Final Report

Michigan Urban Trunkline Intersections Safety Performance Functions (SPFs) Development and Support

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16. Abstract

This study involves the development of safety performance functions (SPFs) for signalized and stop-controlled intersections located along urban and suburban arterials in the state of Michigan. Extensive databases were developed that resulted in the integration of traffic crash information, traffic volumes, and roadway geometry information. After these data were assembled, an exploratory analysis of the data was conducted to identify general crash trends. This included assessment of the base models provided in the Highway Safety Manual (HSM), as well as a calibration exercise, which demonstrated significant variability in terms of the goodness-of-fit of the HSM models across various site types. Michigan-specific SPFs were estimated, including simple models that consider only annual average daily traffic (AADT). More detailed models were also developed, which considered additional geometric factors, such as posted speed limits, number of lanes, and the presence of medians, intersection lighting, and right-turn-on-red prohibition. Crash modification factors (CMFs) were also estimated, which can be used to adjust the SPFs to account for differences related to these factors. Separate SPFs were estimated for intersections of only two-way streets and for those where at least one of the intersecting streets was one-way as the factors affecting traffic safety were found to vary between these site types. Severity distribution functions (SDFs) were also estimated, which can be used to predict the proportion of injury crashes which result in different injury severity levels. The SDFs may include various geometric, operation, and traffic variables that will allow the estimated proportion to be specific to an individual intersection. Ultimately, the results of this study provide MDOT with a number of methodological tools that will allow for proactive safety planning activities, including network screening and identification of high-risk sites. These tools have been calibrated such that they can be applied at either the statewide level or within any of MDOT's seven geographic regions, providing additional flexibility to accommodate unique differences across the state. The report also documents procedures for maintaining and calibrating these SPFs over time, allowing for consideration of general trends that are not directly reflected by the predictor variables.

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LIST OF ACRONYMS

3SG	Three-leg signalized
3ST	Three-leg minor leg stop-controlled
4SG	Four-leg signalized
4ST	Four-leg minor leg stop-controlled
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADA	Americans with Disabilities Act
CMF	Crash Modification Factor
DOT	Department of Transportation
EB	Empirical Bayes
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
GHSA	Governors Highway Safety Association
GIS	Geographic Information System
HSIP	Highway Safety Improvement Program
HSIS	Highway Safety Information System
HSM	Highway Safety Manual
IHSDM	Interactive Highway Safety Design Model
MAP-21	Moving Ahead for Progress in the 21st Century Act
MCGI	Michigan Center for Geographic Information
MDOT	Michigan Department of Transportation
MiGDL	Michigan Geographic Data Library
MMUCC	Model Minimum Uniform Crash Criteria
MPO	Metropolitan Planning Organization
MSP	Michigan State Police
MTA	Median Turn-Around
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
PDO	Property Damage-Only
PR	Physical Road
QA/QC	Quality Assurance/Quality Control
RAP	Research Advisory Panel
RTM	Regression to Mean
RTOR	Right Turn on Red
SDF	Severity Distribution Function
SPF	Safety Performance Function
TRB	Transportation Research Board
TWLTL	Two-way Left-Turn Lane

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EXECUTIVE SUMMARY

Problem Statement

Federal legislation requires all states to have in place a Highway Safety Improvement Program (HSIP) that is data-driven and allows for proactive policies and programs aimed at improving highway safety by reducing the frequency and severity of traffic crashes. Given the prevailing focus on implementing roadway safety practices that are data-driven, there has been much research focused on gaining a more thorough understanding of how various factors affect the frequency, type, and severity of traffic crashes at specific roadway sites, such as intersections. Gaining a better understanding of these complex relationships provides traffic safety professionals with the ability to develop well-informed, targeted policies and programs to reduce traffic crashes and the resultant injuries and fatalities.

An important tool in this process is the American Association of State Highway and Transportation Officials' (AASHTO) *Highway Safety Manual* (*HSM*). Part C of the *HSM* provides a series of predictive models that can be utilized to estimate the frequency of traffic crashes on specific road facilities as a function of traffic volumes, roadway geometry, type of traffic control, and other factors. These models, referred to as safety performance functions (SPFs), are useful for estimating the safety impacts of site-specific design alternatives or for prioritizing candidate locations for safety improvements on a network basis. As a part of this process, these SPFs can also be integrated with decision support tools, such as *SafetyAnalyst* and the *Interactive Highway Safety Design Model* (*IHSDM*).

While the SPFs presented in the *HSM* provide a useful tool for road agencies, it is recommended that these functions are either calibrated for local conditions or re-estimated using local data to improve their accuracy and precision. A variety of states have conducted research to this end, though research has shown that the accuracy of the SPFs from the *HSM* vary considerably from state to state, a result that may be reflective of differences in geography, design practices, driver behavior, differences in crash reporting requirements, or other factors. The variation in the performance of HSM SPFs across jurisdictions motivates the need for Michigan-specific SPFs, which will allow the Michigan Department of Transportation (MDOT) to more efficiently invest available safety resources.

Study Objectives

Ultimately, this project aimed to develop a uniform and consistent approach that can be applied to estimate the safety performance of urban trunkline intersections at the aggregate (i.e., total crash) level, as well as to within specific crash types and crash severity categories. The product of this research provides important guidance to allow MDOT to make informed decisions as to planning and programming decisions for safety projects. The specific study objectives addressed as a part of this project in order to meet this goal are as follows:

1. Review and summarize previous and existing efforts to generate Safety Performance Function(s) for agencies.
2. Identify sites for the following urban intersection types from existing Safety Analyst output:
    a. Urban Trunkline Three-Leg Minor Road Stop Control
    b. Urban Trunkline Three-Leg Signalized
    c. Urban Trunkline Four-Leg Minor Road Stop Control
    d. Urban Trunkline Four-Leg Signalized
3. Develop SPFs for each of the urban intersection types listed above.
4. Define a maintenance cycle and process for updating SPFs

Data Collection

In order to develop a series of SPFs that will provide an accurate prediction of the safety performance of urban trunkline intersections, it was imperative to develop a robust high-quality database, which includes traffic crash information, traffic volumes, and roadway geometry. These data were obtained from the following sources:

- Michigan State Police Statewide Crash Database;
- MDOT SafetyAnalyst Calibration File;
- Michigan Geographic Data Library (MiGDL) All Roads File;
- MDOT SafetyAnalyst Annual Average Daily Traffic File; and
- MDOT Sufficiency File:

In addition to the intersection location, traffic volume, and crash data obtained from these sources, extensive data collection was conducted in order to obtain additional information about the geometric characteristics of each intersection, including:

- Number of intersection legs
- Type of traffic control
- AADT for major and minor road
- Number of approaches with left-turn lanes
- Number of approaches with right-turn lanes
- Presence of lighting
- One-way or two-way traffic
- Intersection sight distance
- Intersection skew angle
- Presence/type of left-turn phasing
- Pedestrian volumes
- Presence of bus stops
- Presence of on-street parking
- Presence of median

These data were aggregated to develop a comprehensive database of intersections over the five-year study period from 2008 to 2012. The final sample was comprised of the following number of locations by site type:

- 353 three-legged stop-controlled (3ST) intersections;
- 350 four-legged stop-controlled (4ST) intersections;
- 210 three-legged signalized (3SG) intersections; and
- 349 four-legged signalized (4SG) intersections.

Data Analysis

After the data were assembled, an exploratory analysis of the data was conducted separately for each intersection type to identify general crash trends using Michigan-specific data. Subsequently, a series of analytical tools were developed, which will allow MDOT to predict the frequency of crashes at each of the four types of intersections noted above.

First, the base SPFs from the Highway Safety Manual (HSM) were applied to the Michigan data. A calibration exercise illustrated that the models, without calibration, provided inconsistent fit across site types, crash types, and severity levels. After the calibration exercise, a series of Michigan-specific SPFs were developed. These SPFs included a series of simple models which consider only annual average daily traffic (AADT) estimates for the major and minor roads. As MDOT collects AADT for its trunkline system on a regular basis and has developed models to estimate AADT for local cross-streets, these AADT-only models provide a viable short-term tool for use in high-level safety planning activities.

More detailed SPFs were also estimated that considered the full level of detail resulting from the large-scale data collection activities. These statistical models may be utilized to account for the effects of a wide range of factors including traffic volumes, roadway geometry, and other effects. Separate SPFs were estimated for intersections of only two-way streets and for those where at least one of the intersecting streets was one-way as the factors affecting traffic safety were found to vary between these site types. The SPFs can be used to estimate the average crash frequency for stated base conditions, which are as follows:

- No left-turn lanes on the major road;
- No right-turn lanes on the major road;
- Skew angle of 0º; and
- No intersection lighting present.

Crash modification factors (CMFs) are then used to adjust the SPF estimate when the attributes of the subject site are not consistent with the base conditions. Several variables were incorporated in the development of the SPFs and CMFs including AADT, MDOT region, median presence, intersection lighting presence, number of lanes, posted speed limit, right-turn-on-red prohibition, and left-turn-lane presence.

The SPFs can be used to predict the vehicle-involved crash frequency (i.e. single- and multi-vehicle crashes), as well as the number of pedestrian- or bicycle-related crashes as a proportion of the vehicle-only crashes. Similar proportion data are provided for collision types, which can be used to disaggregate multi-vehicle crashes into various categories (e.g. rear-end, head-on, angle etc.).

In addition to the Michigan-specific SPFs and CMFs, severity distribution functions (SDFs) were also developed for predicting the proportion of injury crashes that result in different injury severity levels. Due to the small number of fatal crashes, K and A crashes were combined for purpose of SDF development. The SDFs can be used with the SPFs to estimate the expected crash frequency for each severity category. The SDFs may include various geometric, operation, and traffic variables that will allow the estimated proportion to be specific to an individual intersection.

Conclusions

Ultimately, the results of this study provide MDOT with a number of methodological tools for performing proactive safety planning activities such as network screening and identification of sites with the largest potential for safety improvement. These tools have been calibrated such that they can be applied at either the statewide level or within any of MDOT's seven geographic regions, providing additional flexibility to accommodate unique differences across the state.

In addition to these tools, this study also provides important insights into various aspects of MDOT's existing data systems. This included the identification of various quality assurance/quality control issues, as well as the development of methods for effectively integrating available resources for safety analyses.

This report also documents procedure for maintaining and calibrating these SPFs over time. Calibration will allow for MDOT to account for yearly changes in traffic volumes and general trends in crashes over time that are not directly reflected by the predictor variables (e.g., recent declines in crashes at the statewide level). As MDOT continues to build its data system, the use of additional geographically-referenced geometric, operational, and traffic control data will allow for further refinements to these analytical tools.

1.0 INTRODUCTION

The *Moving Ahead for Progress in the 21st Century Act* (*MAP-21*) requires all states to have in place a Highway Safety Improvement Program (HSIP) that "emphasizes a data-driven, strategic approach to improving highway safety on all public roads that focuses on performance" [*1*]. Given the prevailing focus on implementing roadway safety practices that are data-driven, there has been much research focused on gaining a more thorough understanding of how various factors affect the frequency, type, and severity of traffic crashes at specific roadway sites, such as intersections. Gaining a better understanding of these complex relationships provides traffic safety professionals with the ability to develop well-informed, targeted policies and programs to reduce traffic crashes and the resultant injuries and fatalities.

An important tool in this process is the American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual* (*HSM*) [*2*]. Part C of the *HSM* provides a series of predictive models that can be utilized to estimate the frequency of traffic crashes on specific road facilities as a function of traffic volumes, roadway geometry, type of traffic control, and other factors. These models, referred to as safety performance functions (SPFs), are useful for estimating the safety impacts of site-specific design alternatives or for prioritizing candidate locations for safety improvements on a network basis. As a part of this process, these SPFs can also be integrated with decision support tools, such as *SafetyAnalyst* and the *Interactive Highway Safety Design Model* (*IHSDM*).

While the SPFs presented in the *HSM* provide a useful tool for road agencies, it is recommended that these functions are either calibrated for local conditions or re-estimated using local data to improve their accuracy and precision [*2*]. A variety of states have conducted research to this end, including Colorado, Florida, Georgia, Illinois, Kansas, North Carolina, Oregon, Utah, and Virginia [*3-15*]. Collectively, these studies have shown the accuracy of the SPFs from the *HSM* vary considerably from state to state, a result that may be reflective of differences in geography, design practices, driver behavior, differences in crash reporting requirements, or other factors.

This study involves the estimation of SPFs for urban and suburban trunkline intersections maintained by the Michigan Department of Transportation (MDOT). These SPFs were developed using a robust database, which combines information from the MDOT Sufficiency

File, the Michigan State Police (MSP) crash database, and field data from select locations. Ultimately, the decision support tools derived from this research will allow MDOT to more efficiently invest available resources, perform more effective network surveillance, and make data-driven design decisions.

1.1 Background

The first edition of the *HSM* includes separate families of SPFs for three specific facility types: (1) Rural Two-Lane, Two-Way Roads; (2) Rural Multilane Highways; and (3) Urban and Suburban Arterials. Chapters 10, 11, and 12 of the *HSM* provide full details of the SPFs for these respective facility types, which were developed based upon the results of empirical studies [*16-21*]. Subsequent research that will be integrated into the second edition of the *HSM* has analyzed other facility types, which include freeways and interchanges [*22*], as well as six-lane and one-way urban and suburban arterials [*23*].

Within each facility type, separate SPFs have been developed for intersections and road segments. For each location type, these SPFs can be used to estimate the total number of crashes expected during a given (typically one-year) time period under "base" conditions. Similar to the nomenclature from the *Highway Capacity Manual* [*24*], these base conditions generally refer to roadways with standard design elements (e.g., 12-ft lane widths). The *HSM* SPFs have been statistically estimated such that any variation from these base conditions is then captured in the form of crash modification factors (CMFs), which provide an estimate of the change in predicted crash frequency that would correspond to specific changes in these baseline conditions (e.g., decreasing lane widths from 12 ft. to 11 ft.). The "base" SPFs provided in the *HSM* have been developed using data from the *Highway Safety Information System* (*HSIS*) [*16-21*]. Table 1 provides a summary of the data used to develop the SPFs for urban and suburban arterials, which are presented in Chapter 12 of the HSM.

Table 1. Data Used in the Development and Validation of SPFs for Urban and Suburban Arterial Intersections in the *Highway Safety Manual* [*22-23*]

HSM Chapter	Site Type	No. Of Sites	State		HSM Chapter	Site Type	No. Of Sites	State
12	3ST	36	MN		12	3SG	42	NC
12	3SG	34	MN		12	4ST	48	NC
12	4ST	48	MN		12	4SG	44	NC
12	4SG	64	MN		12	4SG	454	FL
12	3ST	47	NC					

Note: (3ST) three-leg intersections w/STOP control on minor approach; (3SG) three-leg signalized intersections; (4ST) four-leg intersections w/STOP control on minor approaches; (4SG) four-leg signalized intersections.

It should be noted that these models were developed and validated using data for only three states. Given differences in Michigan's drivers, roadways, and environmental conditions, it is unclear how well these SPFs would predict safety performance for urban trunkline intersections in Michigan. Since the publication of the *HSM*, recent studies have involved the analysis of local data from numerous states [*3-15*]. Collectively, these studies have indicated that direct application of the SPFs from the HSM does not tend to provide accurate results without either careful calibration or re-estimation using local data. These findings provide motivation for the development of SPFs that are unique to Michigan's trunkline intersections.

In addition to providing tools to predict the total number of crashes at a given intersection, the *HSM* also presents methods for estimating crashes by type and injury severity level. The ability to provide estimates at this disaggregate level is important for several reasons. First, specific safety treatments often have differential effects on crashes by type. For example, the installation of a traffic signal may decrease the frequency of certain crash types (e.g., angle collisions) while increasing other types (e.g., rear-end collisions). Consequently, if reliable estimates are available at the crash type level, road agencies will be able to more precisely estimate potential cost savings that coincide with implementation of a specific treatment. The provision of crash estimates by severity level is similarly important since safety treatments are generally given higher priority at those locations that are prone to more severe crashes due to the higher societal costs involved with the resultant injuries and fatalities. While several methodological approaches could conceivably be utilized to provide such disaggregate level estimates, there are three distinct approaches considered in the HSM:

1. In Chapters 10 and 11, the total expected number of crashes are estimated for each location. These totals are then disaggregated based upon aggregate-level proportions provided by default collision type and crash severity distributions [25].
2. In Chapter 12, separate SPFs are provided to estimate the total expected number of crashes by crash type. Separate SPFs are also provided for fatal-and-injury (FI) crashes and property-damage-only (PDO) crashes.
3. More recently, NCHRP 17-45 and NCHRP 17-58 [*22, 23*] have utilized a third approach, which involves the estimation of the total expected number of crashes for each location. In addition to this estimate, the proportions of crashes by collision type and severity level are also estimated as a function of traffic volumes and roadway geometry. The estimates from this two-step process are then combined to determine the total expected number of crashes at each site by type and severity.

Beyond the statistical issues involved with SPF development, it must be noted that the *HSM* "is written for practitioners at the state, county, metropolitan planning organization (MPO), or local level" [*26*]. This is important to recognize because it is imperative that a balance is struck between the accuracy of a model and its usefulness to practitioners.

1.2 Objectives

This research aims to develop a uniform, consistent approach that can be applied to estimate the safety performance of urban trunkline intersections at the aggregate (i.e., total crash) level, as well as to within specific crash types and crash severity categories. The study results provide important guidance to allow MDOT to make informed decisions as to planning and programming decisions for safety projects. The specific objectives of this study are as follows:

1. Review and summarize previous and existing efforts to generate Safety Performance Function(s) for agencies.
2. Identify sites for the following urban intersection types from existing Safety Analyst output:
    a. Urban Trunkline Three-Leg Minor Road Stop Control
    b. Urban Trunkline Three-Leg Signalized
    c. Urban Trunkline Four-Leg Minor Road Stop Control
    d. Urban Trunkline Four-Leg Signalized

3. Develop SPFs for each of the urban intersection types listed above.
4. Define a maintenance cycle and process for updating SPFs

1.3 Report Structure

This report documents the activities involved in the development of safety performance functions (SPFs) and crash modification factors (CMFs) for signalized and stop-controlled intersections in Michigan. The report is divided into six chapters. Chapter 2 provides a summary of the state-of-the-art research literature. Chapter 3 describes the data collection, including details of the data sources and activities involved in database development. Chapter 4 provides a preliminary visual analysis of the data, as well as a brief summary of the statistical methods utilized as a part of this study. Chapter 5 presents the study results, with a comparison of the goodness-of-fit of several alternate SPF formulations. Simple models, using only AADT and MDOT region as predictor variables, are presented, as well as more detailed SPFs that consider a variety of geometric factors. In these instances, separate SPFs are estimated for intersections of two-way and one-way streets. The chapter also presents a series of CMFs, as well as details of severity distribution functions (SDFs) that are used to estimate crashes by severity. Chapter 6 discusses calibration and maintenance processes for updating the SPFs over time, as well as provides a demonstration of how crash frequency can be estimated for a given intersection. Conclusions and directions for future research are discussed in Chapter 7.

2.0 LITERATURE REVIEW

Given the current emphases on data-driven strategic approaches for safety analysis, a priority area at the national level has been the identification of high-risk intersections and road segments. Site identification is a critical component of a safety improvement program and the effective identification of sites that are candidates for improvements can be costly [27]. Historically, a variety of methods have been used to identify and prioritize candidate sites for safety treatments. These have largely included simple methods such as the ranking of sites based upon system-wide crash frequency or crash rate data. There are several drawbacks to such approaches. For example, considering only crash frequency tends to ignore sites with low traffic volumes while using crash rates tends to disproportionately prioritize very low volume sites [28]. The use of crash rates also implicitly assumes a linear relationship between crashes and traffic volume, which is not necessarily well supported by safety research [29]. However, due to the minimal data requirements, these methods are still widely used by DOTs in site screening and the identification of crash hot spots [*30, 31*].

A bigger concern is that, given the random nature of crashes on a location-by-location basis, short-term trends in crash frequency or rate are not necessarily good predictors of long-term crash frequency [*30*]. This concern relates largely to a phenomenon called regression-to-the-mean (RTM). In practical terms, RTM is reflected by the fact that roadway locations that experience particularly high short-term (e.g., one year) crash frequencies are likely to decrease closer to the average of similar sites (i.e., regress to the mean) over the long term [*31, 32*]. To address such concerns, short-term site-specific crash counts can be combined with estimates from predictive regression models to develop more accurate estimates of long-term (i.e., future) safety performance. An important tool in this process is the American Association of State Highway and Transportation Officials (AASHTO) *Highway Safety Manual* (*HSM*) [*2*]. Part C of the *HSM* provides a series of predictive models, referred to as safety performance functions (SPFs), which can be utilized to estimate the frequency of traffic crashes on specific road facilities as a function of traffic volumes, roadway geometry, type of traffic control, and other factors.

2.1 Safety Performance Functions (SPFs) and Crash Modification Factors (CMFs)

Safety performance functions (SPFs) establish a basis for evaluating roadway safety in consideration of the effects of traffic volume (AADT) roadway geometry, and other factors. SPFs for intersections take the following general form:

$$N_{spf} = exp(\beta_0) AADT_{major}^{\beta_1} AADT_{minor}^{\beta_2}$$

where:
N_{spf} = predicted average crash frequency for a site with base conditions;
$AADT_{major}$ = annual average daily traffic (AADT) for the major road;
$AADT_{minor}$ = annual average daily traffic (AADT) for the minor road; and
$\beta_0, \beta_1, \beta_2$ = estimated parameters.

Although HSM provides default SPF models, it is noteworthy that these models were developed using data from only a few states. This makes the transferability of the SPFs a critical issue that needs to be handled by state agencies and DOTs when they attempt to implement these models. While these SPFs can be directly applied, the HSM recommends that the equations are either calibrated using local (i.e., state or regional) data or that jurisdiction-specific SPFs are developed. The calibrated model must sufficiently capture local road and traffic features [*33*]. Calibration of the SPFs is relatively straightforward, requiring the estimation of a calibration factor, *C*, as shown in the following equation:

$$N_{predicted} = N_{spf} \times C \ ,$$

where:
$N_{predicted}$ = predicted annual average crash frequency for a specific site;
N_{spf} = predicted average crash frequency for a site with base conditions; and
C = calibration factor to adjust SPF for local conditions.

This calibration factor is simply equal to the ratio of the number of observed crashes within the jurisdiction to the predicted number of crashes as estimated by the SPF. While calibration generally results in improved goodness-of-fit, research has shown that the suggested sample sizes for sites (30-50) and crashes (100 per year) in the HSM do not necessarily minimize predictive error in calibration [*34*].

In addition to calibration for local factors, it is also important to note that the SPFs from the HSM are estimated for "base" conditions. For example, the SPF for stop-controlled intersections assume the following base conditions:

- Intersection skew angle = 0º;
- No left-turn lane on major road;
- No right-turn lane on major road; and
- No lighting present.

At locations where base conditions are not met, the SPFs are multiplied by crash modification factors (CMFs), which adjust the SPF for non-base conditions as shown in the following equation:

$N_{predicted} = N_{spf} \times C \times CMF_i$,
where:
$N_{predicted}$ = predicted annual average crash frequency for a specific site;
N_{spf} = predicted average crash frequency for a site with base conditions;
C = calibration factor to adjust SPF for local conditions; and
CMF_i = crash modification factor for condition i.

These CMFs allow for crash estimates that distinguish between sites with various geometric or traffic control features. For example, the HSM provides a series of CMFs in Chapter 12 specific to intersections on urban and suburban arterials. Chapter 14 provides a catalog of various intersection CMFs based on prior empirical research. In addition, the Federal Highway Administration (FHWA) maintains the Crash Modification Factor (CMF) Clearinghouse [*35*], a web-based database of CMFs that provides supporting documentation to assist users in estimating the impacts of various safety countermeasures.

2.2 Summary of State Efforts in SPF Calibration and Development

A recent study summarized the results of a nation-wide survey that was employed to assess the current status of safety analysis at state departments of transportation [*36*]. The results of this survey demonstrated that most states experienced data-related issues that inhibited their ability to effectively conduct safety analyses. A Florida study cited the data requirements of the HSM were challenging as many of the factors were not available in the state's roadway characteristics inventory database [*37*]. Similar results were found in Pennsylvania where several variables suggested in the *HSM* could not be included in SPFs due to lack of available data [*38*]. Several other studies have also identified data availability and completeness as hurdles in meeting the input requirements of the *HSM* and other related tools such as *SafetyAnalyst* [*37-39*]. A study in Georgia found that data quality and availability significantly affect the quality and reliability of SPFs [*15*] while research in Kansas noted that the scarcity of intersection data did not allow for the development of separate models for 3-leg and 4-leg stop-controlled intersections [*39*].

Specific areas of concern included lack of sufficient data on traffic volumes and roadway characteristics, as well as a lack of geo-referenced spatial data [*36*]. In most states, traffic data is generally available for higher classes of roadways (e.g., interstates, state routes, etc.), but is limited for local and low volume roads [*36*]. Research in Colorado found that volume data for side-streets were not generally available for more than one or two years, and in many cases the count data did not coincide with the study period [*4*]. Thus, it was necessary to normalize available side-street AADT data over the study period using growth rates derived from the mainline AADT volumes [*4*].

International studies [*40-45*] also show that sampling of sites is often hindered by the availability of data. Studies in Brazil [*42*] and Italy [*44, 45*] found the need for manually collected data on traffic volumes, roadway geometry, and functional characteristics limited the number of sites that could feasibly be included in SPF estimation.

Despite these limitations, Table 2 shows a significant number of recent state-level efforts aimed at either calibrating the HSM SPFs or developing state-specific SPFs using local data. The table summarizes recent studies, including details of the types of intersections that were considered as a part of each study, the number of sites that were included by type, and the number of years of data that were used for model calibration of estimation.

When examining SPF calibration for local conditions, there is significant variability in terms of whether the base models from the HSM over- or under-predict crashes within specific states.

Table 2. Summary of studies involving calibration or development of specific SPFs

Ref. #	State/ Country	Site Type(s)	No. of Sites	No. of Years	Calibrated HSM SPFs	Jurisdiction Specific SPFs
46-48	AB	4SG	99	3-7	No	Yes
49, 33	AB; ON	4SG	515; 1629	6	Yes	Yes
50	Brazil	4SG; 4ST	353; 132	6	No	Yes
42	Brazil	4SG; 4ST	89; 92	3	Yes	No
51	BC	SG	98	9	No	Yes
52	BC	SG	51	3	No	Yes
32	CA; ON	4ST; 3SG/4SG	2202; >20	-	No	Yes
53	CA	3ST; 4ST	378; 264	10	No	Yes
54	CA	3ST, 4ST	1381, 907	10	No	No
55	FL	4SG	519	6	No	Yes
56	FL	4SG	177	6	No	Yes
37	FL	3ST, 4ST, 4SG	31-321; 58; 34-43; 21-459	3	No	Yes
44	ITA	4ST (one-way)	92	7	No	Yes
34	MD	3ST, 4ST, 4SG	152-162; 26-167; 10-115; 35-244	3	Yes	No
57	MO	3ST, 4ST	35-70; 25-70	1	Yes	No
58	OH	3ST, 4ST, 4SG	50-200; 50-200; 125-250; 50-200	3	Yes	No
43	ON	3SG; 4SG	40; 230	6	No	Yes
59	ON	3ST; 3SG; 4ST; 4SG	117; 250; 59; 868	6	No	Yes
60	ON	3SG, 4SG	306, 1410	5	Yes	Yes
61	ON	3SG	59	6	No	Yes
62	ON	3SG; 4SG	137; 1691	6	Yes	Yes
63	OR	3ST; 4SG	202; 298	3	Yes	Yes
38	PA	3ST; 4ST; 3SG; 4SG	414; 86; 45; 105	8	No	Yes
64	SK	3ST; 4ST; 3SG/4SG	123; 121; 143	5	Yes	Yes
65	South Korea	3SG; 4SG	247; 201	2	No	Yes
66	VA	3ST; 3SG; 4ST; 4SG	5367-8411; 183-836; 1239-1570; 182-568	6	No	Yes
67	VA	4SG	35	4	No	Yes
68	VA	4SG	127	5	Yes	Yes

Site Type Key: U: Urban, US: Urban and Suburban, S: Sub-Urban, RML: Rural Multilane, R2L: Rural 2-Lane 2-Way, 3SG: 3-Leg Signalized, 4SG: 4 Leg Signalized, 3ST: 3-Leg Minor Stop-Controlled, 4ST: 4-Leg Minor Stop Controlled, 4AWST: 4-Leg All-Way Stop

Research in Kansas found a calibration factor of 0.21, indicating that crashes were significantly over-predicted at unsignalized three-leg and four-leg intersections in the state [*39*]. However, these studies note that the calibration factors were developed using a small sample dataset and, as such, they should be used with caution. Calibration factors for urban intersections in Maryland ranged from 0.1562 for three-leg stop controlled intersections to 0.4747 for four-leg signalized intersections [*34*]. Research in Oregon [*63*] and North Carolina [*9*] also tended to show significantly lower crashes than would be predicted by the base models from the HSM. Statewide HSM model calibration in Missouri generally showed calibration factors less than 1.0, suggesting that Missouri facilities experienced fewer crashes than the national average [*57*]. However, the converse was true for urban three-leg and four-leg signalized intersections, where calibration factors of 3.03 and 4.91 were observed, respectively. The magnitude of these calibration factors was attributed differences in crash definitions between Missouri and the states used as the basis for the *HSM*.

In contrast, a Florida study showed the base HSM models to underestimate fatal and injury crashes by a factor of two [*69*] while SPFs that were calibrated for intersections in Ohio showed significant under-prediction at urban three-leg and four-leg signalized intersections [*58*]. Research in Saskatchewan [*64*] showed the HSM SPFs to typically under-predict crashes across the three intersection types examined. Additional international work in Brazil explored the transferability of HSM models to urban intersections [*42*]. The results suggest that the calibrated HSM baseline SPFs should be used with caution, with the authors noting the importance of analyzing the effects of the calibration sample size on model stability. Ultimately, it has been postulated that the differences in calibration factors are reflective of differences between individual jurisdictions and those states where the HSM models were developed [*34, 57*].

Given the significant variability in predictive performance across regions, a number of states have developed SPFs specific to their jurisdictions. Virginia is one of several states that have conducted extensive research on SPFs, including the development of SPFs for 3-leg and 4-leg signalized and stop-controlled intersections in urban and rural areas. Separate SPFs were developed on statewide basis, as well as at the regional-specific (Northern, Western, and Eastern regions) level to account for differences in various geographic areas of the state [*3*].

Research in Colorado resulted in the development of SPFs for ten types of urban intersections, including separate SPFs for total and injury crashes [*4*]. SPFs were developed in Oregon for eight intersection types based on traffic control, land use, and number of legs [*63*]. These categories were chosen to align with the intersection types in the HSM.

A recent study in Pennsylvania [*38*] examined rural two-lane intersections. SPFs were developed for three-leg and four-leg intersections with both signal and minor street stop-control. SPFs were also estimated for four-leg all-way stop controlled intersections on two-lane rural roads.

Collectively, the domestic and foreign studies have indicated that direct application of the SPFs from the HSM (or other non-local source) does not tend to provide accurate results without either careful calibration or re-estimation using local data. Consequently, the primary purpose of this study was to develop a series of SPFs and other safety tools that can be used by the Michigan Department of Transportation (MDOT) as a part of their continuing traffic safety efforts.

3.0 DATA COLLECTION

Ultimately, the accuracy of an SPF depends largely on the quality of the data from which it is developed. The development of robust SPFs requires a crash database this is comprehensive and includes information on specific crash location, collision type, severity, relationship to junction, and types of maneuvers of the involved vehicles. Roadway data is also important, including the physical features within the right-of-way. Roadway geometry data that are recommended for use in safety analyses include: lane width; shoulder width and type; horizontal curve length, radius, and superelevation; grade; driveway density; and indicator variables for features such as auxiliary turn lanes [*2*].

In 2008, the Model Minimum Uniform Crash Criteria (MMUCC) guidelines were developed with funding provided by the National Highway Traffic Safety Administration (NHTSA) in collaboration with the Governor's Highway Safety Association (GHSA), Federal Highway Administration (FHWA), Federal Motor Carrier Safety Administration (FMCSA), State DOTs, law enforcement agencies, and other traffic safety stakeholders. The MMUCC consists of a recommended minimum set of data elements for States to include in their crash forms and databases [*70*]. This set includes 110 data elements, 77 of which are to be collected at the scene, 10 data elements to be derived from the collected data, and 23 data elements to be obtained after linkage to driver history, injury and roadway inventory data.

As a part of this study, the research team developed a comprehensive checklist of important data elements to be collected for the purposes of SPF development. As a starting point, an inventory file was obtained from MDOT. This file included location information for the following four types of site locations:

- 3-leg signalized intersections
- 4-leg signalized intersections
- 3-leg intersections with stop-control on the minor approach
- 4-leg intersections with stop-control on the minor approaches

For the purposes of SPF development, the HSM suggests a minimum sample size of 30 to 50 sites, which collectively experience a minimum of 100 total crashes per year. For the purposes of this study, another objective was to provide SPFs that are able to account for important differences across each of MDOT's seven geographic regions. Consequently, the research began with the random selection of 50 intersections from each region within the four site types illustrated in Figure 1. This figure also indicates the total number of intersections maintained by MDOT according to this inventory file.

3-Leg, Minor Approach Stop-Controlled
(N = 5,731 Sites)

3-Leg Signalized
(N = 485 Sites)

4-Leg, Minor Approach Stop-Controlled
(N = 2,695 Sites)

4-Leg Signalized
(N = 1,710 Sites)

Figure 1. Intersection Site Types

While 50 sites were identified within most regions and site types, there are several regions where sufficient numbers of sites were not available as shown in Table 3. This was particularly true for three-leg signalized intersections as there are only 485 such locations across Michigan.

Table 3. Sites by MDOT Region and Intersection Type

Intersection Type	MDOT Region							
	Superior	North	Grand	Bay	Southwest	University	Metro	Total
3SG	9	24	26	21	38	38	55	211
3ST	50	51	51	50	51	50	50	353
4SG	48	50	51	50	52	50	50	351
4ST	50	50	50	50	50	50	50	350

Once intersections were identified within each of the seven regions and four site types, data were collected from existing data sources that were either available publicly or through MDOT. These data sources included the following databases and files:

- Michigan State Police Statewide Crash Database;
- MDOT SafetyAnalyst Calibration File;
- Michigan Geographic Data Library (MiGDL) All Roads File;
- MDOT SafetyAnalyst Annual Average Daily Traffic File; and
- MDOT Sufficiency File.

A quality assurance/quality control (QA/QC) process was implemented to verify the data in these sources using the MDOT PR Finder and Google Earth. Further details of each respective data source is provided in the following sections of this report.

3.1 Michigan State Police Statewide Crash Database

The Michigan State Police (MSP) crash database contains details of all reported crash records in the state of Michigan. Records in this database are maintained at the crash-, vehicle-, and person-levels. There are a total of nine separate spreadsheets included in the database as illustrated in Figure 2.

Figure 2. Spreadsheets of the MSP Crash Database

For the purposes of this report, only crash level data was needed from the “1 crash” and “2 crash location” files. The only field required from the “2 crash location” sheet was the “intr_id” field which corresponds to a specific intersection node. These sheets were linked using the “crsh_id” field, as shown in Figure 3.

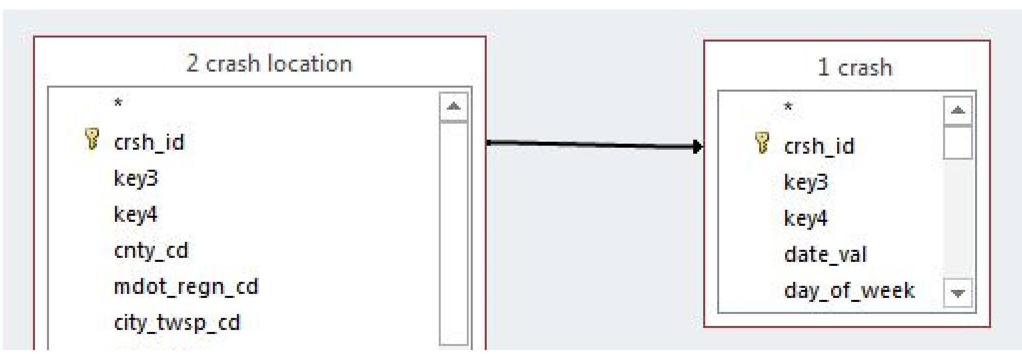


Figure 3. Joining of the MSP Crash Database sheets

After joining the two sheets together, the information relevant to the report was exported. The relevant fields are defined below.

- crsh_id- unique identifier for each crash, and was used as the basis for linking the spreadsheets
- date_val-contains the date the crash occurred, which allowed the crash to be assigned to a particular year
- fatl_crsh_ind-identifies the crash as having at least one fatality
- num_injy_a-total number of people sustaining “A level” injuries in the crash
- num_injy_b-total number of people sustaining “B level” injuries in the crash
- num_injy_c-total number of people sustaining “C level” injuries in the crash

- prop_damg_crsh_ind-identifes the crash as being property damage only (PDO)
- crsh_typ_cd-defines the crash as single-vehicle or one of nine multiple-vehicle collision types
- rdwy_area_cd-indicates where on the roadway a crash occurred, only crashes with codes relavent to intersections were considered
- ped_invl_ind-indicates that a pedestrian was involved in the crash
- bcyl_invl_ind-indicates that a bicycle was involved in the crash
- intr_id-assigns the crash to a specific intersection node in the Calibration file
- crnt_x_cord-the longitude at which the crash occurred
- crnt_y_cord-the latitude at which the crash occurred

As was previously mentioned, this crash was focused on "crash" level data. Crashes were defined based on the most significant injury sustained by anyone involved in the crash. Crashes involving bicycles or pedestrians were separated from vehicle-only crashes for the purpose of the data analysis.

3.2 MDOT Calibration File

The file containing potential intersections to be considered in this study, Urban Calibration Data MAIN.xlsx, was furnished by MDOT. The file contained four spreadsheets relevant to this study, title 3ST, 3SG, 4ST, and 4SG. In all, 12,241 locations were identified in the file. In addition to identifying the sites, the file contained some information for each location which is described below:

- Site ID-a unique identifier in the form of I#####, where the I indicates intersection and the ##### could be up to five numbers
- Lanes North (Misc 1)-typically a count of the number of lanes on the northern leg of an intersection, however various other information is sometimes present, or may be blank
- Lanes South (Misc 2)-typically a count of the number of lanes on the southern leg of an intersection, however various other information is sometimes present, or may be blank
- Lanes East (Misc 3)-typically a count of the number of lanes on the eastern leg of an intersection, however various other information is sometimes present, or may be blank
- Lanes West (Misc 4)-typically a count of the number of lanes on the western leg of an intersection, however various other information is sometimes present, or may be blank
- Legs (Misc 5)-usually describes the number of legs of the intersection (3leg or 4leg) however various other information is sometimes present
- Misc 6-word/acronym describing the intersection, such as blvd, or xovr, or left blank
- Misc 7- word/acronym describing the intersection, such as blvd, or xovr, or left blank
- Misc 8- word/acronym describing the intersection, such as blvd, or xovr, or left blank
- Misc 9-not present on 3SG, this field is blank more often than not but may contain words

or acronyms describing the intersection such as “odd”

- Site ID Review-the same as Site ID
- iSectID-a unique identifier corresponding to “intr_id” field in the crash database
- PR|PRMP-the location of the intersection based on Michigan’s linear referencing scheme “Physical Road” and “Physical Road Mile Point”

A screen shot capturing the calibration file can be seen in Figure 4.

