Project No. 17-58 Copy No.__

SAFETY PREDICTION MODELS FOR SIX-LANE AND ONE-WAY URBAN AND SUBURBAN ARTERIALS

FINAL REPORT

Prepared for
National Cooperative Highway Research Program
Transportation Research Board
of
The National Academies

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PRELIMINARY DRAFT
FINAL REPORT

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June 22, 2016

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- Dr. Srinivas Geedipally.
- Mr. Mike Pratt.
- Dr. Eun Sug Park.
- Mr. S. Hadi Khazraee.

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ABSTRACT

Safety prediction procedures have been developed for estimating the safety performance of rural two-lane highways, rural multilane highways, urban and suburban arterials with five or fewer lanes, and freeway segments and interchanges. However, the *Highway Safety Manual* does not include a safety prediction methodology for urban and suburban arterials with six or more lanes and one-way segments. This research was undertaken to address this need by developing methodologies suitable for inclusion in the *Highway Safety Manual*. To accomplish this objective, data collected in California, Illinois, Michigan, Oregon, and Texas were assembled that included a wide range of geometric design features, traffic control features, traffic characteristics, and crash records for two-way urban and suburban arterials with six or more lanes, one-way urban and suburban arterials, and intersections located on these facilities. The data were used to calibrate predictive models, each of which included a safety performance function (SPF) and several crash modification factors (CMFs). The SPFs were estimated using the negative binomial modeling structure. In total, predictive models were estimated for seven types of segments and 12 types of intersections that were separated by traffic movements (i.e., two-way or one-way operation), and 18 CMFs were proposed from this work. Separate severity distribution functions were also calibrated using these data. These functions are used with the predictive models to estimate the expected crash frequency for each of five severity levels (i.e., fatal, incapacitating injury, non-incapacitating injury, possible injury, and property-damage-only crash).

EXECUTIVE SUMMARY

INTRODUCTION

Chapter 12 of the *Highway Safety Manual* (HSM) provides a predictive method for two- and four-lane urban and suburban arterial facilities with both undivided and divided cross-sections. The chapter does not cover arterials with six or more lanes or one-way streets. Research is therefore needed to develop an enhanced prediction methodology and safety analysis tools for six-or-more-lane and one-way urban and suburban arterial segments as well as intersections located on these facilities.

Thus, the objectives of this research were to develop:

- An overall framework for the enhancement of safety prediction methodologies for urban and suburban highways for both roadway segments and intersections of arterials with six or more lanes and one-way streets to support decision making for planning, network analysis, corridor analysis, and individual site evaluation.
- Safety analytical models and procedures within that framework.
- Models and procedures to estimate crash frequency and severity for these types of facilities.
- A proposed methodology that is consistent or compatible with the methods and procedures in the current version of HSM Chapter 12.
- A revised Chapter 12 for the future edition of the HSM.
- Training materials and a spreadsheet for the application of the new models.

WORK PLAN

Crash and roadway data from California and Illinois were obtained from the Highway Safety Information System (HSIS), while data from Texas, Michigan, and Oregon were obtained directly from the state highway agencies. Data for the five states were combined for model calibration and the development of crash modification factors (CMFs). These data were enriched through the inclusion of additional road inventory data extracted from Google Earth and Google Street View. The enhanced database was then combined with the crash data to form the highway safety database needed for model and CMF development and calibration.

Since pedestrian exposure data were not available in the electronic databases that were assembled for this project, on-site data collection activities were done to supplement the data already collected. A sample of 40 intersections in California and 24 intersections in San Antonio, Texas, were therefore selected for data collection for the pedestrian evaluation. The data for pedestrians were used to assess and recalibrate the existing predictive method for estimating pedestrian safety in HSM Chapter 12.

Safety performance functions (SPFs) and CMFs were estimated for the following four types of two-way and three types of one-way roadway segments on urban and suburban arterials:

- Six-lane two-way undivided arterials (6U).
- Six-lane two-way divided arterials (i.e., including a raised or depressed median) (6D).
- Seven-lane two-way arterials including a center two-way left-turn lane (TWLTL) (7T).
- Eight-lane two-way divided arterials (i.e., including a raised or depressed median) (8D).
- Two-lane one-way arterials (2O).
- Three-lane one-way arterials (3O).
- Four-lane one-way arterials (4O).

SPFs and CMFs were estimated for the following intersection types for both two-way street intersections and one-way street intersections on urban and suburban arterials:

- Three-leg intersections with stop control on the minor-road approaches (3ST).
- Three-leg signalized intersections (3SG).
- Four-leg intersections with stop control on the minor-road approaches (4ST).
- Four-leg signalized intersections (4SG).

Furthermore, the intersections were separated by the type of operational characteristics of each leg: two-way (x2) or one-way (x1). Hence, the models and CMFs were estimated for 12 different intersection types: 2×2, 1×2, and 1×1 for all four categories of intersections.

