5	3.011	-78.208	84.229	0.307	-10.723	11.337	$ 24,688	$ 34,041	$ 58,729	$ 293,646.66
206	2005	5	-0.783	-87.979	86.414	0.279	-7.037	7.595	$ (6,420)	$ 30,915	$ 24,495	$ 122,473.13
13	2006	4	-1.236	239.637	-242.109	1.513	-14.536	17.562	$ (10,135)	$ 167,805	$ 157,670	$ 630,679.96
252	2007	3	0.952	-14.356	16.261	0.496	-1.693	2.686	$ 7,810	$ 55,035	$ 62,845	$ 188,534.58
98	2002	8	-1.264	-90.715	88.187	0.418	-10.655	11.490	$ (10,368)	$ 46,332	$ 35,964	$ 287,711.84
102	2002	8	-0.105	1.433	-1.643	0.392	-5.332	6.116	$ (861)	$ 43,470	$ 42,609	$ 340,875.54
104	2004	6	-1.356	-72.764	70.053	-0.208	-11.876	11.460	$ (11,116)	$ (23,086)	$ (34,201)	$ (205,208.56)
18	2005	5	-2.185	-111.526	107.156	0.421	-15.791	16.633	$ (17,916)	$ 46,718	$ 28,801	$ 144,007.48
206	2005	5	0.313	-242.221	242.847	-0.295	-4.423	3.833	$ 2,570	$ (32,713)	$ (30,143)	$ (150,714.72)
13	2006	4	2.935	-21.454	27.323	0.398	-5.623	6.420	$ 24,064	$ 44,169	$ 68,232	$ 272,929.26
252	2007	3	0.402	-3.053	3.857	0.099	-0.337	0.535	$ 3,296	$ 10,967	$ 14,263	$ 42,788.33
		78								TOTAL	**$ 26,744.17**	**$ 2,086,046**

Cost analysis could not be undertaken because no installation cost data were available for these passing relief lanes.

At an assumed average installation cost of $350,000 for each passing lane, the equivalent uniform annual benefit (EUAB) is less than 1.0:[3]

$$\$350{,}000 * 0.103 * 14\ lanes = \$504{,}700 > \$447{,}833$$

$$\$447{,}833\ /\ \$504{,}700 = 0.887$$

To obtain an EUAB of 1.0 (or better), the maximum installation cost is calculated as:

$$\$447{,}833\ /\ (14\ lanes * 0.103) = \$310{,}564$$

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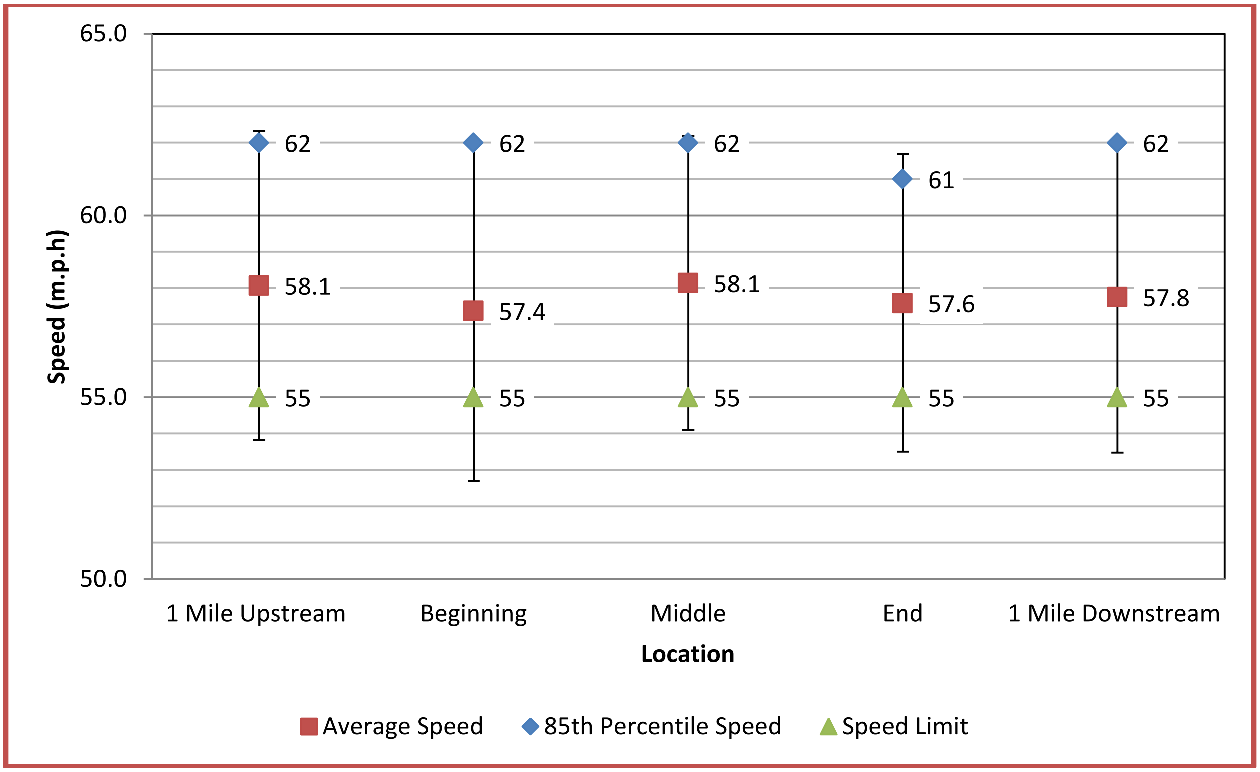
[3] Assumes a 15-year pavement life and a 6% Capital Recovery Factor

8.0 Conclusions

8.1 OPERATIONAL ANALYSIS

The 10 passing relief lane study sites evaluated as part of this analysis are functioning at optimum performance levels. As demonstrated by the level of service analysis, all 10 of the passing lane sites, at the time of the speed studies, were performing at a level of service "A". The study also found that, at the time of the speed studies, drivers were not behaving recklessly or excessively and unsafely exceeding the posted speed limits. The highest speed recorded at any passing lane sites was 76 m.p.h and the lowest speed, 40 m.p.h.