<table>
<tr><th></th><th>J</th><th>K</th><th>L</th><th>M</th></tr>
<tr><th>8</th><th>Misc 9</th><th>Site ID Review</th><th>iSectID</th><th>PR|PRMP</th></tr>
<tr><td></td><td></td><td>I32874</td><td>80001955</td><td>D|578110|0.696000</td></tr>
<tr><td></td><td></td><td>I2618</td><td>11007382</td><td>D|1360705|0.417000</td></tr>
<tr><td>r</td><td></td><td>I34514</td><td>82091526</td><td>D|1600604|0.356000</td></tr>
<tr><td></td><td></td><td>I5547</td><td>28001621</td><td>D|994307|0.292000</td></tr>
<tr><td></td><td></td><td>I11137</td><td>31020950</td><td>D|1176202|0.059000</td></tr>
<tr><td></td><td></td><td>I30373</td><td>82083838</td><td>D|4706057|0.065000</td></tr>
<tr><td></td><td></td><td>I30807</td><td>82083835</td><td>D|4706055|0.066000</td></tr>
<tr><td></td><td></td><td>I33193</td><td>82023247</td><td>D|4704222|0.059000</td></tr>
<tr><td></td><td></td><td>I25203</td><td>74018494</td><td>D|4502633|9.467000</td></tr>
</table>

Figure 4. Sample of utilized data in the 3ST tab in the Urban Calibration MAIN.xlsx file

The information contained in the calibration file was ultimately used as the basis for the selection of locations included in this study. Although much of the information in the file is potentially useful, some problems arise when trying to use it. First, directions are of little concern for the creation of SPFs, while information such as which is the major leg and which is the minor leg is much more useful. Second, each entry in the file does not necessarily correspond to a complete intersection, but just a node in a link node network. The intersection of a boulevard with a two-way street is typically represented by two nodes, meaning that many of the entries in the file must be paired with another entry. Much of the information in this file was captured in more detail during a thorough data collection process leading to the creation of the final data set.

3.3 Geographic position from Michigan Geographic Data Library (MiGDL) All Roads file

In order to facilitate the use of GIS software for this project, a GIS shapefile, allroads_miv13a.shp, was obtained from the Michigan Geographic Data Library from the Michigan Center for Geographic Information (MCGI) website. The file consists of all the road segments found statewide. Although the file has a total of 36 attribute fields, the following three were of particular use for this project:

- PR-Physical Road ID number
- BMP-Beginning PR mile point for linear referencing system
- EMP-Ending PR segment mile point

3.4 Annual average daily traffic estimates from MDOT Safety Analyst file

An excel file supplied by MDOT titled “SA_Int_2000-2012.7z” was used as the source for AADT information for this project. A .csv file was extracted from the zip file containing major and minor road AADT information for 34,915 nodes for the years 2000-2012. In addition to this information, the file also contained several identification fields listed below.

- INTERSECTIONID- a unique identifier in the form of I#####, where the I indicates intersection and the ##### could be up to five numbers
- ROUTEDISPLAYNAME-indicates if the road is a US, state, interstate, etc. highway and gives the route number (e.g., SR0013 is M-13)
- SITESUBTYPEENUM-identification of the SafetyAnalyst subtype
- COMMENT_C-contains the names of the two intersecting roads
- LOCATION-the PR and PRMP of the intersection on the major road
- MAJORROADDIRECTION-either EW or NS, or X if no major road information was available
- MINROADNAME-the name of the minor road
- MINROADLOCATION-the PR and PRMP of the intersection on the minor road

The MDOT Safety Analyst AADT file contained a field called “INTERSECTIONID” for which each node was assigned a value of the form “I#####” where the “#####”s were from one to five digits, and the Urban Calibration MAIN file contained the field “Site ID” which was numbered in the same manner. Initially, it was thought that this value could be used to link the AADT values to the calibration sites. Investigation into this matter found that these sites did not reference the same location in terms of PR and MP. Examples of this are shown in Figure 5 and Figure 6.

Site ID	IsectID	PR|PRMP
I10023	39005972	D|10208|5.977000
I19110	50019678	D|833209|0.468000
I31820	82043984	D|1924107|0.242000
I4993	13005235	D|1296303|3.749000
I9985	25017619	D|1497008|3.921000

Figure 5. Calibration Site ID, IsectID, PR, and PRMP for five random sites

INTERSECTIONID	LOCATION	MINORLOCATION
I10023	D|22207|9.924000	D|10208|5.977000
I19110	D|1560808|32.790000	D|1561802|0.000000
I31820	D|3830528|8.163000	D|3831030|0.000000
I4993	D|1296303|3.749000	D|1296304|0.627000
I9985	D|1351805|7.847000	D|1353706|0.210000

Figure 6. SafetyAnalyst INTERSECTIONID, LOCATION, and MINORLOCATION for the same sites

These figures illustrate that five sites which were chosen at random, the "Site ID" from the calibration file and the "INTERSECTIONID" field from the AADT file only reference the same location for two instances: in "I4993" the calibration file "PR" and "PRMP" correspond to the "PR" and "PRMP" in the "LOCATION" field, while the "I10023" calibration file "PR" and "PRMP" correspond to the "PR" and "PRMP" in the AADT file "MINORLOCATION" field. The other three locations do not match either, meaning that if AADT were assigned to the calibration file intersections using this approach, AADT values would potentially be assigned to the wrong intersections. The process that was actually used to match the AADT to the calibration sites is discussed later.

3.5 MDOT Sufficiency File

MDOT sufficiency files were made available for the years 2004 through 2012. The sufficiency files contain 122 fields for the state maintained roads in Michigan. The data is broken into segments of varying length. As the research ultimately involved a detailed site review of each intersection the Sufficiency file was primarily used to determine major road speed limits as a part of this study.

3.6 Construction of the Preliminary Dataset

For the purposes of this analysis, a study period from 2008 to 2012 was considered, based on the availability of data at the beginning of the project. To assemble the data set, the observations in the intersection specific tabs of the calibration file were converted into one large list of 12,241 locations. The "PR|PRMP" field in the calibration file and the "LOCATION" field in the SafetyAnalyst AADT file were separated from one field into two as shown in Figure 7.

M	N	O	P
PR|PRMP		PR	PRMP
D|4706056|0.000000		4706056	0
D|1813007|0.000000		1813007	0
D|21502|8.873000		21502	8.873
D|4705565|3.810000		4705565	3.81
D|4705565|5.873000		4705565	5.873
D|3702046|2.597000		3702046	2.597
D|802803|7.347000		802803	7.347
D|1600206|18.325000		1600206	18.325

Figure 7. Separation of combined PR and PRMP fields

AADT values for the major and minor roads were joined to the calibration file AADT by matching the AADT to the intersection nodes on the basis of PR and PRMP as well. Figure 8 illustrates how the join was performed.

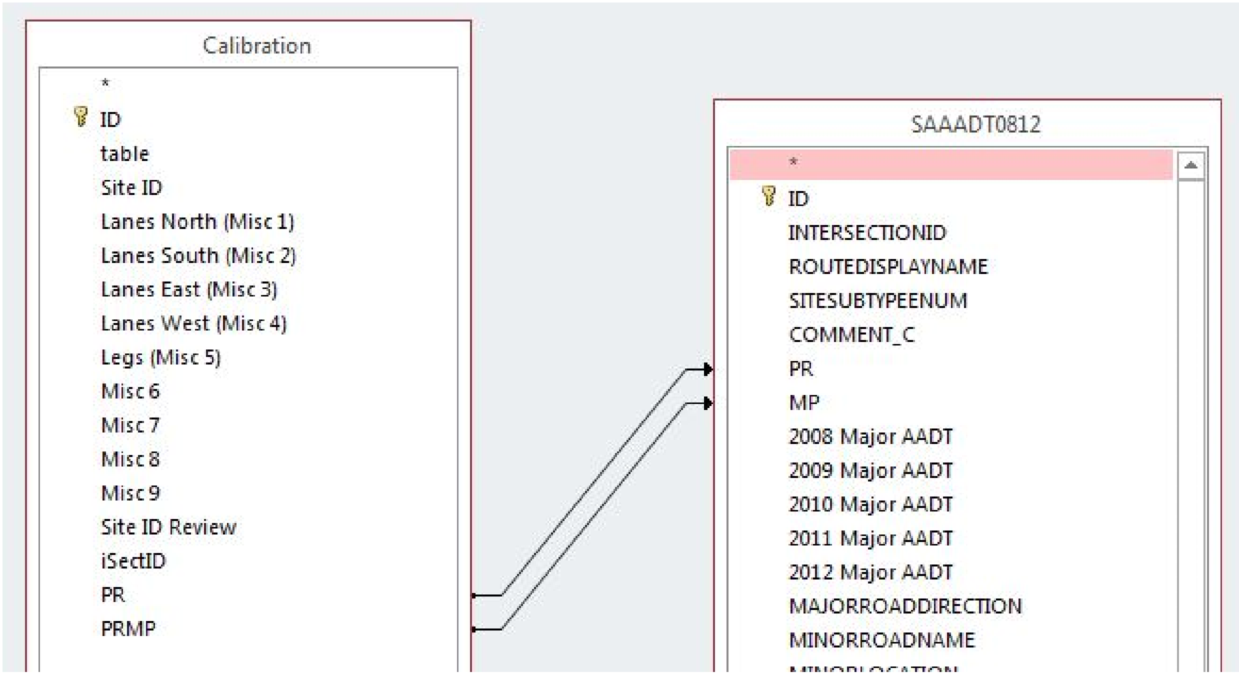


Figure 8. Calibration File Joined to the SafetyAnalystAADT file

Crashes were queried from the MSP crash database for each of the 12,241 nodes in the MDOT Calibration file by matching the "iSectID" field in the Calibration file to the "intr_id" field in the MSP crash database as shown in Figure 9.

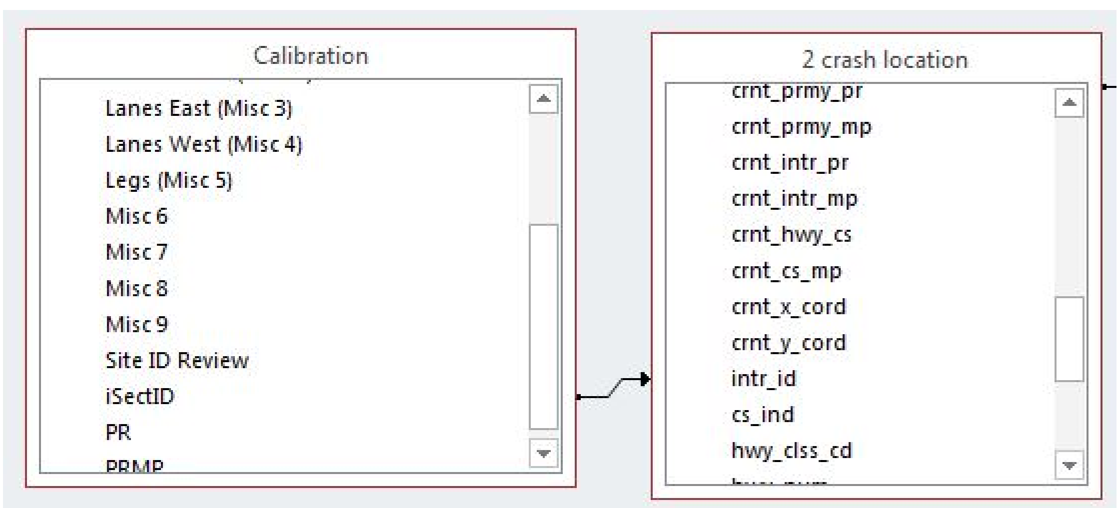


Figure 9. Calibration locations used to extract crashes

This crash query was exported as an excel file containing the 14 fields discussed in the MSP Crash Database section. A threshold value of 0.04 miles was established as the maximum distance from an intersection node that a crash would be considered an "intersection" crash, requiring the mapping of the intersections and crashes using GIS software. The All Roads file was used as the framework for the map. Linear referencing was utilized to locate the intersection nodes (which did not have coordinates for location) on Michigan's roadway network by Physical Road (PR) and Mile Point (MP). Crashes were then added to the map by latitude and longitude coordinates included in the crash report. To exclude crashes that were outside of the established 0.04 miles, a buffer was used around each of the intersection nodes. Figure 10 shows an image of a calibration intersection (triangle), buffer (large circle) and crashes (small circles) occurring on the roadway network (lines).

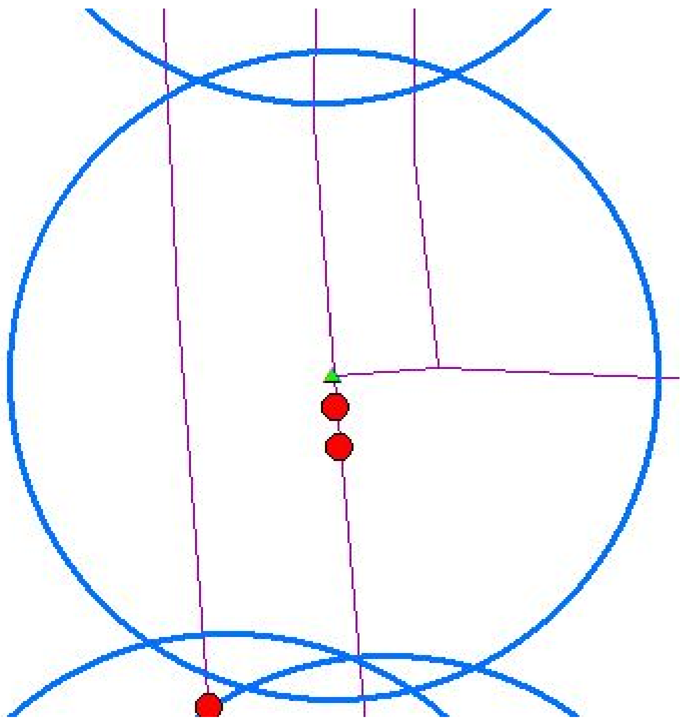


Figure 10. Intersection with crashes and buffer

The crashes that were within 0.04 miles of an intersection node were then tabulated by year, type, and severity for each "intr_id" so that each node would have a count of the crashes that occurred near it by type and severity. Of the 12,241 nodes provided in the Calibration file, 12,170 were able to be paired with AADT from the Safety Analyst file and mapped onto the All Roads file, with 71 nodes having a PR or PRMP that did not correspond to one of either the Safety Analyst AADT file, or the All Roads file.

While many of the aforementioned intersection nodes were representative of a complete intersection, many others were a portion of a more complex intersection such as a boulevard intersecting a two-way street, or the intersection of two boulevards, as shown in Figure 11.

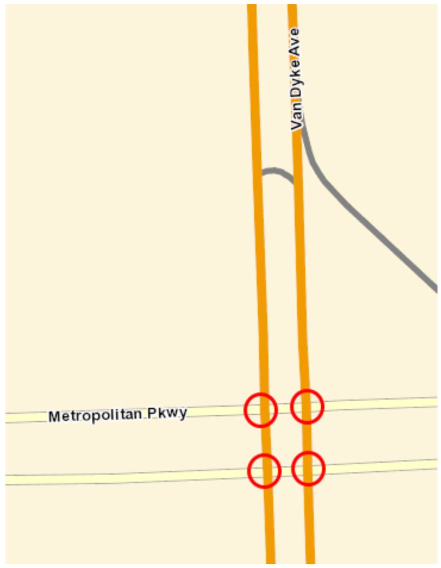


Figure 11. Boulevard-Style Four-Node Intersection

Other nodes were not intersections at all, but the beginning or end point of a boulevard, the location of a median turnaround (Michigan Left), or the location of yield-controlled or uncontrolled merging and diverging lanes as shown in Figure 12.

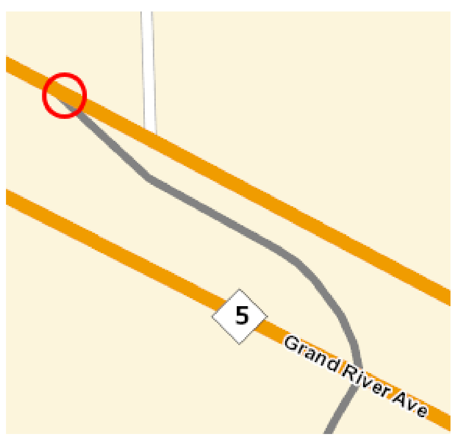


Figure 12. Example of Merge/Diverge Point Classified as an Intersection

This necessitated an exhaustive QA/QC of the data to join nodes of the same intersection together, as well as to remove the nodes that would not be considered an intersection from the dataset. Utilizing the "COMMENT_C" field from the AADT file containing names of both streets comprising the intersection, nodes potentially belonging to the same intersection were identified. The PR Finder was used to locate the sites and view initial satellite imagery, with Google Earth providing additional satellite imagery. Images were reviewed to verify whether nodes were properly identified as a complete intersection. Nodes that were found to not be an intersection were excluded from further analysis, leaving a final data set consisting 10,621 intersections. In order for the properly linked intersection nodes to have characteristics representative of the entire intersection, the crashes assigned to these nodes were summed, as was the AADT for each side of a boulevard, non-boulevard streets had their AADT values averaged. Table 4 provides details of the resulting data set, including a count of the number of intersections by type, as well as averages of the major AADT, minor AADT, and total annual crashes.

Table 4. Average Major AADT, Minor AADT and Annual Crashes by Intersection Type

	3SG	3ST	4SG	4ST
Number of Intersections	485	5,731	1,710	2,695
Average Major Road AADT	20,709	15,985	23,892	14,571
Average Minor Road AADT	4,967	1,234	9,547	1,776
Average Annual Crashes	2.67	0.42	7.78	1.05

3.7 Manual Data Collection and Review

In order to create a data set containing geometric data (e.g. road width, number of lanes), as well as road use characteristics (e.g. bus stops, roadside parking), a detailed site review was conducted utilizing Google Earth and the MDOT PR Finder. Detailed geometry and site characteristics data were obtained, with the following list summarizing the data collection process:

- Number of Lanes: The number of lanes was determined for each approach and receiving leg. This information was disaggregated into the number of exclusive left-turn lanes, exclusive right-turn lanes, and through lanes. While both the entry approach and receiving lanes were reviewed, only the inbound lanes were considered for the purpose of the subsequent analysis.
- Road widths: the widths of intersecting roads were measured from curb to curb for all approaches. For the purpose of analysis, if both legs were present these measured widths were averaged along the same street, otherwise the measured values were directly used.

- Skew angle: The skew angle for each intersection was calculated as the smallest absolute difference between the headings of the intersecting approaches. The smallest angle was the variable of interest since it is the controlling situation where the available sight distance is minimum resulting in greater potential for crash occurrence. A sample skew angle measurement is shown in Figure 13.

Figure 13. Skew Angle Measurement Example

- Number of driveways: The total number of driveways were collected on both sides of the intersecting streets up to a distance of 0.04 miles from the center of the intersection along both the major and minor street.

- Bike Lanes and Roadside Parking: Presence of exclusive bike lanes and roadside parking was also specified.
- Bus Stops: Presence of bus stops within a distance of 1000 feet from the center of the intersection was investigated both for the major and minor road. Although bus stops are usually depicted on Google Maps, not all the bus stops can be located using the aerial view. Hence, more detailed exploration through Google Street View was required.
- Schools: A distance of 0.5 mile from the center of the intersection was used to explore for schools both on major and minor road. As with bus stops, Street View was used for verification where the aerial view was unclear. This field includes K-12 schools, as well as universities and colleges.
- Pedestrian features: The presence of sidewalks and ADA ramps was specified both for the major and minor road.
- Median Turn-around (MTA): A median turn-around refers to the case where, near an intersection, at least one road is a divided boulevard and left-turns onto the divided highway are prohibited. In such instances, left-turns are generally accommodated by vehicles making a right-turn, followed by a U-turn through the median as shown in Figure 14. All such instances were indicated for vehicles attempting to turn left from both the major and minor road.
- Distance of MTA: In cases were the presence of a median turn around was specified, its distance from the center of the intersection was also measured.

Figure 14. Median Turn-around Field Example

- Presence and length of storage lanes: The presence and lengths of storage lanes were determined as illustrated in Figure 15. For the case of intersections with two-way left-turn lanes (TWLTLs), no storage length was specified, though the presence of the turn lane was indicated in the database.

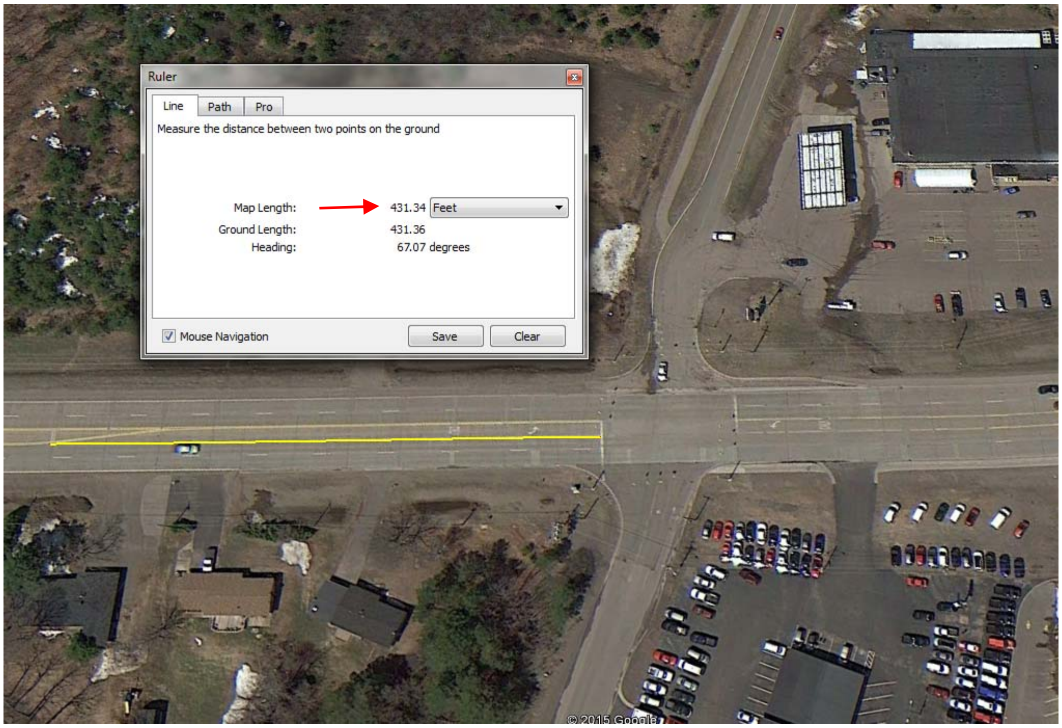


Figure 15. Storage Lane Length Measurement Example

- Median Types: In cases where either of the major or minor road was divided the type of the median was also identified. Medians were classified into different categories including curbed, curbed with grass, curbed with grass and vegetation, grass only, concrete barrier, guardrail barrier, and asphalt medians.
- Right-Turn-on-Red (RTOR): This field indicates those signalized intersections where vehicles are allowed to turn right while the signal head is red.
- Flashing Beacon: Those intersections where a flashing beacon is installed as well as/instead of a stop sign were flagged during the data collection process.

Table 5 and Table 6 provide summary statistics for all relevant variables among the stop-controlled and signalized intersection databases, respectively. Each table presents the minimum, maximum, and mean values, along with the standard deviation for each variable.

Table 5: Descriptive Statistics for variables of interest for Stop-Controlled Intersections

Intersection Type	3-Leg Minor Stop Controlled				4-Leg Minor Stop Controlled			
Variable	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Maj Rd AADT	97.00	48824.00	13040.90	7541.93	929.00	50206.00	13618.02	7913.74
Min Rd AADT	42.50	11630.50	516.65	965.36	85.00	44209.00	1898.66	3409.95
Maj Rd Through Lanes	2.00	8.00	3.07	1.07	1.00	6.00	3.12	1.09
Maj Rd Left Turn Lanes	0.00	2.00	0.58	0.81	0.00	2.00	0.99	0.98
Min Rd Through Lanes	0.00	2.00	0.96	0.24	0.00	4.00	1.98	0.26
Skew	0.01	69.33	7.89	12.13	0.00	64.00	8.41	12.63
Lighting Presence	0.00	1.00	0.72	0.45	0.00	1.00	0.76	0.43
Right Turn on Red Permitted	NA	NA	NA	NA	NA	NA	NA	NA
Maj Rd Driveway Count	0.00	15.00	2.87	2.49	0.00	10.00	2.19	2.18
Min Rd Driveway Count	0.00	8.00	1.70	1.39	0.00	10.00	2.47	2.30
Maj Rd Sidewalk Presence	0.00	1.00	0.59	0.49	0.00	1.00	0.71	0.46
Min Rd Sidewalk Presence	0.00	1.00	0.40	0.49	0.00	1.00	0.67	0.47
Ramp/Curb Cut Presence	0.00	1.00	0.52	0.50	0.00	1.00	0.45	0.50
Maj Rd Width	24.76	155.24	52.77	19.08	22.00	171.00	51.26	18.58
Min Rd Width	12.60	115.84	30.39	10.64	14.00	65.50	30.79	7.37
Presence of Maj Rd Bike Lanes	0.00	1.00	0.00	0.07	0.00	1.00	0.03	0.16
Presence of Min Rd Bike Lanes	0.00	1.00	0.00	0.05	0.00	1.00	0.01	0.08
Bus Stop within 1000' on Maj Rd	0.00	1.00	0.18	0.38	0.00	1.00	0.20	0.40
Bus Stop within 1000' on Min Rd	0.00	1.00	0.04	0.19	0.00	1.00	0.01	0.12
Presence of Parking on Maj Rd	0.00	1.00	0.07	0.25	0.00	1.00	0.16	0.36
Presence of Parking on Min Rd	0.00	1.00	0.21	0.41	0.00	1.00	0.55	0.50
Presence of Maj Rd Median	0.00	1.00	0.02	0.13	0.00	1.00	0.04	0.20
Presence of Min Rd Median	0.00	1.00	0.06	0.24	0.00	1.00	0.01	0.11
Within 1/2 mile of K-12 school	0.00	1.00	0.34	0.47	0.00	1.00	0.27	0.44
Superior Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
North Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
Grand Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
Bay Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
Southwest Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
University Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
Metro Region	0.00	1.00	0.14	0.35	0.00	1.00	0.14	0.35
Maj Rd Speed Limit	25.00	55.00	43.07	9.05	25.00	65.00	38.70	9.21
Maj Rd One-Way	0.00	1.00	0.15	0.36	0.00	1.00	0.12	0.33
Min Rd One-Way	0.00	0.00	0.00	0.00	0.00	1.00	0.02	0.15

Table 6: Descriptive Statistics for Variables of interest for Signalized Intersections

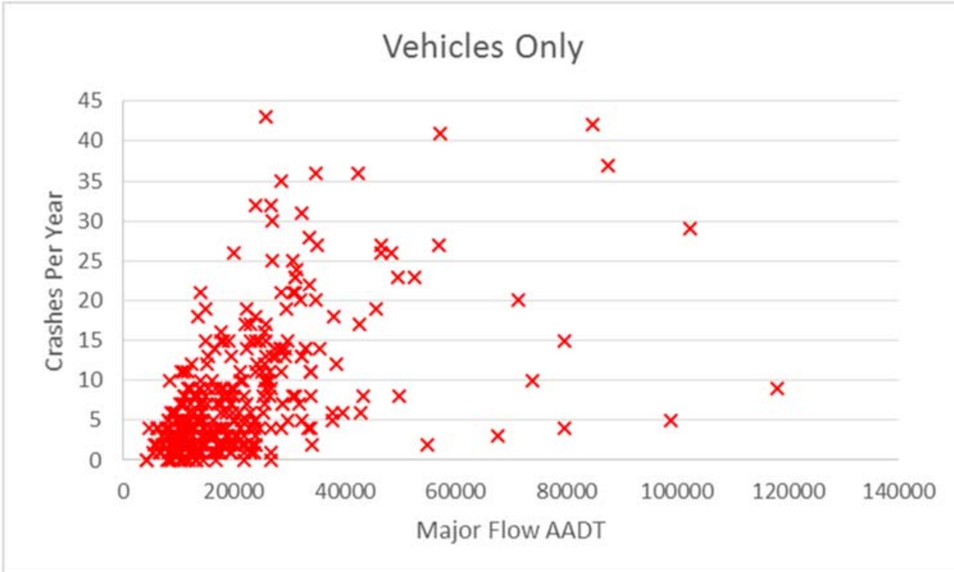
Intersection Type	3-Leg Signalized				4-Leg Signalized			
Variable	Min	Max	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.
Maj Rd AADT	4391.00	62094.00	20012.12	10001.91	4033.00	120082.00	21159.07	15155.69
Min Rd AADT	45.00	42828.00	3810.40	4911.33	88.00	69321.00	8901.74	7999.21
Maj Rd Through Lanes	0.00	10.00	3.60	1.29	0.00	10.00	3.64	1.24
Maj Rd Left Turn Lanes	0.00	2.00	1.06	0.77	0.00	4.00	1.35	0.93
Min Rd Through Lanes	0.00	4.00	0.46	0.76	0.00	8.00	2.64	1.07
Skew	0.00	74.34	10.21	14.51	0.00	61.04	9.85	14.25
Lighting Presence	0.00	1.00	0.73	0.44	0.00	1.00	0.96	0.20
Right Turn on Red Permitted	0.00	1.00	0.90	0.31	0.00	1.00	0.91	0.29
Maj Rd Driveway Count	0.00	10.00	2.38	2.18	0.00	13.00	3.40	2.71
Min Rd Driveway Count	0.00	7.00	1.34	1.41	0.00	14.00	3.74	2.61
Maj Rd Sidewalk Presence	0.00	1.00	0.71	0.45	0.00	1.00	0.79	0.40
Min Rd Sidewalk Presence	0.00	1.00	0.63	0.48	0.00	1.00	0.77	0.42
Curb Cut Presence	0.00	1.00	0.67	0.47	0.00	1.00	0.83	0.37
Maj Rd Width	25.42	282.62	69.21	35.27	27.91	314.48	65.74	29.50
Min Rd Width	14.77	176.45	45.17	16.58	25.99	188.98	50.23	21.68
Presence of Maj Rd Bike Lanes	0.00	1.00	0.01	0.12	0.00	1.00	0.03	0.16
Presence of Min Rd Bike Lanes	0.00	1.00	0.01	0.10	0.00	1.00	0.02	0.14
Bus Stop within 1000' on Maj Rd	0.00	1.00	0.26	0.44	0.00	1.00	0.31	0.46
Bus Stop within 1000' on Min Rd	0.00	1.00	0.06	0.23	0.00	1.00	0.20	0.40
Presence of Parking on Maj Rd	0.00	1.00	0.09	0.28	0.00	1.00	0.14	0.35
Presence of Parking on Min Rd	0.00	1.00	0.15	0.36	0.00	1.00	0.15	0.36
Presence of Maj Rd Median	0.00	1.00	0.12	0.32	0.00	1.00	0.11	0.31
Presence of Min Rd Median	0.00	1.00	0.10	0.29	0.00	1.00	0.04	0.20
Within 1/2 mile of K-12 school	0.00	1.00	0.16	0.37	0.00	1.00	0.40	0.49
Superior Region	0.00	1.00	0.04	0.20	0.00	1.00	0.13	0.34
North Region	0.00	1.00	0.11	0.32	0.00	1.00	0.14	0.35
Grand Region	0.00	1.00	0.12	0.33	0.00	1.00	0.15	0.35
Bay Region	0.00	1.00	0.10	0.30	0.00	1.00	0.14	0.35
Southwest Region	0.00	1.00	0.18	0.38	0.00	1.00	0.15	0.36
University Region	0.00	1.00	0.18	0.38	0.00	1.00	0.14	0.35
Metro Region	0.00	1.00	0.26	0.44	0.00	1.00	0.14	0.35
Maj Rd Speed Limit	25.00	55.00	41.05	8.41	25.00	70.00	38.70	9.44
Maj Rd One-Way	0.00	1.00	0.08	0.27	0.00	1.00	0.12	0.32
Min Rd One-Way	0.00	1.00	0.09	0.29	0.00	1.00	0.11	0.31

4.0 PRELIMINARY DATA ANALYSIS

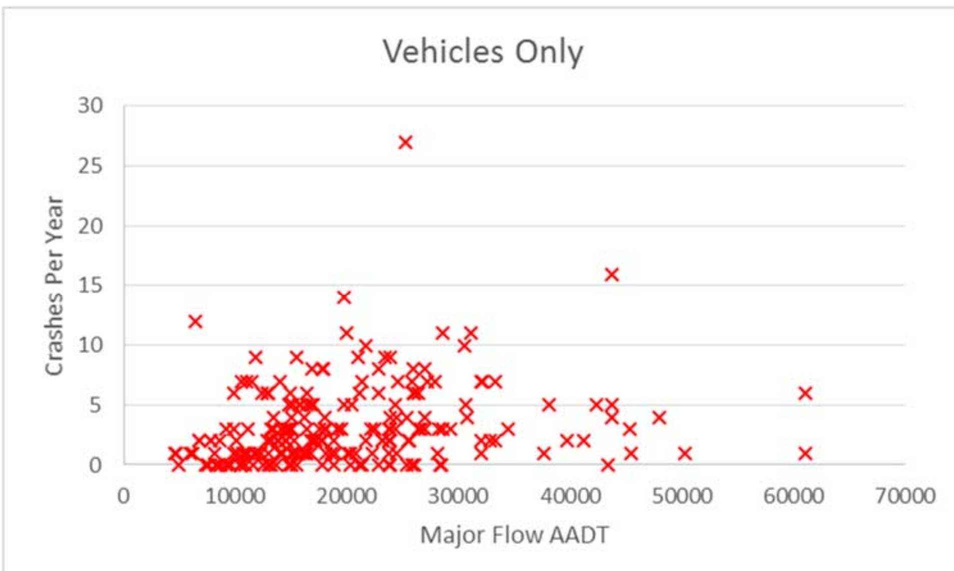
After the database was assembled, a series of preliminary analyses were conducted to examine general trends across the sample of study locations. This included assessing the univariate relationships between traffic crashes and each prospective predictor variable. Correlation among predictor variables was also examined and helped to inform the subsequent estimation of the SPFs.

Figure 16 through Figure 21 provide summary plots of the average annual number of crashes versus major road annual average daily traffic (AADT) for various site and crash types. Figure 16 and Figure 17 show the relationship between the number of crashes (all severities) and the Annual Average Daily Traffic (AADT) for the major approaches. These figures show that a non-linear relationship generally exists between traffic flow and the number of crashes. Crashes are shown to increase less rapidly at higher volumes, which is consistent with prior research in this area.

When examining these figures, there are several intersection locations that experienced significantly higher or lower numbers of crashes over the study period. As a part of the data collection process, careful quality assurance and quality control procedures were followed. This included a review of these potential outliers. Ultimately, all of the intersections included in the study were similar in terms of their geometric and traffic control characteristics. No sites were removed on the basis of their crash history during the study period. It is important to note that these figures represent only the effects of major road traffic volumes. Consequently, the effects of other important predictor variables are not reflected here. As an example, fewer crashes tended to be observed at locations with medians or where specific turning movements were prohibited. This explains several of the high volume locations that experienced fewer crashes on average.

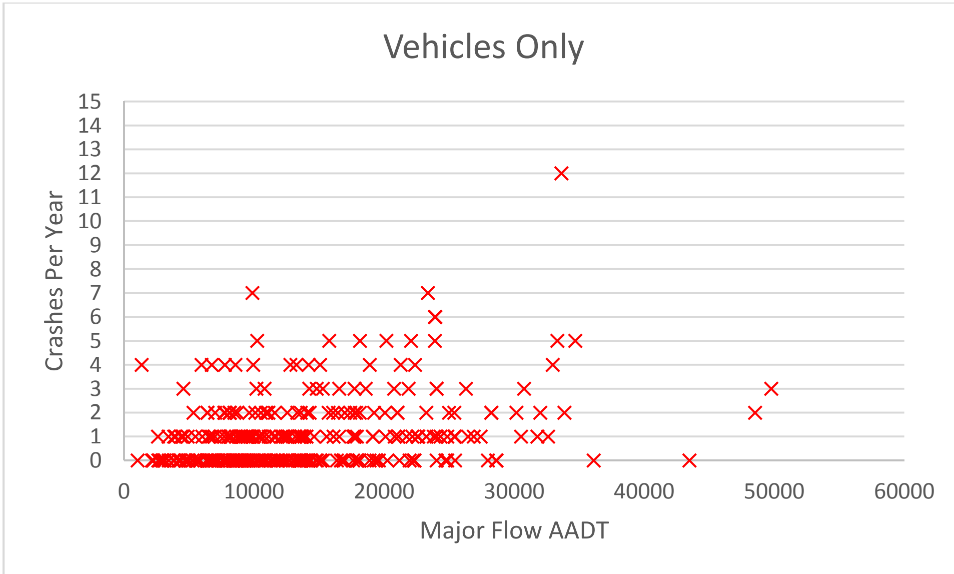


Four-Leg Intersections

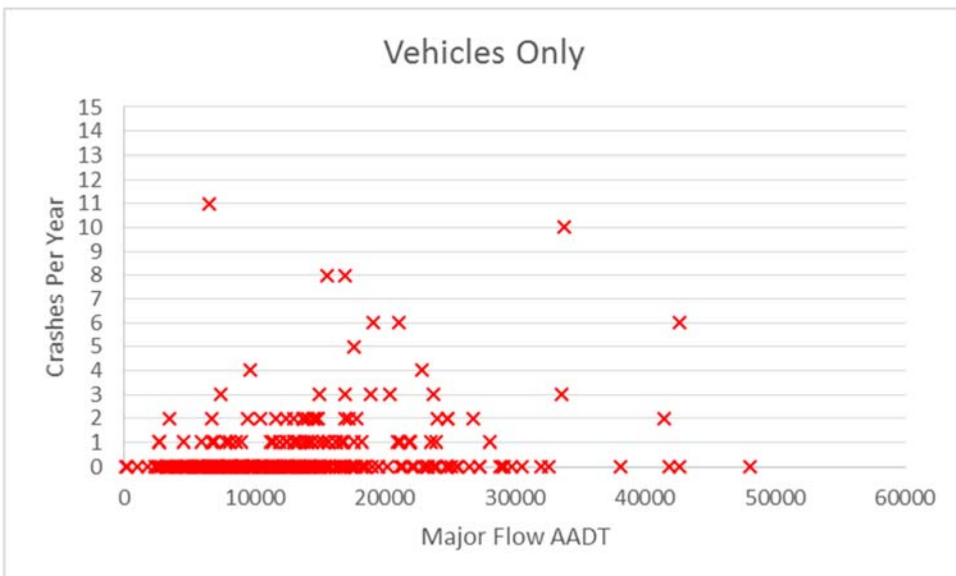


Three-Leg Intersections

Figure 16. Relationship Between the Number of Vehicle-Only Crashes and Major flow AADT for Signalized Intersections.



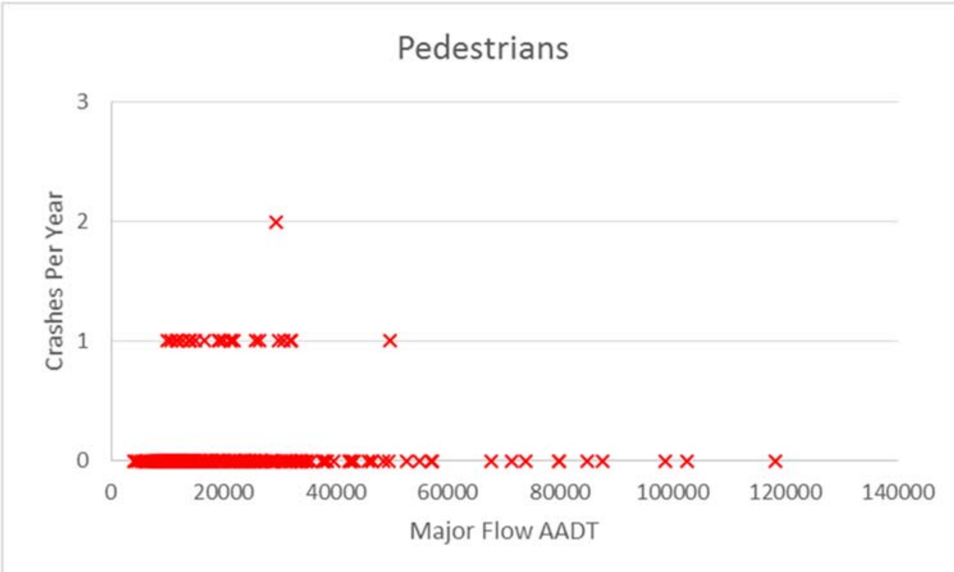
Four-Leg Intersections



Three-Leg Intersections

Figure 17. Relationship Between the Number of Vehicle-Only Crashes and Major flow AADT for Stop-Controlled Intersections.

Figure 18 and Figure 19 show the relationship between the number of pedestrian crashes and major flow AADT. The relationship shows that more crashes involving pedestrians occur at lower major AADT volumes.