FINDINGS

This report documents a safety prediction method for six-or-more-lane and one-way urban and suburban arterials, as well as intersections located on these facilities, that is suitable for incorporation in the HSM. The method includes CMFs that describe the observed relationship between crash frequency and on-street parking, roadside fixed objects, median width, lighting, automated speed enforcement, lane width, outside shoulder width, rail-highway crossing, median barriers, major industrial driveways, major commercial driveways, minor driveways, and right shoulder width for six-or-more-lane and one-way segments. For intersections, the CMFs influencing crash counts include those related to intersection left-turn lanes, intersection left-turn signal phasing, intersection right-turn lanes, right turn on red (RTOR), lighting, red-light cameras, number of lanes, intersection right-turn channelization, and U-turn prohibition. Finally, the CMFs influencing vehicle/pedestrian crashes include those associated with bus stops, schools, and alcohol sales establishments.

This report also documents a safety prediction method for estimating the proportion of crashes by severity levels. The severity distribution functions (SDFs) are available for urban and suburban six-or-more-lane arterials; one-way streets; 2×2 signalized intersections with six or more lanes; 1×2 and 1×1 signalized intersections; and 2×2 (with six or more lanes), 1×2, and 1×1 stop-controlled intersections. Various factors influence the severity of collisions. They include lane width, right shoulder width, the presence of exclusive left-turn lane on the major road/street, the presence of right-turn channelization on the major road/street, the presence of right-turn channelization on the minor road, and street lighting.

RECOMMENDATIONS

The safety prediction methods developed in this research should be incorporated into the HSM.

Although not very common, a few segments categorized as eight-lane undivided, eight-lane with two-way left-turn lane, 10-lane divided, and one-lane and five-lane one-way arterials do exist. Predictive models could not be estimated for these facilities due to the small sample size. Further research may be needed to include such facilities in safety prediction methodologies.

Frontage roads mostly serve one-way traffic. One-way frontage roads were included in this research for developing models for 1×2/1×1 intersections. However, the safety performance of these intersections may differ from a typical one-way intersection. Additional research is needed to quantify the difference.

Since the speed limits are higher in suburban areas, the geometric variables may have a different effect in suburban areas than in urban areas. Although the SDFs capture the overall safety performance difference, more research is needed to describe the performance of each geometric feature by area type. This need is not just applicable to this research but also to the first edition of HSM Chapter 12.

CHAPTER 1: INTRODUCTION

The HSM (American Association of State Highway and Transportation Officials [AASHTO], 2010) serves as a tool to help practitioners make planning, design, and operations decisions based on safety. The HSM provides the best information and tools in a useful and widely accepted form to facilitate explicit consideration of safety in the decision-making process. It provides tools to conduct quantitative safety analyses for various types of highway facilities.

In Part C of the first edition of the HSM, procedures are available for estimating the safety performance of rural two-lane highways, rural multilane highways, and urban and suburban arterials. More recently, AASHTO released additional chapters covering freeway segments and interchanges as a separate document. The procedures use base models to predict the number of crashes by collision type and severity level for highway sections and intersections meeting nominal conditions most commonly used by state and local transportation agencies. The predicted values can be modified by CMFs to reflect changes in design and operational characteristics. This activity can be performed both for existing and proposed highway facilities.

HSM Chapter 12 provides a predictive method for two- and four-lane urban and suburban arterial facilities with both undivided and divided cross-sections. The chapter does not cover six-or-more-lane arterials or one-way streets. These types of arterials account for a significant portion of urban and suburban arterials in the United States. For instance, analyses conducted by the research team with the Highway Performance Monitoring System database from 2008 show that there are 8,200 mi of roadways with six or more lanes and 4,132 mi of one-way streets in the United States. Furthermore, the research conducted for these types of facilities is very limited. Only a few studies have specifically examined six-or-more-lane facilities or one-way streets.

Research is therefore needed to develop an enhanced prediction methodology and safety analysis tool for urban and suburban arterial facilities. These results will lead to the development of a revised HSM Chapter 12 for predicting the safety performance of a more comprehensive list of urban and suburban streets and documentation for the expansion of the Interactive Highway Safety Design Model (IHSDM).

RESEARCH OBJECTIVES AND STRATEGIES

The objectives of this research were to develop:

- An overall framework for the enhancement of safety prediction methodologies for urban and suburban highways for both roadway segments and intersections of arterials with six or more lanes and one-way streets to support decision making for planning, network analysis, corridor analysis, and individual site evaluation.
- Safety analytical models and procedures within that framework.
- Models and procedures to estimate crash frequency and severity for these types of facilities.
- A proposed methodology consistent or compatible with the methods and procedures in the current version of HSM Chapter 12.