Passing Relief Lane	County	Highway	Length (miles)	Level Of Service
178	Mackinac	US-2	2.9	A
179	Mackinac	US-2	1.0	A
73	Emmet	US-31	1.4	A
75	Emmet	US-31	1.1	A
102	Iosco	M-65	1.6	A
129	Isabella	M-20	1.3	A
145	Kalkaska	M-72	1.3	A
146	Kalkaska	M-72	2.1	A
226	Osceola	M-115	1.6	A
252	Wexford	M-55	2.1	A



The 10 passing relief lanes evaluated as a part of this safety analysis appeared to be operating optimally.

The site visits were performed under non-peak conditions as a function of project time constraints. It is likely that the outcome of this study under peak volume conditions would not closely reflect these findings.

8.2 SAFETY ANALYSIS

CMFs could not be developed from a before-after analysis, given the small number of available sites. Thus, the recommended CMFs are based on cross-sectional analyses of sites with and without passing lanes. These CMFs, which were generally corroborated by the limited before-after results and by expectations based on previous research are summarized in the Table below. They may be used in justifying a passing lane installation program and, with caution, in planning applications to estimate potential safety impacts of future passing lane installations, including the upstream and downstream locations.

The CMFs are applicable to all AADT values and for sites with different geometric characteristics. This is because they were developed from regression models which had the same AADT parameter for sites with and without passing lanes, and which could not include geometric characteristics due to unavailability of such information.

Where it is desired to consider the variation in CMFs with site AADTs in, e.g., prioritizing future installations on existing roads, an SPF-based empirical Bayes procedure is provided.

Crash Type	**CMF**
Non-animal Non-intersection Total crashes/mile-year	0.67
Non-animal Non-intersection Injury crashes/mile-year	0.71[1]
Non-animal Non-intersection Target crashes/mile-year	0.53
Non-animal Non-intersection Day crashes/mile-year	0.60
Non-animal Non-intersection Night crashes/mile-year	0.91[1]
Non-animal Non-intersection Wet crashes/mile-year	0.81[1]
Non-animal Non-intersection Dry crashes/mile-year	0.53
Non-animal Non-intersection Peak crashes/mile-year	0.54
Non-animal Non-intersection Off-Peak crashes/mile-year	0.72[1]

[1] CMF has low confidence level.

9.0 References

Emoto, T.C., and A.D. May (1988). *Operational Evaluation of Passing Lanes in Level Terrain. FinalReport.* Report UCB-RR-88-13. Institute of Transportation Studies, University of California at Berkeley, July 1988.

Fong, H.K. and F.D. Rooney (1990). *Passing Lane Diverge Taper.* Report No. CA-TO-OR-90-1, Division of Traffic Operations, CALTRANS

Frost, E., and J. Morall (1998). *A Comparison and Evaluation of The Geometric Design Practices with Passing Lanes, Wide-Paved Shoulders and Extra-Wide Two-Lane Highways In Canada and Germany,* Paper No. 34, Transportation Research Board (1998)

Gattis, J.L., M.S. Alguire, K. Townsend, and S. Rao (1997). *Rural Two-Lane Passing Headway and Platooning.* Paper presented during 76th annual meeting of Transportation Research Board, January 12-16, 1997, Washington, D.C.

Harwood, D.W., C.J. Hoban, and D.L. Warren (1987). *Low- Cost Methods of Improving Traffic Operations on Two-Lane Roads: Information Guide.* Report No. FHWA-IP-78-2. Federal Highway Administration, Washington, D.C.

Harwood, D.W., and A.D. St. John, *Passing Lanes and Other Operational Improvements on Two-Lane Highways*, Report No. FHWA-RD-85/028, Federal Highway Administration, July 1984.

Morrall, J.F., and L. Blight (1984). *Evaluation of Test Passing Lanes on the Trans-Canada Highway in Banff National Park, Proceedings of International Transport Congress, Roads and Transportation Association of Canada.* Vol. 5, Montreal, September 23-27, 1984, pp B63-B93.

Potts, I., and D.W. Harwood, *Benefits and Design/Location Criteria for Passing Lanes,* Missouri Department of Transportation (2004)

Staba,G.R., H.O. Phung, and A.D. May (1991). *Development of Comprehensive Passing Lane Guidelines, vol.1: Final Report.* Report UCB-ITS-RR-91-1, Institute of Transportation Studies, University of California at Berkeley, January 1991.

Taylor, W.C. and M.K. Jain (1991). *Warrants for Passing Lanes.* Transportation Research Record 1303, Transportation Research Board, National Research Council, Washington, D.C. pp 83-91.