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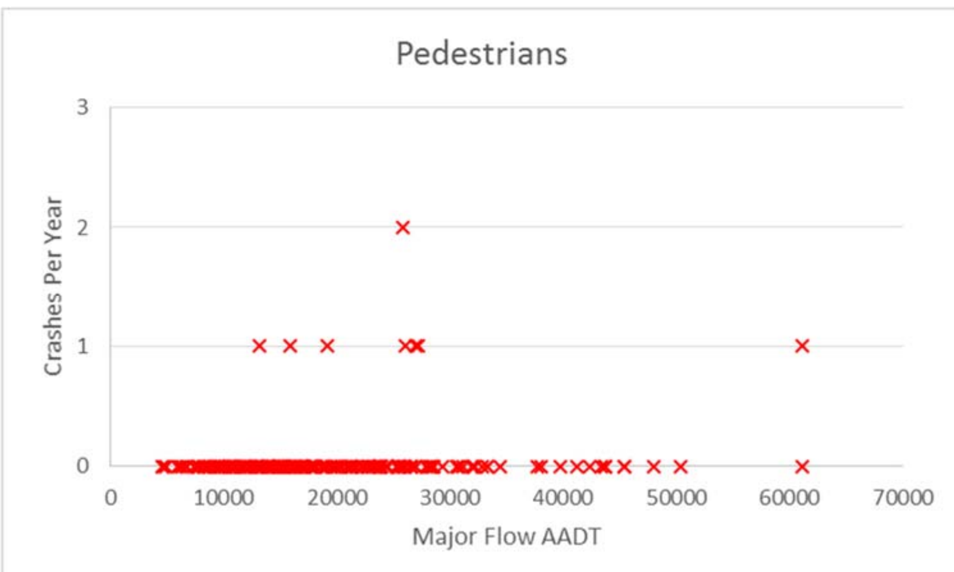
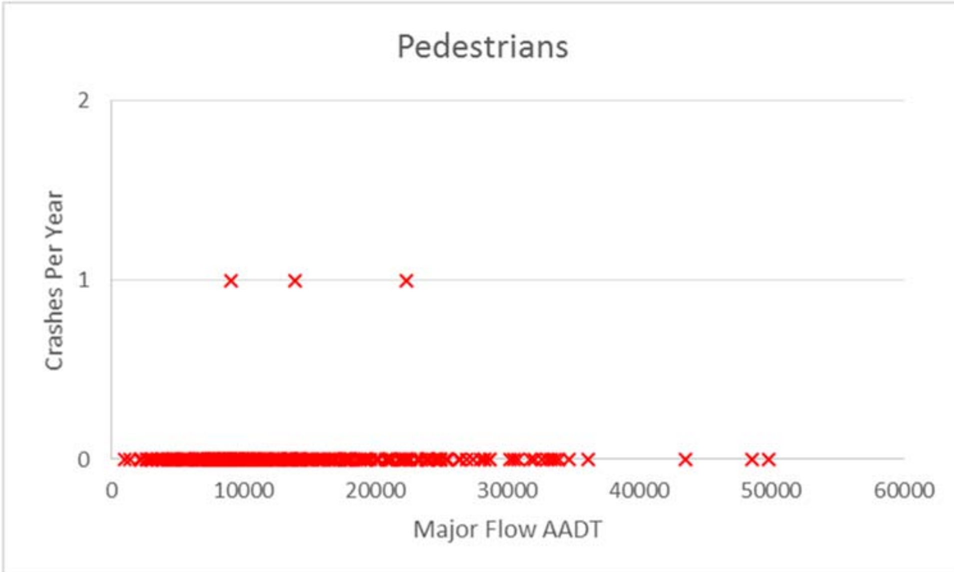
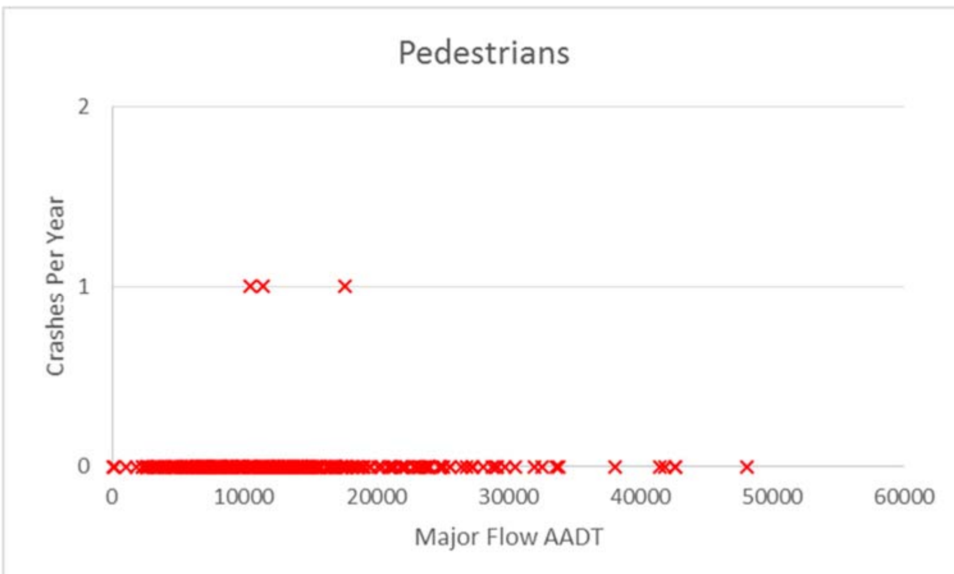


Three-Leg Intersections

Figure 18. Relationship Between the Number of Pedestrian Crashes and Major flow AADT for Signalized Intersections.



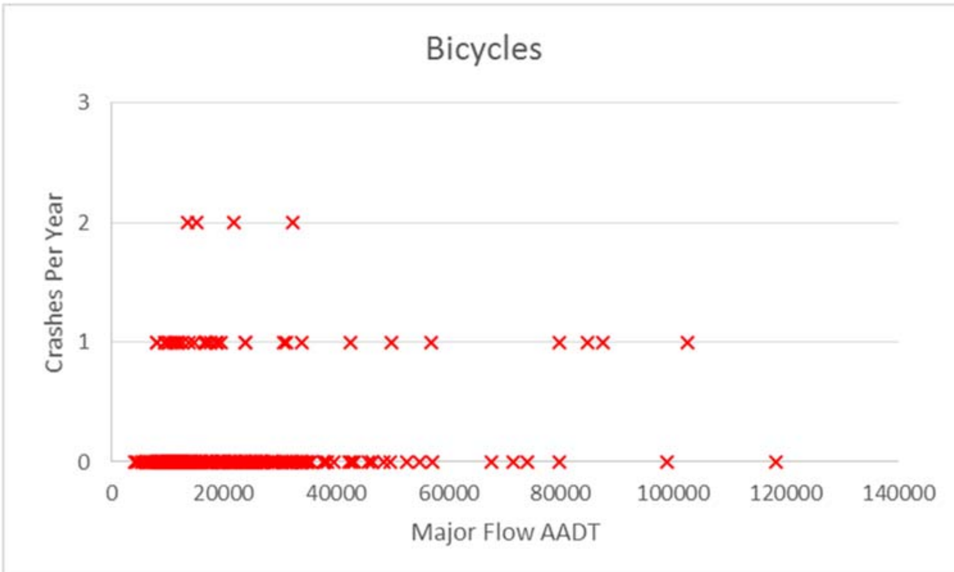
Four-Leg Intersections



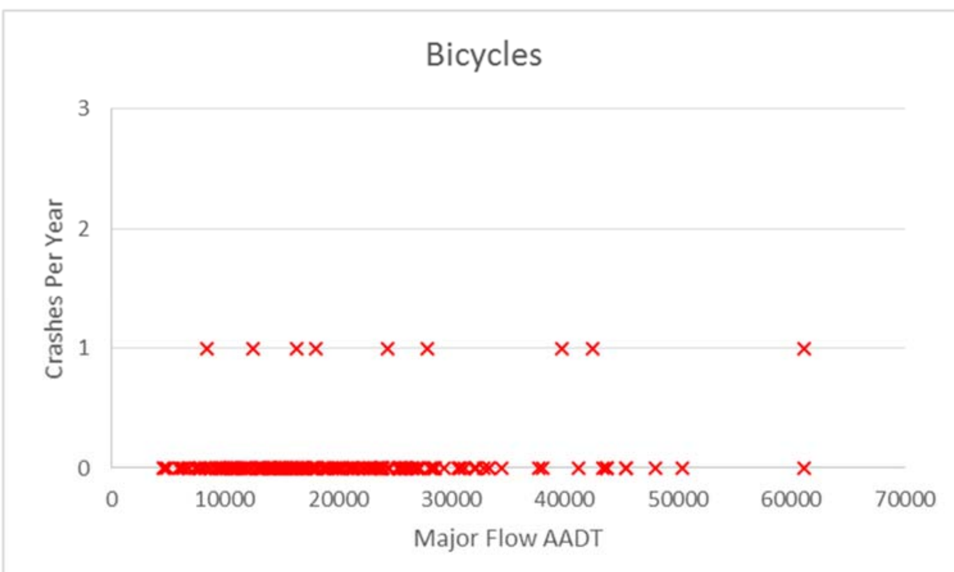
Three-Leg Intersections

Figure 19. Relationship Between the Number of Pedestrian Crashes and Major flow AADT for Stop-Controlled Intersections.

Figure 20 and Figure 21 show the relationship between the number of bicycle crashes and major flow AADT. The relationship shows that crashes involving bicycles occur at similar levels as a function of major AADT volumes.

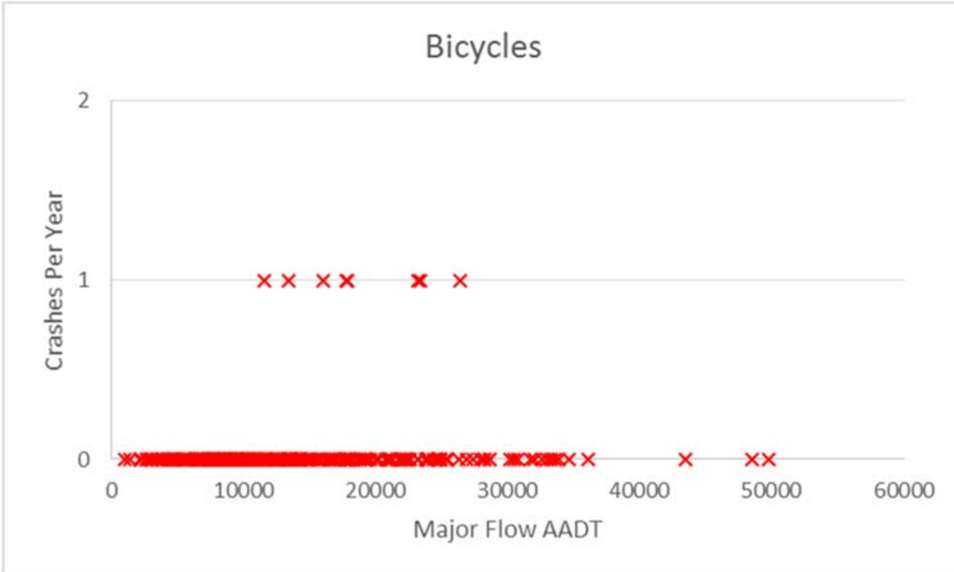


Four-Leg Intersections

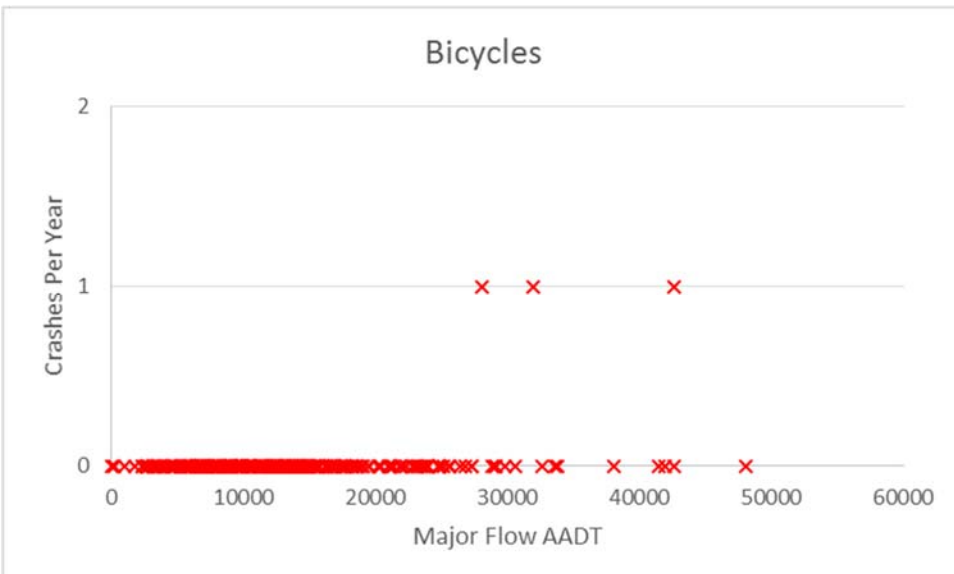


Three-Leg Intersections

Figure 20. Relationship Between the Number of Bicycle Crashes and Major flow AADT for Signalized Intersections.



Four-Leg Intersections



Three-Leg Intersections

Figure 21. Relationship Between the Number of Bicycle Crashes and Major flow AADT for Stop-Controlled Intersections.

4.1 Development of Safety Performance Functions

After examining these general relationships between crashes and traffic volume within each of the four site types, a series of SPFs were developed at varying degrees of complexity. These SPFs take the form of generalized linear models. As crash data are comprised of non-negative integers, traditional regression techniques (e.g., ordinary least-squares) are generally not appropriate. Given the nature of such data, the Poisson distribution has been shown to provide a better fit and has been used widely to model crash frequency data. In the Poisson model, the probability of intersection *i* experiencing y_i crashes during a one-year period is given by:

$$P(y_i) = \frac{EXP(-\lambda_i)\lambda_i^{y_i}}{y_i!},$$

where $P(y_i)$ is probability of intersection *i* experiencing y_i crashes and λ_i is the Poisson parameter for intersection *i*, which is equal to the segments expected number of crashes per year, $E[y_i]$. Poisson models are estimated by specifying the Poisson parameter λ_i (the expected number of crashes per period) as a function of explanatory variables, the most common functional form being $\lambda_i = \exp(\beta X_i)$, where X_i is a vector of explanatory variables and β is a vector of estimable parameters.

A limitation of this model is the underlying assumption of the Poisson distribution that the variance is equal to the mean. As such, the model cannot handle overdispersion wherein the variance is greater than the mean. Overdispersion is common in crash data and may be caused by data clustering, unaccounted temporal correlation, model misspecification, or ultimately by the nature of the crash data, which are the product of Bernoulli trials with unequal probability of events [*71*]. Overdispersion is generally accommodated through the use of negative binomial models (also referred to as Poisson-gamma models).

The negative binomial model is derived by rewriting the Poisson parameter for each intersection as $\lambda_i = \exp(\beta X_i + \varepsilon_i)$, where $EXP(\varepsilon_i)$ is a gamma-distributed error term with mean 1 and variance α. The addition of this term allows the variance to differ from the mean as $VAR[y_i] = E[y_i] + \alpha E[y_i]^2$. The negative binomial model is preferred over the Poisson model since the latter cannot handle overdispersion and, as such, may lead to biased parameter estimates [*72*]. Consequently, the *HSM* recommends using the negative binomial model for the development of SPFs.

If the overdispersion parameter (α) is equal to zero, the negative binomial reduces to the Poisson model. Estimation of λ_i can be conducted through standard maximum likelihood procedures. While alternatives, such as the Conway-Maxwell model, have the advantage of accommodating both overdispersion and underdispersion (where the variance is less than the mean) [*73*], the negative binomial model remains the standard in SPF development.

The overdispersion parameter from the negative binomial model is also utilized in the empirical Bayes (EB) method for evaluating the effectiveness of safety improvements as described in the *HSM*. The α parameter is used to determine the weighted adjustment factor, *w*, which is then used to estimate the expected number of crashes at a given location when combining observed crash data with the number of crashes predicted by an SPF. The formula for this weighting factor is:

$$w = \frac{1}{1 + (\alpha \times N_{spf})},$$

where:

α = overdispersion parameter, and
N_{spf} = predicted number of crashes by SPF.

Upon determining *w*, the expected number of crashes can then be determined as follows:

$$N_{expected} = w \times N_{spf} + (1 - w) \times N_{observed} \ ,$$

where:

$N_{expected}$ = expected number of crashes determined by the EB method,
w= weighted adjustment factor, and
$N_{observed}$ = observed number of crashes at a site.

For further details of the EB method, the reader is referred to the HSM [*2*].

As noted previously, several SPFs were developed at a part of this project at varying degrees of complexity. The complexity of the SPFs is reflective, in part, on the underlying data requirements. MDOT may eventually maintain a database that includes a comparable degree of detail to that which was collected for the purposes of this study. When such a database is available, very detailed statistical models may be utilized that account for the effects of this wide range of factors. Such models would provide the greatest degree of accuracy as they would be able to account for the effects of traffic volumes, roadway geometry, regional differences, and other effects.

In the absence of such data on a system-wide basis, it will not be possible to apply such models for all state-maintained intersections. However, these models will still be useful in the interim for detailed analyses at a smaller scale where manual collection of such data by MDOT staff is feasible. For larger scale studies, such as statewide or network-level screening, simpler models are necessary that do not have as rigorous data requirements. In this case, it is recommended that annual average daily traffic (AADT) estimates are provided for both the major and minor road as an absolute minimum. MDOT collects or estimates AADT on its entire trunkline system on a regular basis. While this is not necessarily the case with minor roads that are not state-maintained, AADT estimates have been developed for all such roads and were provided in the SafetyAnalyst AADT File that was used for the purposes of this study. Consequently, these simpler AADT-only models will provide a viable short-term tool for use in high-level safety planning activities. As a part of this study, SPFs were examined at four levels of detail:

- Uncalibrated HSM – The intersection models from Chapter 12 of the HSM were applied directly using traffic volume data for the study sites.
- Calibrated HSM – The predicted number of crashes based upon the SPFs from the HSM were calibrated based upon the observed crashes at the study sites.
- Michigan-Specific Models with AADT and Regional Indicators – A series of Michigan-specific models were developed using only AADT for the major and minor roads. A simple statewide model was estimated, as well as a similar model that included a series of binary indicator variable for each MDOT region.
- Fully Specified Michigan-Specific Models – A series of detailed models were subsequently developed in consideration of AADT, regional indicator variables, and a diverse range of geometric variables.

The uncalibrated and calibrated HSM models are discussed in Section 4.3 while the Michigan-specific SPFs are presented in Chapter 5.

4.3 Comparison of Uncalibrated and Calibrated HSM Models

The base SPFs from Chapter 12 of the HSM were first applied to the datasets for each of the four intersection types. These base models require only the AADT for the major and minor road as input values. While these models generally apply to base conditions (i.e., no left-turn or right-turn lanes on the major road, no skew, and no intersection lighting), they were applied directly to the study datasets without adjusting for those locations where the base conditions were not present (e.g., sites with auxiliary turn lanes). This was done as the data for base conditions are not available at the system-wide level in MDOT's SafetyAnalyst files. Separate estimates were obtained for total crashes, property damage only (PDO) crashes, and fatal/injury (F/I) crashes.

After applying these models, the resulting estimates for each study location were then compared to the observed values. The ratio of the total observed crashes to the estimated crashes (from the base SPFs) for the entire sample is used to estimate a calibration factor, which provides a measure of how close the base SPFs from the HSM fit the Michigan data. The calibration factor for each of the three models (i.e., total, PDO, and F/I) and each of the four site types (3SG, 3ST, 4SG, and 4ST) are presented in Table 7.

Table 7: Calibration Factors for HSM Models

	Intersection Types	3SG	3ST	4SG	4ST
Single-Vehicle	Total	0.950	0.266	0.977	0.333
	PDO	0.825	0.232	0.648	0.311
	Fatal-Injury	1.338	0.353	2.002	0.512
Multi-Vehicle	Total	0.876	0.294	1.094	0.469
	PDO	1.100	0.340	1.331	0.563
	Fatal-Injury	0.561	0.171	0.750	0.301

By briefly scanning the calibration factors for the *HSM* models, it is evident that the accuracy of the base SPFs from the HSM vary widely by site type, crash type, and crash severity level. It is also very clear that the parameter estimates of the Michigan specific models are noticeably different from the parameters for the *HSM* models. These differences are reflective of several factors, including state-specific differences (e.g., driver characteristics, road design standards, weather, etc.), as well as the fact that only AADT was considered (and not geometric or road use characteristics).

5.0 MICHIGAN-SPECIFIC SAFETY PERFORMANCE FUNCTIONS

Having established that the base SPFs from the HSM do not generally provide consistent fit across intersection types, crash types, and crash severity levels, the research team developed a series of Michigan-specific SPFs. These SPFs were developed in two general forms:

- Michigan-Specific Models with AADT and Regional Indicators – A series of Michigan-specific models were developed using only AADT for the major and minor roads. A simple statewide model was estimated, as well as a similar model that included a series of binary indicator variable for each MDOT region.
- Fully Specified Michigan-Specific Models – A series of detailed models were subsequently developed in consideration of AADT, regional indicator variables, and a diverse range of geometric variables.

5.1 SPFs with AADT only and SPFs with AADT and Regional Indicator Variables

This section presents the results of separate SPFs for fatal and injury (F/I) crashes and property damage only (PDO) crashes for each of the four site types. Results are presented in Table 8 through Table 14. For each site type, the results are first presented for a model that has been calibrated at the regional level. These models account for general differences in safety performance across the seven MDOT regions. For these models, parameter estimates are provided for AADT on the major and minor road. In each model, the Metro region serves as the baseline and indicator variables are then used to adjust the estimates to each of the other (i.e., non-Metro) regions.

These regional models are immediately followed by a more general statewide model. Graphical representation of the SPFs are provided in Figure 22 to Figure 28. These figures are also provided for both the regional and statewide SPFs.

Table 8 and Figure 22 present the SPFs for three-leg signalized (3SG) intersections. These locations showed crashes to increase much more rapidly with respect to major road AADT as compared to minor road AADT. When controlling for the effects of traffic volume, crashes were highest in the Superior and North regions and lowest in the Metro region.

Table 8. SPF for Crashes at 3SG Intersections with AADT and Regional Indicators

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-7.84	0.85	-9.26	-8.98	0.73	-12.23
Major AADT	0.65	0.08	7.86	0.81	0.07	11.52
Minor AADT	0.12	0.02	5.11	0.19	0.02	9.24
Added effect of Superior region	0.76	0.18	4.21	1.02	0.16	6.45
Added effect of North region	0.68	0.12	5.76	1.03	0.10	10.01
Added effect of Grand region	0.33	0.13	2.64	0.62	0.10	5.90
Added effect of Bay region	0.43	0.14	3.17	0.61	0.11	5.31
Added effect of Southwest region	0.67	0.12	5.81	0.87	0.10	8.88
Added effect of University region	0.48	0.12	4.07	0.65	0.10	6.53
Inverse Dispersion Parameter	14.93	NA	NA	1.98	0.16	12.10
*Note: Metro region serves as baseline reference category						

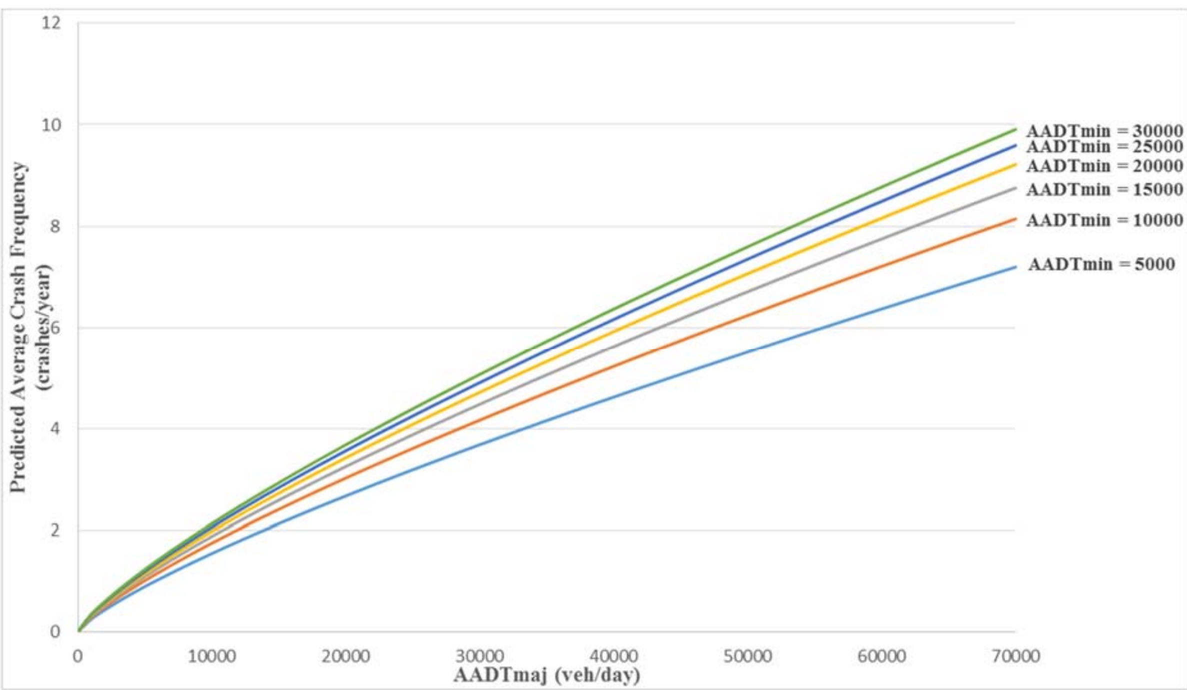


Figure 22. Graphical Form of SPF for Three-Leg Signalized (3SG) Intersections

Table 9 and Figure 23 present the AADT only SPFs for three-leg signalized (3SG) intersections. These locations behaved consistently with the regional indicator models and showed crashes to increase much more rapidly with respect to major road AADT as compared to minor road AADT.

Table 9. AADT Only SPF for Crashes at 3SG Intersections

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-5.35	0.71	-7.52	-5.96	0.68	-8.79
Major AADT	0.43	0.07	6.06	0.57	0.07	8.45
Minor AADT	0.13	0.02	5.22	0.19	0.02	8.89
Inverse Dispersion Parameter	10.64	NA	NA	1.58	0.119	13.28

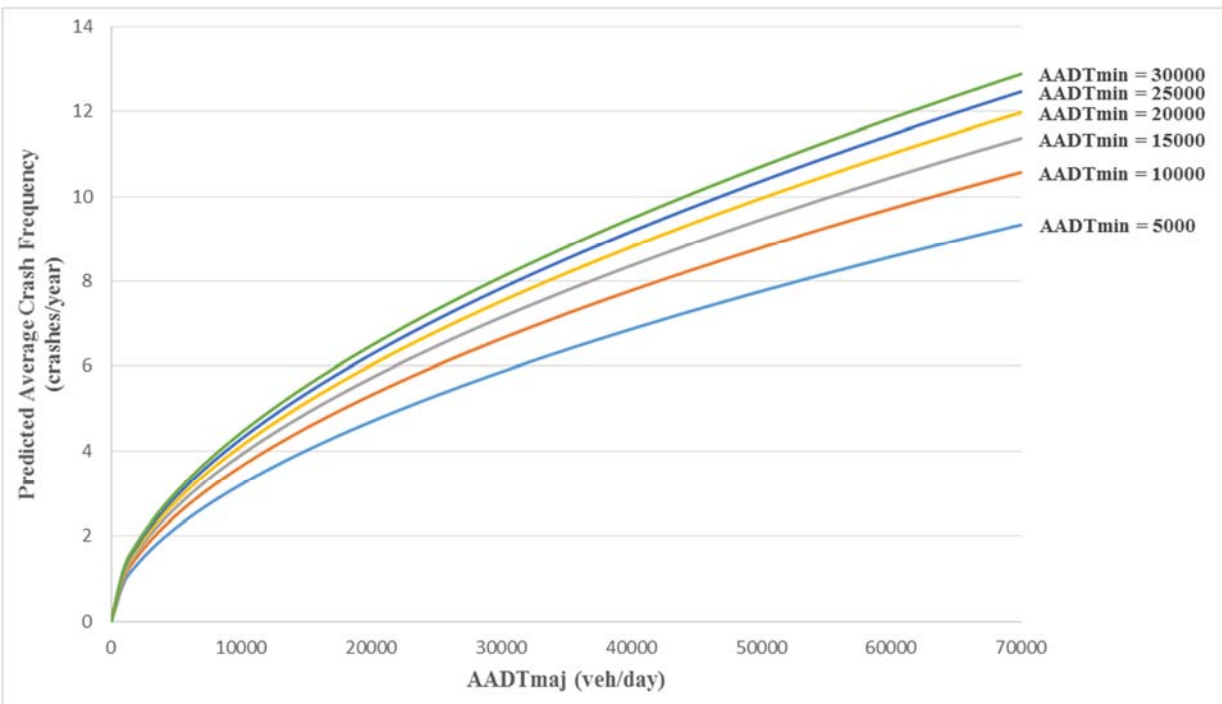


Figure 23. Graphical Form of AADT Only SPF for Three-Leg Signalized (3SG) Intersections

Table 10 and Figure 24 present the SPFs for three-leg stop-controlled (3ST) intersections. As, expected, major road AADT had a much more significant impact than minor road AADT, however the discrepancy is not as exaggerated as with the signalized intersections. Crashes were again highest in the Superior region and lowest in the Metro region.

Table 10. SPF for Crashes at 3ST Intersections with AADT and Regional Indicators

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-13.96	1.83	-7.62	-15.08	1.14	-13.22
Major AADT	0.91	0.18	5.15	1.16	0.11	10.46
Minor AADT	0.43	0.09	4.77	0.46	0.06	8.02
Added effect of Superior region	0.83	0.33	2.50	0.64	0.22	2.97
Added effect of North region	0.44	0.33	1.31	0.45	0.20	2.26
Added effect of Grand region	0.78	0.30	2.61	0.25	0.20	1.24
Added effect of Bay region	0.05	0.36	0.13	0.19	0.21	0.90
Added effect of Southwest region	0.71	0.33	2.13	0.77	0.21	3.69
Added effect of University region	0.26	0.35	0.76	0.34	0.21	1.64
Inverse Dispersion Parameter	0.49	0.14	3.54	0.56	0.07	7.81
*Note: Metro region serves as baseline reference category						

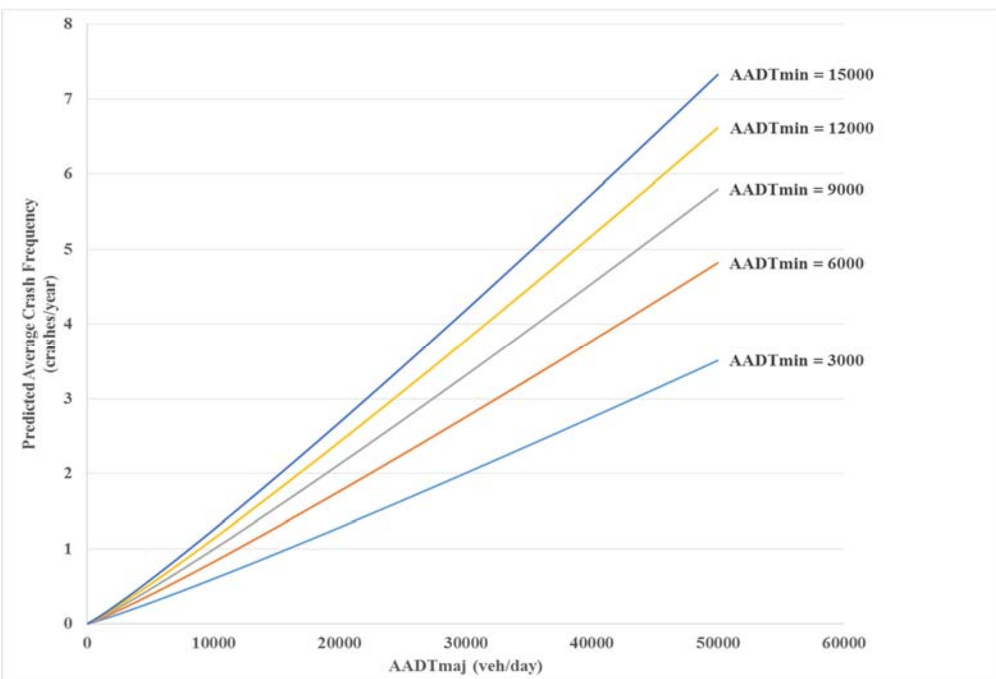


Figure 24. Graphical Form of SPF for Three-Leg Stop-Controlled (3ST) Intersections

Table 11 and Figure 25 present the AADT only SPFs for three-leg stop-controlled (3ST) intersections. When regional variations are not accounted for, the rate of increase of the predicted crash frequency tends to gradually decrease as the volume increases, which is opposite of the SPF with regional indicators.

Table 11. AADT Only SPF for Crashes at 3ST Intersections

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-11.89	1.53	-7.78	-13.06	0.97	-13.46
Major AADT	0.75	0.15	4.86	0.99	0.10	9.98
Minor AADT	0.42	0.09	4.75	0.46	0.06	8.22
Inverse Dispersion Parameter	0.45	0.12	3.65	0.53	0.07	8.04

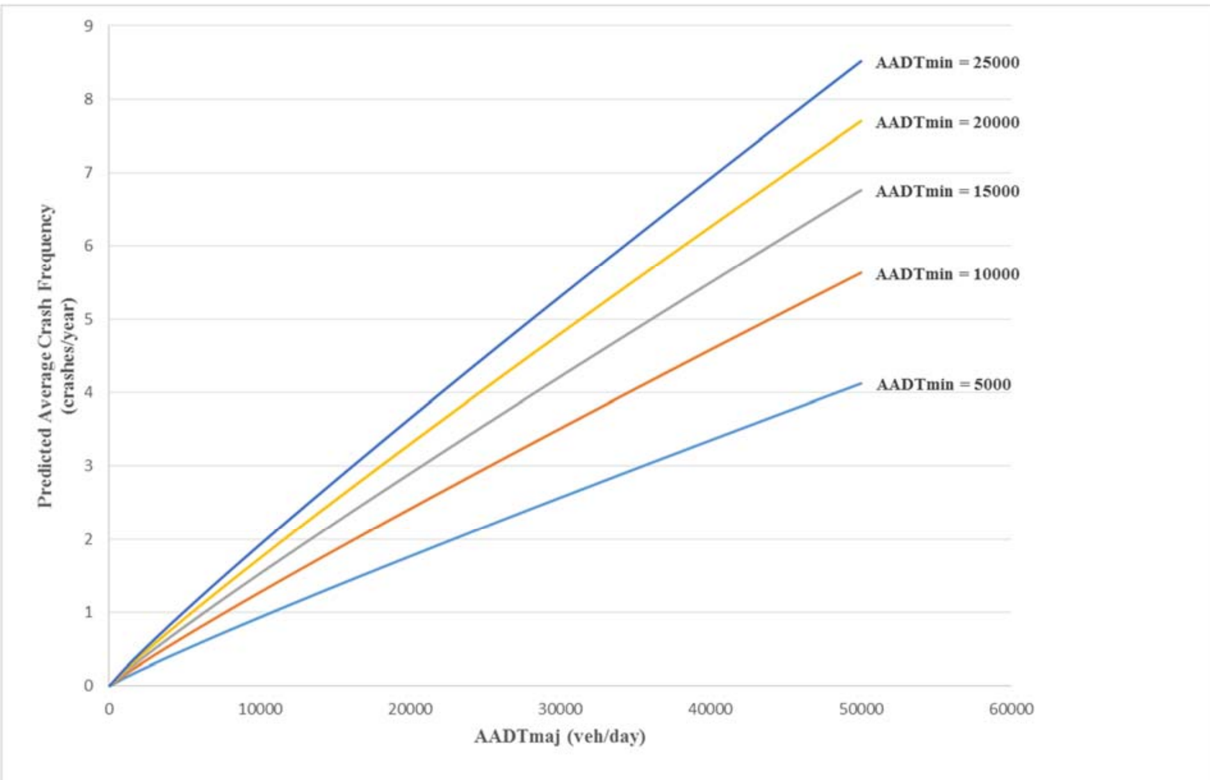


Figure 25. Graphical Form of AADT Only SPF for Three-Leg Stop-Controlled (3ST) Intersections

Table 12 and Figure 26 present the SPFs for four-leg signalized (4SG) intersections. As in the case of 3SG intersections, the major road AADT had a much more pronounced impact on crashes than the minor road AADT. This was true for both fatal and injury, as well as property damage only crashes. Fatal and injury crashes were highest in the Superior region and lowest in the Metro region while property damage only crashes were highest in the Southwest region, followed by Superior.

Table 12. SPF for Crashes at 4SG Intersections with AADT and Regional Indicators

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-9.60	0.53	-18.24	-10.70	0.40	-26.58
Major AADT	0.84	0.05	16.29	0.97	0.04	24.56
Minor AADT	0.18	0.02	7.78	0.28	0.02	15.88
Added effect of Superior region	0.52	0.10	4.99	0.62	0.08	7.74
Added effect of North region	0.27	0.09	2.94	0.59	0.07	8.41
Added effect of Grand region	0.30	0.08	3.67	0.40	0.06	6.16
Added effect of Bay region	0.36	0.09	3.89	0.52	0.07	7.29
Added effect of Southwest region	0.39	0.09	4.42	0.83	0.07	12.29
Added effect of University region	0.31	0.09	3.42	0.47	0.07	6.73
Inverse Dispersion Parameter	3.06	0.29	10.40	3.04	0.16	18.54
*Note: Metro region serves as baseline reference category						

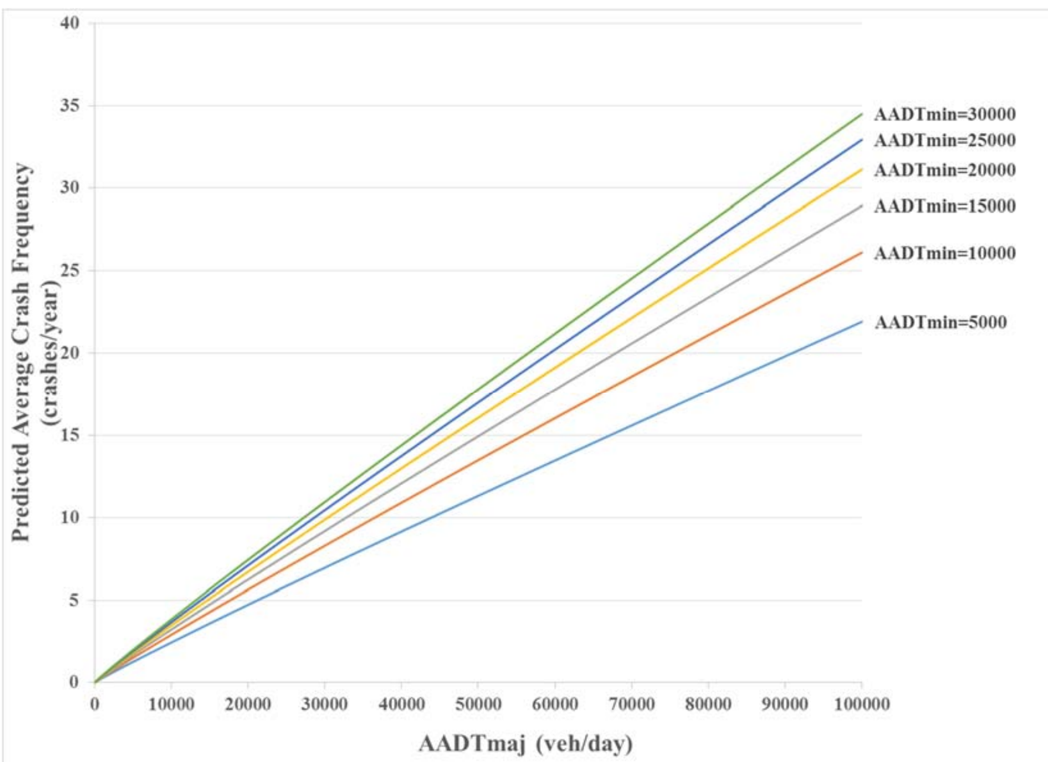


Figure 26. Graphical Form of SPF for Four-Leg Signalized (4SG) Intersections

Table 13 and Figure 27 present the AADT only SPFs for four-leg signalized (4SG) intersections. The AADT only SPF behaves similarly to the model with regional indicators.

Table 13. AADT Only SPF for Crashes at 4SG Intersections

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-7.90	0.40	-19.75	-8.44	0.34	-25.01
Major AADT	0.71	0.04	16.07	0.80	0.04	22.01
Minor AADT	0.17	0.02	7.40	0.26	0.02	14.82
Inverse Dispersion Parameter	2.95	0.281	10.51	2.63	0.13	19.58

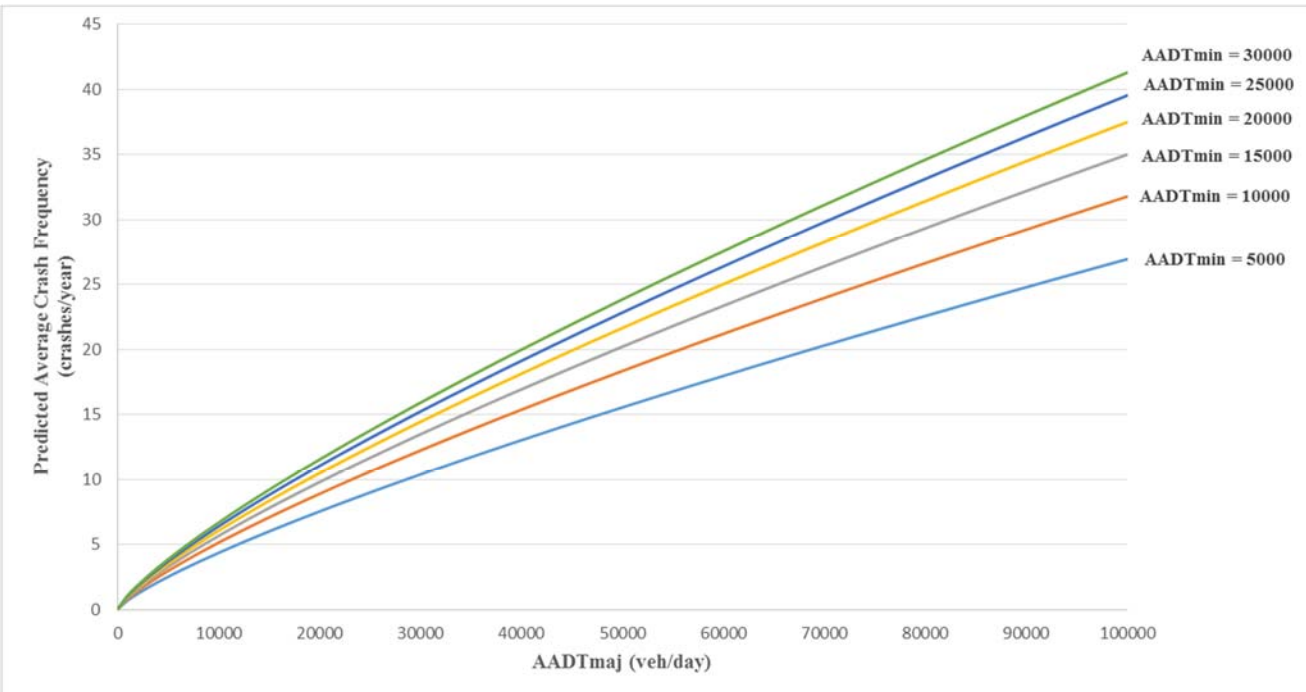


Figure 27. Graphical Form of AADT Only SPF for Four-Leg Signalized (4SG) Intersections

Table 14 and Figure 28 present the SPFs for four-leg stop-controlled (4ST) intersections. For both fatal and injury, as well as property damage only crashes, major road AADT had a stronger influence on crashes than minor road AADT. However, this difference was less pronounced than in the case of signalized intersections. Four-leg stop-controlled intersections were the only type where crash rates were not the highest in the Superior region, which actually exhibited the second lowest rates behind the Metro Region.

Table 14. SPF for Crashes at 4ST Intersections with AADT and Regional Indicators

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	**Std. Dev**	**t-statistic**	**Value**	**Std. Dev**	**t-statistic**
Intercept	-9.77	1.02	-9.62	-8.88	0.63	-14.17
Major AADT	0.59	0.10	6.12	0.53	0.06	8.99
Minor AADT	0.37	0.05	6.80	0.44	0.04	12.35
Added effect of Superior region	0.32	0.22	1.40	0.54	0.14	3.76
Added effect of North region	0.53	0.20	2.62	0.83	0.13	6.33
Added effect of Grand region	0.54	0.19	2.90	0.76	0.12	6.10
Added effect of Bay region	0.52	0.20	2.62	0.55	0.13	4.12
Added effect of Southwest region	0.57	0.20	2.92	0.64	0.13	4.85
Added effect of University region	0.53	0.19	2.80	0.58	0.13	4.58
Inverse Dispersion Parameter	1.17	0.23	5.04	1.74	0.19	9.02
*Note: Metro region serves as baseline reference category						

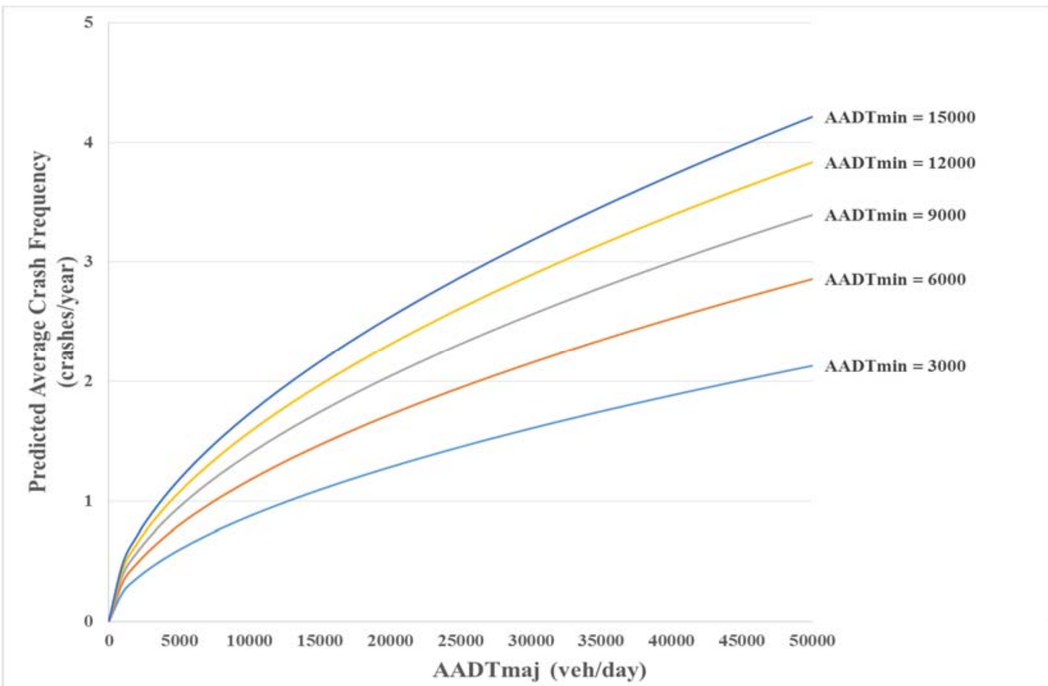


Figure 28. Graphical Form of SPF for Four-Leg Stop-Controlled (4ST) Intersections

Table 15 and Figure 29 present the AADT only SPFs for four-leg stop-controlled (4ST) intersections. For both fatal and injury, as well as property damage only crashes, major road AADT had a stronger influence on crashes than minor road AADT. This SPF exhibits the smallest difference in effect between the major road AADT and minor road AADT of any SPF developed.

Table 15. AADT Only SPF for Crashes at 4ST Intersections

Variable	Fatal and Injury Crashes			Property Damage Only Crashes		
	Value	Std. Dev	t-statistic	Value	Std. Dev	t-statistic
Intercept	-9.21	0.90	-10.25	-7.94	0.46	-17.33
Major AADT	0.56	0.09	6.33	0.50	0.05	10.69
Minor AADT	0.38	0.05	7.42	0.43	0.03	16.68
Inverse Dispersion Parameter	1.09	0.21	5.24	10.53	NA	NA

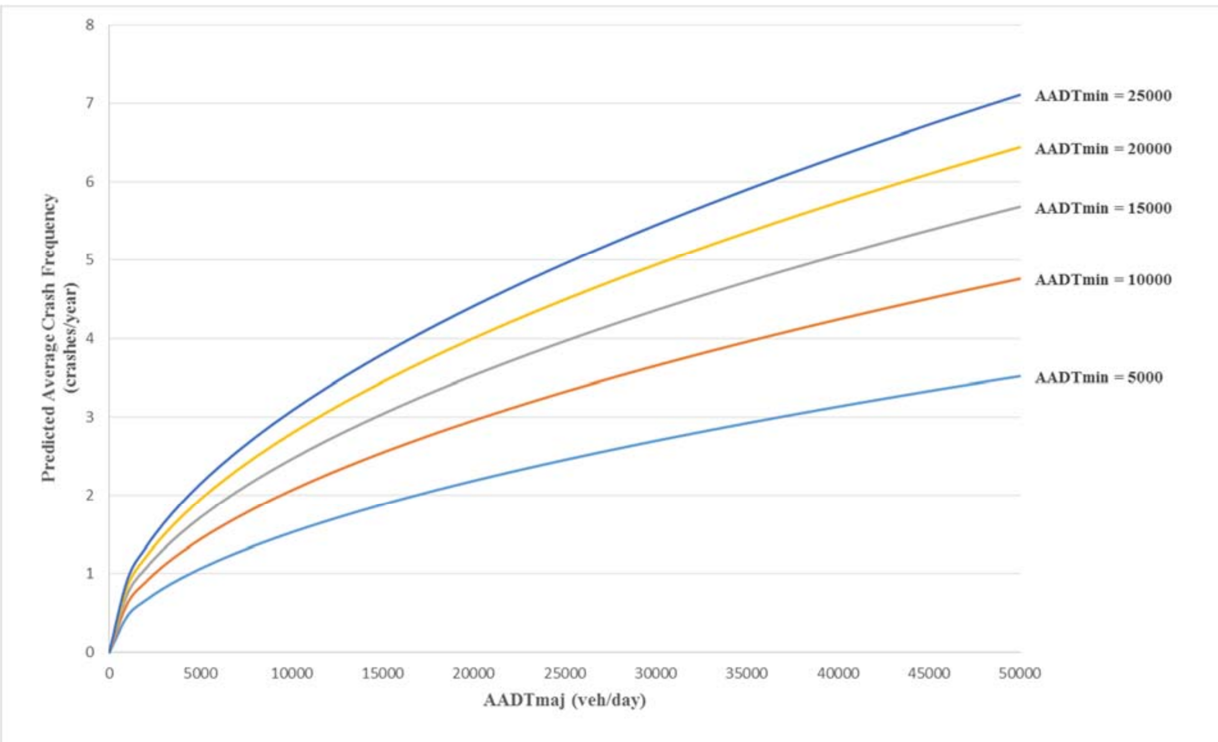


Figure 29. Graphical Form of AADT Only SPF for Four-Leg Stop-Controlled (4ST) Intersections

In addition to providing estimated of crashes by site type and region, it is also useful to predict how many crashes may be expected by type at a specific location. To this end, Table 16 provides details of the crash type distributions for each of the four site types by severity level (fatal/injury versus property damage only). Table 17 to Table 23 provide similar distributions for each of the MDOT regions.

Table 16. Statewide Distribution of Crashes by Collision type

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.04	0.05	0.03	0.06	0.02	0.02	0.05	0.06
Rear-end	0.42	0.51	0.28	0.35	0.35	0.45	0.16	0.24
Rear-end Left-turn	0.01	0.02	0.04	0.03	0.01	0.02	0.02	0.02
Rear-end Right-turn	0.01	0.03	0.03	0.04	0.01	0.02	0.01	0.02
Head-on	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.00
Head-on Left-turn	0.13	0.04	0.11	0.04	0.09	0.05	0.07	0.03
Angle	0.25	0.20	0.30	0.32	0.37	0.25	0.53	0.44
Sideswipe-Same	0.02	0.10	0.03	0.11	0.02	0.12	0.03	0.11
Sideswipe-Opposite	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02
Other MV	0.02	0.03	0.01	0.03	0.02	0.03	0.02	0.04
Pedestrian	0.04	0.00	0.05	0.00	0.03	0.00	0.04	0.00
Bicycle	0.03	0.00	0.07	0.01	0.04	0.00	0.05	0.00

Table 17. Distribution of Crashes by Collision type for Superior Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.11	0.05	0.03	0.09	0.02	0.03	0.06	0.08
Rear-end	0.49	0.58	0.31	0.18	0.30	0.40	0.16	0.29
Rear-end Left-turn	0.00	0.03	0.00	0.06	0.00	0.02	0.00	0.03
Rear-end Right-turn	0.00	0.02	0.03	0.01	0.01	0.02	0.00	0.03
Head-on	0.04	0.01	0.00	0.03	0.02	0.01	0.02	0.01
Head-on Left-turn	0.09	0.04	0.07	0.00	0.12	0.05	0.02	0.01
Angle	0.22	0.15	0.34	0.52	0.44	0.31	0.53	0.43
Sideswipe-Same	0.00	0.10	0.03	0.06	0.01	0.10	0.02	0.06
Sideswipe-Opposite	0.02	0.01	0.00	0.01	0.00	0.02	0.02	0.03
Other MV	0.02	0.01	0.00	0.03	0.01	0.03	0.04	0.04
Pedestrian	0.00	0.00	0.10	0.00	0.03	0.00	0.04	0.00
Bicycle	0.00	0.01	0.00	0.00	0.03	0.00	0.08	0.00

Table 18. Distribution of Crashes by Collision type for North Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.02	0.05	0.04	0.05	0.02	0.03	0.04	0.05
Rear-end	0.30	0.51	0.20	0.39	0.36	0.47	0.12	0.24
Rear-end Left-turn	0.00	0.01	0.00	0.04	0.00	0.02	0.00	0.03
Rear-end Right-turn	0.04	0.04	0.04	0.11	0.01	0.02	0.00	0.02
Head-on	0.01	0.01	0.04	0.00	0.01	0.01	0.01	0.00
Head-on Left-turn	0.27	0.05	0.32	0.05	0.15	0.05	0.12	0.04
Angle	0.22	0.19	0.24	0.20	0.34	0.26	0.56	0.48
Sideswipe-Same	0.01	0.10	0.04	0.11	0.01	0.09	0.00	0.07
Sideswipe-Opposite	0.01	0.02	0.04	0.01	0.01	0.02	0.01	0.00
Other MV	0.04	0.02	0.00	0.02	0.01	0.02	0.03	0.05
Pedestrian	0.00	0.00	0.00	0.00	0.03	0.00	0.04	0.00
Bicycle	0.06	0.00	0.00	0.02	0.03	0.00	0.04	0.00

Table 19. Distribution of Crashes by Collision type for Grand Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.04	0.06	0.00	0.07	0.03	0.03	0.03	0.04
Rear-end	0.48	0.51	0.31	0.29	0.35	0.49	0.22	0.28
Rear-end Left-turn	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.02
Rear-end Right-turn	0.01	0.03	0.08	0.04	0.01	0.03	0.01	0.04
Head-on	0.02	0.01	0.03	0.00	0.01	0.01	0.00	0.00
Head-on Left-turn	0.10	0.03	0.13	0.05	0.10	0.06	0.10	0.06
Angle	0.20	0.17	0.21	0.31	0.38	0.22	0.49	0.40
Sideswipe-Same	0.01	0.11	0.03	0.12	0.01	0.10	0.02	0.11
Sideswipe-Opposite	0.02	0.01	0.00	0.02	0.00	0.01	0.02	0.01
Other MV	0.02	0.04	0.03	0.05	0.02	0.03	0.03	0.04
Pedestrian	0.06	0.00	0.13	0.00	0.04	0.00	0.02	0.00
Bicycle	0.04	0.00	0.05	0.02	0.04	0.00	0.02	0.00

Table 20. Distribution of Crashes by Collision type for Bay Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.08	0.05	0.06	0.07	0.03	0.03	0.08	0.08
Rear-end	0.41	0.48	0.19	0.28	0.28	0.41	0.14	0.19
Rear-end Left-turn	0.00	0.02	0.00	0.04	0.00	0.02	0.00	0.01
Rear-end Right-turn	0.01	0.01	0.00	0.04	0.01	0.01	0.03	0.00
Head-on	0.02	0.01	0.06	0.01	0.01	0.01	0.00	0.01
Head-on Left-turn	0.12	0.05	0.13	0.08	0.09	0.05	0.05	0.03
Angle	0.26	0.22	0.19	0.36	0.44	0.32	0.55	0.48
Sideswipe-Same	0.03	0.13	0.13	0.09	0.03	0.11	0.03	0.13
Sideswipe-Opposite	0.02	0.01	0.00	0.01	0.01	0.02	0.00	0.02
Other MV	0.00	0.03	0.06	0.03	0.02	0.03	0.01	0.05
Pedestrian	0.02	0.00	0.00	0.00	0.03	0.00	0.03	0.00
Bicycle	0.02	0.00	0.19	0.00	0.02	0.00	0.05	0.00

Table 21. Distribution of Crashes by Collision type for Southwest Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.02	0.04	0.00	0.07	0.02	0.03	0.02	0.11
Rear-end	0.38	0.48	0.22	0.29	0.39	0.49	0.19	0.24
Rear-end Left-turn	0.00	0.02	0.00	0.06	0.00	0.02	0.00	0.03
Rear-end Right-turn	0.00	0.01	0.00	0.02	0.01	0.02	0.02	0.02
Head-on	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.01
Head-on Left-turn	0.13	0.05	0.15	0.02	0.07	0.03	0.05	0.02
Angle	0.33	0.25	0.41	0.34	0.34	0.23	0.47	0.39
Sideswipe-Same	0.01	0.08	0.04	0.11	0.02	0.13	0.04	0.11
Sideswipe-Opposite	0.01	0.02	0.00	0.00	0.01	0.01	0.00	0.03
Other MV	0.02	0.05	0.00	0.08	0.04	0.03	0.02	0.04
Pedestrian	0.07	0.00	0.00	0.00	0.02	0.00	0.12	0.00
Bicycle	0.02	0.00	0.07	0.00	0.05	0.00	0.06	0.01

Table 22. Distribution of Crashes by Collision type for University Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.05	0.06	0.00	0.09	0.02	0.02	0.03	0.05
Rear-end	0.41	0.49	0.29	0.36	0.31	0.41	0.14	0.19
Rear-end Left-turn	0.00	0.02	0.00	0.01	0.00	0.02	0.00	0.01
Rear-end Right-turn	0.00	0.02	0.00	0.00	0.02	0.02	0.00	0.02
Head-on	0.03	0.00	0.10	0.00	0.02	0.01	0.00	0.00
Head-on Left-turn	0.09	0.04	0.00	0.02	0.06	0.05	0.05	0.01
Angle	0.30	0.21	0.48	0.38	0.39	0.30	0.65	0.47
Sideswipe-Same	0.01	0.10	0.00	0.11	0.03	0.13	0.05	0.18
Sideswipe-Opposite	0.00	0.03	0.00	0.01	0.00	0.02	0.00	0.02
Other MV	0.01	0.02	0.00	0.01	0.02	0.02	0.01	0.05
Pedestrian	0.04	0.00	0.00	0.01	0.06	0.00	0.01	0.00
Bicycle	0.06	0.01	0.10	0.00	0.07	0.01	0.04	0.01

Table 23. Distribution of Crashes by Collision type for Metro Region Intersections

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single Vehicle	0.03	0.06	0.11	0.01	0.01	0.02	0.09	0.06
Rear-end	0.51	0.53	0.41	0.53	0.42	0.45	0.12	0.22
Rear-end Left-turn	0.00	0.02	0.00	0.00	0.00	0.01	0.00	0.06
Rear-end Right-turn	0.03	0.04	0.00	0.01	0.02	0.04	0.00	0.02
Head-on	0.03	0.01	0.04	0.00	0.02	0.01	0.03	0.00
Head-on Left-turn	0.08	0.02	0.00	0.03	0.09	0.04	0.07	0.04
Angle	0.19	0.15	0.26	0.23	0.30	0.21	0.47	0.42
Sideswipe-Same	0.04	0.12	0.00	0.14	0.04	0.16	0.07	0.11
Sideswipe-Opposite	0.01	0.01	0.00	0.02	0.00	0.02	0.00	0.03
Other MV	0.02	0.04	0.00	0.02	0.03	0.03	0.02	0.03
Pedestrian	0.05	0.00	0.07	0.00	0.03	0.00	0.03	0.00
Bicycle	0.02	0.01	0.11	0.02	0.03	0.00	0.07	0.01

5.2 Michigan Specific SPFs for Pedestrian- and Bicycle-Involved Crashes

Pedestrian and cyclist volumes were not readily available for this study, however, the research team attempted to develop models for pedestrian and bicycle crashes based on vehicular AADT for total, fatal-injury, and PDO crashes as shown in Table 24 and Table 25.

Table 24: Michigan Specific AADT Only Pedestrian Crash Models

Severity	Intersection Types	Intercept (a)	AADTmaj (b)	AADTmin (c)	Overdispersion factor (k)
Total	3ST	-15.512	0.765	0.385	2.143
	3SG	-9.044	0.402*	0.187	1.057
	4ST	-11.613	0.547	0.269	2.254
	4SG	-7.578	0.364	0.173	0.959
FI	3ST	-15.099	0.742	0.338	1.000
	3SG	-9.223	0.418*	0.182*	1.354
	4ST	-11.52	0.529	0.271	2.712
	4SG	-7.583	0.366	0.157	0.779
PDO	3ST	-20.711	0.886	0.661	1.168E-13
	3SG	-10.221	0.158*	0.283*	1.431E-16
	4ST	-16.547	0.793*	0.247*	0.000
	4SG	-10.535	0.316	0.311	0.977
*The variable was not significant at 95% confidence interval					

Table 25: Michigan Specific AADT Only Bicycle Crash Models

	Intersection Types	Intercept (a)	AADTmaj (b)	AADTmin (c)	Overdispersion factor (k)
Total	3ST	-14.744	0.778	0.394	1.214
	3SG	-11.092	0.575	0.232	1.000
	4ST	-11.173	0.618	0.188	1.184
	4SG	-6.958	0.256	0.227	0.884
FI	3ST	-15.567	0.873	0.353	0.939
	3SG	-10.889	0.551	0.204	1.000
	4ST	-11.555	0.659	0.157	0.083
	4SG	-7.834	0.340	0.203	0.702
PDO	3ST	-13.646	0.340*	0.591	1.648E-07
	3SG	-14.18	0.654*	0.331*	7.56E-11
	4ST	-11.718	0.408*	0.313	1.000
	4SG	-6.087	-0.072*	0.323	0.749
*The variable was not significant at 95% confidence interval					

In contrast to the prior models, the pedestrian- and bicycle-specific SPFs included AADT and crash data for the entire population of intersection locations. This was due to the fact that the study intersections included a relatively small number of such crashes, which inhibited the ability to estimate detailed models for non-motorized users.

Each of the models show that crashes increase with respect to major road and minor road traffic volumes. However, even in the highest volume cases, intersections are generally expected to experience only a fraction of a crash per year. In any case, these models provide a general starting point for pedestrian and bicycle safety analyses. As additional data become available, these models may be expanded to better understand the effects of geometric and traffic control factors on crash risk for pedestrians and bicyclists. The lack of a reliable exposure measure to represent the amount of pedestrian or bicyclist activity at a given intersection is also a limitation, which may be addressed through future programs aimed at collecting data for non-motorized users.

Another point worth noting is that most of the parameters in the property damage only (PDO) models are not statistically significant. This is reflective of the fact that pedestrian- or bicycle-involved crashes that result in no injury are very rare as most crashes of this type tend to go unreported.

5.3 Fully-Specified SPFs with AADT, Regional Indicators, and Geometric Variables

After estimating the models considering only traffic volumes and MDOT region, more detailed models were specified that considered the full database developed by the research team. These fully-specified models were developed in a format similar to those presented in Chapter 12 of the HSM. This section briefly outlines the format of these SPFs, which are estimated in combination with crash modification factors (CMFs) where sufficient data are available. Separate models are estimated for intersections of two-way streets and one-way streets as the factors contributing to crashes in each setting are found to vary, as are the magnitudes of the relevant predictors.

The predicted average crash frequency for each intersection with a particular traffic control is computed as the sum of predicted average crash frequency of all crash types that occurred at the intersection. The predicted average crash frequency is computed using the predictive model, where a model is the combination of a SPF and several CMFs. The SPF is used to estimate the average crash frequency for the stated base conditions. The CMFs are used to adjust the SPF estimate when the attributes of the subject site are not consistent with the base conditions. The predicted average crash frequency of an intersection is calculated as shown below.

$$N_i = N_{bi} + N_{pedi} + N_{bikei}$$

with,

$$N_{bi} = N_{mvi} + N_{svi}$$

$$N_{mvi} = N_{spfmv} \times (CMF_1 \times \ldots . \times CMF_p)$$

$$N_{svi} = N_{spfsv} \times (CMF_1 \times \ldots . \times CMF_p)$$

$$N_{pedi} = N_{bi} \times f_{ped}$$

$$N_{bikei} = N_{bi} \times f_{bike}$$

where,

$N_i =$ *predicted average crash frequency of an individual intersection for the selected year;*

$N_{bi} =$ *predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);*

$N_{pedi} =$ *predicted average crash frequency of vehicle-pedestrian collisions for an intersection ;*

$N_{bikei} =$ *predicted average crash frequency of vehicle-bicycle collisions for an intersection;*

$N_{mvi} =$ *predicted average crash frequency of multiple-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for an intersection ;*

$N_{svi} =$ *predicted average crash frequency of single-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for an intersection ;*

$N_{spfmv} =$ *predicted average crash frequency of multiple-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for base conditions ;*

$N_{spfmv} =$ *predicted average crash frequency of single-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for base conditions ;*

$f_{ped} =$ *pedestrian crash adjustment factor ;*

$f_{bike} =$ *bicycle crash adjustment factor ;*

$CMF_1 \times \ldots . \times CMF_p =$ *crash modification factors at a site with specific geometric design features p.*

SPFs and CMFs are provided for the following intersection types on urban and suburban arterials shown in Table 26.

Table 26. SPFs and CMFs by Site Type

Site Type	Site Types with SPFs
Two-way Street Intersections (both major and minor streets are two-way)	Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST) Signalized three-leg intersections (3SG) Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST) Signalized four-leg intersection (4SG)
One-way Street Intersections (either major or minor street is one-way)	Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST) Signalized three-leg intersections (3SG) Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST) Signalized four-leg intersection (4SG)

5.4 Model Development – Two-Way Street Intersections

The following regression model form was used to predict the average crash frequency at an individual intersection.

$$N_j = (N_{spfmv}I_{mv} + N_{spfsv}I_{sv}) \times CMF_{mp} \times CMF_{lgt} \times CMF_{lanes} \times CMF_{psl} \times CMF_{rtor} \times CMF_{lt}$$

with,

$$N_{spfmv} = n \times e^{b_{mv}+b_{mv1}\,ln(AADT_{maj})+b_{mv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$

$$N_{spfsv} = n \times e^{b_{sv}+b_{sv1}\,ln(AADT_{maj})+b_{sv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$

$$CMF_{mp} = CMF_{mp1} \times CMF_{mp2} = e^{b_{mp1}(I_{mp1})} \times e^{b_{mp2}(I_{mp2})}$$

$$CMF_{lgt} = e^{b_{lgt}(I_{lgt})}$$

$$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2} = \left[e^{b_{lanes}(N_{maj}-4)}P_{maj} + (1-P_{maj})\right] \times \left[e^{b_{lanes}(N_{min}-2)}P_{min} + (1-P_{min})\right]$$

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj}+AADT_{min}}$$

$$P_{min} = \frac{AADT_{min}}{AADT_{maj}+AADT_{min}}$$

$$CMF_{psl} = e^{b_{psl}(PSL-40)}$$

$$CMF_{rtor} = e^{b_{rtor}(1-I_{rtor})}$$

$$CMF_{lt} = e^{b_{lt}(I_{lt})}$$

where,

N_j = *predicted annual average crash frequency for model j (j=mv, sv);*

N_{mv} = *predicted annual average multiple-vehicle crash frequency;*

N_{sv} = *predicted annual average single-vehicle crash frequency;*

I_{mv} = *multiple-vehicle crash indicator variable (=1.0 if multiple-vehicle crash data, 0.0 otherwise) ;*

I_{sv} = *single-vehicle crash indicator variable (=1.0 if single-vehicle crash data, 0.0 otherwise) ;*

n = *number of years of crash data;*

$AADT_{maj}$ = *major street average annual daily traffic, veh/day;*

$AADT_{min}$ = *minor street average annual daily traffic, veh/day;*

I_{r1} = *Superior region indicator variable (=1.0 if site is in Superior region, 0.0 if it is not);*

I_{r2} = *North region indicator variable (=1.0 if site is in North region, 0.0 if it is not);*

I_{r3} = *Grand region indicator variable (=1.0 if site is in Grand region, 0.0 if it is not);*

I_{r4} = *Bay region indicator variable (=1.0 if site is in Bay region, 0.0 if it is not);*

I_{r5} = *Southwest region indicator variable (=1.0 if site is in Southwest region, 0.0 if it is not);*

I_{r6} = *University region indicator variable (=1.0 if site is in University region, 0.0 if it is not);*

CMF_{mp} = *median presence crash modification factor;*

CMF_{lgt} = *lighting presence crash modification factor;*

CMF_{lanes} = *number-of-lanes crash modification factor;*

CMF_{psl} = *major street posted speed limit crash modification factor;*

CMF_{rtor} = *right-turn-on-red prohibition crash modification factor;*

CMF_{lt} = *major street left-turn-lane presence crash modification factor;*

I_{mp1} = *median presence on major street indicator variable (=1.0 if present, 0.0 if it is not);*

I_{mp2} = *median presence on minor street indicator variable (=1.0 if present, 0.0 if it is not);*

I_{lgt} = *lighting presence at intersection indicator variable (=1.0 if present, 0.0 if it is not);*

N_{maj} = *number of through lanes on the major street;*

P_{maj} = *proportion of average daily traffic volume on the major street;*

N_{min} = *number of through lanes on the minor street;*

P_{min} = *proportion of average daily traffic volume on the minor street;*

PSL = *major street posted speed limit, miles/hr;*

I_{rtor} = *right-turn-on-red indicator variable (=1.0 if allowed, 0.0 if it is not);*

I_{lt} = *major street left-turn-lane presence indicator variable (=1.0 if present on all approaches, 0.0 if it is not);*

b_i = *calibration coefficient for variable i.*

5.4.1 Model Calibration

The predictive model calibration process consisted of the simultaneous calibration of multiple-vehicle and single-vehicle crash models and CMFs using the aggregate model represented by Equations above. The simultaneous calibration approach was needed because the CMFs were common to multiple-vehicle and single-vehicle crash models. The database assembled for calibration included two replications of the original database. The dependent variable in the first replication was set equal to the multiple-vehicle crashes. The dependent variable in the second replication was set equal to the single-vehicle crashes. The results of the multivariate regression model calibration are presented in the following tables. Table 27 and Table 28 summarize the results for fatal and injury, and PDO crashes respectively at two-way street intersections. The t-statistics indicate a test of the hypothesis that the coefficient value is equal to 0.0. Those t-statistics with an absolute value that is larger than 2.0 indicate that the hypothesis can be rejected with the probability of error in this conclusion being less than 0.05. For those few variables where the absolute value of the t-statistic is smaller than 2.0, it was decided that the variable was important to the model and its trend was found to be consistent with previous research findings (even if the specific value was not known with a great deal of certainty as applied to this database). The indicator variables for different regions in the state were found to be significant. For the same conditions, the Superior Region experiences the highest number of fatal and injury crashes (in the case of PDO crashes, it is the southwest region), while the Metro Region experiences the least. The trend could not be explained by difference in road design among the regions. It is likely due to the differences between regions that are due to unobserved variables such as vertical grade, crash reporting, and weather.

Table 27. Calibrated Coefficients for Fatal and Injury Crashes on Two-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_{mv}	Intercept for MV crashes	3SG	-10.228	0.846	-12.10
		3ST	-16.764	2.330	-7.20
		4SG	-10.300	0.785	-13.13
		4ST	-11.235	1.492	-7.53
b_{mv1}	Major AADT on MV crashes	3SG	0.831	0.078	10.64
		3ST	1.067	0.239	4.46
		4SG	0.831	0.078	10.64
		4ST	0.677	0.150	4.52
b_{mv2}	Minor AADT on MV crashes	3SG	0.170	0.046	3.72
		3ST	0.594	0.119	4.98
		4SG	0.231	0.036	6.48
		4ST	0.447	0.083	5.37
b_{sv}	Intercept for SV crashes	3SG	-10.205	2.609	-3.91
		3ST	-8.953	3.838	-2.33
		4SG	-8.204	2.099	-3.91
		4ST	-7.585	3.323	-2.28
b_{sv1}	Major AADT on SV crashes	3SG	0.279	0.224	1.24
		3ST	0.108	0.335	0.32
		4SG	0.279	0.224	1.24
		4ST	0.108	0.335	0.32
b_{sv2}	Minor AADT on SV crashes	3SG	0.450	0.173	2.59
		3ST	0.292	0.203	1.44
		4SG	0.196	0.131	1.50
		4ST	0.292	0.203	1.44
b_{r1}	Added effect of Superior region	All	0.596	0.123	4.86
b_{r2}	Added effect of North region	All	0.447	0.111	4.05
b_{r3}	Added effect of Grand region	All	0.446	0.106	4.23
b_{r4}	Added effect of Bay region	All	0.444	0.117	3.79
b_{r5}	Added effect of Southwest region	All	0.559	0.113	4.97
b_{r6}	Added effect of University region	All	0.473	0.111	4.26
b_{mp1}	Median presence on major street	All	-0.344	0.107	-3.22
b_{mp2}	Median presence on minor street	All	-0.326	0.130	-2.51
b_{lgt}	Lighting presence	3ST/4ST	-0.305	0.145	-2.10
b_{lanes}	Number of lanes	3SG/4SG	0.068	0.019	3.67
		3ST/4ST	0.046	0.037	1.25
b_{psl}	Major street posted speed limit	3SG/4SG	0.019	0.004	4.83
		3ST/4ST	0.010	0.007	1.36
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	-0.301	0.115	-2.61
b_{lt}	Major street left-turn-lane	3SG	-0.067	0.178	-0.38
		3ST	-0.404	0.261	-1.55
k_{mv}	Inverse dispersion parameter for MV crashes	3SG	2.123	0.387	5.48
		3ST	1.451	0.691	2.10
		4SG	3.821	0.513	7.45
		4ST	1.354	0.264	5.13
k_{sv}	Inverse dispersion parameter for SV crashes	3SG	0.938	0.907	1.03
		3ST	1.023	1.565	0.65
		4SG	5.183	6.106	0.85
		4ST	1.023	1.565	0.65
Observations		1059 intersections (3SG=176; 3ST=299; 4SG=283;4ST=301)			

Table 28. Calibrated Coefficients for PDO Crashes at Two-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_{mv}	Intercept for MV crashes	3SG	-10.731	0.710	-15.11
		3ST	-17.258	1.807	-9.55
		4SG	-10.882	0.654	-16.63
		4ST	-9.891	1.027	-9.64
b_{mv1}	Major AADT on MV crashes	3SG	0.953	0.066	14.38
		3ST	1.325	0.188	7.07
		4SG	0.953	0.066	14.38
		4ST	0.607	0.103	5.90
b_{mv2}	Minor AADT on MV crashes	3SG	0.233	0.039	6.00
		3ST	0.462	0.092	5.01
		4SG	0.287	0.029	9.80
		4ST	0.483	0.066	7.36
b_{sv}	Intercept for SV crashes	3SG	-7.549	1.349	-5.60
		3ST	-6.952	1.909	-3.64
		4SG	-8.672	1.133	-7.65
		4ST	-6.213	1.689	-3.68
b_{sv1}	Major AADT on SV crashes	3SG	0.287	0.121	2.38
		3ST	0.049	0.174	0.28
		4SG	0.287	0.121	2.38
		4ST	0.049	0.174	0.28
b_{sv2}	Minor AADT on SV crashes	3SG	0.297	0.081	3.67
		3ST	0.350	0.107	3.27
		4SG	0.377	0.077	4.87
		4ST	0.350	0.107	3.27
b_{r1}	Added effect of Superior region	All	0.633	0.096	6.58
b_{r2}	Added effect of North region	All	0.716	0.086	8.28
b_{r3}	Added effect of Grand region	All	0.589	0.084	7.04
b_{r4}	Added effect of Bay region	All	0.509	0.093	5.49
b_{r5}	Added effect of Southwest region	All	0.775	0.088	8.84
b_{r6}	Added effect of University region	All	0.533	0.088	6.04
b_{mp1}	Median presence on major street	All	-0.237	0.085	-2.78
b_{mp2}	Median presence on minor street	All	-0.301	0.102	-2.94
b_{lgt}	Lighting presence	3ST/4ST	-0.137	0.108	-1.27
b_{lanes}	Number of lanes	3SG/4SG	0.053	0.015	3.46
		3ST/4ST	0.014	0.028	0.52
b_{psl}	Major street posted speed limit	3SG/4SG	0.006	0.003	1.85
		3ST/4ST	-0.010	0.006	-1.76
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	-0.063	0.091	-0.69
b_{lt}	Major street left-turn-lane	3SG	-0.104	0.138	-0.75
		3ST	-0.187	0.210	-0.89
k_{mv}	Inverse dispersion parameter for MV crashes	3SG	2.211	0.293	7.54
		3ST	0.796	0.140	5.69
		4SG	3.952	0.390	10.14
		4ST	1.574	0.201	7.83
k_{sv}	Inverse dispersion parameter for SV crashes	3SG	1.686	0.678	2.49
		3ST	0.817	0.295	2.77
		4SG	8.638	8.257	1.05
		4ST	0.817	0.295	2.77
Observations		1059 intersections (3SG=176; 3ST=299; 4SG=283;4ST=301)			

Depending on the scope of a particular project, MDOT may wish to utilize SPFs that do not feature regional indicators. For this purpose, Table 51 and Table 52 illustrate the coefficients for such SPFs.