APPENDIX A

Safety Performance Functions for Passing Lanes and Non-Passing Lane Segments

The SPFs developed for passing lane and non-passing lane segments are for non-animal non-intersection crashes only. The model form is:

Crashes/mile-year = $\exp^{(\alpha)}\text{AADT}^{\beta 1}$

SPFs For Passing Lane Sites

Crash Type	α (s.e.)	β1 (s.e.)	k (s.e.)
Non-animal Non-intersection Total crashes/mile-year	-7.3356 (1.6154)	0.8273 (0.1924)	1.6584 (0.2497)
Non-animal Non-intersection Injury crashes/mile-year	-7.7977 (1.5224)	0.7346 (0.1798)	1.1747 (0.2386)
Non-animal Non-intersection Target crashes/mile-year	-10.9987 (1.6952)	1.1313 (0.2004)	1.1237 (0.2178)
Non-animal Non-intersection Day crashes/mile-year	-8.3260 (1.6194)	0.8953 (0.1925)	1.4640 (0.2359)
Non-animal Non-intersection Night crashes/mile-year	-7.8368 (1.5471)	0.7541 (0.1832)	1.2238 (0.2296)
Non-animal Non-intersection Wet crashes/mile-year	-7.3102 (1.6241)	0.7711 (0.1932)	1.5319 (0.2438)
Non-animal Non-intersection Dry crashes/mile-year	-9.5090 (1.6137)	0.9584 (0.1908)	1.2751 (0.2394)
Non-animal Non-intersection Peak crashes/mile-year	-9.4216 (1.6977)	0.8705 (0.1999)	1.1471 (0.2664)
Non-animal Non-intersection Off-Peak crashes/mile-year	-7.5420 (1.6083)	0.8286 (0.1914)	1.5503 (0.2393)

SPFs For Non-Passing Lane Sites

Crash Type	α (s.e.)	β1 (s.e.)	k (s.e.)
Non-animal Non-intersection Total crashes/mile-year	-5.2360 (1.4403)	0.6329 (0.1713)	1.2739 (0.2014)
Non-animal Non-intersection Injury crashes/mile-year	-6.3763 (1.4648)	0.6200 (0.1732)	1.1201 (0.2304)
Non-animal Non-intersection Target crashes/mile-year	-5.8249 (1.3896)	0.5955 (0.1646)	1.0264 (0.1905)
Non-animal Non-intersection Day crashes/mile-year	-4.8837 (1.3881)	0.5557 (0.1649)	1.2173 (0.1979)
Non-animal Non-intersection Night crashes/mile-year	-9.2051 (1.7696)	0.9359 (0.2090)	1.1802 (0.2587)
Non-animal Non-intersection Wet crashes/mile-year	-6.2468 (1.7676)	0.6782 (0.2100)	1.8431 (0.3040)
Non-animal Non-intersection Dry crashes/mile-year	-5.6419 (1.5394)	0.5862 (0.1827)	1.3560 (0.2464)
Non-animal Non-intersection Peak crashes/mile-year	-4.2996 (2.3827)	0.3353 (0.2833)	3.8566 (0.8240)
Non-animal Non-intersection Off-Peak crashes/mile-year	-6.2963 (1.7372)	0.7302 (0.2066)	1.7325 (0.2787)

APPENDIX B

Raw Speed Study Data

A-6

EMMET CO

US-31 (E)

1 Mile Upstream		Beginning		Middle		End		1 mile Downstream	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
64	72	53	56	59	53	60	57	57	53
63	69	54	58	57	56	60	56	57	52
63	65	41	55	56	54	56	54	61	58
63	62	47	55	57	61	55	61	62	54
62	62	48	54	58	56	56	60	63	57
61	62	52	57	57	55	49	55	55	59
61	61	49	51	55	60	59	56	57	60
61	61	57	52	63	56	55	59	61	56
61	61	52	52	56	52	65	60	63	56
60	61	52	55	58	52	60	60	64	55
59	60	51	55	64	57	62	56	57	58
59	60	53	56	61	59	55	55	58	61
59	60	45	53	53	55	60	55	59	51
58	60	50	52	53	67	56	67	57	65
58	60	54	49	58	60	57	60	52	55
58	60	46	57	57	58	53	56	58	50
57	60	56	51	55	51	60	51	58	55
57	59	54	48	60	57	60	56	60	58
57	59	50	60	60	59	60	56	57	56
57	59	61	52	58	60	57	55	57	55
57	59	55	51	58	56	55	64	57	60
57	58	57	57	63	55	61	53	57	55
57	58	55	57	50	55	63	56	57	48
57	58	60	52	55	56	60	53	54	52
57	58	54	59	58	65	57	60	57	58
57	58	58	55	57	60	60	60	54	55
57	58	54	61	62	54	55	59	63	55
56	58	53	65	53	57	59	55	56	55
56	58	62	48	58	55	56	53	57	61
56	58	55	53	49	60	54	60	57	58
55	57	50	56	53	58	56	56	54	60
55	57	57	55	66	57	57	62	55	62
55	57	57	47	62	59	56	56	55	62
55	57	56	53	49	60	52	56	61	57
54	57	57	57	56	57	52	56	54	57
54	57	63	49	53	53	62	60	54	57
54	57	53	47	57	55	56	59	57	59
54	57	55	61	60	56	60	60	51	56
53	57	52	53	56	58	50	60	53	59

52	57	55	41	62	57	53	56	55	72
51	57	48	54	60	61	49	61	54	60
51	57	55	51	56	55	55	66	58	69
50	56	61	53	61	56	56	56	52	61
50	56	56	52	62	53	53	61	59	61
49	55	54	49	59	56	63	60	49	55
	55	51	55	60	53	54	56	58	53
	55	57	65		58	65	52	57	59
	55	55	60		55	63	59	61	58
	55	50	54		58	59	59	59	58
	55	56			54	57		55	58
	55	57			65			58	57
	55	58			63				58
	55	53			59				51
	55	55			57				57
	54								62
	54								60
	54								60
	53								60
	53								58
	52								
	52								
	51								
	50								
	50								
	48								

EMMET CO

US-31 (W)