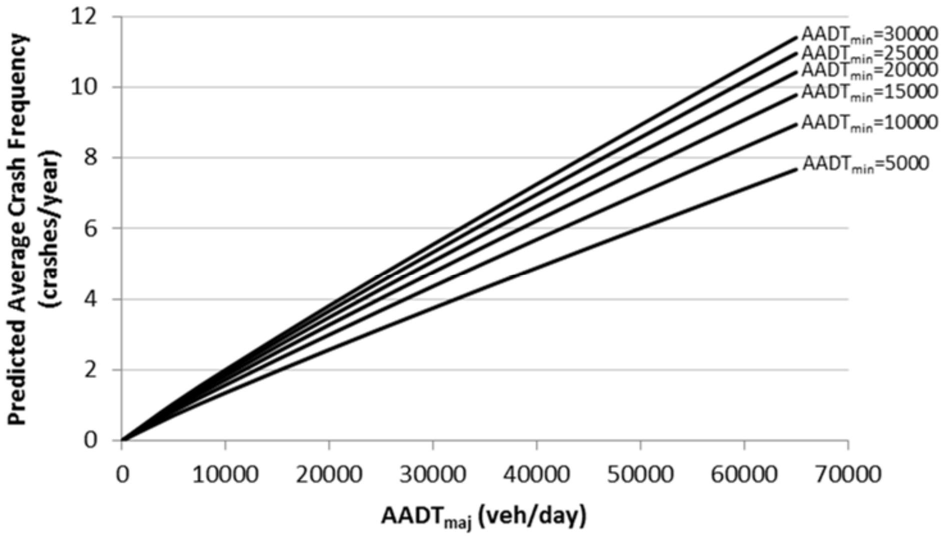
Table 29. Calibrated Coefficients for Statewide Fatal and Injury Crashes on Two-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_{mv}	Intercept for MV crashes	3SG	-8.611	0.807	-10.67
		3ST	-15.373	2.314	-6.64
		4SG	-8.545	0.717	-11.92
		4ST	-10.283	1.480	-6.95
b_{mv1}	Major AADT on MV crashes	3SG	0.715	0.076	9.41
		3ST	0.978	0.239	4.09
		4SG	0.715	0.076	9.41
		4ST	0.621	0.150	4.15
b_{mv2}	Minor AADT on MV crashes	3SG	0.170	0.047	3.64
		3ST	0.586	0.119	4.92
		4SG	0.221	0.036	6.21
		4ST	0.452	0.084	5.39
b_{sv}	Intercept for SV crashes	3SG	-8.805	2.580	-3.41
		3ST	-8.069	3.798	-2.12
		4SG	-6.891	2.039	-3.38
		4ST	-6.725	3.286	-2.05
b_{sv1}	Major AADT on SV crashes	3SG	0.194	0.220	0.88
		3ST	0.061	0.331	0.18
		4SG	0.194	0.220	0.88
		4ST	0.061	0.331	0.18
b_{sv2}	Minor AADT on SV crashes	3SG	0.440	0.176	2.51
		3ST	0.298	0.203	1.47
		4SG	0.201	0.133	1.51
		4ST	0.298	0.203	1.47
b_{mp1}	Median presence on major street	All	-0.347	0.105	-3.32
b_{mp2}	Median presence on minor street	All	-0.333	0.130	-2.57
b_{lgt}	Lighting presence	3ST/4ST	-0.308	0.147	-2.09
b_{lanes}	Number of lanes	3SG/4SG	0.044	0.019	2.26
		3ST/4ST	0.036	0.037	0.97
b_{psl}	Major street posted speed limit	3SG/4SG	0.021	0.004	5.41
		3ST/4ST	0.011	0.007	1.46
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	-0.277	0.115	-2.40
b_{lt}	Major street left-turn-lane	3SG	-0.098	0.180	-0.55
		3ST	-0.490	0.262	-1.87
k_{mv}	Inverse dispersion parameter for MV crashes	3SG	1.965	0.344	5.72
		3ST	1.342	0.622	2.16
		4SG	3.614	0.476	7.59
		4ST	1.259	0.237	5.32
k_{sv}	Inverse dispersion parameter for SV crashes	3SG	0.726	0.530	1.37
		3ST	1.259	2.281	0.55
		4SG	4.708	5.630	0.84
		4ST	1.259	2.281	0.55
Observations		1059 intersections (3SG=176; 3ST=299; 4SG=283;4ST=301)			

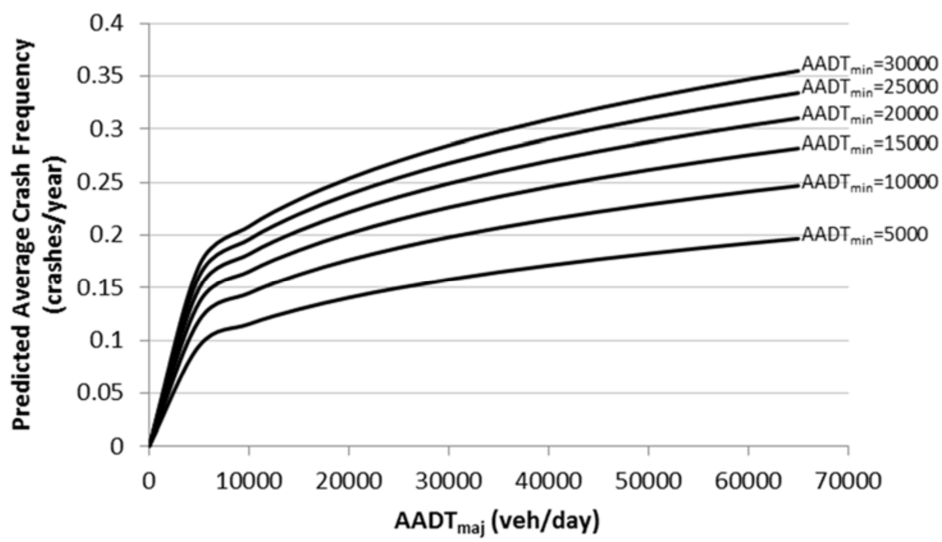
Table 30. Calibrated Coefficients for Statewide PDO Crashes at Two-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_{mv}	Intercept for MV crashes	3SG	-9.172	0.723	-12.68
		3ST	-16.328	1.819	-8.98
		4SG	-9.291	0.643	-14.45
		4ST	-8.615	1.027	-8.39
b_{mv1}	Major AADT on MV crashes	3SG	0.874	0.068	12.77
		3ST	1.299	0.190	6.83
		4SG	0.874	0.068	12.77
		4ST	0.548	0.104	5.26
b_{mv2}	Minor AADT on MV crashes	3SG	0.218	0.042	5.24
		3ST	0.459	0.093	4.92
		4SG	0.273	0.030	9.08
		4ST	0.466	0.066	7.10
b_{sv}	Intercept for SV crashes	3SG	-5.571	1.306	-4.27
		3ST	-5.852	1.914	-3.06
		4SG	-6.891	1.078	-6.39
		4ST	-5.130	1.692	-3.03
b_{sv1}	Major AADT on SV crashes	3SG	0.160	0.117	1.36
		3ST	0.001	0.175	0.01
		4SG	0.160	0.117	1.36
		4ST	0.001	0.175	0.01
b_{sv2}	Minor AADT on SV crashes	3SG	0.286	0.081	3.55
		3ST	0.348	0.109	3.21
		4SG	0.395	0.079	4.98
		4ST	0.348	0.109	3.21
b_{mp1}	Median presence on major street	All	-0.246	0.087	-2.84
b_{mp2}	Median presence on minor street	All	-0.323	0.106	-3.06
b_{lgt}	Lighting presence	3ST/4ST	-0.153	0.109	-1.40
b_{lanes}	Number of lanes	3SG/4SG	0.019	0.017	1.14
		3ST/4ST	0.006	0.028	0.21
b_{psl}	Major street posted speed limit	3SG/4SG	0.010	0.004	2.79
		3ST/4ST	-0.010	0.006	-1.63
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	-0.032	0.094	-0.34
b_{lt}	Major street left-turn-lane	3SG	-0.149	0.145	-1.02
		3ST	-0.357	0.211	-1.69
k_{mv}	Inverse dispersion parameter for MV crashes	3SG	1.817	0.226	8.03
		3ST	0.748	0.127	5.88
		4SG	3.443	0.328	10.48
		4ST	1.455	0.179	8.15
k_{sv}	Inverse dispersion parameter for SV crashes	3SG	1.651	0.615	2.69
		3ST	0.732	0.249	2.94
		4SG	8.139	7.863	1.04
		4ST	0.732	0.249	2.94
Observations		1059 intersections (3SG=176; 3ST=299; 4SG=283;4ST=301)			

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 30 for three-leg signalized intersections. Note that since the coefficients for different regions were not considered in the calculations, the predicted crashes are for Metro region.



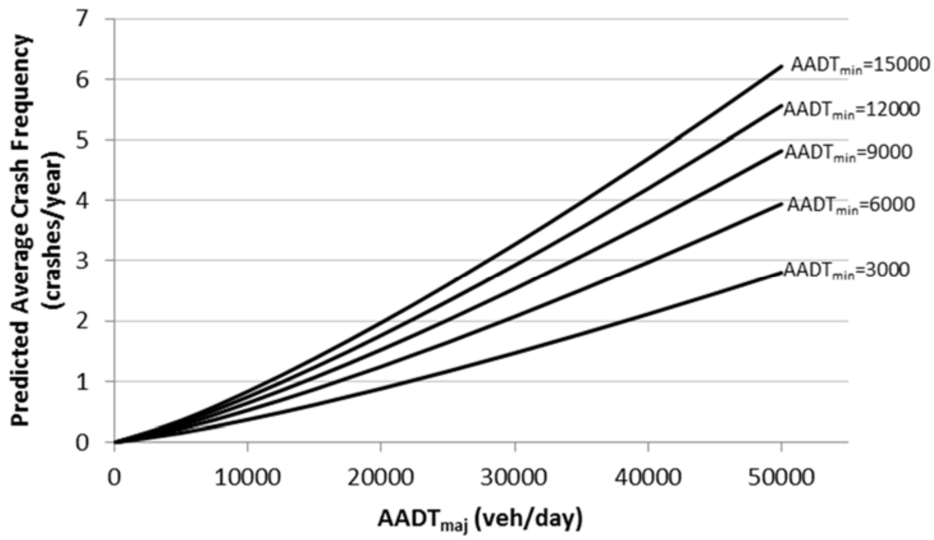
Multiple-Vehicle Crashes



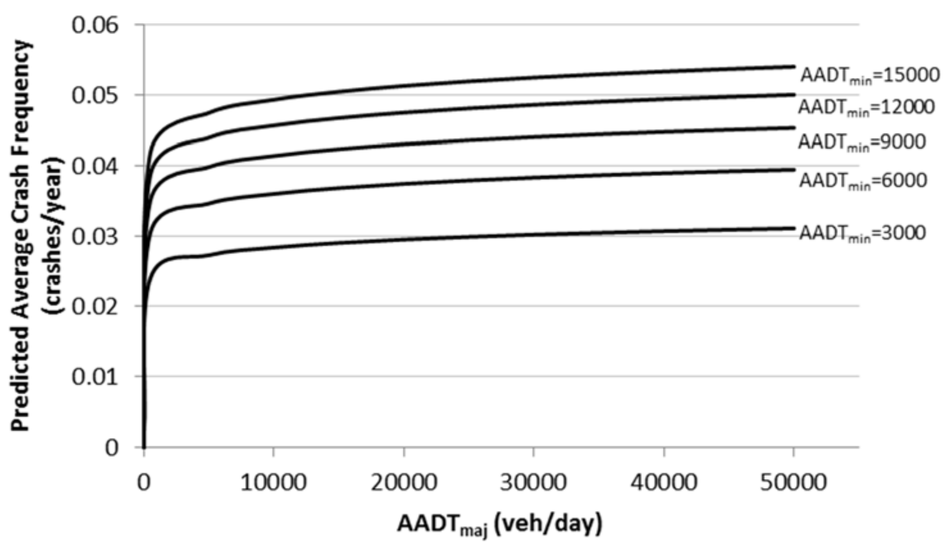
Single-Vehicle Crashes

Figure 30. Graphical Form of the Intersection SPF for Crashes on Three-Leg Signalized Intersections (3SG)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 31 for three-leg stop-controlled intersections.



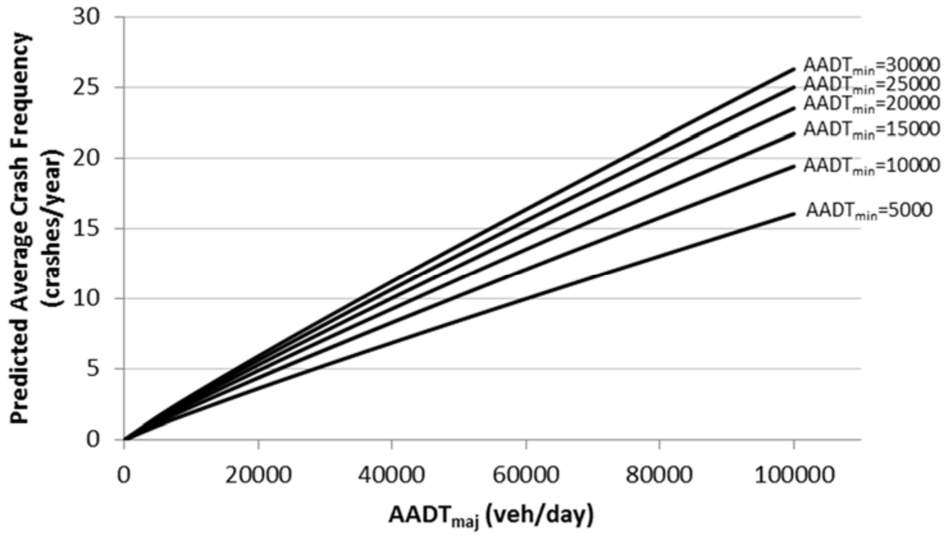
Multiple-Vehicle Crashes



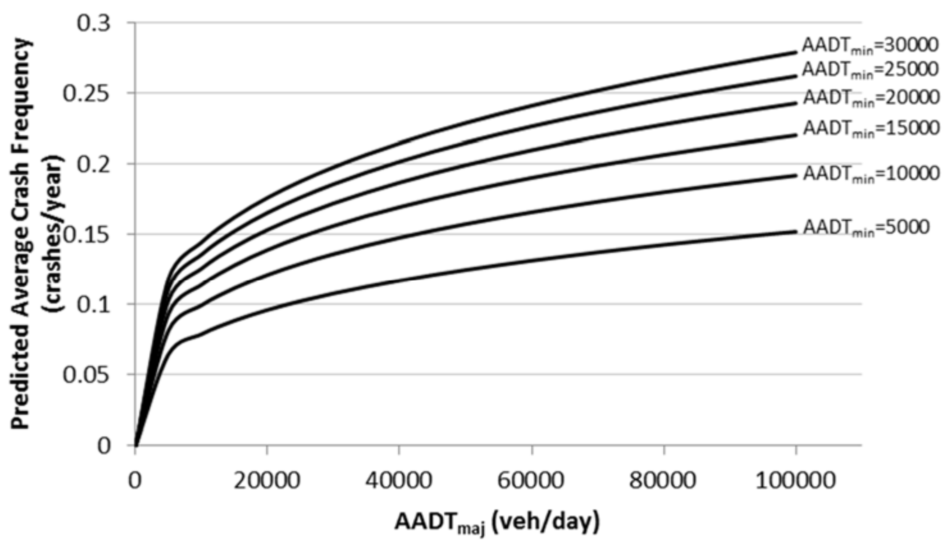
Single-Vehicle Crashes

Figure 31. Graphical Form of the Intersection SPF for Crashes on Three-Leg Stop-Controlled Intersections (3ST)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 32 for four-leg signalized intersections.



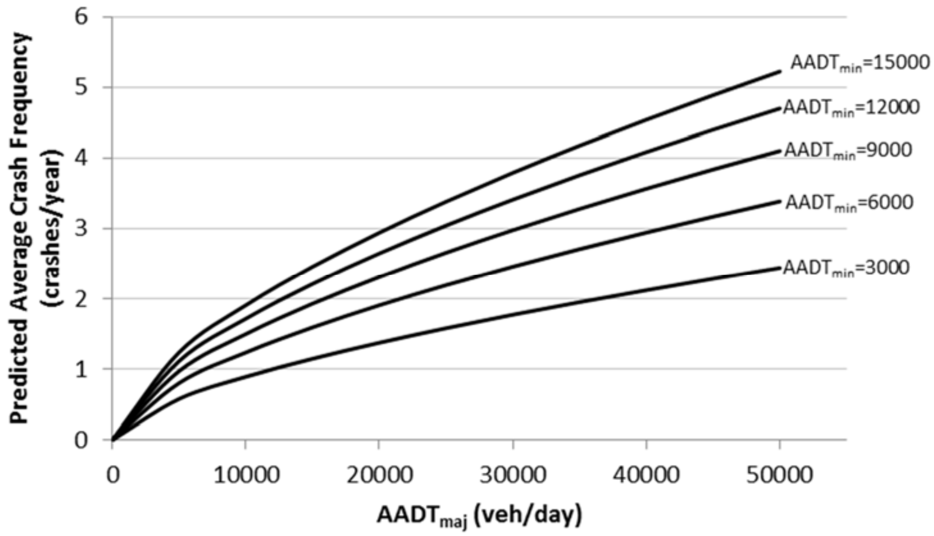
Multiple-Vehicle Crashes



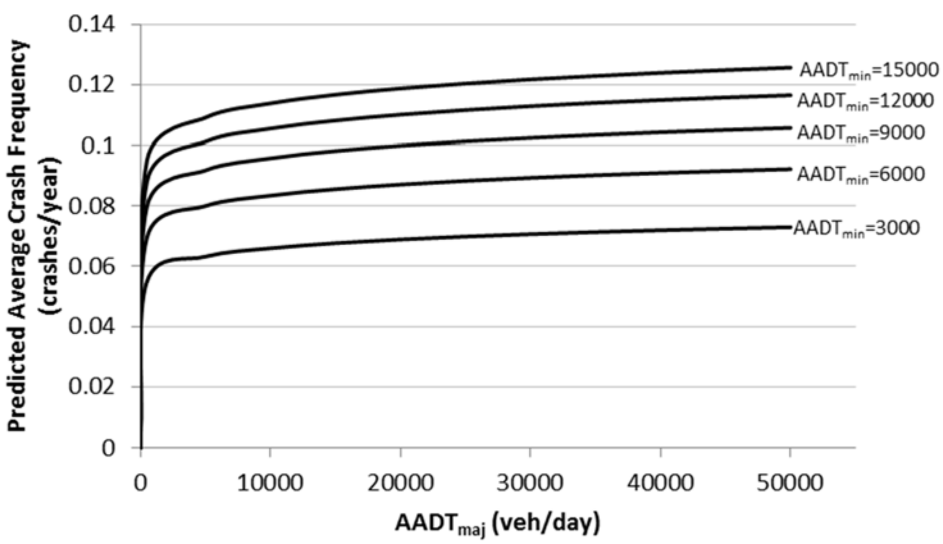
Single-Vehicle Crashes

Figure 32. Graphical Form of the Intersection SPF for Crashes on Four-Leg Signalized Intersections (4SG)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 33 for four-leg stop-controlled intersections.



Multiple-Vehicle Crashes



Single-Vehicle Crashes

Figure 33. Graphical Form of the Intersection SPF for Crashes on Four-Leg Stop-Controlled Intersections (4ST)

Figure 34 presents the relationship between multiple-vehicle predicted average crash frequency (FI plus PDO crashes) on four-leg signalized intersections and traffic demand for base conditions in different regions of the state. For similar geometric and traffic conditions, the southwest region has the highest predicted average crash frequency, while the metro region has the lowest. The trend could not be explained by difference in road design among the regions. It is likely due to the differences between regions that are due to unobserved variables such as vertical grade, crash reporting, and weather.

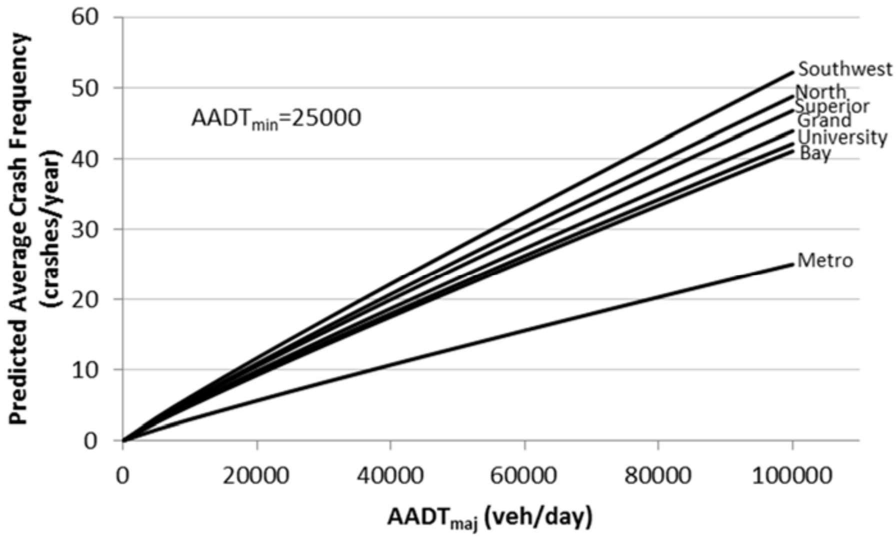


Figure 34. Prediction of Crashes on Four-Leg Signalized Intersections (4SG) by Region

The predicted average crash frequency obtained can be multiplied by the proportions in Table 31 through Table 38 to estimate the predicted average multiple-vehicle crash frequency by collision type category.

Table 31. Distribution of Multiple-Vehicle Crashes by Collision Type – Statewide

	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end	0.47	0.54	0.31	0.33	0.41	0.50	0.19	0.27
Rear-end Left-turn	0.01	0.02	0.06	0.04	0.01	0.02	0.03	0.02
Rear-end Right-turn	0.01	0.03	0.03	0.04	0.02	0.03	0.01	0.03
Head-on	0.02	0.01	0.03	0.01	0.02	0.01	0.01	0.00
Head-on Left-turn	0.16	0.04	0.15	0.04	0.11	0.05	0.09	0.04
Angle	0.29	0.21	0.36	0.38	0.38	0.24	0.60	0.46
Sideswipe- Same	0.01	0.10	0.04	0.10	0.02	0.11	0.03	0.10
Sideswipe- Opposite	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.02
Other MV	0.02	0.03	0.01	0.04	0.02	0.03	0.03	0.05

Table 32. Distribution of Multiple-Vehicle Crashes by Collison Type – Superior Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.55	0.54	0.36	0.42	0.32	0.48	0.21	0.25
Rear-end Left-turn	0.00	0.01	0.08	0.04	0.01	0.02	0.00	0.03
Rear-end Right-turn	0.00	0.05	0.04	0.11	0.01	0.02	0.00	0.02
Head-on	0.05	0.01	0.00	0.00	0.02	0.01	0.00	0.00
Head-on Left-turn	0.10	0.05	0.08	0.06	0.14	0.05	0.03	0.05
Angle	0.25	0.20	0.40	0.22	0.48	0.27	0.65	0.50
Sideswipe-Same	0.00	0.10	0.04	0.11	0.01	0.10	0.03	0.08
Sideswipe-Opposite	0.03	0.02	0.00	0.01	0.00	0.02	0.03	0.00
Other MV	0.03	0.02	0.00	0.02	0.01	0.03	0.06	0.05

Table 33. Distribution of Multiple-Vehicle Crashes by Collison Type – North Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.33	0.54	0.21	0.42	0.40	0.48	0.14	0.25
Rear-end Left-turn	0.02	0.01	0.04	0.04	0.02	0.02	0.02	0.03
Rear-end Right-turn	0.04	0.05	0.04	0.11	0.01	0.02	0.00	0.02
Head-on	0.02	0.01	0.04	0.00	0.01	0.01	0.02	0.00
Head-on Left-turn	0.29	0.05	0.33	0.06	0.17	0.05	0.14	0.05
Angle	0.24	0.20	0.25	0.22	0.36	0.27	0.64	0.50
Sideswipe-Same	0.01	0.10	0.04	0.11	0.01	0.10	0.00	0.08
Sideswipe-Opposite	0.02	0.02	0.04	0.01	0.01	0.02	0.02	0.00
Other MV	0.04	0.02	0.00	0.02	0.01	0.03	0.03	0.05

Table 34. Distribution of Multiple-Vehicle Crashes by Collison Type – Grand Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.56	0.54	0.35	0.42	0.39	0.48	0.24	0.25
Rear-end Left-turn	0.01	0.01	0.04	0.04	0.01	0.02	0.04	0.03
Rear-end Right-turn	0.00	0.05	0.08	0.11	0.02	0.02	0.01	0.02
Head-on	0.02	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Head-on Left-turn	0.12	0.05	0.19	0.06	0.10	0.05	0.11	0.05
Angle	0.23	0.20	0.27	0.22	0.43	0.27	0.52	0.50
Sideswipe-Same	0.01	0.10	0.04	0.11	0.01	0.10	0.03	0.08
Sideswipe-Opposite	0.02	0.02	0.00	0.01	0.00	0.02	0.02	0.00
Other MV	0.02	0.02	0.04	0.02	0.02	0.03	0.04	0.05

Table 35. Distribution of Multiple-Vehicle Crashes by Collison Type – Bay Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.48	0.54	0.30	0.42	0.35	0.48	0.20	0.25
Rear-end Left-turn	0.00	0.01	0.00	0.04	0.03	0.02	0.04	0.03
Rear-end Right-turn	0.01	0.05	0.00	0.11	0.01	0.02	0.02	0.02
Head-on	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00
Head-on Left-turn	0.16	0.05	0.20	0.06	0.13	0.05	0.08	0.05
Angle	0.27	0.20	0.30	0.22	0.40	0.27	0.60	0.50
Sideswipe-Same	0.03	0.10	0.10	0.11	0.03	0.10	0.04	0.08
Sideswipe-Opposite	0.01	0.02	0.00	0.01	0.02	0.02	0.00	0.00
Other MV	0.00	0.02	0.10	0.02	0.01	0.03	0.02	0.05

Table 36. Distribution of Multiple-Vehicle Crashes by Collison Type – Southwest Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.42	0.54	0.24	0.42	0.52	0.48	0.19	0.25
Rear-end Left-turn	0.01	0.01	0.12	0.04	0.02	0.02	0.00	0.03
Rear-end Right-turn	0.00	0.05	0.00	0.11	0.02	0.02	0.03	0.02
Head-on	0.01	0.01	0.00	0.00	0.01	0.01	0.02	0.00
Head-on Left-turn	0.16	0.05	0.16	0.06	0.09	0.05	0.07	0.05
Angle	0.37	0.20	0.44	0.22	0.29	0.27	0.64	0.50
Sideswipe-Same	0.01	0.10	0.04	0.11	0.01	0.10	0.02	0.08
Sideswipe-Opposite	0.01	0.02	0.00	0.01	0.01	0.02	0.00	0.00
Other MV	0.02	0.02	0.00	0.02	0.04	0.03	0.03	0.05

Table 37. Distribution of Multiple-Vehicle Crashes by Collison Type – University Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.47	0.54	0.32	0.42	0.39	0.48	0.17	0.25
Rear-end Left-turn	0.01	0.01	0.05	0.04	0.01	0.02	0.01	0.03
Rear-end Right-turn	0.00	0.05	0.00	0.11	0.02	0.02	0.00	0.02
Head-on	0.04	0.01	0.11	0.00	0.03	0.01	0.00	0.00
Head-on Left-turn	0.11	0.05	0.00	0.06	0.08	0.05	0.07	0.05
Angle	0.36	0.20	0.53	0.22	0.43	0.27	0.69	0.50
Sideswipe-Same	0.01	0.10	0.00	0.11	0.01	0.10	0.04	0.08
Sideswipe-Opposite	0.00	0.02	0.00	0.01	0.00	0.02	0.00	0.00
Other MV	0.01	0.02	0.00	0.02	0.02	0.03	0.01	0.05

Table 38. Distribution of Multiple-Vehicle Crashes by Collison Type – Metro Region

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end	0.59	0.54	0.55	0.42	0.46	0.48	0.17	0.25
Rear-end Left-turn	0.00	0.01	0.00	0.04	0.01	0.02	0.06	0.03
Rear-end Right-turn	0.01	0.05	0.00	0.11	0.02	0.02	0.00	0.02
Head-on	0.02	0.01	0.09	0.00	0.02	0.01	0.06	0.00
Head-on Left-turn	0.11	0.05	0.00	0.06	0.10	0.05	0.09	0.05
Angle	0.22	0.20	0.36	0.22	0.32	0.27	0.51	0.50
Sideswipe-Same	0.03	0.10	0.00	0.11	0.04	0.10	0.09	0.08
Sideswipe-Opposite	0.01	0.02	0.00	0.01	0.00	0.02	0.00	0.00
Other MV	0.02	0.02	0.00	0.02	0.03	0.03	0.03	0.05

5.4.2 Vehicle-Pedestrian Crashes

The number of vehicle-pedestrian collisions per year for an intersection is estimated as:

$$N_{pedi} = N_{bi} \times f_{ped}$$

where:

$N_{bi} =$ *predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);*
$N_{pedi} =$ *predicted average crash frequency of vehicle-pedestrian collisions for an intersection; and*
$f_{ped} =$ *pedestrian crash adjustment factor.*

The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the sum of single-vehicle and multiple-vehicle crashes for each intersection type. Table 39 presents the values of f_{ped}. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes.

Table 39. Pedestrian Crash Adjustment Factors

Intersection Type	Total Pedestrian Crashes	Total MV and SV Crashes*	f_{ped}
3SG	33	3486	0.0095
3ST	9	700	0.0129
4SG	97	12433	0.0078
4ST	16	1792	0.0089

*Excludes pedestrian and bicycle crashes

5.4.3 Vehicle-Bicycle Crashes

The number of vehicle-bicycle collisions per year for an intersection is estimated as:

$$N_{bikei} = N_{bi} \times f_{bike}$$

where:

N_{bi} = *predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);*
N_{bikei} = *predicted average crash frequency of vehicle-bicycle collisions for an intersection; and*
f_{bike} = *bicycle crash adjustment factor.*

The bicycle crash adjustment factor is estimated by dividing the vehicle-bicycle crashes by the sum of single-vehicle and multiple-vehicle crashes for each intersection type. Table 40 presents the values of f_{bike}. The vehicle-bicycle collisions by severity are estimated using the following equation.

$$N_{bikei,fi} = N_{bikei} \times P_{fi}$$

$$N_{bikei,pdo} = N_{bikei} \times (1 - P_{fi})$$

where:

$N_{bikei,fi}$ = *predicted average fatal and injury crash frequency of vehicle-bicycle collisions for an intersection ;*
$N_{bikei,pdo}$ = *predicted average property damage only crash frequency of vehicle-bicycle collisions for an intersection; and*
P_{fi} = *proportion of fatal and injury vehicle-bicycle crashes.*

Table 40. Bicycle Crash Adjustment Factors

Intersection Type	Bicycle Crashes			Total MV and SV Crashes*	f_{bike}
	Total	Fatal and Injury only	P_{fi}		
3SG	35	25	0.71	3486	0.0100
3ST	15	11	0.73	700	0.0214
4SG	140	113	0.81	12433	0.0113
4ST	22	19	0.86	1792	0.0123

*Excludes pedestrian and bicycle crashes

5.4.4 Crash Modification Factors

The CMFs for geometric design features of intersections are presented below. The CMFs are used to adjust the SPF for intersections to account for differences between the base conditions and the local site conditions.

CMF_{mp}- Median Presence. The base condition for median presence is the absence of median on both streets. This CMF applies to both MV and SV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes). Table 41 presents the relationship between median presence and fatal and injury predicted average crash frequency.

Table 41. Crash Modification Factor for Median Presence

Median Presence on Major Street	Median Presence on Minor Street	
	No	Yes
No	1.00	0.72
Yes	0.71	0.51

CMF_{lgt}- Lighting. The base condition for lighting is the absence of intersection lighting. This CMF applies to both MV and SV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes) at stop-controlled intersections. Table 42 presents the relationship between lighting presence and fatal and injury predicted average crash frequency.

Table 42. Crash Modification Factor for Lighting Presence

Lighting Presence	CMF
No	1.00
Yes	0.74

CMFlanes- Number of Lanes. The base condition for this CMF is 4 lanes on the major street and 2 lanes on the minor street. Separate CMFs are developed for signalized and stop-controlled intersections. Table 43 and Table 44 present the relationship between number of lanes and fatal and injury predicted average crash frequency at signalized and stop-controlled intersections respectively. This CMF applies to both MV and SV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions).

Table 43. Crash Modification Factor for Through Lanes at a Signalized Intersection

Number of Major-Street Through Lanes	Number of Minor-Street Through Lanes				
	2	3	4	5	6
2	0.92	--	--	--	--
3	0.96	0.98	--	--	--
4	1.00	1.02	1.05	--	--
5	1.05	1.07	1.10	1.13	--
6	1.10	1.12	1.15	1.18	1.21

Note: Values based on minor-street volume equal to one-half of the major-street volume.

Table 44. Crash Modification Factor for Through Lanes at a Stop-Controlled Intersection

Number of Major-Street Through Lanes	Number of Minor-Street Through Lanes				
	2	3	4	5	6
2	0.94	--	--	--	--
3	0.97	0.99	--	--	--
4	1.00	1.02	1.03	--	--
5	1.03	1.05	1.07	1.08	--
6	1.06	1.08	1.10	1.12	1.14

Note: Values based on minor-street volume equal to one-half of the major-street volume.

CMF_{psl}- Major Street Posted Speed Limit. The base condition for CMF_{psl} is posted speed limit of 40 miles per hour. Separate CMFs are developed for signalized and stop-controlled intersections. Table 45 presents the relationship between major street speed limit and fatal and injury predicted average crash frequency at signalized and stop-controlled intersections. This

CMF applies to both MV and SV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions).

Table 45. Crash Modification Factor for Posted Speed Limit

Major Posted Speed Limit (miles/hour)	Intersection Control	
	Signalized	Stop-Controlled
25	0.76	0.86
30	0.83	0.90
35	0.91	0.95
40	1.00	1.00
45	1.10	1.05
50	1.20	1.11
55	1.32	1.16
60	1.45	1.22
65	1.59	1.29
70	1.74	--

CMF_{rtor}- Right-Turn-On-Red. The base condition for CMF_{rtor} is permitting a right-turn-on-red at all approaches to a signalized intersection. This CMF applies to both SV and MV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. Table 46 presents the relationship between right-turn-on-red and fatal and injury predicted average crash frequency.

Table 46. Crash Modification Factor for Right-Turn-On-Red

Right-Turn-On-Red	CMF
Allowed	1.00
Prohibited	0.74

CMF_{lt}- Left Turn Lanes. The base condition for intersection left turn lanes is the absence of left turn lanes on the intersection approaches. Although, the research team tried developing the CMF for installing the left turn lane on each approach, the results were either insignificant or counterintuitive. This is due to the fact that there is no enough variability among the data used in the model development. Finally, only the indicator variable that shows the presence of left turn lane on the major street approach of 3SG and 3ST was found be statistically significant. The CMFs for the presence of left turn lane on the major street are presented in Table 47.

Table 47. Crash Modification Factor for Major Street Left Turn Lane

Intersection Type	CMF
3SG	0.94
3ST	0.67

These are closer to the CMFs presented in the HSM. Since the proposed coefficients are highly insignificant, the research team recommends using the CMFs in the HSM. These CMFs apply to both SV and MV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes).

Table 48 shows the CMFs presented in the HSM.

Table 48. Crash Modification Factor for Installation of Left Turn Lanes (Source: HSM)

		Number of Approaches with Left Turn Lanes			
Intersection Type	**Intersection Traffic Control**	One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg	Minor-road stop control	0.67	0.45	--	--
	Traffic Signal	0.93	0.86	0.80	--
Four-leg	Minor-road stop control	0.73	0.53	--	--
	Traffic Signal	0.90	0.81	0.73	0.66

5.5 Model Development – One-way Street Intersections

Although various model forms and CMFs were evaluated, the best fit model included functional form with total AADT (i.e. sum of major and minor street AADT) and the CMF for number of lanes. The insignificance of various variables is attributed to the small sample size of the data and a minimum variability among the observations. The following regression model form is used to predict the average crash frequency at an individual intersection.

$$N_j = N_{spf} \times CMF_{lanes}$$

with,

$$N_{spf} = n \times e^{b_1 + b_2 \ln(AADT_{maj} + AADT_{min}) + b_{r1} I_{r1} + b_{r2} I_{r2} + b_{r3} I_{r3} + b_{r4} I_{r4} + b_{r5} I_{r5} + b_{r6} I_{r6}}$$

$$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2}$$
$$= \left[e^{b_{lanes}(N_{maj}-4)} P_{maj} + (1 - P_{maj})\right] \times \left[e^{b_{lanes}(N_{min}-2)} P_{min} + (1 - P_{min})\right]$$
$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj}+AADT_{min}}$$
$$P_{min} = \frac{AADT_{min}}{AADT_{maj}+AADT_{min}}$$

where,

N_j = *predicted annual average crash frequency;*
n = *number of years of crash data;*
$AADT_{maj}$ = *major street average annual daily traffic, veh/day;*
$AADT_{min}$ = *minor street average annual daily traffic, veh/day;*
I_{r1} = *Superior region indicator variable (=1.0 if site is in Superior region, 0.0 if it is not);*
I_{r2} = *North region indicator variable (=1.0 if site is in North region, 0.0 if it is not);*
I_{r3} = *Grand region indicator variable (=1.0 if site is in Grand region, 0.0 if it is not);*
I_{r4} = *Bay region indicator variable (=1.0 if site is in Bay region, 0.0 if it is not);*
I_{r5} = *Southwest region indicator variable (=1.0 if site is in Southwest region, 0.0 if it is not);*
I_{r6} = *University region indicator variable (=1.0 if site is in University region, 0.0 if it is not);*
CMF_{lanes} = *number-of-lanes crash modification factor;*
N_{maj} = *number of through lanes on the major street;*
P_{maj} = *proportion of average daily traffic volume on the major street;*
N_{min} = *number of through lanes on the minor street;*
P_{min} = *proportion of average daily traffic volume on the minor street;*
b_i = *calibration coefficient for variable i.*

5.5.1 Model Calibration

Table 49 and Table 50 summarize the results for fatal and injury, and PDO crashes respectively at one-way street intersections. The indicator variables for different regions in the state were found to be significant. For the same conditions, the southwest region experiences the highest number of crashes, while the metro region experiences the least. The trend could not be explained by difference in road design among the regions. It is likely due to the differences between regions that are due to unobserved variables such as vertical grade, crash reporting, and weather.

Table 49. Calibrated Coefficients for Fatal and Injury Crashes at One-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_1	Intercept	3SG	-11.284	3.829	-2.95
		3ST	-16.437	7.304	-2.25
		4SG	-4.902	1.890	-2.59
		4ST	-9.799	3.685	-2.66
b_2	Total AADT	3SG	0.966	0.355	2.72
		3ST	1.314	0.702	1.87
		4SG	0.427	0.177	2.42
		4ST	0.800	0.367	2.18
b_{r1}	Added effect of Superior region	All	0.000	--	--
b_{r2}	Added effect of North region	All	0.000	--	--
b_{r3}	Added effect of Grand region	All	0.000	--	--
b_{r4}	Added effect of Bay region	All	0.642	0.231	2.78
b_{r5}	Added effect of Southwest region	All	0.694	0.219	3.17
b_{r6}	Added effect of University region	All	0.490	0.231	2.13
b_{lanes}	Number of lanes	3SG/4SG	0.058	0.049	1.18
		3ST/4ST	0.053	0.090	0.59
k	Inverse dispersion parameter	3SG	1.138	0.439	2.59
		3ST	0.328	0.224	1.47
		4SG	3.449	1.054	3.27
		4ST	2.161	1.422	1.52
Observations		203 intersections (3SG=34; 3ST=54; 4SG=66;4ST=49)			

Table 50. Calibrated Coefficients for PDO Crashes at One-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_1	Intercept	3SG	-9.952	3.165	-3.14
		3ST	-13.749	3.925	-3.50
		4SG	-5.538	1.541	-3.59
		4ST	-13.910	3.552	-3.92
b_2	Total AADT	3SG	0.964	0.295	3.26
		3ST	1.221	0.380	3.22
		4SG	0.606	0.145	4.18
		4ST	1.302	0.354	3.68
b_{r1}	Added effect of Superior region	All	0.972	0.379	2.56
b_{r2}	Added effect of North region	All	0.000	--	--
b_{r3}	Added effect of Grand region	All	0.000	--	--
b_{r4}	Added effect of Bay region	All	0.771	0.190	4.05
b_{r5}	Added effect of Southwest region	All	1.109	0.179	6.19
b_{r6}	Added effect of University region	All	0.886	0.190	4.67
b_{lanes}	Number of lanes	3SG/4SG	0.019	0.040	0.47
		3ST/4ST	-0.128	0.111	-1.15
k	Inverse dispersion parameter	3SG	1.275	0.353	3.61
		3ST	0.362	0.104	3.49
		4SG	3.809	0.776	4.91
		4ST	1.257	0.341	3.68
Observations		203 intersections (3SG=34; 3ST=54; 4SG=66;4ST=49)			

Depending on the scope of a particular project, MDOT may wish to utilize SPFs that do not feature regional indicators. For this purpose, Table 51 and Table 52 illustrate the coefficients for such SPFs.

Table 51. Calibrated Coefficients for Statewide Fatal and Injury Crashes at One-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_1	Intercept	3SG	-7.743	3.921	-1.97
		3ST	-14.268	7.077	-2.02
		4SG	-1.933	1.765	-1.10
		4ST	-9.861	3.502	-2.82
b_2	Total AADT	3SG	0.661	0.367	1.80
		3ST	1.113	0.680	1.64
		4SG	0.189	0.171	1.10
		4ST	0.849	0.348	2.44
b_{lanes}	Number of lanes	3SG/4SG	0.064	0.051	1.27
		3ST/4ST	0.016	0.085	0.18
k	Inverse dispersion parameter	3SG	0.952	0.343	2.78
		3ST	0.351	0.241	1.46
		4SG	2.718	0.746	3.64
		4ST	2.421	1.601	1.51
Observations		203 intersections (3SG=34; 3ST=54; 4SG=66;4ST=49)			

Table 52. Calibrated Coefficients for Statewide PDO Crashes at One-way Street Intersections

Coefficient	Variable	Type	Value	Std. Dev	t-statistic
b_1	Intercept	3SG	-3.960	3.422	-1.16
		3ST	-9.391	3.549	-2.65
		4SG	-2.024	1.720	-1.18
		4ST	-12.769	3.434	-3.72
b_2	Total AADT	3SG	0.444	0.322	1.38
		3ST	0.819	0.343	2.39
		4SG	0.343	0.167	2.05
		4ST	1.263	0.343	3.69
b_{lanes}	Number of lanes	3SG/4SG	0.019	0.046	0.42
		3ST/4ST	-0.128	0.119	-1.08
k	Inverse dispersion parameter	3SG	1.035	0.267	3.88
		3ST	0.387	0.114	3.40
		4SG	2.632	0.495	5.32
		4ST	1.080	0.282	3.83
Observations		203 intersections (3SG=34; 3ST=54; 4SG=66;4ST=49)			

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 35 for one-way street three-leg signalized intersections. Note that since the coefficients for different regions were not considered in the calculations, the predicted crashes are for Metro region.

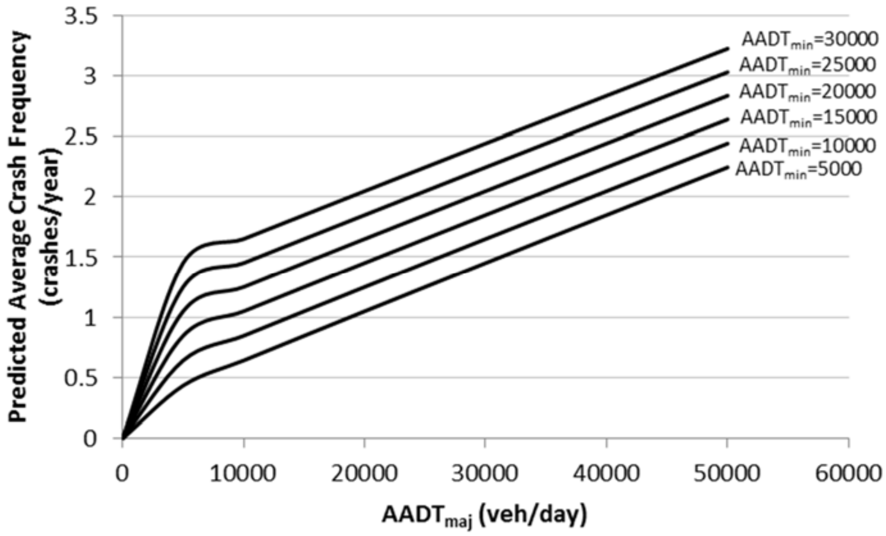


Figure 35. SPF for One-Way Street Three-Leg Signalized Intersections (3SG)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 36 for one-way street three-leg stop-controlled intersections.

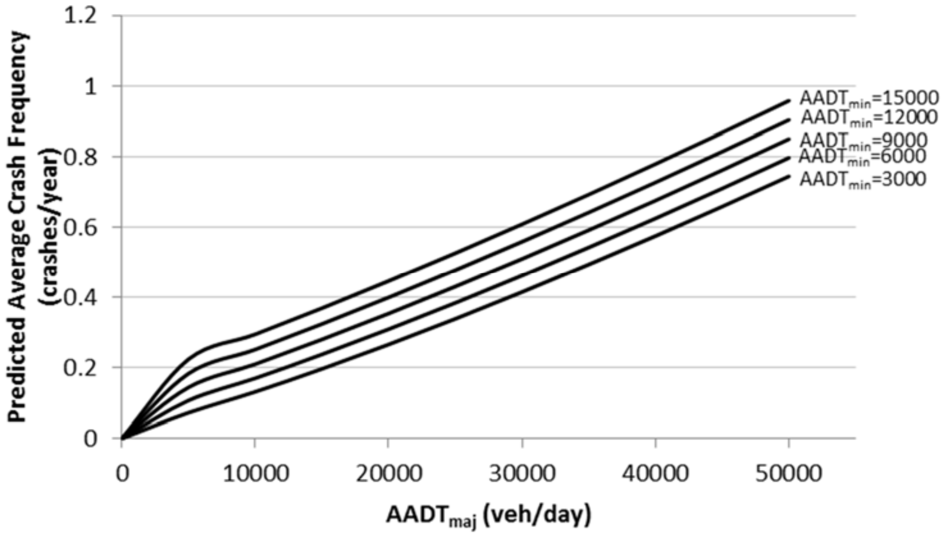


Figure 36. SPF for One-Way Street Three-Leg Stop-Controlled Intersections (3ST)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 37 for one-way street four-leg signalized intersections.

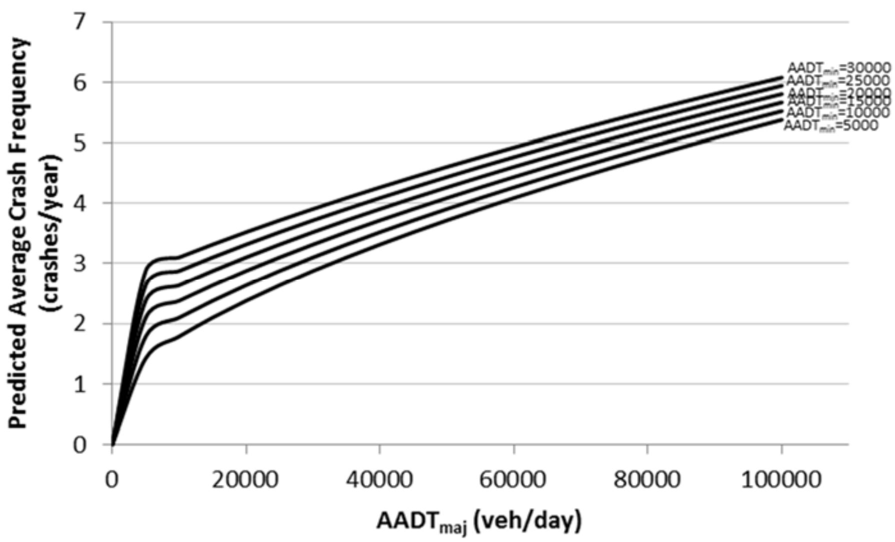


Figure 37. Graphical Form of the Intersection SPF for Crashes on One-Way Street Four-Leg Signalized Intersections (4SG)

The relationship between predicted average crash frequency (FI plus PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 38 for one-way street four-leg stop-controlled intersections.

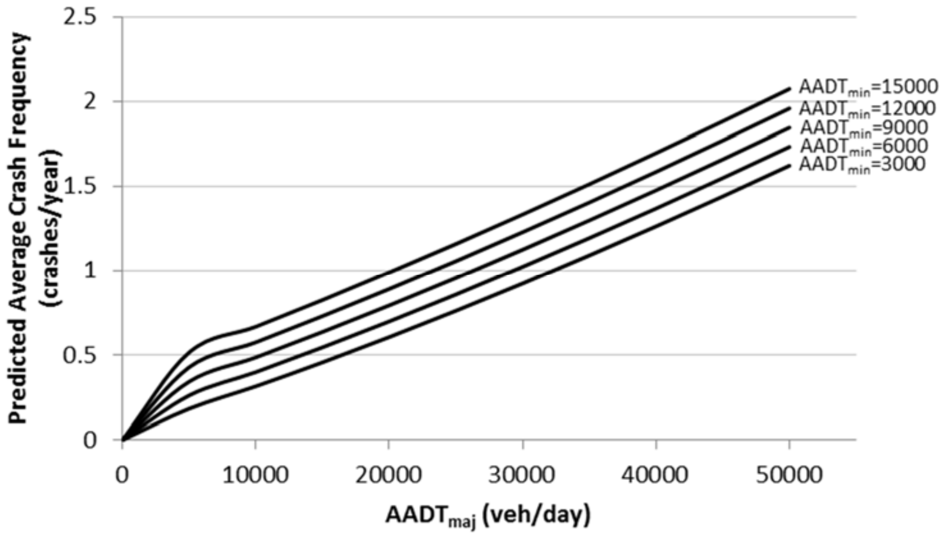


Figure 38. Graphical Form of the Intersection SPF for Crashes on One-Way Street Four-Leg Stop-Controlled Intersections (4ST)

The total predicted average crash frequency obtained for one-way street intersections can be multiplied by the proportions in Table 53 to estimate the predicted average crash frequency by collision type category.

Table 53. Distribution of All Crashes by Collision Type

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3SG		3ST		4SG		4ST	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Single-Vehicle	0.03	0.05	0.06	0.03	0.02	0.03	0.05	0.04
Rear-end	0.56	0.47	0.47	0.52	0.24	0.29	0.14	0.15
Rear-end Left-turn	0.00	0.01	0.00	0.00	0.01	0.01	0.02	0.03
Rear-end Right-turn	0.06	0.05	0.06	0.04	0.01	0.01	0.02	0.00
Head-on	0.01	0.01	0.12	0.00	0.01	0.01	0.02	0.00
Head-on Left-turn	0.01	0.01	0.00	0.01	0.03	0.02	0.05	0.02
Angle	0.24	0.21	0.24	0.19	0.56	0.38	0.65	0.48
Sideswipe- Same	0.04	0.15	0.06	0.17	0.08	0.21	0.08	0.23
Sideswipe- Opposite	0.01	0.02	0.00	0.02	0.01	0.01	0.00	0.02
Other MV	0.02	0.04	0.00	0.02	0.04	0.03	0.00	0.03

5.5.2 Vehicle-Pedestrian Crashes

The number of vehicle-pedestrian collisions per year for an intersection is estimated as:

$$N_{pedi} = N_{bi} \times f_{ped}$$

N_{bi} = *predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);*
N_{pedi} = *predicted average crash frequency of vehicle-pedestrian collisions for an intersection ;*
f_{ped} = *pedestrian crash adjustment factor ;*

The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the sum of single-vehicle and multiple-vehicle crashes for each intersection type.

Table 54 presents the values of f_{ped}. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes.

Table 54. Pedestrian Crash Adjustment Factors

Intersection Type	Total Pedestrian Crashes	Total MV and SV Crashes*	f_{ped}
3SG	6	471	0.0127
3ST	2	138	0.0145
4SG	33	1937	0.0170
4ST	6	313	0.0192

*Excludes pedestrian and bicycle crashes

5.5.3 Vehicle-Bicycle Crashes

The number of vehicle-bicycle collisions per year for an intersection is estimated as:

$$N_{bikei} = N_{bi} \times f_{bike}$$

N_{bi} = *predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);*
N_{bikei} = *predicted average crash frequency of vehicle-bicycle collisions for an intersection ;*

f_{bike} = *bicycle crash adjustment factor.*

The bicycle crash adjustment factor is estimated by dividing the vehicle-bicycle crashes by the sum of single-vehicle and multiple-vehicle crashes for each intersection type.

Table 55 presents the values of f_{bike}. The vehicle-bicycle collisions by severity are estimated using the following equation.

$$N_{bikei,fi} = N_{bikei} \times P_{fi}$$

$$N_{bikei,pdo} = N_{bikei} \times (1 - P_{fi})$$

$N_{bikei,fi}$ = *predicted average fatal and injury crash frequency of vehicle-bicycle collisions for an intersection ;*

$N_{bikei,pdo}$ = *predicted average property damage only crash frequency of vehicle-bicycle collisions for an intersection ;*

P_{fi} = *proportion of fatal and injury vehicle-bicycle crashes.*

Table 55. Bicycle Crash Adjustment Factors

Intersection Type	Bicycle Crashes			Total MV and SV Crashes*	f_{bike}
	Total	Fatal and Injury only	P_{fi}		
3SG	8	6	0.75	471	0.0170
3ST	3	1	--	138	0.0217
4SG	25	18	0.72	1937	0.0129
4ST	9	6	0.67	313	0.0288

*Excludes pedestrian and bicycle crashes
-- cannot be determined due to small sample size

5.5.4 Crash Modification Factor

The CMFs for geometric design features of intersections are presented below. The CMFs are used to adjust the SPF for differences between base conditions and local site conditions.

CMF_{lanes}- Number of Lanes: The base condition for this CMF is 4 lanes on the major street and 2 lanes on the minor street. Separate CMFs are developed for signalized and stop-controlled intersections.

Table 56 and Table 57 present the relationship between number of lanes and fatal and injury predicted average crash frequency at signalized and stop-controlled intersections respectively. This CMF applies to both MV and SV intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions).

Table 56. Crash Modification Factor for Through Lanes at a Signalized Intersection

Number of Major-Street Through Lanes	**CMF based on Number of Minor-Street Through Lanes**				
	2	3	4	5	6
2	0.93	--	--	--	--
3	0.96	0.98	--	--	--
4	1.00	1.02	1.04	--	--
5	1.04	1.06	1.08	1.11	--
6	1.08	1.10	1.13	1.15	1.18

Note: Values based on minor-street volume equal to one-half of the major-street volume.

Table 57. Crash Modification Factor for Through Lanes at a Stop-Controlled Intersection

Number of Major-Street Through Lanes	**CMF based on Number of Minor-Street Through Lanes**				
	2	3	4	5	6
2	0.93	--	--	--	--
3	0.97	0.98	--	--	--
4	1.00	1.02	1.04	--	--
5	1.04	1.06	1.07	1.10	--
6	1.07	1.09	1.11	1.14	1.16

Note: Values based on minor-street volume equal to one-half of the major-street volume.

5.6 Development of Severity Distribution Functions

This section documents the development of severity distribution function (SDF) for both signalized and stop-controlled intersections. Section 5.6.1 describes the functional form. Section 5.6.2 covers the model development, while Section 5.6.3 summarizes the predicted capabilities of the models.

5.6.1 Functional Form

An SDF is represented by a discrete choice model. In theory, it could be used to predict the proportion of crashes in each of the following severity categories: Fatal = K, Incapacitated injury = A, Non-incapacitated injury = B, or Possible injury = C. However, when a particular category has a very few reported crashes, some combination of the severity categories may be needed to obtain statistically reliable estimates (e.g., K+A, B, C). The SDF can be used with the safety performance functions to estimate the expected crash frequency for each severity category. It may include various geometric, operation, and traffic variables that will allow the estimated proportion to be specific to an individual intersection.

The multinomial logit (MNL) model was used to predict the probability of crash severities. Given the characteristics of the data, the MNL is the most suitable model for estimating a SDF. A linear function is used to relate the crash severity with the geometric and traffic variables. SAS's non-linear mixed modeling procedure (NLMIXED) was used for the evaluation of MNL model.

Due to a small number of reported fatal crashes, the fatal and incapacitating injury crashes are combined into one category during the final model calibration. The probability for each crash severity category is given by the following equations:

$$
\begin{aligned}
P_K &= \frac{e^{V_{K+A}}}{e^{V_{K+A}} + e^{V_B}} \times P_{K|K+A} \\
P_A &= \frac{e^{V_{K+A}}}{e^{V_{K+A}} + e^{V_B}} \times \left(1 - P_{K|K+A}\right) \\
P_B &= \frac{e^{V_B}}{e^{V_{K+A}} + e^{V_B}} \\
P_C &= 1 - (P_{K+A} + P_B)
\end{aligned}
$$

where,

P_j *= probability of the occurrence of crash severity j;*

$P_{K|K+A}$ *= probability of a fatal K crash given that the crash has a severity of either fatal or incapacitating injury A; and*

V_j *= systematic component of crash severity likelihood for severity j.*

5.6.2 Modeling Development

The database assembled for calibration included crash severity level as a dependent variable and the geometric and traffic variables of each site as independent variables. Each row (site characteristics) is repeated to the frequency of each severity level. Thus, an intersection with 'n' crashes will be repeated 'n' number of times. It should be noted that the intersections without injury (plus fatal) crashes are not included in the database. The total sample size of the final dataset for model calibration will be equal to total number of injury (plus fatal) crashes in the data. During the model calibration, the "possible injury" category is set as the base scenario with coefficients restricted at zero.

For signalized intersections, a value of 0.0867 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at signalized intersections. A model for estimating the systematic component of crash severity V_j for signalized intersections is described by the following equation.

$$V_{K+A} = ASC_{K+A} + b_{sl,K+A} \times I_{sl} + b_{rtorp,K+A} \times I_{rtorp} + b_{mjSW,K+A} \times I_{mjSW} + b_{mjRL,K+A} \times I_{mjRL} + b_{mnRL,K+A} \times I_{mnRL} + b_{r5} \times I_{r5}$$

$$V_B = ASC_B + b_{sl,B} \times I_{sl} + b_{sw,K+A} \times I_{sw} + b_{mjRL,K+A} \times I_{mjRL} + b_{r5} \times I_{r5}$$

where,

I_{sl}	=	*posted speed greater than 45 miles/hr indicator variable (=1.0 if greater than 45 miles/hr, 0.0 otherwise);*
I_{rtorp}	=	*right-turn-on-red prohibition indicator variable (=1.0 if prohibited, 0.0 if it is not);*
I_{mjSW}	=	*major street sidewalk presence indicator variable (= 1.0 if present, 0.0 otherwise);*
I_{mjRL}	=	*major street right turn lane presence indicator variable (=1.0 if present, 0.0 if it is not);*
I_{mnRL}	=	*minor street right turn lane presence indicator variable (=1.0 if present, 0.0 if it is not);*
I_{r5}	=	*Southwest region indicator variable (=1.0 if site is in Southwest region, 0.0 if it is not);*
ASC_j	=	*alternative specific constant for crash severity j; and*
$b_{k,j}$	=	*calibration coefficient for variable k and crash severity j.*

For stop-controlled intersections, a value of 0.141 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at stop-controlled intersections. A model for estimating the systematic component of crash severity V_j for stop-controlled intersections is described by the following equation.

$$V_{K+A} = ASC_{K+A} + b_{sl,K+A} \times I_{sl} + b_{mp,K+A} \times I_{mp} + b_{mjSW,K+A} \times I_{mjSW}$$

$$V_B = ASC_B + b_{sl,B} \times I_{sl} + b_{mp,B} \times I_{mp} + b_{mjSW,B} \times I_{mjSW}$$

where,

I_{mp} = *median presence on any street indicator variable (=1.0 if median present on at least one street, 0.0 otherwise);*

The final form of the regression models is described here, before the discussion of regression analysis results. However, this form reflects the findings from several preliminary regression analyses where alternative model forms were examined. The form that is described represents the best fit to the data while also having coefficient values that are logical and constructs that are theoretically defensible and properly bounded.

Table 58 summarizes the estimation results of MNL model. An examination of the coefficient values and their implication on the corresponding crash severity levels are documented in a subsequent section. In general, the sign and magnitude of the regression coefficients in Table 58 are logical and consistent with previous research findings.

Table 58. Parameter Estimation for SDF

Control Type	Coefficient	Variable	Fatality (K) + Incapacitating injury (A)		Non-Incapacitating injury (B)	
			Value	t-statistic	Value	t-statistic
Signalized	ASC	Alternative specific constant	-1.685	-11.74	-1.084	-10.90
	b_{sl}	Major street speed limit greater than 45 miles/hr	0.178	1.19	0.193	1.93
	b_{rtorp}	Right-turn-on-red prohibition	-0.473	-1.92	--	--
	b_{mjSW}	Sidewalk on major street	-0.498	-3.67	-0.125	-1.32
	b_{mjRL}	Right turn lane on major street	-0.067	-0.88	-0.104	-2.19
	b_{mnRL}	Right turn lane on minor street	-0.167	-1.93	--	--
	b_{r5}	Location in southwest region	-0.351	-3.50	-0.351	-3.50
Stop-controlled	ASC	Alternative specific constant	-1.595	-5.82	-0.857	-4.16
	b_{sl}	Major street speed limit greater than 45 miles/hr	0.399	1.25	0.317	1.31
	b_{mp}	Median presence on any street	-0.745	-1.16	-0.945	-1.86
	b_{mjSW}	Sidewalk on major street	-0.418	-1.41	-0.280	-1.27

Note: Possible injury is the base scenario with coefficients restricted at zero.

Indicator variables were included for all regions in the state. However, only the coefficient for southwest region was statistically significant for signalized intersections. The coefficient for this variable is shown in Table 58. Its value indicates that the crashes at signalized intersections in southwest region are less severe than those in other regions. The trend could not be explained by difference in road design among the regions. It is likely due to the differences between regions that are due to unobserved variables such as vertical grade, reporting, and weather.

5.6.3 Predicted Probabilities

This section describes the change in probability of each crash severity for a given change in particular variable. It is divided into two parts. The first part describes the variable influence at signalized intersections. The second part describes the variable influence at stop-controlled intersections.

5.6.3.1 Signalized Intersections

Posted Speed Limit. This variable reflects whether the speed limit on the major street of the intersection is greater than 45 miles/hr or not. The positive coefficient in Table 58 indicates that the probability of K+A, and B crash severities for the intersections with major street speed limit greater than 45 miles/hr is higher than other intersections. As seen in Table 59, the likelihood of a fatal plus incapacitating injury crash changes from 7.1% with speed limit less than or equal to 45 miles/hr to 7.9% with speed limit greater than 45 miles/hr. Similar trend but a larger effect is seen for non-incapacitating crash severity.

Table 59. Predicted Probabilities for Posted Speed Limit

Major Street Posted Speed Limit (miles/hour)	**Crash Severity**		
	K+A	B	C
≤ 45	7.1%	19.7%	73.2%
> 45	8.0%	22.6%	69.4%

Right-Turn-On-Red Prohibition. The right-turn-on-red prohibition variable indicates the right-turn movement at a signalized intersection. The negative sign for right-turn-on-red prohibition variable in Table 58 indicates that chance of fatal and incapacitating injury crash severity decreases when the right-turn-on-red is prohibited. Table 60 suggests that the probability of high severe crashes (i.e., K and A) decreases from 7.6% when right-turn-on-red is allowed to 4.8% when prohibited.

Table 60. Predicted Probabilities for Right-Turn-On-Red

Right-Turn-On-Red	Crash Severity		
	K+A	B	C
Allowed	7.6%	20.2%	72.2%
Prohibited	4.9%	20.8%	74.3%

Sidewalks on Major Street. This variable indicates the presence of sidewalks on the major street. The negative sign for sidewalks variable in Table 58 indicates that chance of fatal and incapacitating injury crash severity decreases when the sidewalks are present. Table 61 suggests that the probability of high severe crashes (i.e., K and A) decreases from 10.1% to 6.5% when sidewalks are present. Similar trend is seen for non-incapacitating crash severity.

Table 61. Predicted Probabilities for Sidewalks on Major Street

Sidewalks on Major Street	Crash Severity		
	K+A	B	C
Not Present	10.1%	21.1%	68.8%
Present	6.6%	19.9%	73.5%

Right-Turn Lane on Major Street. This variable indicates the presence of right-turn lane on the major street. The negative sign for right-turn lane variable in Table 58 indicates that chance of high severe crashes decreases when the right-turn lane is present. Table 62 suggests that the probability of severe crashes (i.e., K, A and B) decreases from 29% to 27.1% when right-turn lane is present.

Table 62. Predicted Probabilities for Right-Turn_lane on Major Street

Right-Turn-Lane on Major Street	Crash Severity		
	K+A	B	C
Not Present	7.5%	21.5%	71.0%
Present	7.3%	19.9%	72.8%

Right-Turn Lane on Minor Street. This variable indicates the presence of right-turn lane on the minor street. The negative sign for right-turn lane variable in Table 58 indicates that chance of high severe crashes decreases when the right-turn lane is present. Table 63 suggests that the likelihood of fatal plus incapacitating injury crash decreases from 8% to 7% when right-turn lane is present. No major change is seen for non-incapacitating crash severity.

Table 63. Predicted Probabilities for Right-Turn_lane on Minor Street

Right-Turn-Lane on Minor Street	Crash Severity		
	K+A	B	C
Not Present	8.1%	20.1%	71.8%
Present	7.0%	20.3%	72.7%

Southwest Region. This variable indicates whether the intersection is in southwest region or not. Table 64 suggests that the likelihood of severe crashes (i.e. K, A, and B) in southwest region is 22.1% when compared to 28.7% in other regions.

Table 64. Predicted Probabilities for Different Regions

Region	Crash Severity		
	K+A	B	C
Southwest	5.8%	16.2%	77.9%
Other	7.6%	21.1%	71.3%

5.6.3.2 Stop-Controlled Intersections

Posted Speed Limit. This variable reflects whether the speed limit on the major street of the intersection is greater than 45 miles/hr or not. The positive coefficient in Table 58 indicates that the probability of K+A, and B crash severities for the intersections with major street speed limit greater than 45 miles/hr is higher than other intersections. As seen in Table 65, the likelihood of a fatal plus incapacitating injury crash changes from 9.7% with speed limit less than or equal to 45 miles/hr to 12.9% with speed limit greater than 45 miles/hr. For non-incapacitating crash severity, the likelihood changes from 22.8% to 27.5% with the change in speed limit.

Table 65. Predicted Probabilities for Posted Speed Limit- Stop Controlled Intersections

Major Street Posted Speed Limit (miles/hour)	Crash Severity		
	K+A	B	C
≤ 45	9.9%	22.6%	67.6%
> 45	13.0%	27.3%	59.7%

Presence of Median. This variable indicates the presence of median either on major or minor street. The median is present at 5% of stop-controlled intersections. The negative coefficient in Table 58 indicates that the probability of K+A, and B crash severities for the intersections without median is higher than intersections with median. As seen in Table 66, the likelihood of a fatal plus incapacitating injury crash changes from 10.6% without median to 6.3% with median. Similar trend but a larger effect is seen for non-incapacitating crash severity.

Table 66. Predicted Probabilities for Median Presence- Stop Controlled Intersections

Median on Either Street	**Crash Severity**		
	K+A	B	C
Not Present	10.8%	24.3%	64.9%
Present	6.4%	11.9%	81.7%

Sidewalks on Major Street. This variable indicates the presence of sidewalks on the major street. The negative sign for sidewalks variable in Table 58 indicates that chance of fatal and incapacitating injury crash severity decreases when the sidewalks are present. Table 67 suggests that the probability of high severe crashes (i.e., K and A) decreases from 12.9% to 9.4% when sidewalks are present. Similar trend is seen for non-incapacitating crash severity.

Table 67. Predicted Probabilities for Sidewalks on Major Street- Stop Controlled Intersections

Sidewalks on Major Street	**Crash Severity**		
	K+A	B	C
Not Present	13.0%	26.4%	60.6%
Present	9.6%	22.4%	68.0%

6.0 CALIBRATION, MAINTENANCE, AND USE OF SPFS

6.1 SPF Calibration Overview

When applied to different jurisdictions or over different time periods, SPFs need to be calibrated to reflect differences due to temporal or spatial trends. This calibration is achieved through the estimation of a calibration factor C_x. The recommended crash prediction algorithm takes the following form:

$$N_{predicted} = N_{spf,x} \times \left(CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}\right) \times C_x \ ,$$

where:

$N_{predicted}$ = *predicted average crash frequency for a specificyear for a site of type x;*
$N_{spf,x}$ = *predicted average crash frequency determined for base conditions of the SPF developed for site type x;*
CMF_{yx} = *Crash modification factors specific to SPF for site type x, and*
C_x = *calibration factor to adjust SPF for local conditions for site type x.*

Calibration capabilities are built into existing software support packages, such as the Interactive Highway Safety Design Model (IHSDM), which includes a calibration utility within its Administration Tool to assist agencies in implementing the calibration procedures described in HSM. The IHSDM also allows state agencies to develop and implement their own SPFs, in addition to modifying the crash severity and crash type distribution values [74].

6.2 SPF Calibration Procedure

Calibration can be used to account for changes in safety performance over time, which may be reflective of effects outside of the factors included in the SPFs developed as a part of this study. The calibration process is relatively straight-forward and can be applied following the steps outlined in Appendix A from Part C of the *HSM.* This procedure is briefly described on the following pages.

1. Identify facility type for which the applicable SPF is to be calibrated. For the case of the Michigan specific SPFs documented in this report, eight specific facility types are identified. This study considered intersections in which both streets have two-way flow as well as intersections which had one-way flow on one or both of the streets. Additionally, the intersections were classified as being three-leg minor road stop controlled, three-leg signalized, four-leg minor road stop controlled, or four-leg signalized.
2. Select sites for calibration of the predictive model for each facility type. The *HSM* procedure recommends using 30-50 sites for a given facility type. The *HSM* also recommends that for jurisdictions attempting calibration that do not have enough sites of a particular type to use all sites within that jurisdiction of said type. For calibration purposes, sites should be selected without regard for the crash experience at individual sites, as selecting sites based on crash experience will potentially result in high or low calibration values. The selected sites should represent a total of at least 100 crashes. Sites should be selected so that they are representative of intersections for the entire area for which the calibration will be applied but do not need to be stratified by traffic volume or other site characteristics. The *HSM* states that site selection for calibration need only occur once, as the same sites may be used for calibration in subsequent years.
3. Obtain data for each facility type available to a specific calibration period. For annual calibration, one year of data should be used. Crashes for all severity levels should be included in the calibration.
    a. Observed crashes at each intersection
    b. Major street AADT (entering intersection)
    c. Minor street AADT (entering intersection)
    d. MDOT region of the intersection
    e. Presence of a median on major street
    f. Presence of a median on the minor street
    g. Presence of lighting at the intersection
    h. Posted speed limit on the major street
    i. Number of through lanes on the major street
    j. Number of through lanes on the minor street
    k. Whether or not right-turn-on-red is permitted
    l. Whether or not left-turn lanes are present on all approaches of the major leg
4. Apply the applicable SPF to predict the total predicted average crash frequency for each site during the calibration period as a whole. This is done using the equations in sections 5.3 and 5.4 of this report. Following the example of shown in Section 6.5, the following steps should be taken for each intersection in the calibration set.
5. Calculate the number of expected fatal and injury multiple-vehicle crashes prior to the application of CMFs, N_{spfmv}
6. Calculate the number of expected fatal and injury single-vehicle crashes prior to the application of CMFs, N_{spfsv}
7. Calculate the CMFs for fatal and injury vehicular crashes, $CMF_1 \times \ldots . \times CMF_p$
8. Sum N_{spfmv} and N_{spfsv}, and apply the CMFs to calculate N_{bi} for fatal and injury crashes
9. Calculate the number of expected PDO multiple-vehicle crashes prior to the application of CMFs, N_{spfmv}
10. Calculate the number of expected PDO single-vehicle crashes prior to the application of

CMFs, N_{spfsv}

11. Calculate the CMFs for PDO crashes, $CMF_1 \times \ldots . \times CMF_p$
12. N_{spfmv} and N_{spfsv}, and apply the CMFs to calculate N_{bi} for PDO crashes
13. Add the fatal and injury N_{bi} with the PDO N_{bi} to obtain the predicted total of all automobile-only crashes
14. Apply the pedestrian and bicycle proportions to the total automobile-only N_{bi}, to obtain the predicted number of pedestrian and bicycle involved crashes
15. Add the pedestrian and bicycle crashes to N_{bi} to obtain the predicted amount of total crashes
16. Compute calibration factors for use with each SPF. The purpose of the calibration factor is to scale the SPF to more accurately match the intersections it is being used on. If an SPF predicts fewer total crashes than actually occur for the sum of all crashes of the calibration data set, a calibration factor greater than one is required. If the SPF predicts more crashes than actually occur for the calibration year, then a calibration factor less than one is need to reduce the predicted crashes. The calibration factors for intersections of a particular facility type, C_i, are computed with the following equation:

$$C_i = \frac{\Sigma_{observed\ crashes}}{\Sigma_{predicted\ crashes}}$$

6.3 Example Calibration

To illustrate this point, consider the following example: A set of 30 calibration sites experience a total of 100 crashes during the calibration year. The appropriate SPF predicts that the calibration sites should experience 105.099 crashes during the calibration year. The calibration factor of this facility type is calculated by

$$C_i = \frac{100}{105.099} = 0.951$$

This calibration factor can then be applied when predicting crashes for intersections of the appropriate facility type. This concept is illustrated in Table 68.

Table 68. Example Calibration

Hypothetical Intersection	Hypothetical Observed Crashes	Hypothetical Predicted Crashes	Calibrated Predictions
1	4	2.983	2.839
2	3	3.283	3.124
3	3	2.983	2.839
4	2	3.583	3.409
5	1	3.283	3.124
6	0	3.883	3.695
7	6	4.183	3.980
8	3	3.583	3.409
9	4	3.283	3.124
10	2	3.583	3.409
11	1	3.583	3.409
12	2	3.883	3.695
13	3	2.533	2.410
14	5	4.483	4.266
15	1	2.983	2.839
16	8	3.283	3.124
17	9	3.133	2.981
18	0	3.433	3.267
19	3	2.683	2.553
20	6	4.783	4.551
21	3	4.183	3.980
22	5	4.183	3.980
23	3	3.283	3.124
24	0	3.283	3.124
25	4	3.583	3.409
26	6	4.483	4.266
27	4	2.683	2.553
28	4	2.983	2.839
29	5	3.583	3.409
30	0	3.433	3.267
Total	100	105.099	100
Calibration Factor		0.951	

6.4 Long Term Maintenance and SPF Re-estimation

In the future, MDOT may wish to re-estimate the SPFs developed in this research. In order to accomplish this task, data should be collected and organized as described in Section 3 of this report. Data available in *SafetyAnalyst* may be sufficient to estimate SPFs when used in conjunction with crash data from the Michigan State Police. In lieu of the discontinuation of the Sufficiency File maintained by MDOT, manual data collection may be necessary if available data sources do not contain geometric data. This research found the following variables to significantly influence crashes within at least one of the intersection site types:

- Major road AADT
- Minor road AADT
- Number of through lanes on the major and minor road
- Presence of lighting (for unsignalized intersections)
- Presence of median on the major and minor road
- Right-turn-on-red prohibition (for signalized intersections)
- Presence of left-turn lanes on all major legs (for three-leg intersections)
- Major road speed limit

These characteristics provide a starting point for data collection to re-estimate the SPFs, however changes in driver behavior and roadway characteristics may lead to additional characteristics becoming significant in the future. In addition to roadway characteristics, this research found variation in estimated crash frequency between MDOT regions, making the inclusion of MDOT region in the data set relevant. However, it is important to note that a newly proposed regional scheme is scheduled for implementation by MDOT in the near future.

Once the dataset has been assembled, statistical analysis software must be utilized to estimate the effects of each roadway characteristic on each facility type. Negative binomial models, the standard for SPF development, should be used. A functional form of the model must be identified. Two functional forms were used in this project, the first, used on the "Two-Way" intersections analyzed the major and minor AADT separately, while the AADTs were summed in the analysis of the "One-Way" intersections. The form of the Two-Way intersection SPF is shown here. Recall that separate models have been developed for single-vehicle and multiple-vehicle crashes at fatal-injury and PDO severity levels. For a given severity level, the general equation for the predicted number of crashes is shown below.

$$N_j = (N_{spfmv} I_{mv} + N_{spfsv} I_{sv}) \times CMF_{mp} \times CMF_{lgt} \times CMF_{lanes} \times CMF_{psl} \times CMF_{rtor} \times CMF_{lt}$$

The equation for multiple vehicle crashes based on the natural log of AADT and the MDOT regional indicators is shown below.

$$N_{spfmv} = n \times e^{b_{mv} + b_{mv1}\, ln(AADT_{maj}) + b_{mv2}\, ln(AADT_{min}) + b_{r1} I_{r1} + b_{r2} I_{r2} + b_{r3} I_{r3} + b_{r4} I_{r4} + b_{r5} I_{r5} + b_{r6} I_{r6}}$$

Ultimately, the results of the statistical analysis will yield parameter estimates, or coefficients, as well as significance levels and information regarding the accuracy of the parameter estimation. The parameter estimates will serve as the “b” values in the SPF equations, provided they are significant at 95 percent confidence interval or their inclusion can otherwise be justified using engineering judgement. The equation above illustrates that AADT is generally log-transformed, which has been shown to provide improved fit.

The effects of other roadway characteristics, such as major road speed limit, are accounted for through the creation of CMFs. In Section 3, it was mentioned that the “base” scenario is represented with a CMF of 1.0 for a specific roadway characteristic. Based on engineering judgement, it may be desirable to transform the data collected for any specific roadway feature so that a particular case is used as the base scenario. For example, in this research it was determined that a major road posted speed limit of 40 miles per hour was the base scenario, so all cases which had a posted speed limit of 40 miles per hour on the major road would have a CMF of 1.0. To accomplish this, the speed limit for each site was transformed by subtracting 40 miles per hour from it. For an example of the form of a CMF, consider the posted speed limit.

$$CMF_{psl} = e^{b_{psl}(PSL-40)}$$

Re-estimation/long-term maintenance of the SPFs will require careful data collection and analysis. The resulting SPFs can only be as good as the data they are based upon. The SPFs presented in this report are the result of extensive data collection and analysis, and ultimately serve as a guideline for the re-estimation of Michigan-specific SPFs in the future.

6.5 Sample Problems using SPFs

6.5.1 Three-Leg Signalized (3SG) Intersection Example

To illustrate the process by which the expected crash rate at a given intersection can be calculated, please consider the following example of a 3-leg signalized (3SG) intersection with two-way traffic on both streets shown in Figure 39.

Figure 39. Woodward Avenue and State Fair Avenue, Detroit.

AADT:

- 22,360 vehicles per day entering the intersection on Woodward Avenue
- 7,522 vehicles per day entering the intersection on West State Fair Avenue

Based on the aerial imagery and street level investigation using Google Earth, the following information can be obtained:

- A median is present on the major street
- No median is present on the minor street
- The posted speed limit on Woodward Avenue is 40 miles per hour
- There are 10 though lanes on Woodward Avenue
- There is 1 through lane on West State Fair Avenue (the lane is considered through as vehicles may turn right or left even though median turn-arounds (Michigan lefts) are available on Woodward Avenue)
- There are no signs prohibiting right-turn-on red
- There are no left turn lanes present on Woodward Avenue

Based on the provided intersection information, the expected average total crash frequency (all types and severities) at the intersection of Woodward Avenue and West State Fair Avenue can be calculated using the equations from Sections 5.3 and 5.4 of this report. Recall from Section 5.3 that the predicted average crash frequency at an intersection is equal to the sum of the multiple vehicle crashes, single vehicle crashes, pedestrian crashes, and bike crashes. Also recall that the predicted number of multiple-vehicle crashes for base conditions multiplied by the appropriate crash modification factors yields the predicted number of multiple-vehicle crashes at the intersection.

From Section 5.3,

$$N_{bi} = N_{mvi} + N_{svi}$$

$$N_{mvi} = N_{spfmv} \times (CMF_1 \times \dots . \times CMF_p)$$

$$N_{svi} = N_{spfsv} \times (CMF_1 \times \dots . \times CMF_p)$$

And from Section 5.4,

$$N_j = (N_{spfmv} I_{mv} + N_{spfsv} I_{sv}) \times CMF_{mp} \times CMF_{lgt} \times CMF_{lanes} \times CMF_{psl} \times CMF_{rtor} \times CMF_{lt}.$$

Knowing that I_{mv} *and* I_{sv} will always be 1 unless data regarding collision type is not available, then, $N_j = N_{bi}$. Note that the results of these equations will differ depending on which severity level (Fatal/Injury or PDO) is being considered, as each severity level has specific coefficients. The procedure for estimation of crash frequency at an intersection will also vary if one or more of the roads involved is a one-way street. First the frequency of either fatal/injury crashes or PDO crashes can be calculated for three-leg signalized intersections based on two sets of coefficients. Table 27 in Section 5.4 contains the coefficients for fatal/injury crashes for Two-way street intersections, while Table 28 contains the coefficients for PDO crashes.

The equation for N_j is dependent on two smaller equations representing single vehicle crashes and multiple vehicle crashes, as well as six possible crash modification factors for a given severity level. As the presence of lighting was not found to be a significant predictor of crash frequency for signalized intersections, only five of the six CMFs are utilized for this calculation.