1 Mi Upstream (North)		End (North)		Middle		End (South)		1 Mile Downstream (South)	
NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
62	57	57	55	55	58	60	60	61	60
55	56	55	65	61	57	56	56	53	58
60	52	63	60	54	55	55	57	53	51
56	52	56	62	54	63	55	53	58	57
57	62	58	55	57	56	56	60	57	59
53	56	64	60	61	58	65	60	55	56
60	60	61	55	61	64	60	60	60	53
60	63	53	61	55	55	54	57	60	57
57	55	53	53	53	56	57	55	49	60
54	60	58	59	59	59	56	61	55	56
63	56	52	58	58	60	57	63	56	62
56	57	52	58	59	60	55	60	53	56
57	53	57	58	56	56	67	56	63	54
57	60	59	57	58	55	60	55	54	61
54	60	55	58	64	60	56	56	65	60
57	57	67	49	61	57	51	49	63	49
59	55	60	59	53	60	56	59	59	47
55	55	58	55	53	55	56	55	57	61
67	61	51	55	58	59	55	65	51	53
60	54	57	55	56	56	56	60	65	41
58	54	54	61	54	56	60	62	59	54
51	57	56	58	61	53	59	55	60	51
57	61	53	60	56	63	60	53	57	53
54	61	60	62	55	54	60	60	53	52
57	55	60	54	60	65	56	60	49	53
54	53	59	54	56	63	61	59	59	58
63	59	55	57	52	59	60	55	55	65
56	58	53	61	52	57	56	53	65	62
57	59	60	61	57	53	61	60	60	62
57	56	56	52	59	56	62	56	62	62
54	54	62	52	55	53	59	62	55	61
55	56	56	57	67	58	60	59	60	61
55	57	56	59	58	55	52	60	56	61
61	56	56	55	58	58	52	57	57	60
54	52	60	67	63	54	62	53	51	60
54	52	59	60	50	65	56	55	53	57

57	62	60	58	55	63	60	56	45	54
54	56	60	51	58	59	50	66	50	63
63	60	54	57	57	57	53	56	54	56
56	50	55	54	62	57	49	61	46	57
57	53	55	53	53	55	61	60	60	57
57	59	61	41	58	60	60	56	60	55
54	55	54	54	49	58	60	52	56	50
55	61	55	51	53	57	60	59	57	55
54	65	55	53	66	64	60	59	60	58
55	48	55	52	62	53	60	54	55	56
55	53	61	57	49	56	60	56	59	55
61	56	58	54	58		54	57	56	60
54	55	65		57		41	56	54	55
54	47	62		61		47		56	48
	53	62		55		48		57	52
	57	61		56		52		56	
	49	55				49			
						57			
						52			
						52			

IOSCO CO.									
1 Mi Upstream (North)		End (North)		Middle		End (South)		1 Mile Downstream (South)	
NB	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**	**NB**	**SB**
63	72	66	66	65	65	63	64	62	66
62	70	63	61	65	64	63	61	62	66
62	69	62	61	64	64	63	60	61	65
61	69	62	61	63	64	61	60	61	65
61	68	62	61	63	63	60	60	60	64
60	66	61	61	62	63	60	60	60	63
60	66	60	61	62	62	60	59	60	63
60	65	60	60	61	62	59	59	60	62
60	65	60	60	60	62	59	59	59	62
59	64	60	60	60	61	59	59	59	61
59	63	60	60	60	61	59	59	59	61
59	62	59	60	60	61	58	59	58	61
59	62	59	60	59	60	58	58	58	61
59	61	59	60	59	60	58	58	57	61
58	61	58	60	59	60	58	57	57	61
58	60	57	59	59	60	58	56	57	60
58	60	57	59	59	60	57	56	58	59
57	60	57	59	59	60	57	56	58	59
57	60	57	59	59	60	57	56	58	59
57	59	56	59	58	60	56	56	58	59
57	59	56	59	58	60	56	56	58	59
56	59	56	59	58	59	56	56	58	59
55	59	56	59	57	59	56	56	58	59
55	59	55	58	57	59	55	56	58	58
55	59	55	58	57	59	55	55	55	58
55	59	55	58	57	59	55	55	55	58
55	58	55	58	57	59	55	54	55	58
55	58	55	58	56	59	55	54	55	58
54	58	54	58	56	59	55	54	54	57
53	58	53	58	56	59	55	54	54	57
53	58	52	58	55	59	55	53	54	57
53	58	52	57	55	58	55	53	54	57
50	57	52	57	55	58	54	52	54	57
49	57	52	57	55	58	54	50	54	56
49	57	52	57	55	58	54		53	56
48	57	51	57	54	58	53		53	56
48	57	51	57	54	58	53		53	56
47	57	50	57	54	58	53		53	56

45	57	50	56	54	57	52		53	55
	57	50	56	54	57	52		53	55
	57	49	56	53	56	52		52	55
	57		55	52	56	51		50	55
	57		55	52	55			50	55
	56		55	52	55				55
	56		55	50	55				54
	56		55		55				54
	56		55		55				54
	56		55		55				54
	55		55		55				54
	55		54		55				54
	55		54		55				53
	55		54		55				53
	55		54		55				52
	55		53		54				52
	55		53		53				52
	54		53		53				51
	53		53		52				50
	53		52		52				49
	53		50		50				48
	52		50		50				
	52		47		50				
	51		47		40				
	50								