First, the average expected frequency of fatal and injury multiple vehicle crashes is calculated:

$$N_{spfmv} = n \times e^{b_{mv}+b_{mv1}\,ln(AADT_{maj})+b_{mv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$
$$= 1 \times e^{-10.228+0.831*ln(22360)+0.170*ln(7522)+0.596*0+0.447*0+0.446*0+0.444*0+0.549*0+0.473*0}$$
$$= 0.678\ fatal\ and\ injury\ multiple\ vehicle\ crashes\ per\ year.$$

Next, the average expected frequency of single vehicle fatal and injury crashes per year is calculated:

$$N_{spfsv} = n \times e^{b_{sv}+b_{sv1}\,ln(AADT_{maj})+b_{sv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$
$$= 1 \times e^{-10.205+0.279*ln(22360)+0.450*ln(7522)+0.596*0+0.447*0+0.446*0+0.444*0+0.549*0+0.473*0}$$
$$= 0.034\ fatal\ and\ injury\ single\ vehicle\ crashes\ per\ year.$$

Crash modification factors can now be calculated (or taken from tables in sections 5.4 and 5.5, beginning with the CMF for median presence (Table 41).

$$CMF_{mp} = CMF_{mp1} \times CMF_{mp2} = e^{b_{mp1}(I_{mp1})} \times e^{b_{mp2}(I_{mp2})} = e^{-.344(1)} \times e^{-.326(0)} = 0.709.$$

Four tables in the report (Table 43, Table 44, Table 56, and Table 57) illustrate CMFs for various combinations of major and minor through lanes. To develop these tables, CMFs for the number of lanes are determined by assuming that the traffic volume on the major road is twice the volume on the minor road. To manually calculate the CMF_{lanes},, the proportion of traffic on the major street relative to the total incoming intersection traffic, P_{maj}, and the proportion of incoming traffic on the minor road relative to the total volume of incoming intersection traffic, P_{min}, must be calculated based on the actual proportions of traffic, and coefficients in Table 27 and Table 28.

$$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2} = \left[e^{b_{lanes}(N_{maj}-4)}P_{maj} + (1 - P_{maj})\right] \times \left[e^{b_{lanes}(N_{min}-2)}P_{min} + (1 - P_{min})\right] = \left[e^{0.068(10-2)}\left(\frac{22360}{22360+7522}\right) + \left(1 - \frac{22360}{22360+7522}\right)\right] \times \left[e^{.068(1-2)}\left(1 - \frac{7522}{22360+7522}\right) + \left(\frac{7522}{22360+7522}\right)\right] = 1.354.$$

The crash modification factor for posted speed limit (also, see Table 45),

$$CMF_{psl} = e^{b_{psl}(PSL-40)} = e^{0.019(40-40)} = 1.$$

The crash modification factor for right-turn-on-red (also, see Table 46),

$CMF_{rtor} = e^{b_{rtor}(1-I_{rtor})} = e^{-0.301(1-1)} = 1.$

The crash modification factor for major street left-turn-lane (also, see Table 47),

$CMF_{lt} = e^{b_{lt}(I_{lt})} = e^{-0.067(0)} = 1.$

Now, revisiting the equation for N_j,

$N_j = (0.678 * 1 + 0.034 * 1) \times 0.709 \times 1.354 \times 1 \times 1 \times 1 =$
$0.683\ fatal\ and\ injury\ automobile\ only\ crashes\ per\ year.$

Now that the fatal and injury crashes have been calculated, the PDO crashes can be calculated using the same process, but utilizing the coefficients from Table 28. Multiple-vehicle crashes prior to the application of the CMFs are calculated to be 2.442, while single-vehicle crashes prior to the application of the CMFs are calculated to be 0.132. Summing the multiple- and single-vehicle crashes and multiplying by the appropriate CMFs yields 2.466 PDO automobile crashes per year. Summing this with the fatal and injury automobile only crashes yields 3.250 total automobile only crashes per year.

The number of pedestrian crashes at the intersection can be calculated using the total number of automobile only crashes multiplied by a pedestrian adjustment factor from Table 39 of Section 5.4.2. Although the total number of automobile crashes are used to calculate the estimated number of crashes involving pedestrians, all of the crashes involving pedestrians are considered to be fatal or injury crashes.

$N_{pedi} = N_{bi} \times f_{ped} = 3.250 \times 0.0095 = 0.031\ crashes\ involving\ pedestrians$

The same process can be used based on Table 40 of Section 5.4.3 for bicycle crashes. This yields 0.032 crashes involving bicycles per year. Also from Table 40, the proportions of fatal/injury bicycle crashes and PDO bicycle crashes can be calculated using a proportion.

$N_{bikei,fi} = N_{bikei} \times P_{fi} = 0.032 \times 0.71 =$
$0.023\ fatal\ and\ injury\ crashes\ involving\ bicycles.$

$N_{bikei,pdo} = N_{bikei} \times \left(1 - P_{fi}\right) = 0.031 \times (1 - .71) =$
$0.009\ PDO\ crashes\ involving\ bicycles.$

Summing the total crashes involving bicycles, pedestrians, and automobiles indicates that the expected total crash frequency at this intersection is 3.176 crashes per year. A summary table detailing the results of each individual crash calculation is shown in Table 69.

Table 69. Summary of Predicted Crash frequency for Woodward Avenue and West State Fair Avenue

Crash Type	Predicted Frequency (crashes/year)
Fatal and Injury Multiple-Vehicle Crashes before CMFs	0.678
Fatal and Injury Single-Vehicle Crashes before CMFs	0.034
Fatal and Injury Automobiles only, CMFs applied	0.683
PDO Multiple-Vehicle Crashes before CMFs	2.442
PDO Single-Vehicle Crashes before CMFs	0.132
PDO Automobiles only, CMFs applied	2.567
Total Automobile only crashes	3.250
Crashes involving pedestrians	0.035
Fatal and Injury crashes involving bicycles	0.026
PDO crashes involving bicycles	0.009
Total Crashes	3.313

6.5.2 Three-Leg Stop-Controlled (3ST) Intersection Example

For an example of the calculations performed on a stop-controlled intersection, consider the three-leg, minor leg stop-controlled intersection (3ST) of Eastman Avenue and Pleasant Ridge Drive in Midland, illustrated in Figure 40.

Figure 40. Eastman Avenue and Pleasant Ridge Drive, Midland.

AADT:

- 23,521 vehicles per day entering the intersection on Eastman Avenue
- 508 vehicles per day entering the intersection on Main Street

Based on the aerial imagery and street level investigation using Google Earth, the following information can be obtained:

- No median is present on the major street
- No median is present on the minor street
- The posted speed limit on Eastman Avenue is 45 miles per hour
- There are 4 though lanes on Eastman Avenue
- There is one through lane on Pleasant Ridge Drive
- Lighting is present at the intersection
- There are left turn lanes in each direction on Eastman Avenue

Based on the provided intersection information, the expected average total crash frequency (all types and severities) at the intersection of Eastman Avenue and Pleasant Ridge Drive can be calculated. First, the average expected frequency of fatal and injury multiple vehicle crashes is calculated:

$$N_{spfmv} = n \times e^{b_{mv}+b_{mv1}\,ln(AADT_{maj})+b_{mv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$
$$= 1 \times e^{-16.764+1.067*ln(23521)+0.594*ln(508)+0.596*0+0.447*0+0.444*0+0.446*0+0.559*0+0.473*0}$$
$$= 0.153\ fatal\ and\ injury\ multiple\ vehicle\ crashes\ per\ year.$$

Next, the average expected frequency of single vehicle fatal and injury crashes per year is calculated:

$$N_{spfsv} = n \times e^{b_{sv}+b_{sv1}\,ln(AADT_{maj})+b_{sv2}\,ln(AADT_{min})+b_{r1}I_{r1}+b_{r2}I_{r2}+b_{r3}I_{r3}+b_{r4}I_{r4}+b_{r5}I_{r5}+b_{r6}I_{r6}}$$
$$= \ 1 \times e^{-8.953+0.108*ln(23521)+0.292*ln(7522)+0.596*0+0.447*0+0.444*0+0.446*0+0.559*0+0.473*0}$$
$$= 0.004\ fatal\ and\ injury\ single\ vehicle\ crashes\ per\ year.$$

Crash modification factors can now be calculated (or taken from tables in sections 5.4 and 5.5, beginning with the CMF for median presence (Table 41).

$$CMF_{mp} = CMF_{mp1} \times CMF_{mp2} = e^{b_{mp1}(I_{mp1})} \times e^{b_{mp2}(I_{mp2})} = e^{-.344(0)} \times e^{-.326(0)} = 1.$$

The crash modification factor for the presence of lighting (also, see Table 42)

$CMF_{lgt} = e^{b_{lgt}(I_{lgt})} = e^{-.305(1)} = 0.737.$

The crash modification factor for the number of major and minor through lanes (also, see Table 44*)*

$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2} = \left[e^{b_{lanes}(N_{maj}-4)}P_{maj} + \left(1 - P_{maj}\right)\right] \times \left[e^{b_{lanes}(N_{min}-2)}P_{min} + (1 - P_{min})\right] = \left[e^{0.019(4-2)}(\frac{23521}{23521+508}) + (1 - \frac{23521}{23521+508})\right] \times \left[e^{.019(1-2)}(1 - \frac{508}{23521+508}) + (\frac{508}{23521+508})\right] = 0.999.$

The crash modification factor for posted speed limit (also, see Table 42),

$CMF_{psl} = e^{b_{psl}(PSL-40)} = e^{0.010(45-40)} = 1.051.$

The crash modification factor for right-turn-on-red is not applicable to stop-controlled intersections, therefore CMF_{rtor} = 1.00.

No left turn lane is present, therefore $CMF_{lt} = 1.00$.

Now, revisiting the equation for N_j,

$N_j = (0.153 * 1 + 0.004 * 1) \times 1 \times 0.737 \times 0.999 \times 1.051 \times 1 \times 1 = 0.121$ $fatal\ and\ injury\ automobile\ only\ crashes\ per\ year.$

Now that the fatal and injury crashes have been calculated, the PDO crashes can be calculated using the same process, but utilizing the coefficients from Table 28. Multiple-vehicle crashes prior to the application of the CMFs are calculated to be 0.587, while single-vehicle crashes prior to the application of the CMFs are calculated to be 0.023. Summing the multiple- and single-vehicle crashes and multiplying by the appropriate CMFs yields 0.505 PDO automobile crashes per year. Summing this with the fatal and injury automobile only crashes yields 0.626 total automobile only crashes per year.

The number of pedestrian crashes at the intersection can be calculated using the total number of automobile only crashes multiplied by a pedestrian adjustment factor from Table 39 of Section 5.4.2.

$$N_{pedi} = N_{bi} \times f_{ped} = 0.626 \times 0.0129 = 0.008\ crashes\ involving\ pedestrians$$

The same process can be used based on Table 40 of Section 5.4.3 for bicycle crashes. This yields 0.013 crashes involving bicycles per year. Also from Table 40, the proportions of fatal/injury bicycle crashes and PDO bicycle crashes can be calculated using a proportion.

$$N_{bikei,fi} = N_{bikei} \times P_{fi} = 0.013 \times 0.73 = 0.010\ fatal\ and\ injury\ crashes\ involving\ bicycles.$$

$$N_{bikei,pdo} = N_{bikei} \times \left(1 - P_{fi}\right) = 0.013 \times (1 - .73) = 0.003\ PDO\ crashes\ involving\ bicycles.$$

Summing the total crashes involving bicycles, pedestrians, and automobiles indicates that the expected total crash frequency at this intersection is 0.648 crashes per year. A summary table detailing the results of each individual crash calculation is shown in Table 70.

Table 70. Summary of Predicted Crash frequency for Eastman Avenue and Pleasant Ridge Avenue

Crash Type	Predicted Frequency (crashes/year)
Fatal and Injury Multiple-Vehicle Crashes before CMFs	0.153
Fatal and Injury Single-Vehicle Crashes before CMFs	0.004
Fatal and Injury Automobiles only, CMFs applied	0.121
PDO Multiple-Vehicle Crashes before CMFs	0.587
PDO Single-Vehicle Crashes before CMFs	0.023
PDO Automobiles only, CMFs applied	0.505
Total Automobile only crashes	0.626
Crashes involving pedestrians	0.013
Fatal and Injury crashes involving bicycles	0.010
PDO crashes involving bicycles	0.003
Total Crashes	0.648

6.5.3 Four-Leg Signalized (4SG) Intersection Example with One-Way Street

Intersections involving "one-way" traffic flow have specially estimated SPFs, as illustrated by the example of four-leg signalized intersection of West Cross Street and Ballard in Ypsilanti, illustrated in Figure 41.

Figure 41. West Cross Street and Ballard Street, Ypsilanti.

AADT:

- 8,748 vehicles per day entering the intersection on West Cross Street
- 3,965 vehicles per day entering the intersection on Ballard Street

As westbound West Cross Street is a one-way, the only relevant information for the CMFs is the number of through lanes on each road street, which is two.

Based on the provided intersection information, the expected average total crash frequency (all types and severities) at the intersection of West Cross Street and Ballard Street can be calculated using the equations from Section 5.3 and 5.4 of this report. Recall from Section 5.3 that the predicted average crash frequency at an intersection is equal to the sum of the multiple vehicle crashes, single vehicle crashes, pedestrian crashes, and bike crashes. The model for intersections where at least one of the legs is a one-way street does not require separate estimation of the single-vehicle and multiple-vehicle crashes.

From Section 5.4, the estimated fatal and injury crashes at the intersection can be estimated by:

$N_j = N_{spf} \times CMF_{lanes}.$

Based on the coefficients from Table 49,

$$N_{spf} = n \times e^{b_1 + b_2 \ln(AADT_{maj} + AADT_{min}) + b_{r1}I_{r1} + b_{r2}I_{r2} + b_{r3}I_{r3} + b_{r4}I_{r4} + b_{r5}I_{r5} + b_{r6}I_{r6}}$$
$$= 1 \times e^{-4.902 + 0.427 * \ln(8{,}748 + 3{,}965) + 1 * 0.49} = 0.686$$

and,

$$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2} = \left[e^{b_{lanes}(N_{maj}-4)} P_{maj} + \left(1 - P_{maj}\right)\right] \times \left[e^{b_{lanes}(N_{min}-2)} P_{min} + (1 - P_{min})\right] = \left[e^{0.058(2-4)}\left(\frac{8748}{8748+3965}\right) + \left(1 - \frac{8748}{8748+3965}\right)\right] \times \left[e^{.058(2-2)}\left(1 - \frac{3965}{8748+3965}\right) + \left(\frac{3965}{8748+3965}\right)\right] = 0.925.$$

Therefore, the predicted number of fatal and injury crashes at the intersection is,

$N_j = N_{spf} \times CMF_{lanes} = 0.686 \times 0.927 = 0.634\,.$

The process can be repeated for PDO crashes using values from Table 50, yielding 2.855 PDO crashes. Summing this with the fatal and injury crashes indicates an expected crash frequency of 3.489 total vehicle crashes per year.

The number of pedestrian crashes can be calculated using Table 54,

$$N_{pedi} = N_{bi} \times f_{ped} = 3.489 \times 0.0170 = 0.059\ pedestrian\ crashes$$

The number of bicycle crashes can be calculated using Table 55,

$$N_{bikei} = N_{bi} \times f_{ped} = 2.489 \times 0.0129 = 0.045\ bicycle\ crashes$$

The number of Fatal and Injury bicycle crashes can also be estimated based on Table 55,

$$N_{bikei,fi} = N_{bikei} \times P_{fi} = 0.045 \times 0.72 = 0.032\ fatal\ and\ injury\ bicycle\ crashes$$

Summing all of these gives 3.593 predicted total crashes per year. A summary of the predicted crashes can be seen in Table 71.

Table 71. Summary of Predicted Crash frequency for West Cross Street and Ballard Street

Crash Type	Predicted Frequency (crashes/year)
Fatal and Injury Crashes before CMFs	0.686
PDO Crashes before CMFs	2.930
Fatal and Injury Crashes after CMFs	0.634
PDO Crashes after CMFs	2.930
Total Crashes after CMFs	2.489
Crashes involving pedestrians	0.045
Fatal and Injury crashes involving bicycles	0.032
PDO crashes involving bicycles	0.013
Total Crashes	3.593

7.0 CONCLUSIONS

This project involved the development of a uniform, consistent approach that can be applied to estimate the safety performance of urban trunkline intersections at the aggregate (i.e., total crash) level, as well as to within specific crash types and crash severity categories. The study results provide important guidance to allow MDOT to make informed decisions as to planning and programming decisions for safety projects.

This report documents the processes involved in developing safety performance functions (SPFs) and crash modification factors (CMFs) for signalized and stop-controlled intersections in Michigan. These tools were developed using a robust database, which combined traffic crash, volume, and roadway geometric data. These data were obtained from the following sources:

- Michigan State Police Statewide Crash Database;
- MDOT SafetyAnalyst Calibration File;
- Michigan Geographic Data Library (MiGDL) All Roads File;
- MDOT SafetyAnalyst Annual Average Daily Traffic File; and
- MDOT Sufficiency File.

Using intersection location, volume, and crash information from the above data sources, geometric data were obtained manually using Google Earth. These data were aggregated to develop a comprehensive database of intersections over the five-year study period from 2008 to 2012. The final sample was comprised of the following number of locations by site type:

- 353 three-legged stop-controlled (3ST) intersections;
- 350 four-legged stop-controlled (4ST) intersections;
- 210 three-legged signalized (3SG) intersections; and
- 349 four-legged signalized (4SG) intersections.

After the data were assembled, an exploratory analysis of the data was conducted separately for each intersection type to identify general crash trends using Michigan-specific data. The results indicated a non-linear relationship between traffic flow and the number of vehicle-only crashes for both signalized and stop-controlled intersections. With respect to pedestrian crashes, it was found that more crashes involving pedestrians occur at lower major road AADT volumes. Additionally, it was found that crashes involving bicycles occur at similar levels as a function of major AADT volumes.

In order to provide MDOT with a tool to calculate predicted crash frequency at a particular intersection, a series of SPFs were developed. First, the base SPFs from the Highway Safety Manual (HSM) were applied to the Michigan data. A calibration exercise illustrated that the models, without calibration, provided inconsistent fit across site types, crash types, and severity levels.

After the calibration exercise, a series of Michigan-specific SPFs were developed. These included a series of simple models, which consider only annual average daily traffic (AADT) estimates for the major and minor roads. As MDOT collects AADT for its trunkline system on a regular basis and has developed models to estimate AADT for local cross-streets, these AADT-only models provide a viable short-term tool for use in high-level safety planning activities. In addition to these SPFs, crash type distributions were also developed at a statewide and regional level. While AADT-only SPFs are provided for single- and multi-vehicle crashes within each of the four intersection types, preliminary models are also provided for pedestrian- and bicycle-involved crashes.

Lastly, more detailed SPFs were estimated that considered the full level of detail resulting from the large-scale data collection activities. These detailed statistical models may be utilized that account for the effects of this wide range of factors as they provide the greatest degree of accuracy. The models have been calibrated such that they are able to account for the effects of traffic volumes, roadway geometry, regional differences, and other effects. Separate SPFs were estimated for the intersections of two-way streets and for those intersections where at least one intersecting street was one-way. The relevant factors affecting traffic safety were found to vary among these types of intersections.

Within each site type, separate SPFs are also provided to allow for the prediction of vehicle-involved crash frequency (i.e. single- and multi-vehicle crashes), as well as pedestrian- or bicycle-related crashes as a percentage of the vehicular crashes. Distributions are also provided to allow for disaggregation of multi-vehicle crashes into various collision type category (e.g. rear-end, head-on, angle etc.).

In addition to the SPFs, which were developed for specific base conditions, crash modification factors (CMFs) are also developed, which can be used to adjust the SPF estimate when the characteristics of an intersection are not consistent with the base conditions. Several variables were incorporated in the development of the SPFs and CMFs including AADT, MDOT region, median presence, intersection lighting presence, number of lanes, posted speed limit, right-turn-on-red prohibition, and left-turn-lane presence. All of the models developed as a part of this project were calibrated such that they can be applied at either the statewide level or within any of MDOT's seven geographic regions.

In addition to the Michigan-specific SPFs and CMFs developed as a part of this study, severity distribution functions (SDFs) were developed, which can be used to predict the proportion of injury crashes which result in different injury severity levels. Due to the small number of fatal crashes, K and A crashes were combined for purpose of SDF development. The SDFs can be used with the SPFs to estimate the expected crash frequency for each severity category. The SDFs may include various geometric, operation, and traffic variables that will allow the estimated proportion to be specific to an individual intersection.

This report also documents procedure for maintaining and calibrating these SPFs over time. Calibration will allow for MDOT to account for yearly changes in traffic volumes and general trends in crashes over time that are not directly reflected by the predictor variables (e.g., recent declines in crashes at the statewide level). As MDOT continues to build its data system, the use of additional geographically-referenced geometric, operational, and traffic control data will allow for further refinements to these analytical tools.

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APPENDIX: SITE LIST

Table 72. Superior Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
3170836	17.489	Ashmun	Arlington
1902204	1.368	Portage	Kimball
3170836	17.318	Ashum	Dawson
3170836	15.803	Mackinac	18th
1467209	1.752	3 Mile	8th
3170005	0.802	Tone	Feole
3170836	16.509	Ashmun	7th
1349906	1.82	M-35	Clark
1349006	21.967	US-2	18.3 Rd
1349006	19.535	Lincoln	20th
1349006	15.849	Lincoln	23rd
1349906	2.382	M-35	Sjoquist
1551710	3.036	US-2	Stanton
1551710	4.841	US-2	Jackson
1553305	0.965	Carpenter	Henford
1551710	8.284	US-2	Pine
1476001	0.636	Cloverland	Walnut
1476001	1.84	Cloverland	Wemple
1476001	2.512	Cloverland	Wilson
1176203	14.617	US-41	Sportsman
1177301	0.763	Depot	Boones
1176203	11.37	US-41	Millionaire
1176203	3.284	US-41	Lake Annie
1176203	2.798	US-41	Lower Pewabic
1176203	2.365	US-41	French Town
1176203	1.707	Lincoln	Scott
1176203	1.448	Lincoln	3rd
1177509	1.837	Canal	Atlantic
1177509	0.558	Quincy	Dakota
1176203	0.335	Hancock	Church
1176203	0.048	Front	Center
1178404	15.592	College	Prospect
1175707	4.917	Memorial	6th
1175707	8.764	M-26	6th
1178404	13.573	US-41	Waylene
1175707	2.452	M-26	Erickson
1178404	7.993	US-41	2nd
1177509	18.251	Pine	2nd
1175707	1.641	M-26	Erickson
1177509	18.201	Pine	3rd
1176203	14.296	US-41	Centennial 6
1175707	5.742	M-26	Royce
1562009	29.645	US-41	Brebner
3520167	0.996	McClellan	Vistanna
1562009	33.884	US-41	Chippewa
1562009	34.261	US-41	Maple
1562009	37.158	Palms	Beech
1562009	37.525	Palms	3rd
1562009	38.336	US-41	North
3520776	0.289	Lake Shore	Empire

Table 73. Superior Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1902204	1.173	Portage	Bingham
3170836	16.076	Ashmun	14th
1465607	27.955	Ashmun	20th
3170005	0.619	Tone	Fair
1349006	29.061	US 2	Days River 24.5
1349006	18.82	Lincoln	13th
1349006	16.202	Lincoln	18th
1551710	3.222	US 2	Margaret
1553305	2.266	Carpenter	E
1551710	6.368	US 2	Dawns
1476001	0.514	Cloverland	Broadway
1476001	2.191	Cloverland	Zinn
1476103	0.159	Douglas	Ridge
1480110	0.426	Aurora	Lawerence
1176203	13.897	US 41	Dump
1177509	17.649	M 203	11th
1177509	17.961	Pine	7th
1176203	12.305	Calumet	Depot
1177301	0.5	3rd	Osceola
1185203	0.294	Hecla	4th
3310007	3.051	Lake Linden	Wyandotte
1176203	1.552	Lincoln	Elevation
1176203	0.978	Lincoln	Elevation
1177509	0.948	Quincy	Michigan
1177408	0.111	Quincy	Reservation
1176203	0.39	Hancock	Ravine
1176202	0.51	Shelden	Bridge
1176202	0.086	Shelden	Lake
1176201	0.083	Montezuma	Lake
1175707	4.567	Memorial	Calverley
1175707	1.783	M 26	Naumkeg
1178404	8.646	US 41	Upper Massie
1178404	7.619	US 41	5th
3520167	1.422	McClellan	Grove
1562009	30.971	US 41	Pond
1562009	31.434	US 41	Airport
1562009	31.987	US 41	Perala
1562009	37.06	Palms	Walnut
1562009	37.318	Palms	Hickory
3520187	0.199	Teal Lake	Clark
1562009	39.24	US 41	Cooper Lake
1562009	39.93	US 41	North Lake
1563209	3.13	Division	4th
1562009	40.621	US 41	Westwood
1562406	2.178	M28	Hiawatha
1322610	0.599	M 35	44th
1322610	0.117	M 35	40th
1322308	2.483	10th	38th
1322308	1.044	10th	15th
3520187	0.066	Teal Lake Ave	Case Street

Table 74. Superior Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
3170836	15.55	Mackinac Spur	Davitt
1467209	1.835	W 3 Mile Rd	S Mackinaw Tr
1349006	19.397	N Lincoln Rd	Danforth Rd
1176203	12.541	Calumet Ave	1st St
1322308	2.557	10th St	M-35

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1322308	1.983	10th St	30th Ave
1551710	0.665	US-2	M-95
1551710	4.716	US-2	H St
3220755	0.119	US-2	US-141

Table 75. Superior Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
3170836	17.625	Ashmun St	E Portage Ave
1902204	1.488	E Portage Ave	Johnston St
3170061	0.895	3 Mile Rd	Dixie Hwy
1349906	1.486	M 35	P 5
1349006	26.075	4th Ave	US 2
1349006	18.13	N Lincoln Rd	5th Ave
1349006	17.897	N Lincoln Rd	3rd Ave
1351805	11.897	US 2	N 30th St
1351805	12.153	US 2	26th St
1351805	12.404	Highway 2	S Lincoln Rd
1349006	17.227	S Lincoln Rd	5th Ave
1551710	2.434	US 2	Lake Antoine Rd
1552105	0.804	E Ludington St	US 2
1553305	2.533	S Carpenter Ave	A St
1551710	4.14	US 2	E A St
1553305	2.466	S Carpenter Ave	B St
1551710	4.204	US 2	E B St
1553305	2.043	S Carpenter Ave	W H St
1551710	5.222	US 2	Michigan Ave
1553305	1.792	S Carpenter Ave	Woodward Ave
1551710	8.318	US 2	Quinnesec Ave
1553305	1.371	S Carpenter Ave	East Blvd
1553305	1.025	S Carpenter Ave	W Breitung Ave

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1551710	5.692	US 2	Ridgeview Dr
1476001	1.136	Cloverland Dr	Douglas Blvd
1476001	1.753	Cloverland Dr	Lake St
1476001	2.286	Cloverland Dr	Luxmore St
1477503	0.577	E Ayer St	S Suffolk St
1480110	0.603	E Aurora St	S Suffolk St
1476102	1.45	Lowell St	W Aurora St
3310007	4.108	Lake Linden Ave	Calumet Ave
1176202	0.275	Shelden Ave	Isle Royal Ave
1178404	14.875	Townsend Rd	Macinnes Dr
1175707	4.247	M 26	W Sharon Ave
1175707	3.48	M 26	Green Acres Rd
1562009	24.04	US 41	Grove St
1562009	23.183	S Front St	Genesee St
1562009	34.114	US 41	Maas St
1562009	34.524	US 41	Baldwin Ave
1562009	34.856	US 41	N Teal Lake Ave
1562009	37.585	US 41	N 2nd St
1562009	38.457	US 41	Lakeshore Dr
1562009	19.573	US 41	Silver Creek Rd
1562406	0	US 41	Cherry Creek Rd
1322308	0.98	US 41	14th Ave
1322308	0.537	US 41	13th St

Table 76. North Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1725704	5.205	US-23	Gruff
1725704	0.521	US-23	Martel
1023609	21.93	Washington	Tawas
1023609	20.626	M-32	Washington
1024309	14.995	State	Dunbar
1024309	13.978	US-23	Thunder Bay
1024309	11.938	US-23	Birch
1164507	2.224	US-31	Hampton
1164507	1.123	US-31	Rosedale
1164305	5.084	Charlevoix	Resort Pike
1164305	4.798	Charlevoix	Quarry
994002	5.972	US-31	Shore
994002	5.272	US-31	Crest Haven
993610	4.411	Front	Peninsula
992703	14.173	Division	10th
992703	13.351	US-31	Fitzhugh
992204	7.811	US-31	E Commerce
992703	8.39	US-31	Blair Valley
992204	6.68	US-31	Silver Lake Crossing
1251607	29.93	Huron	Aaron
1251607	27.139	Huron	Jordanville
1251607	24.576	Huron	Cedar Lake
1251607	23.642	Huron	Cameron
3450711	23.406	W. Bay Shore	Apple Ridge
1153803	8.279	Parkdale	Guthrie
1154207	0.964	Caberfae	Main

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1154207	3.013	Caberfae	Franklin
1079903	11.776	M-32	Hayes
1086304	11.58	Ostego	5th
1052204	2.771	M-55	Northway
1052204	4.785	Houghton Lake	Ithaca
1052204	5.112	Houghton Lake	Catalpa
1052204	12.274	West Branch	Lake
1052204	5.971	Houghton Lake	Knollside
1052204	6.372	Houghton Lake	Hawley
1052204	10.906	Houghton Lake	6th
1052204	10.601	Houghton Lake	Bright Angel
1052204	9.143	Houghton Lake	Devonshire
1052204	8.593	Houghton Lake	Maple Bluff
1052204	8.238	Houghton Lake	Schott
1052204	7.794	Houghton Lake	Roberts
1052204	7.454	Houghton Lake	Guernsey
1053202	10.119	Gladwin	Pine
1053202	9.861	Gladwin	Tamarac
1052204	11.416	Houghton Lake	Midland
3830970	3.423	Mitchell	Webber
3830970	2.396	Mitchell	Beech
1127810	23.777	M-115	Lake Mitchell
1127810	24.327	M-115	Sunnyside
1127310	0.449	Sunnyside	Iowa
1126103	17.951	M-55	Locust

Table 77. North Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1725704	5.352	US 23	Main
1024202	2.36	US 23	Golf Course
1024202	0.79	Chisholm	8TH
1024202	0.525	Chisholm	5TH
1024109	2.526	3rd	Sable
1024201	1.245	2nd	Lockwood
1023609	21.545	Washington Ave	W Mirre St
1024202	0.176	Chisholm	1ST
1024309	14.42	State	Blair
1164507	3.241	US-31	Pickerel Lake Rd
1164507	1.524	US 31	Encampment
1166601	6.241	Mitchell	Liberty
1166601	5.842	Mitchell	Jackson
1166601	5.398	Spring St	Hillcrest St
1166601	3.728	US 131	Intertown
994703	1.442	Center	Mathison
992703	14.74	Division St	3rd St
992703	14.499	Division	6TH
994002	0.272	Munson	Davis
992703	10.61	US 31	Silver Pines
992703	9.825	US 31	Meadow Lane
992703	9.062	US 31	Rennie School
992703	8.267	US 31	Valley View
1251607	27.029	Huron	Interlake
1251607	23.871	Huron Rd	E Mill St

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1153803	7.984	Parkdale	Frost
1153803	7.018	Parkdale	Hill
1154207	1.632	Caberfae	Pine Creek
1153803	5.099	Cypress	Filer
1153803	5.037	Cypress	Clay
1153803	4.849	Cypress	3rd
1153803	4.725	Cypress	5th
1153803	4.536	Cypress St	7th St
216003	0.489	Ludington	Lavinia
216003	0.559	Ludington	Emily
216003	0.068	Ludington	Robert
216403	0.073	W Ludington Ave	Lewis St
215605	0.339	James	Filer
215605	0.128	James	Melendy
217004	8.959	Pere Marquette	6th
1079903	11.587	Main	Maple
1079903	10.994	Main	Indiana
1052204	8.922	Houghton Lake	Stratford
1053202	9.977	Gladwin	Cypress
1131507	11.893	US 34	Hanthorn
3830970	2.634	Mitchell	Bremer
1127601	1.317	M 55	US 131
3830970	2.195	Mitchell St	Chapin St
1127310	2.535	Granite	Laurel
1127810	25.322	M 115	44 Rd

Table 78. North Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1023609	19.86	Washington Ave	Home Depot
1164507	2.673	US-31	M-119
1164507	0.013	US-31	E Mitchell St
1164305	3.968	US-31	Bay Harbor Dr
1166601	5.038	US-131	Anderson Rd
3450666	0.053	W. Bay Shore Dr	E Traverse
993906	0.933	Center Rd	Peninsula Dr
993906	0.61	Center Rd	Eastern Ave
994002	4.99	US-31	Bunker Hill Rd
993209	1.434	US-31	N Park St
993610	3.95	E Front St	US-31
994002	0.825	US-31	Airport
994002	1.824	US-31	3 Mile Rd
994002	3.301	US-31	Holiday Rd
993209	0.584	Grandview Blvd	Division St
992703	12.311	US-31	Market Place Cr
216003	1.384	US-10	N Nelson Rd
216003	1.842	US-10	Pere Marquette Hwy
216003	0.209	Ludington Ave	S James St
1086304	11.015	S Ostego Ave	Commerce Blvd
1079903	8.913	M-32	Meijer Dr
3830970	1.946	S Mitchell St	South St
1127810	24.173	M-115	M-55
3830970	0.876	S Mitchell St	Mackinaw Tr

Table 79. North Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1024202	1.811	US 23	Long Rapids Rd
1024003	0.923	N 11th Ave	W Chisholm St
3040011	0.671	S 9th Ave	W Chisholm St
1024109	2.665	S 3rd Ave	W Chisholm St
1024201	1.314	S 2nd Ave	W Chisholm St
1813803	1.202	S Ripley St	W Washington
1023609	20.236	W Washington Ave	S Bagley St
1024309	13.727	S State Ave	S Ripley Rd
1024309	13.368	US 23	Werth Rd
1164507	0.072	US 31	E Lake St
1164305	6.336	Chalevoix Ave	W Mitchell St
1166601	5.249	Spring Rd	W Sheridan Rd
3240865	0.382	Lears Rd	US 131
994002	5.662	US 31	M 72
993610	5.02	E Front St	Fair St
993610	4.694	E Front St	S Garfield Ave
993610	4.196	E Front St	Barlow St
993610	2.762	W Front St	S Division St
992703	14.417	S Division St	Seventh St
993010	2.746	E Eighth St	Munson Ave
992703	13.806	US 31	Silver lake Rd
994002	2.932	Munson Ave	N Four Mile Rd
992906	1.101	W South Airport Rd	US 31
992204	8.188	US 31	M 37
998910	10.891	County Road 633	US 31
1251607	24.218	S State Rd	River Rd
3450711	25.49	SW Bay Shore Dr	E Cherry Bend Rd
216003	1.639	W Ludington Ave	Jebay Dr
216003	1.132	W Ludington Ave	S Jackson Rd
216003	3.625	US 31	S Brye Rd
216003	0.629	W Ludington Ave	Washington Ave
216003	0.279	W Ludington Ave	S Harrison St
216003	0.139	W Ludington Ave	Rath Ave
216003	2.682	E Ludington Ave	S Meyers Rd
1079903	11.283	W Main St	N Center Ave
1086304	11.994	N Otsego Ave	W Main St
1079903	10.863	W Main St	S Wisconsin Ave
1079903	9.802	M 32	McVannel Rd
1086304	11.27	S Otsego Ave	Grandview Blvd
1086304	10.276	S Otsego Ave	W McCoy Rd
1052204	3.019	W Houghton Lake Dr	Old US Hwy 27
1052204	4.411	W Houghton Lake Dr	Loxley Rd
1052204	8.179	W Houghton Lake Dr	Reserve Rd
1052204	7.137	Houghton Lake Dr	Town Line Rd
1131507	12.138	34 Rd	Plett Rd
3830970	4.561	US 131 BR	34 Rd
1127810	21.743	M 115	W 13th St
3830970	3.177	N Mitchell St	Gunn St
3830970	2.489	N Mitchell Rd	W Pine St
3830970	2.267	S Mitchell St	W Cass St

Table 80. Grand Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
3412445	5.184	M-37	Sparta
3410246	0.317	Remembrance	Senior
3415605	6.386	Grandville	A
3415605	6.217	Grandville	Beacon
3415605	6.068	Grandville	Hughart
3415605	5.721	Grandville	Stolpe
3415605	5.629	Grandville	High
3415605	5.177	Chicago	Leestma
3415605	4.946	Chicago	Wendler
3415605	4.546	Chicago	Delwood
3415605	3.623	Chicago	Wyoming
3412181	0.118	Beltline	University
3412182	4.454	Beltline	Pine Forest
3412182	0.919	Beltline	Windcrest
3412182	1.899	Beltline	Celebration
3412182	1.98	Beltline	Peregrine
3540813	4.201	Perry	Watertower
1204902	5.656	Greenville	Eugene
1204902	5.119	Lafayette	North
1204902	4.525	Lafayette	State
1202910	2.734	Washington	Irving
1202910	2.008	Washington	Nelson
1202910	3.791	Washington	Edgewood
1204902	3.594	Lafayette	Sunny Side
860003	1.414	Holton	Linden
3611477	0.992	Shoreline	1st

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
857803	7.521	Apple	Delora
857803	7.312	Apple	Holiday
857803	6.447	Apple	Chandler
857803	5.951	Apple	Ellison
857803	0.529	Apple	Ambrosia
857803	0.981	Apple	Maple
857803	1.15	Apple	Holt
857803	1.864	Apple	Evart
859917	2.531	Seaway	Peninnsula
860003	0.36	Holton	Ridgeview
712309	3.907	W Main St	Westwood Ave
754007	0.991	Savidge	Church
754007	1.354	Savidge	Parkhurst
740406	22.429	Beacon	Coho
740406	21.957	Beacon	Elliott
742605	21.433	Beacon	Colfax
751907	0.649	Ironwood	4 Mile
3702045	8.671	Lake Michigan	2nd
3702046	1.607	Lake Michigan	Rosewood
3701952	8.011	Chicago	Van Buren
742605	19.104	N US 31	Rosy Mound
3702045	1.848	Lake Michigan	56th
3702045	2.71	Lake Michigan	Radcliff
3702170	0.17	River Hill	Dicarlo
732002	12.957	Lake Michigan	Red Hawk

Table 81. Grand Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
503009	4.181	State	Pleasant
503510	0.424	State	Forest
503406	6.663	Lincoln	Jackson
503406	6.325	Lincoln	Union
503406	5.327	Bluewater	Jermyn
504502	13.751	State	Riverside
407503	1.893	Webber	Grand River
405307	4.748	Plainfield	Miramar
409008	0.522	Wilson	Richmond
409008	2.153	Wilson	Grand
409105	1.161	Lake Michigan	Hampton
409005	9.219	Fulton	Alta Dale
409005	0.478	Fulton	Marion
409005	0.785	Fulton	Indiana
409005	0.978	Fulton	Gold
409005	5.877	Fulton	Robinhood
409003	0.299	Oaks	Commerce
409008	4.538	Wilson	Hall
3415605	5.868	Grandville	Shamrock
409005	19.775	Main	Jackson
409005	19.631	Main	Washington
3415605	4.644	Chicago	Federal
409005	19.011	Main	Pleasant
409008	9.383	28th	Meyer
409008	10.959	28th	Longstreet
409008	15.707	28th St	Shaffer
407204	1.408	Broadmoor	76th
525201	0.252	Maple	Stewart
524603	16.722	Northland	Elm
524603	16.631	Northland	Sanborn
3540813	4.688	Perry	Division
1202910	3.062	Washington	Clay
1202910	2.312	Washington	Luray
1204902	4.103	Lafayette	Benton
1204902	3.67	Lafayette	South
860702	0.276	Water	Hunt
860003	2.511	Holton	Roberts
857803	6.132	Apple	Carr
857803	2.996	Apple	Center
857803	1.736	Apple	Roberts
712309	3.789	Main	Connie
712309	4.916	Main	Darling
712604	0.643	Stewart	Maple
754007	0.458	Savidge	School
754007	0.884	Savidge	Bouchanan
740406	21.31	Beacon	Woodlawn
3702045	6.114	Lake Michigan	Trillium
740406	5.728	US 31	Ransom
740803	5.775	I 196	92nd
857910	1.278	E Colby St	Covell St

Table 82. Grand Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
503009	2.622	Belding Rd	Storey Rd
503406	5.963	W Lincoln Ave	N Dexter St
504502	14.099	S Dexter St	S Steele St
405307	4.405	Plainfield Ave NE	Woodworth St NE
409105	2.929	Lake Michigan Dr NW	Lakleigh Ave NW
3030181	14.109	Division Ave N	Library St NE
3030181	14.059	Division Ave N	Monroe Center St
409005	7.287	Fulton St E	Crahen Ave NE
409005	11.299	Fulton St E	Ada Dr SE
3415605	4.746	Chicago Dr SW	Havana Ave SW
409008	10.494	28th St SW	Jenkins Ave SW
407503	2.075	Northland Dr NE	Plainfield Ave Cutoff
410309	0.112	54th St SW	S US-131 Ramps

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
409003	0.191	Oakes St SW	BUS 131
3412182	0.075	East Beltline Ave NE	Calvary Church Access
407305	3.36	36 St SE	I-96 Ramps
524603	16.813	Northland Dr	Maple St
524603	16.54	Northland Dr	Locust St
524603	15.818	Northland Dr	Ferris Dr
859506	5.736	Sherman Blvd	S US-31 Off Ramp
3611477	0.281	Shoreline Dr	W Western Ave
712309	3.607	W Main St	Market Ave
410509	0.674	Pearl St NW	Division Ave N
743007	2.12	Main Ave	Chicago Dr
407204	12.18	E Beltline Ave NE	Michigan St
3415605	5.5	Chicago Dr SW	Clyde Park Ave SW

Table 83. Grand Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
740406	0	US 31	32nd St
503004	3.523	S Bridge St	W State St
504502	12.446	S State Rd	W Tuttle Rd
445005	11.012	N US 131 ramp	17 Mile Rd NE
407607	2.845	Belding Rd NE	Myers Lake Ave NE
423610	6.699	Alpine Ave NW	7 Mile Rd NW
407503	3.147	Northland Dr NE	Rouge River Rd NE
405307	6.331	Plainfield Ave NE	Coit Ave NE
405602	2.714	West River Dr NE	US 31 Ramp
405307	4.868	Plainfield Ave NE	Jupiter Ave NE
423610	2.661	Alpine Ave NW	3 Mile Rd NW
409008	0	Wilson Ave NW	Remembrance Rd NW
407204	14.229	E Beltine Ave NE	Kpp St SE
3415604	1.443	Leonard St NW	Wilson Ave NW
405310	0.408	Leonard St	Front Ave NW
409105	0.428	Lake Michigan Dr	Wilson Ave SW
409105	3.43	Lake Michigan Dr NW	Covell Ave NW
405405	0.137	Mt Vernon Ave NW	Fulton Ave
409005	1.846	Fulton St	Division Ave
456703	6.155	Oaks St SW	Market Ave SW
408807	0.191	Franklin St SW	Sheridan Ave SW
407204	9.961	E Beltine Ave SE	Lake Dr SE
434810	11.561	Burlingame Ave	Chicago Dr SW
3410250	1.144	S US 131 ramp	Burton St SW
407204	9.209	E Beltine Ave SE	Burton St
409008	10.276	28th St SW	Michael Ave
409008	12.231	28th St SE	Madison Ave SE
409008	15.527	28th St SE	Radcliff Ave SE
409008	13.695	28th St SE	Kalamazoo Ave SE
3410286	5.313	44th St SE	Broadmoor Ave SE
3410879	0	Byron Center Ave SW	W M 6 ramp
525201	0.1	Maple St	N Michigan Ave
1204902	4.763	N Laffayette St	Charles St
1202910	1.657	W Washington St	S Greenville W Dr
859906	1.096	M 120	Lake Ave
859809	4.765	S Getty St	Moses J Jones Pkwy
858204	1.438	Moses J Jones Pkwy	Marquette Ave
868705	2.501	Sanford St	W Apple Ave
857803	2.748	Apple Ave	Quarterline Rd
857803	1.99	E Apple Ave	Creston St
859613	5.48	Seaway Dr	W Southern Ave
859613	4.665	Seaway Dr	W Hackley Ave
3611477	0.839	Shoreline Dr	3rd St/ Terrace Point Rd
754007	3.005	Cleveland St	148th Ave
740406	21.496	Beacon Blvd	Grant Ave
3701952	11.015	Chicago Dr SW	12th Ave
3701952	7.328	Chicago Dr SW	36th Ave
740406	5.203	US 31	Quincy St
740406	3.133	US 31	James St
740803	3.294	I 196 BL	112th Ave
740406	1.582	US 31	E 8th St

Table 84. Bay Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
767610	14.174	Huron	Lebourdais
766409	1.878	Euclid	Lynmar
766409	1.294	Euclid	Hidden Rd
766409	1.019	Euclid	Kawkawlin
767610	7.151	Huron	Valley
766409	0.221	Euclid	Schumann
768604	1.507	Thomas	Westlawn
3090057	2.107	Center	Heavenridge
3090057	3.368	Center	Rosemary
3090057	3.113	Center	Hampstead
766609	8.594	Tuscola	Avalon
767610	3.141	Euclid	Clover
765710	3.234	Westside Saginaw	Ziegler
768604	2.94	Mckinley	Water
3090057	3.471	Center	Underwood
1494503	12.105	Vienna	Berkshire
1494503	11.047	Vienna	Water
1494503	10.963	Vienna	Hamilton
1494503	8.612	Vienna	Nichols
1497008	13.551	Dort	Main
1497008	9.46	Dort	Maryland
1501502	11.357	State	Mill
1497008	8.559	Dort	Nebraska
1497008	8.042	Dort	Windemere
1498006	5.788	Court	Cedar

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1494107	10.652	Corunna	Barbyn
1494107	10.207	Corunna	Hughes
1494107	8.504	Corunna	Diamond
1497008	5.076	Dort	Red Arrow
1497008	3.048	Dort	Fisher
1501502	9.079	State	Golfview
1494001	0.365	Sheridan	Willow
243206	1.913	Mission	Mission
754110	14.24	Lapeer	Saginaw
754110	12.392	Main	3rd
3560069	3.71	Meridian	Star
889906	14.658	Meridian	Ash
885901	8.68	Eastman	Pleasant Ridge
3560073	0.294	Buttles	Fitzhugh
885110	16.776	Isabella	Albee
885110	15.046	Isabella	Welch
3730053	5.141	Holland	Morley
3730053	2.51	Holland	4th
3730210	7.378	Graham	Lake Circle
3730053	2.748	Holland	16th
1013004	13.838	Huron	Vulcan
1015507	5.211	Lakeshore	Kilkare
1015507	4.123	Lakeshore	Maple
1015507	0.044	Lakeshore	Eden Beach
1015507	2.951	Lakeshore Rd	Sunset Blvd

Table 85. Bay Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
767610	10.092	Huron	Jose
767610	7.437	S Huron Rd	2 Mile Rd
766409	0.724	Euclid	Wheeler
767610	4.221	Euclid	Jane
768706	1.038	Jenny	Dean
768706	0.49	Jenny	Mountain
3090057	0.506	Center	Grant
768604	2.366	Thomas	Catherine
768604	1.82	Thomas	Alp
3090057	1.549	Center	Green
766609	9.5	Trumbull	6th
767404	0.732	Garfield	19th
767401	0.846	Salzburg	Raymond
767310	0.054	Lafayette	Stanton
767110	3.478	Broadway	31st
1494503	10.856	Vienna	Liberty
1497008	15.834	Dort	Lewis
1498006	6.122	W Court St	Oak
1498006	6.06	Court	Stockon
1494107	10.748	Corunna	Downey
1494107	8.838	Corunna	Pound
1501502	12.622	State	Potter
497604	12.061	Washington	Franklin
494801	7.518	State	Hoffman
246704	4.463	Mission	Bennett

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
246401	15.757	High	Fancher
754110	12.345	Main	2nd
754110	11.892	Main	Liberty
754110	10.19	Lapeer	Thurill
885605	0.301	Indian	Gordon
3560073	0.469	Buttles	McDonald
3560054	0.452	Lyon	Carpenter
885110	15.935	Isabella	Vance
885605	0.87	Indian	Haley
472110	10.782	Washington	Towerline
472110	9.18	Washington	Findley
459610	2.488	Davenport	Passolt
459610	0.93	Davenport	Mershon
459605	0.701	State	Oakley
459605	3.315	State	Sullivan
472110	6.262	Washington	Meredith
3730000	1.196	Remington	Alger
3730053	2.651	Holland	15th
466004	19.905	Gratiot	Stephens
460805	0.468	Stephens	Webster
461709	1.362	Sheridan	Garey
472110	4.422	S Washington Ave	Wisner St
1015507	6.988	Main	Lester
1015507	2.112	Lakeshore	Galbraith Line
267604	16.67	State	Millwood

Table 86. Bay Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
767610	5.361	Euclid	Kiesel Rd
3090057	1.81	Center Ave	Livingston St
767401	0.617	Salzburg Ave	Wenona St
765710	4.992	Westside Saginaw Rd	Salzburg Rd
765710	2.624	Westside Saginaw	3 Mile Rd
1497008	13.432	N Dort Hwy	E Coldwater Rd
1497008	11.784	N Dort Hwy	E Webster Rd
1501502	10.629	S State Rd	Cypress Dr
1494107	8.154	Corunna Rd	T A Mansour Blvd
1497008	6.198	S Dort Hwy	Eldon Baker Dr
3252007	1.464	Silver Lake Rd	US-23 Ramp
246401	15.096	W High St	Watson Rd
754110	14.405	Lapeer Rd	Daley Rd
477106	2.148	Midland Rd	Hospital Rd
459605	4.528	State St	Lawndale Rd
3730053	3.054	E Holland Rd	Cumberland St
1497102	20.86	N Saginaw Rd	N Dort Hwy
1512407	7.545	Pierson Rd	N Dort Hwy
885110	18.355	Jerome St	Indian St
1497008	10.416	N Dort Hwy	N Franklin Ave
484408	0	Midland Rd	State St

Table 87. Bay Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
767610	12.656	S Huron Rd	E Parish Rd
766409	0.623	Euclid Rd	Old Kawkawlin
767610	4.362	S Euclid Ave	W Midland St
768706	1.141	E Thomas St	S Henry St
3090057	0.277	Center Ave	Madison Ave
767610	4.043	Euclid Ave	W Thomas St
768604	2.99	McKinley St	Saginaw St
767404	0.468	Garfield Ave	Lafayette Ave
1497102	22.93	Saginaw Rd	W Vienna Rd
1505403	9.588	Mill St	W Vienna Rd
1497008	15.319	Dort Hwy	Mt Morris Rd
1497601	0.114	Richfield Rd	Dort Hwy
1494902	0.54	Beach St	W Court St
1497102	11.104	S Saginaw St	5th St
1497008	7.333	Dort Hwy	Lapeer Rd
1502310	2.566	Grand Traverse	W 5th St
1494902	0.165	Beach St	9th St
1494107	8.906	Corunna Rd	Graham St
1494107	7.406	Corunna Rd	Dye Rd
1497208	3.035	E Atherton Rd	Dort Hwy
1497102	6.093	Saginaw Rd	Dort Hwy
497604	11.902	Washington St	Michigan Ave
496303	0.881	Pine Ave	E Superior St
242308	14.242	E Pickard St	N Brown St
246704	3.578	S Mission St	E High St
246401	15.523	W High St	Main St
246704	3.327	S Mission St	E Bellows St
754110	13.251	N Lapeer Rd	Davis Lake Rd
754110	10.962	S Main St	Baldwin Rd
885901	9.404	Eastman Ave	W Sugnet Rd
885605	0.651	Indian Rd	George St
884809	0.868	Patrick Rd	Washington St
3560054	1	E Lyon Rd	Washington St
893702	14.021	Tittabawassee	Midland Rd
460105	3.424	Bay Rd	Fashion Sq. Mall
460105	2.178	Bay Rd	Enterprise Ct
460105	0.835	Bay St	Davenport Ave
477403	5.77	Michigan Ave	Davenport Ave
459610	0.75	Davenport Ave	N Mason St
459605	0.875	State St	Woodbridge St
459605	3.532	State St	N Center Rd
472110	5.866	Washington	E Remington St
461710	1.09	S Warren Rd	E Remington Rd
466004	19.066	Gratiot Rd	N Wheeler St
466004	16.694	Gratiot Rd	Midland Rd
460805	2.052	Rust Ave	Owen Ave
460805	1.991	Rust Ave	Jefferson Ave
472110	4.895	Washington	Webber St
1015507	7.264	Main St	Huron Ave
266710	0	Ellington St	E Dayton Rd

Table 88. Southwest Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
788009	2.333	Lincoln Rd	34th St
787604	1.462	Grand St	Airport Dr
788201	1.177	Marshall St	Bridge Rd
788201	12.737	W Allegan St	Prospect St
785302	1.587	E Bridge St	Locust St
788009	19.556	M-40	Cabil Dr
983402	0.885	Gun Lake Rd	Cook Rd
982805	1.729	S Hanover St	Shriner St
1368002	13.553	Main St	Verlynda Dr
1363303	2.356	Main St	McCord St
1364005	0.65	S Fair Ave	Nate Wells Sr
3111292	14.102	Niles Ave	Winchester Ave
3111292	13.891	Niles Ave	Mohawk Ln
1360705	3.114	Lakeshore Dr	Hawthorne Ave
1360705	1.282	Red Arrow Hwy	Paulmar Ave
3111292	1.574	M-139	Woodland Dr
1365209	8.513	Ferry St	Hillview Dr
1364810	1.563	N 5th St	Burns St
1361302	4.354	S 11th St	Michigan St
1361302	3.931	S 11th St	Beaver St
1359407	1.972	US-12	Wilton Ave
3111292	8.473	M-139	Anna Ln
923007	17.121	W Chicago St	Jay St
923007	15.293	Chicago St	Airview Dr
3130086	4.913	Capital Ave NE	Swift Rd
1298109	0.127	M-89	Gull Point
1298109	1.675	Michigan Ave W	Stillson Blvd
1298109	2.618	Michigan Ave W	Feld Ave
1298109	3.61	W Michigan Ave	Geiger Ave
1298109	4.349	Michigan Ave W	Hillcrest Ct
1311108	0.063	S Bedford Rd	Lafayette Ave
3130086	1.428	Capital Ave NE	Sanderson St
3130086	1.097	Capital Ave NE	Byron St
1296303	2.116	W Dickman Rd	22nd St N
3130975	1.36	E Michigan Ave	James St
3130975	4.478	Michigan Ave	Lowell Ave
1297108	4.051	Columbia Ave W	Hulbert Ln
1297108	3.829	Columbia Ave W	Romance St
1296507	0.583	Columbia Ave W	Robertson Ave
3130105	1.241	W Michigan Ave	Elliot Rd
1296305	6.917	N Superior St	W Porter St
3390059	4.323	E D Ave	N 48th St
592909	9.195	Spruce St	Tuthill St
593706	7.811	E Division St	Riverside Dr
594006	9.033	Main St	E Shore Dr
10208	7.056	Westnedge Ave	W Prouty St
3750037	1.349	M-60	Oak Park Rd
1915006	3.457	S US-131	Cowling Rd
578110	1.701	Le Grange St	Elkenburg St
579901	12.736	M-40	Sharon Ave
579901	10.156	M-40	S Lagrave St

Table 89. Southwest Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
788009	1.543	Lincoln	Monroe
787604	0.393	Monroe	Chestnut
788201	9.177	Lincoln	Sherman
983402	0.077	State	Park
982909	0.419	Green	Jefferson
1363303	2.176	Main	Nowlen
1364007	0.702	MLK	Hall
1360705	5.858	Main	Market
1366708	3.598	Michigan	Indiana
3111292	13.222	Niles	Columbia
3111292	1.167	M 139	George
1364810	0.899	5th	Wayne
1362801	0.186	Main	Lincoln
1359807	23.969	Pulaski	Bond
1361302	0.484	11th	Gary
923007	18.047	Chicago	Jefferson
1298703	0.362	Bedford	Spaulding
1298109	3.066	Michigan	Mason
3130086	1.801	Capital	Pitman
1298108	1.797	Dickman	Tony Tiger
3130975	0.291	Michigan	Charlton
1297108	4.173	Columbia	Highland
1297108	3.016	Columbia	24th
1301102	1.743	Michigan	Mulberry
1297402	10.959	28 Mile	C
3131051	13.321	Kalamazoo	Hughes
3130105	0.483	Austin	Mallory
1296305	6.645	Superior	Oak
592909	9.393	Main	Lowe
592909	9.136	Spruce St	Paul
594510	2.279	M 60	Gilbert
7407	1.643	Gull	Asbury
7406	0.348	Ransom	Park
10208	6.33	Westnedge	Ransom
10208	6.256	Westnedge	Willard
7405	1.088	Kalamazoo	Water
1410	0.963	Burgess	Beckwith
22207	10.112	Michigan	Church
6906	3.452	King	Parcom
10208	4.15	Westnedge	Edgemoor
238202	11.949	US 131	Moorepark
228406	0.436	Main	Bennett
3750035	1.415	Michigan	Wood
3750035	0.378	Michigan	Erie
228509	0.969	Main	Michigan
1915006	1.923	US 131	Coon Hollow
578110	2.396	Broadway	Huron
578110	2.11	Phillips	Green
579901	11.978	Kalamazoo	Elm
579901	7.013	Main St	Durkee

Table 90. Southwest Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
3031548	1.368	Washington Ave	Matt Urban Dr
788201	0.168	Marshall St	Jenner Dr
788201	11.449	M-89	Cross Oaks Mall
788201	12.604	West Allegan St	Prince St
788201	11.694	M-89	Oaks Crossing
3111292	13.538	Niles Ave	Napier Ave
3111292	12.024	Niles Rd	Lincoln Ave
1360705	1.523	Red Arrow Hwy	Maiden Ln
1360705	0.318	Red Arrow Hwy	Marquette Woods
3111292	1.628	M-139	Graland Ave
1362801	0.445	West Main St	Front St
1366708	2.795	Scottdale Rd	Fairlplan Dr
923007	18.406	Chicago St	S. Sprague St
3130086	4.477	Capital Ave NE	Pennfield Rd
3130086	3.426	Capital Ave NE	Morgan Rd
1298109	3.215	W Michigan Ave	Stringham Rd
1298703	0.237	Bedford Rd N	Oakley St
3130086	0.416	Capital Ave NE	Fremont St
1296303	1.226	W Dickman Rd	Helmer Rd N
3130975	0.659	E Michigan Ave	Union St S
1297108	3.27	Columbia Ave W	S 20th St
1297402	11.461	N Eaton St	E Watson St
1298703	0.729	Bedford Rd N	Morgan Rd
3130975	2.96	Michigan	Pine Knoll Rd
21502	6.244	W Main St	Piccadilly Rd
21502	7.148	W Main St	N Kendall Ave
22207	11.047	E Michigan Ave	Mills St
22207	10.862	E Michigan Ave	King Hwy
22207	10.258	E Michigan Ave	Kalamazoo Mall
22207	6.632	Stadium Dr	Seneca Ln
10208	3.241	S Westnedge Ave	Denway Dr
228406	0.136	N Main St	Portage Ave
1297109	0	W Columbia Ave	Skyline Dr
1296303	4.201	E Dickman Rd	Riverside Dr
1360705	5.583	Main St	Niles Ave
1360705	3.657	Lakeshore Dr	Hilltop Rd
1298109	4.597	W Michigan Ave	N 20th St

Table 91. Southwest Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
7407	4.396	Gull Rd	G Ave
10806	10.588	N Sprinkle Rd	Gull Rd
7407	2.404	Gull Rd	Nazareth Rd
7407	1.821	Gull Rd	Brook Dr
7407	1.061	Gull Rd	Schaffer St/Bixby Rd
8308	0.659	Paterson St	S Westnedge Rd
8308	0.781	W Paterson St	N Park St
7407	0.388	Gull Rd	Riverview Dr
9308	0.429	N Park St	W North St
10208	6.402	S Westnedge Rd	W North St
21502	6.032	W Main St	N Drake Rd
21502	6.562	W Main St	Turwill Ln
21502	6.995	W Main St	Nichols St
21502	5.534	W Main St	Maple Hill Dr
21502	5.036	W Main St	N 10th St
21405	4.598	N 9th St	W Main St
21502	7.476	W Main St	Fletcher Ave
7405	1.009	W Kalamazoo Ave	N Pitcher St
7405	0.923	W Kalamazoo Ave	N Edwards St
7405	0.836	W Kalamazoo Ave	N Burdick St
7405	0.758	W Kalamazoo Ave	N Rose St
7405	0.628	W Kalamazoo Ave	N Park St
21502	7.945	W Main St	Berkley St
22207	9.924	W Michigan Ave	N Westnedge Ave
5007	1.346	Park St	W South St
10208	5.846	S Westnedge Rd	W South St
6906	0.479	King Hwy	Mills St
18209	2.504	S 35th St	Michigan Ave
5007	1.278	Park St	W Lovell St
10208	5.782	S Westnedge Rd	W Lovell St
17403	1.479	River St	King Hwy
10208	5.462	S Westnedge Rd	W Vine St
5007	0.952	Park St	W Vine St
22207	8.889	I 94 BL	Oliver St
21202	0.394	I 94 BL	Lake St
4401	0.623	W Crosstown Pkwy	Park St
22207	8.233	I 94 BL	Howard St
5007	0.405	Park St	Balch St
4401	0.496	W Crosstown Pkwy	S Westnedge Rd
4709	2.439	Howard St	S Westnedge Rd
22207	7.609	I 94 BL	Rambling Rd
21202	1.601	I 94 BL	Olmstead Rd
10806	6.755	Sprinkle Rd	I 94 BL
22207	6.388	I 94 BL	Drake Rd
17403	0.171	River St	I 94 BL
10208	4.277	S Westnedge Rd	Inkster Ave
10208	3.821	S Westnedge Rd	Whites Rd
10208	2.773	S Westnedge Rd	W Kilgore Rd
15007	5.039	N US 131	W U Ave
3390106	1.506	S US 131	W U Ave
15007	3.028	S Grand St (US 131)	Eliza St
21502	8.864	W Main St	Michikal St

Table 92. University Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1877204	0.4	Saginaw St	Eunice Dr
567503	13.812	E Grand Ledge Hwy	Legend Dr
566006	13.429	Lansing	Old Lansing
567504	17.59	Clinton	Parkland
568804	7.506	S Michigan Rd	Grandview Rd
1499310	0.128	8th	Mitchell
3300901	0.311	BRd	Budlong
3300901	4.77	Hudson	Lake
3330526	3.044	East	Samford
3330066	0.171	Grand River	Bardaville
3330526	2.358	Cedar	Gier
3330066	2.912	North	James
3330526	1.485	Larch	Maple
3330065	0.88	Oakland	Clayton
3331424	0.432	Michigan	Center
3330526	0.419	Larch	Park
900409	11.399	Clinton	Woodmere
900409	14.452	Clinton	Hendee
901504	1.975	Cooper	Connable
901504	1.899	Cooper	3rd
898201	0.249	West	Commonwealth
897108	0.425	Eaton Rapids	Michigan
3381120	0.533	Francis	Armory
898201	1.169	West	Webb
3381123	0.775	Michigan	Seymour

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
899407	12.106	Spring Arbor	Fairway
899407	9.156	Main	Melody
899310	2.266	Brooklyn	Miles
947405	15.472	Chicago	Cairns
947405	17.56	Monroe	Saint Andrews
948504	4.218	Adrian	Sutton
946901	0.255	Maumee	Stratford Place
945708	17.961	Beecher	Bradish
932910	12.195	Grand River	Swann
932308	11.363	M 36	Island Shore
932308	8.342	M 36	Scholar
932910	14.402	Grand River	Tahoe
4300001	27.749	Telegraph	Gladys
1227004	16.666	Monroe	Washington
1223803	18.721	Custer	Oak
1227004	12.491	Dixie	Raven
4300001	2.748	Telegraph	Dean
3780087	2.937	Corunna	Park
4604878	0.804	Jackson	Burwood
1427706	3.003	Washtenaw	Chalmers
1427706	5.978	Washtenaw	Cornell
1428902	1.929	Cross	Summit
1428108	1.066	Ecorse	Kennedy
4603870	0.404	Huron	Madison
1427706	1.788	Washtenaw	Service

Table 93. University Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd	Major Rd PR	Major Rd MP	Major Rd	Minor Rd
209503	16.342	Whitmore	Railroad	3381123	0.062	Michigan	Park
208909	14.655	State	Kibbee	897207	14.661	Michigan	Higby
208909	12.925	Blue water	Dewitt	946901	1.198	Maumee	Scott
566510	0.756	Potterville	Main	948701	0.188	Broad	Toledo
567504	19.155	Cochran	Harris	948206	11.461	Main	Metcalf
567304	12.179	Lawerence	Bostwick	946402	21.054	US 223	Winter
565703	2.908	Cochran	Shaw	933209	15.296	Highland	Fenton
3330526	2.826	East	Community	932910	10.07	Grand River	Tooley
3330066	1.518	Grand River	Tecumseh	4104400	0.193	Michigan	Crane
1814703	0.087	Saginaw Cutoff	Haslett	932910	12.982	Grand River	Elm
341208	5.301	Saginaw	Touraine	932910	16.014	Grand River	Westbury
3330065	1.66	Oakland	Seymour	4300001	18.768	Telegraph	Heiss
3330065	1.505	Oakland	Chestnut	1223803	18.613	Custer	Wolverine
3330065	0.63	Oakland	Cawood	1227004	14.297	Monroe	7th
335601	2.74	Grand River	Clippert	1223207	5.157	Memorial	Yankee
341208	1.2	Saginaw	Stanley	4300001	0.013	Telegraph	State Line
335601	6.959	Grand River	Hillcrest	3780087	1.785	Corunna	Aiken
352303	4.276	MLK Jr	Rundle	552701	8.422	Shiawasse	Williams
359606	9.008	Cedar	Denver	551706	14.467	M 52	Chipman
352303	1.851	MLK	Selfridge	553803	0.621	M 71	Reed
359606	0	Cedar	US 127	1427804	4.461	Michigan	Wiard
361110	0.638	Ash	Park	1427706	5.681	Washtenaw	Courtland
335601	6.728	Grand River	Montrose	1427706	6.686	Washtenaw	College
901504	0.375	Cooper	Quarry	1428108	0.944	Ecorse	Glenwood
901504	0.063	Cooper	Pearl	1427301	11.392	Michigan	Davenport

Table 94. University Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
208909	14.132	E State St	N Clinton Ave
208306	9.079	Grand River Ave	Francis Rd
1877204	0.677	Saginaw Hwy	Old M-78
208306	12.185	W Grand River Ave	Airport Rd
3330066	0.699	N Grand River Ave	Capitol City Blvd
567503	15.652	W Saginaw Hwy	Jenne St
566006	10.972	Lansing Rd	Crowner Dr
568804	6.183	S Main St	State St
3330065	1.879	E Oakland Ave	Grand Ave
335601	3.006	W Grand River Ave	Coolidge Rd
341208	0.781	Saginaw St	Rosemary Ave
335601	4.357	Grand River Ave	Division St
335809	0.491	S Grand Ave	E Allegan St
335601	5.756	E Grand River Ave	Northwind Dr
898202	0.074	NW Ave	I-94 Off Ramp
898201	0.082	NW Ave	I-94 Off Ramp
946402	18.939	US-223	Industrial Dr
933209	0.269	Highland Rd	N Burkhart Rd
932910	12.121	Grand River Ave	Byron Rd
932308	12.241	M-36	Pettys Rd
932910	11.572	Grand River	Howell H.S. Dr
4300001	28.538	Telegraph Rd	S Huron River Dr
4300001	19.794	Telegraph Rd	N Monroe St
1227004	18.382	N Monroe St	Nadeau Rd
1227004	17.116	N Monroe St	Mall Rd
4300001	16.38	Telegraph Rd	Holiday Blvd
4300001	17.51	Telegraph Rd	Mall Rd
1202910	2.1	Washington St	Hillcrest St
554210	4.028	Washington St	Corunna Rd
4603186	2.225	N Main St	Depot St
4604878	2.856	E Huron St	Fletcher St
4604878	0.466	Jackson Ave	WB I-94 Off Ramp
1427706	1.361	Washtenaw	Brockman Blvd
1428902	1.875	Cross St	Summit St
1427301	12.029	Michigan Ave	Hopper Dr
3330066	0.073	Grand River	Waverly Rd
897207	13.742	Michigan Ave	Laurence Ave
1428108	0.522	Ecorse Rd	Maus Ave

Table 95. University Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
209503	1.003	Old US 27	W State Rd
566510	8.696	S Clinton St	Edwards St
3231318	6.477	N Creyts Rd	W Saginaw Hwy
565703	3.417	S Cochran Rd	WE Lovett St
565703	3.303	S Cochran Rd	W Seminary St
568804	6.427	S Main St	Knight St
3300901	0.178	N Broad St	McCollum St
3330526	2.3	Old US 27	E Thomas St
335905	5.707	Pennsylvania Ave	E Oakland Ave
352303	6.845	MLK Jr Blvd	W Oakland Ave
341208	4.756	E Saginaw St	N Homer St
335807	1.059	N Capitol Ave	W Saginaw St
352303	6.71	MLK Jr Blvd	W Saginaw St
335601	3.772	Grand River Ave	Harrison Ave
3330526	0.843	N Larch St	E Shiawassee St
359606	11.157	N Cedar St	E Michigan Ave
335807	0.49	S Capitol St	W Allegan St
335601	5.25	Grand River Ave	Hagadorn Rd
352303	5.956	S MLK Jr Blvd	W Kalamazoo St
359606	8.138	S Cedar St	E Cavaugh Rd
343704	0	Pleasant Grove Rd	S MLK Jr Blvd
352303	0.802	Eaton Rapids Rd	Bishop Rd
362604	1.092	S Cedar St	W Columbia St
898805	3.347	W Parll Rd	Cooper St
898201	0.737	N West Ave	W Argyle St
3381123	1.906	E Michigan Ave	E Dettman Rd
898201	1.551	N West Ave	Wildwood Ave
3381123	0.389	E Michigan Ave	S East Ave
900407	0.632	N Blackstone Rd	Louis Glick Hwy
900903	0.626	Washington Ave	S Mechanic Rd
946901	1.443	W Maumee St	McKenzie St N
948701	0.085	N Broad St	E Maumee St
948502	0	S Winter St	W Church St
946402	21.278	US 223	Division St
4104402	0	Oak Grove Rd	W Highland Rd
932910	13.768	Grand River Ave	Golf Club Rd
1223803	18.814	S Custer Rd	S Telegraph Rd
1227004	14.716	S Monroe St	E 1st St
4300001	0.428	Telegraph Rd	Smith Rd
551310	9.645	N Shiawassee St	W Main St
551310	8.652	M 21/ W Main St	N Chestnut St
4603186	2.187	N Main St	Summit St
4604878	0.635	Jackson Ave	N Maple Rd
1427706	0.484	Washtenaw Ave	S University Ave
1427706	5.327	Washtenaw Ave	N Hewitt Rd
1428902	2.142	W Cross St	Ballard St
1427804	2.174	W Michigan Ave	N Park St
1427804	1.669	W Michigan Ave	S Adams St
1433104	5.554	Moon Rd	E Michigan Ave
1427301	10.189	W Michigan Ave	Austin Rd

Table 96. Metro Region Three-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
817204	1.901	Main	Ridge
817204	1.747	S Main St	Churchill St
832010	9.961	Gratiot	Clawson
807106	17.128	23 mile	Cricklewood
832010	4.559	Gratiot	Kuchenmeister
832010	2.898	Gratiot Ave	Mary St
820202	0.793	Hall	Sterritt
813706	2.853	Van Dyke	Ford Country
804806	4.96	Gratiot	Georgia
799108	4.254	Van Dyke Ave	Racine Rd
803208	6.571	11 Mile	Clancy
803009	1.84	Groesbeck	Stephens
807801	3.724	Hall	Hecker
802804	5.279	8 Mile	Wellington
674007	1.815	Perry	Kennett
672206	0.732	Cesar E Chavez	Adelaide
616808	2.535	Woodward	Trowbridge
4502633	19.668	Parker	Delina
1577904	0.032	Van Dyke	Kirby
1604102	7.652	Plymouth	Market
1577103	5.367	Michigan	22nd
1577509	12.709	Jefferson	Bates
1924107	4.27	Ford	Argyle
1589606	0.169	E M 153	Grove
1924107	0.615	Ford	Belmont

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
1595510	9.414	Ford	Cadillac
1595510	5.687	Ford	Sandhurst
1577103	0.562	Michigan	Middlesex
1577103	0.212	Michigan	Charles
1585010	1.699	Fort	Wheelock
4700038	14.358	Telegraph	Harvard
1670203	10.685	Van Born.	Anne
1592106	13.484	Fort	Morris
1592408	0.44	N M 39	Howard
4700038	10.301	Telegraph	Schomberg
1592105	11.932	Fort	Buckingham
4705565	9.412	Michigan	Josephine
1591001	1.526	Woodward	Highland
1577408	6.576	Grand River	Northlawn
1604102	0.298	Ann Arbor	Amberley
4702009	1.852	Davison	Lawton
1595510	1.692	Ford	Trinity
4718578	1.409	Dix Toledo	Stratford Place
1600206	2.666	Michigan	Research
1592106	12.906	Fort	Arlington
1592105	3.276	Fort	Elmhurst
1592105	3.121	Fort	Pinehurst
4700038	3.267	Telegraph	Casa San Marino
4705565	13.47	Michigan	Heatherwood
4705565	4.779	Michigan	Executive

Table 97. Metro Region Four-Leg Stop Controlled Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
807106	18.712	Green	Atwood
807106	18.427	Green	Maria
4208203	12.398	Gratiot	Patterson
4208203	12.038	Gratiot	Scott
4208203	11.785	Gratiot	Gallup
4208203	11.399	Gratiot	New
799108	0.731	Van Dyke Ave	Packard Ave
799108	0.472	Van Dyke	Orchard
799108	0.357	Van Dyke	Prospect
616604	10.686	Washington	Center
616604	9.697	Lapeer	Oakdell
616604	7.498	Park	Shadbolt
627809	0.993	Ortonville	Depot
4413538	11.471	Rochester	Yorktowne
674803	0.318	Cass	Florence
625105	9.859	Auburn	Harrison
625105	9.731	Auburn	Emmons
641407	0.565	Woodward	Clinton
625105	4.25	Auburn	Avalon
648906	18.754	Huron	Lynn
4104142	16.961	Grand River	Orchard
964704	6.391	Lakeshore	Metcalf
963509	20.412	Military	Wall
967105	5.64	Busha	Wills
966604	0.348	Broadway	Mary
4502782	0.514	Main	Pearl
4502633	19.242	Parker	Robertson
4502633	18.77	River	Alger
1588008	0.664	Gunston	Nashville
1588008	0.599	Gunston	College
1588008	0.481	Gunston	Christy
1577408	1.295	Grand River	Fielding
1591001	2.328	Woodward Ave	Boston Blvd
4705742	3.716	Gratiot	Maxwell
4705742	3.014	Gratiot	Helen
1604102	14.538	Plymouth	Virgil
4705742	2.78	Gratiot	Bellevue
1604102	13.355	Plymouth	Royal Grand
1604102	12.985	Plymouth	Rockland
1604102	12.397	Plymouth	Seminole
1604102	6.088	Ann Arbor	Tavistock
1604102	3.171	Ann Arbor	Canton Center
1577103	4.427	Michigan	Goldner
1577103	3.675	Michigan	Gilbert
1595510	13.336	Ford	Highview
1585010	4.728	Fort	10TH
1595510	9.7	Ford	Craig
1595510	7.981	Ford	Harvey
1585010	2.841	Fort	Morrell
4705565	8.466	Michigan	Sophia

Table 98. Metro Region Three-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
813706	20.543	Earle Hwy	Van Dyke Rd
1917409	0.436	Van Dyke Rd	Van Dyke Ave
807106	16.444	23 Mile Rd	DW Seaton Dr
832010	5.11	Gratiot Ave	Cotton Rd
807106	4.305	23 Mile Rd	M-53 Off Ramp
832010	4.312	Gratiot Ave	22 Mile Rd
807801	9.991	Hall Rd	Card Rd
820202	5.342	Hall Rd	Rivergate Dr
807801	2.986	Hall Rd	Cass Ave
803009	9.053	Groesbeck	Carlier St
804806	5.176	Gratiot Ave	Common Rd
820202	7.463	Hall Rd	Elizabeth St
832010	1.471	Gratiot Ave	Frederick Pankow
802803	6.88	8 Mile Rd	Shakespeare St
4413538	13.128	Main Street	Romeo
616604	6.781	Lapeer Rd	Odanah Ave
627809	2.842	Ortonville Rd	Hubbard Rd
689103	2.485	Dixie Hwy	S Main St
4413538	13.358	Main St	Woodward Ave
689103	6.205	Dixie Hwy	Hatchery Rd
672206	0.822	Cesar E Chavez	Summit St
710110	1.561	Telegraph	Mall Dr
1817406	7.944	8 Mile Rd	Birwood St
640807	7.963	8 Mile Rd	Mendota Ave
1817406	2.696	8 Mile Rd	Berg Rd
616604	1.369	Lapeer	Isiah Thomas Dr
4413538	9.545	Rochester Rd	Meijer Dr
4502633	4.356	Dixie Hwy	Palms Rd
964608	0.817	M-25	K-Mart Dr
1588008	2.659	Hoover St	Bringard Dr
1598507	0.587	Woodward	W State Fair
4705742	6.765	Gratiot Ave	Charles Whitier
1591001	0.354	Woodward	Glendale St
1577904	0.902	Van Dyke Ave	Miller Ave
1577408	10.053	Grand River	1st
689103	0.632	Dixie Hwy	Englewood
1577408	7.727	Grand River	Underwood St
1591001	5.663	Woodward	Charlotte
1591001	1.613	Woodward	Cortland
1577408	11.372	Grand River	Ash St
4705742	0.603	Gratiot Ave	Antietam Ave
1577103	5.61	Michigan Ave	20th St
1577103	2.046	Michigan Ave	Weir St
1577904	2.127	Van Dyke	Palmetto
1600206	14.734	Michigan Ave	N US-24 Ramp
1592105	14.755	S Fort St	Downing St
1592106	14.589	S Fort St	Downing St
1600207	14.178	Ecorse Rd	US-24 Ramp
1600206	14.681	Michigan Ave	S US-24 Ramp
1585010	1.091	W Fort St	Lawndale St
4104142	16.187	Grand River	Shiawasse
821205	5.363	Jefferson Ave	23 Mile Rd
811503	0.201	Utica Rd	Gratiot Ave
634003	0	Orchard Lake	Grand River
799108	5.044	Van Dyke Ave	Old 13 Mile Rd

Table 99. Metro Region Four-Leg Signalized Intersections

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
807106	15.81	23 Mile Rd	Sass Rd
807801	7.056	Hall Rd	Garfield Rd
803009	13.106	Groesbeck Hwy	Elizabeth Rd
800808	1.071	Market St	Gratiot Ave
833209	0.259	Broadway Rd	Iroquois St
803009	7.124	Groesbeck Hwy	14 Mile Rd
799108	5.228	Van Dyke Ave	Chicago Rd
799108	0.78	Van Dyke Ave	Hupp Ave
804806	0.587	Gratiot Ave	Toepfer Dr
616604	7.427	S Park Blvd	W Flint St
4413538	13.818	Rochester Rd	Tienken Rd
648906	15.554	Highland Rd	Crescent Lake
648906	20.896	W Huron St	Wayne St
672705	0.534	Woodward Ave	E Pike St
641405	0.099	Orchard Lake	Woodward Ave
616906	1.317	Woodward Ave	South Blvd E
625903	2.142	E Square Lake	Woodward Ave
710010	0.123	Northwestern	14 Mile Rd
710009	4.096	Telegraph Rd	12 Mile Rd
614101	9.598	Woodward Ave	11 Mile Rd
4104142	17.215	Grand River	Power Rd
963509	20.487	Military St	Pine St
963108	1.349	16th St	Griswold St
1586002	4.899	Outer Dr	Van Dyke St
1588008	0.913	Gunston Ave	McNichols Rd

Major Rd PR	Major Rd MP	Major Rd	Minor Rd
4705742	5.579	Gratiot Ave	Conner St
1591001	2.186	Woodward Ave	Trowbridge St
4705258	13.581	Schoolcraft Rd	Grand River
1604102	12.802	Plymouth Rd	Hemingway St
1674403	17.414	Middlebelt Rd	Plymouth Rd
1577408	8.773	Grand River Ave	Whitney Rd
1604102	4.676	Ann Arbor Rd	Lilley Rd
1577504	0	Rosa Parks Blvd	Grand River
4705742	0.85	Gratiot Ave	Russell St
1591001	6.08	Woodward Ave	Montcalm St
1591001	6.23	Woodward Ave	Adams St
1577103	2.523	Michigan Ave	Lonyo Ave
1595510	12.523	Ford Rd	John Daly St
1595510	6.553	Ford Rd	N Hix Rd
1576806	9.047	Telegraph Rd	Wilson Ave
1585010	2.408	Fort St	Dragoon St
1585010	0.74	Fort St	Woodmere St
4719470	6.3	S Wayne Rd	Michigan Ave
1589705	0.195	Schaefer Hwy	Fort St
1600206	5.501	Michigan Ave	Haggerty Rd
1578505	6.465	Northline Rd	Fort St
1578505	1.955	Northline Rd	Telegraph Rd
1674210	4.981	West Rd	Telegraph Rd
4702009	0.763	Davison W	Oakman Blvd
4707964	0.663	McNichols Rd	Grand River