ISABELLA CO									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
73	67	68	68	70	69	70	68	76	71
70	67	67	66	68	65	68	65	69	71
67	62	67	65	68	64	67	64	68	70
67	62	67	63	65	64	64	62	66	69
64	61	66	63	65	64	61	62	65	67
63	61	65	62	65	63	61	61	65	64
62	61	65	62	65	63	61	61	65	63
62	60	64	61	63	63	61	61	64	62
62	60	64	60	62	62	61	60	63	62
61	60	63	60	62	62	60	60	63	62
61	60	63	60	62	62	60	60	63	62
61	59	62	60	62	62	60	60	63	62
61	59	62	59	62	62	60	59	62	62
60	59	62	59	61	61	59	59	62	62
60	59	62	59	61	61	59	59	61	61
60	58	62	59	61	61	59	58	61	61
60	58	62	59	61	61	59	58	61	61
60	58	62	59	60	61	58	58	61	61
60	58	61	58	60	60	58	58	60	60
60	58	61	58	60	60	58	58	60	60
60	58	61	58	60	60	58	58	60	59
60	58	61	58	59	60	58	57	59	59
60	57	61	58	59	60	58	57	59	59
60	57	61	58	59	59	58	57	59	59
59	57	60	58	59	59	57	57	59	58
59	57	60	58	58	59	57	56	58	58
59	57	60	57	58	59	57	56	58	57
59	57	60	57	58	59	57	56	58	57
59	56	60	57	58	58	57	56	58	57
59	56	59	56	58	58	57	56	58	57
59	56	59	56	58	58	56	56	57	57
58	56	59	56	58	57	56	56	57	57
58	55	59	56	58	57	56	55	57	57
58	55	59	56	58	57	56	55	57	57
58	55	58	55	58	57	56	55	57	57
58	54	58	55	58	57	56	55	56	57
58	54	58	55	57	56	56	55	56	56

58	54	58	55	57	56	56	54	56	56
58	53	58	54	57	56	56	54	56	56
57	53	58	54	57	56	55	54	55	56
57		58	53	56	55	55	54	55	56
57		58	52	56	55	55	53	54	56
57		58	46	56	53	55	53	54	55
57		58	45	56	53	55	52	54	55
57		57		55	52	55		53	55
56		57		55	51	55		52	55
56		57		55	50	55			54
56		57		55		54			54
56		57		54		54			53
56		57		52		54			52
56		56				54			
56		56				54			
56		56				54			
55		55				53			
55		55				53			
55		54				53			
55		54							
55		53							
54		51							
54									
53									
52									
50									
48									

OSCEOLA CO									
1 Mile Upstrem (North)		End (North)		Middle		End (South)		1 Mile Downstream (South)	
NB	SB	NB	SB	NB	SB	NB	SB	NB	SB
75	73	71	73	70	71	70	69	70	73
67	73	70	71	69	70	70	67	69	73
66	68	65	70	69	70	70	67	65	70
66	66	65	68	68	70	68	67	63	68
66	65	65	67	66	69	67	67	63	67
63	65	64	67	66	68	66	67	62	66
63	65	64	66	65	68	66	65	62	65
63	65	63	66	65	68	65	65	62	65
63	64	63	66	65	67	65	64	61	65
63	64	63	65	65	67	64	63	61	65
63	64	63	65	65	67	63	63	61	65
62	64	63	65	65	66	63	63	61	65
62	63	62	64	65	66	63	62	61	64
62	63	61	64	65	66	63	62	61	64
62	63	61	64	65	65	63	62	60	64
62	63	61	64	64	65	62	62	60	63
62	63	61	64	64	65	62	62	60	63
61	63	61	64	64	65	62	62	60	63
61	63	60	64	64	65	62	62	60	63
61	63	60	63	63	64	62	61	60	62
61	62	60	63	63	64	61	61	60	62
61	62	59	63	63	64	61	61	60	62
61	62	59	63	63	64	61	61	60	61
61	62	59	63	63	64	61	60	60	61
61	62	59	63	63	64	61	60	60	61
60	62	59	62	62	64	61	60	59	61
60	62	59	62	62	64	61	60	59	61
60	62	58	62	62	63	61	60	59	61
60	62	58	62	62	63	61	60	59	61
59	62	58	62	62	63	60	60	58	61
59	62	58	62	62	63	60	60	58	61
59	62	58	62	62	63	60	60	58	60
59	62	58	62	61	62	60	59	58	60
59	61	58	61	61	62	60	59	58	60
59	61	58	61	61	62	60	59	57	60
59	61	57	61	61	62	60	59	56	59
59	61	57	61	61	62	60	59	56	59
59	61	57	60	61	62	59	59	55	59
59	61	57	60	61	62	59	59	55	59

58	61	57	60	60	62	59	59	55	58
58	61	56	60	60	62	59	59	55	58
58	61	56	60	60	61	59	59	53	58
58	61	56	60	60	61	59	59	50	58
58	61	55	60	60	61	59	58		58
58	60	55	60	60	61	59	58		57
58	60	55	60	60	61	59	58		57
58	60	55	60	60	61	58	58		57
58	60	55	60	60	61	58	58		57
58	60	55	60	59	61	58	58		57
58	60	55	60	59	61	58	58		57
58	60	54	60	59	61	58	58		56
58	60	54	59	59	61	58	57		55
58	60	54	59	59	60	58	57		55
57	60	53	59	59	60	58	57		54
57	59	52	59	59	60	57	57		53
57	59	49	59	59	60	57	57		48
56	59		59	59	60	57	56		
56	59		59	59	60	57	56		
56	59		59	59	60	57	56		
56	59		58	59	60	57	56		
56	58		58	59	60	57	56		
56	58		58	58	59	57	56		
56	58		58	58	59	56	56		
56	58		58	58	59	56	55		
55	58		58	58	59	56	55		
55	58		58	58	59	56	55		
55	58		57	58	59	55	54		
55	58		57	58	59	54	53		
54	57		57	58	59	54	53		
54	57		57	58	59	54	53		
53	57		57	57	59	54	52		
53	56		57	57	58	53	52		
52	56		57	57	58	52			
52	56		57	57	58				
52	56		57	57	58				
	56		57	56	58				
	56		57	56	58				
	56		56	56	57				
	55		56	56	57				
	55		56	54	57				
	55		56	54	57				
	55		56	54	56				

55	56	54	56
54	55	53	56
54	55	52	56
54	55		56
51	55		56
	55		55
	53		55
			55
			55
			55
			54
			54
			54
			54
			54
			53
			52

WEXFORD CO									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
65	73	68	71	69	66	72	64	70	68
64	70	68	69	67	64	67	63	65	67
63	70	68	68	65	64	65	63	65	67
63	68	67	67	64	63	64	62	65	66
61	67	66	66	64	62	64	62	65	66
61	66	65	66	64	62	64	62	64	65
61	66	64	66	64	61	64	62	64	64
60	66	64	64	63	61	64	62	64	64
60	66	64	64	63	61	64	61	64	64
60	65	63	64	62	61	64	61	64	63
59	65	63	64	62	61	62	61	64	63
59	65	62	63	62	60	62	60	63	63
59	65	62	63	62	60	62	60	63	62
59	64	62	63	62	60	62	60	63	62
59	64	62	62	61	60	62	60	63	62
58	63	62	62	61	60	62	60	62	62
58	63	61	62	61	60	62	60	62	61
58	63	61	62	61	60	61	60	62	61
58	63	61	62	61	60	61	60	62	61
58	63	61	62	61	60	61	59	61	61
57	62	61	62	60	60	61	59	61	61
57	62	60	61	60	60	61	59	61	60
57	62	60	60	60	59	61	59	61	60
57	62	60	60	60	59	60	59	60	60
57	62	60	60	60	59	60	59	60	60
57	62	60	60	60	59	60	59	60	60
57	62	59	60	59	59	60	59	60	60
57	62	59	60	59	59	60	58	60	60
57	62	59	60	59	59	60	58	60	60
57	62	59	60	59	59	60	58	60	60
57	62	59	60	59	58	60	58	60	57
57	62	58	60	58	58	60	58	60	57
57	61	58	60	58	58	59	58	60	57
56	61	58	60	58	58	59	58	59	57
56	61	58	60	58	58	59	58	59	56
56	61	58	60	57	58	59	57	59	56
56	61	58	59	57	58	59	57	59	56
56	61	58	59	57	58	59	57	59	56

56	61	58	59	57	58	59	57	59	56
55	61	57	59	57	58	58	57	58	56
55	61	57	59	57	58	58	56	58	56
55	61	57	59	56	58	58	56	58	56
55	60	57	58	56	58	58	56	57	56
55	60	56	58	56	58	58	56	57	55
55	60	56	57	56	57	58	55	57	55
55	60	56	57	56	57	57	55	57	52
55	60	55	57	55	57	57	55	56	52
54	60	54	57	55	57	57	55	56	52
54	60	54	56	55	57	57	55	55	
54	59	53	56	55	57	56	54	55	
54	59	53	55	54	57	56	54	54	
54	58		55	54	57	56	54	52	
54	58		54	54	57	56	52	50	
53	58		53	54	57	56	52		
53	58		53	53	57	56	51		
53	57		51	53	57	56	41		
53	57			50	56	55			
53	57				56	55			
53	56				56	55			
52	56				56	55			
52	56				55	55			
50	55				55	55			
50	55				55	55			
49	55				54	54			
48	55				54				
46	54				53				
	54				53				
	52				52				
	51				52				
					52				
					51				
					51				
					49				

KALKASKA CO									
M-72 (E)									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
66	63	59	48	56	56	57	57	55	67
63	63	56	53	55	65	51	58	60	60
62	63	54	56	60	60	48	57	54	58
62	61	56	55	55	54	60	55	58	51
62	60	57	47	48	57	52	63	54	57
61	60	56	53	52	55	51	56	53	59
60	60	52	57	58	60	57	58	62	60
60	59	52	49	55	58	57	64	55	56
60	59	62	47	55	57	52	61	50	55
60	59	56	61	55	59	59	53	57	55
60	59	60	53	61	60	56	53	57	56
59	58	50	41	58	57	52	58	56	59
70	58	53	54	65	53	52	57	57	56
69	58	49	51	62	49	57	57	63	54
69	58	55	53	62	59	59	54	49	56
68	58	56	52	62	55	55	63	47	57
66	57	53	53	61	65	67	56	61	56
66	57	63	54	61	60	60	57	53	52
65	57	54	41	61	62	58	57	41	52
65	56	65	47	61	55	51	54	54	62
65	56	63	48	60	60	57	55	51	56
65	56	59	52	60	56	54	55	53	60
65	56	57	49	60	57	57	61	52	50
65	60	51	57	60	53	54	54	57	53
65	60	65	52	60	60	63	54	54	49
65	60	55	52	60	60	56	57	55	59
59	60	50	51	57	57	57	56	55	55
58	60	55	53	60	54	57	52	61	65
58	60	58	45	55	63	54	52	54	60
58	60	56	50	59	56	55	57	55	62
58	60	55	54	56	57	55	59	55	55
58	59	60	46	54	57	61	55	55	60
58	59	55	60	56	54	54	67	61	55
58	59	48	60	57	55	54	60	58	61
58	59	52	56	56	55	57	58	65	54
58	59	58	55	52	61	61	51	62	54
57	59	55	56	52	54	61	57	62	57

57	59	55	49	62	54	55	59	61	61
57	59	55	59	56	57	53	60	55	61
57	59	61	55	60	51	59		53	55
57	58	58	65	63	53	58		59	55
57	58	60	60	53	55	58		58	55
57	58	62	62	55	54	58		58	61
57	58	62	55	52	58	57		58	58
57	58	57	60	55	52	58		57	60
57	58	57		48		51		58	62
57	58	57		55		57		51	62
57	58	59		61		53		54	57
56	57	56		56		56		51	57
56	57	59		54		53		57	57
55	57	72		51		58		55	
55	57	60		57		55		50	
55	57	69		55		58		50	
55	57	61		50				55	
55	57	61		56				58	
55	57	55		57				56	
55	56	53		58				55	
55		59		53				60	
55		58		55				55	
		58							
		58							

KALKASKA CO									
MK-72 (W)									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
56	56	56	47	53	49	53	55	67	65
60	59	54	48	56	57	57	60	60	60
50	56	56	52	55	51	49	55	58	54
53	54	57	49	47	48	47	48	51	57
49	56	56	57	53	60	61	52	57	55
55	57	52	52	57	52	53	58	59	60
56	56	52	52	62	51	41	55	60	58
53	52	62	51	62	57	54	55	56	57
63	52	56	53	62	57	51	55	55	48
54	62	60	45	61	52	53	61	55	52
65	56	50	50	61	59	52	54	57	49
63	60	53	54	61	55	58	50	51	57
52	56	57	46	61	61	57	61	48	52
52	59	53	56	60	65	59	55	60	52
57	57	60	56	60	48	60	57	52	51
59	56	60	57	60	53	57	55	51	53
55	57	57	57	60	56	53	60	57	45
67	58	54	54	60	56	49	54	57	50
60	57	63	55	60	55	59	58	52	54
58	55	56	55	57	60	55	54	59	56
51	63	57	61	60	55	65	53	56	58
57	56	53	54	55	48	60	62	41	55
54	58	56	54	59	52	62	55	54	55
60	64	54	57	50	58	55	50	51	54
56	61	61	56	53	55	60	57	53	57
51	53	56	52	49	55	56	59	52	51
56	53	55	52	59	55	57	57	57	63
56	58	60	57	55	61	57	51	54	50
55	57	56	59	65	58	54	65	55	55
64	55	52	57	60	65	55	55	55	58
53	60	52	56	62	57	55	50	61	57
56	60	57	54	55	55	60	55	54	62
53	58	60	61	55	63	60	58	55	53
60	58	60	60	56	56	56	56	55	58
60	60	57	54	59	58	55	55	59	49
59	62	55	58	60	64	56	53	56	53
55	55	61	54	60	61	49	54	54	66

65	60	63	53	56	53	59	41	56	53
60	56	60	62	55	53	55	53	57	52
54	57	57	55	55	58	65	54	56	57
57	53	60	50	67	57	60	41	52	58
55	60	55	57	48	57	58	47	52	55
60	57	59	57	53	54	51	51	62	60
58	54	56	56	56	63	57	57	60	55
57	63	54	57	55	59	59	57	54	
56	56	56	63	47	55	60	52	58	
65		57	49	53	67	56	59	54	
60		52	47	60		55	56	53	
54		52	61	56		55	41	62	
57		55	53	62		56	54		
55		55							
60		56							

MACKINAC CO									
US-2 (E)									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
55	51	41	47	57	57	59	54	57	57
60	62	56	54	54	57	55	59	64	52
55	60	56	55	60	62	53	54	55	53
59	57	53	55	54	49	63	50	57	57
57	47	55	53	54	57	55	54	61	59
60	67	59	60	54	53	55	54	57	55
55	47	55	57	54	49	55	61	56	60
56	55	54	56	62	58	58	60	56	60
55	55	54	57	55	60	59	62	60	56
55	53	59	55	56	62	59	57	57	65
56	54	60	58	54	60	56	52	59	55
67	49	56	58	52	58	56	58	52	60
58	62	58	59	56	60	60	61	63	55
58	55	55	56	62	56	55	57	57	56
53	56	54	62	57	57	65	55	54	57
57	52	54	51	57	58	55	60	54	59
56	55	60	52	54	53	55	56	60	60
56	55	57	53	60	53	60	57	63	55
56	50	52	59	60	57	57	60	60	56
60	53	50	61	56	56	56	72	61	56
56	48	57	55	65	50	56	59	61	60
60	52	56	60	55	49	51	52	58	49
57	65	67	58	60	58	56	54	57	63
61	54	54	56	55	58	53	61	55	55
49	56	60	57	56	57	60	57	61	52
66	55	50	41	57	54	56	55	61	61
58	49	55	65	59	55	55	47	62	61
53	53	53	41	60	60	53	61	57	63
53	41	57	51	55	65	60	60	58	58
60	50	65	54	56	60	55	58	58	53
55	61	55	52	56	58	63	57	56	53
45	52	60	62	60	53	55	57	57	59
60	50	51	58	49	63	51	56	57	61
64	59	55	62	63	61	50	52	57	52
57	57	57	58	55	55	53	53	56	57
53	60	58	60	52	64	58	59	59	54
52	55	57	61	61	65	57	56	57	55

55	55	46	58	53	69	55	62	56	58
59	56	56	48	41	56	57	51	60	55
54	58	60	55	50	57	56	56	52	57
62	57	53	48	61	54	57	55	60	56
55	51	59	55	52	58	57	60	61	55
56	56	54	60	50	59	54	59	53	51
57	54	57	57	59	56	55	55	63	56
55	54	60	65	57	58	60	60	60	57
51	50	55	56	61	55	60	41	45	56
64	52	59	53	60	59	52	57	53	63
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67	56	60	55	58	59	57	58	54	59
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	58	54	55	60	53	52	60	55	52
		60	58	57	58	63	61	48	61
			65	63		56		56	
						59		60	
						57		62	
						59		53	
						56			
						55			

MACKINAC CO									
US-2 (W)									
1 Mi Upstream (East)		End (East)		Middle		End (West)		1 Mile Downstream (West)	
EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
58	53	58	57	60	52	61	55	60	55
60	59	60	59	58	54	62	58	58	51
62	58	59	59	65	60	56	69	61	59
59	58	57	57	58	58	58	61	58	59
59	58	67	55	57	60	55	58	55	62
62	53	62	59	57	57	59	58	60	60
52	57	68	55	55	61	59	60	58	55
65	57	62	57	58	54	57	63	59	59
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56	62	45	58	57	55	59	65	57	54
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53	55	62	60	59	56	59	58	52	55
57	71	56	63	56	58	56	65	60	56
68	56	46	63	58	57	53	57	55	56
61	62	62	56	59	61	58	61	58	63
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59	62	60	56	56	55	60	63	59	66
70	61	59	56	58	57	59	62	54	59
61	61	58	67	61	60	56	64	60	53
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62	55	65	57	56	62	71	52	62	63
59	57	60	58	58	54	59	54	54	56
58	52	60	59	68	64	56	56	58	54
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66	67	60	68	60	54	60	61	48	67
58	56	55	56	60	58	62	62	60	54
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58	61	59	63	53	55	59	57	60	57
60	50	58	65	68	58	56	57	58	68
54	59	67	60	57	61	58	60	54	56
61	61	63	61	65	59	59	67	58	59
64	60	61	61	67	60	70	57	59	
55	62	52	62	60	58	56	53	57	
61	67	56	62	54	57		53	57	
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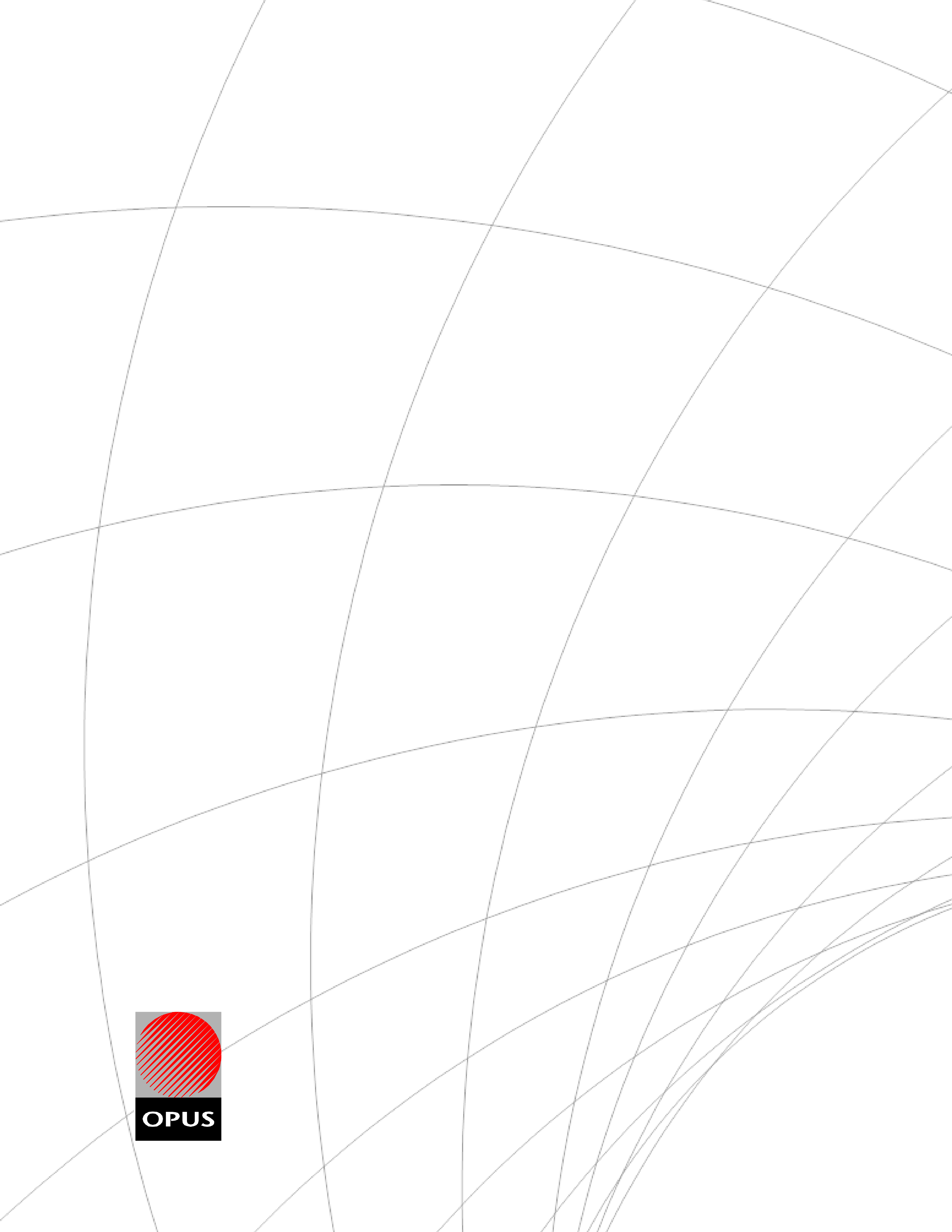
	67	58	58	59	61			57	
	58	57	59	54	62			55	
		63		60	58			62	
		58		56	60			56	
		61		56	53				
				55	58				
				54	57				
				53					
				56					
				56					



OPUS