- A revised Chapter 12 for the future edition of the HSM.
- Training materials and a spreadsheet for the application of the new models.

RESEARCH SCOPE

To achieve the project objectives, the research team ensured that the research products covered a safety prediction methodology for the following components:

- Urban and suburban segments.
- Signalized intersections.
- Unsignalized intersections/driveways.

The safety prediction methodology addresses a wide range of operational and design conditions, such as:

- Six-or-more-lane arterials.
- One-way streets.
- Intersections on six-or-more-lane arterials or one-way streets.
- Parking and driveway characteristics.
- Pedestrian activities and bicycle traffic.

The proposed methodology developed in this project describes the aforementioned predictive models that can be used to support decision making in the planning, design, and operations of the aforementioned highway classifications. The methodology estimates the safety performance of a corridor, intersection, or driveway for a single year or any specified period. It specifically supports the following types of design decisions:

- Segment configuration (e.g., raised median, TWLTL).
- Intersection design (e.g., turning bays, lane geometry).
- Access management (e.g., driveways, land use).
- Parking design.

RESEARCH APPROACH

The research approach was accomplished in two phases. During the first phase, information was gathered and used to develop an overall framework and plan to develop a methodology for evaluating the safety of urban and suburban six-or-more-lane arterials and one-way streets. The information was gathered through a review of HSM Chapter 12 and other related material as well as the transportation literature. During the second phase of the project, the methodology was developed, tested, and refined. Then, it was incorporated into a software tool. Finally, the methodology and tools were evaluated by practitioners through workshop activities and case-study applications.

Achievement of the research objective was completed in 11 work tasks. Tasks 1 through 6 were associated with the first phase of the project. Tasks 7 through 11 were associated with the second phase of the project. The work tasks for this project included:

- Task 1: Conduct review of HSM Chapter 12 and related material.
- Task 2: Prepare working paper.
- Task 3: Conduct GoToMeeting.
- Task 4: Prepare revised work plan.
- Task 5: Prepare interim report.
- Task 6: Meet National Cooperative Highway Research Program (NCHRP) 17-58 Panel.
- Task 7: Execute approved revised work plan.
- Task 8: Develop new Chapter 12.
- Task 9: Develop Microsoft PowerPoint presentation and spreadsheet.
- Task 10: Conduct pilot workshop.
- Task 11: Submit final report.

The primary product of this research was to develop a predictive methodology for estimating the safety performance of urban and suburban six-or-more-lane arterials and one-way streets, which will be incorporated with the methodology for two- and four-lane urban facilities. The methodology includes a series of predictive models and CMFs that will allow users to quantify changes for the planning, design, and operation of urban facilities. A spreadsheet and training manual that will facilitate the application of the methodology by researchers and practitioners were also produced. It is anticipated that the predictive tools developed in this project will be incorporated into the IHSDM. The CMFs will be made available to the Federal Highway Administration's (FHWA's) CMF Clearinghouse.

ORGANIZATION OF THE REPORT

This report presents the results of the research undertaken to develop a safety prediction methodology for six-or-more-lane and one-way urban and suburban arterials as well as the intersections located on these facilities. Chapter 2 documents the findings from a review of the literature addressing urban and suburban arterials and intersections. Chapter 3 presents the proposed framework for safety prediction. Chapter 4 documents the development of the various databases suitable for calibrating the predictive models that comprise the predictive methodology. Chapters 5, 6, 7, and 8 describe the calibration of the predictive models and CMFs for urban and suburban arterial segments with six or more lanes, intersections on urban and suburban arterial segments with six or more lanes, one-way urban and suburban arterial segments, and intersections located on one-way urban and suburban arterial segments, respectively. Chapter 9 summarizes the SDFs that are used to estimate the probability of the severity of crashes as a function of covariates. Chapter 10 presents the conclusions and recommendations of the research.

Appendix A presents the revised draft of HSM Chapter 12. Appendix B provides the training material that was used for the workshop. Appendix C shows the various spreadsheets and worksheets linked to the revised draft of HSM Chapter 12 as well as the User Manual.

CHAPTER 2: LITERATURE REVIEW

This chapter summarizes the review of the literature relevant for this project. The chapter is divided in three sections. The first section describes the main characteristics of the existing predictive methodology in HSM Chapter 12. The second and third sections present the review of papers, manuscripts, and research reports related to six-or-more-lane arterials and one-way urban and suburban arterials, respectively.

OVERVIEW OF HSM CHAPTER 12

Chapter 12 of the HSM presents safety predictive methods for urban and suburban arterial facilities (i.e., urban streets). A safety predictive method represents a process for evaluating the safety of a road facility for a specified period. The types of facility that are addressed in Chapter 12 include two- and four-lane undivided facilities, four-lane divided facilities, and three- and five-lane facilities with center TWLTLs. These facilities are abbreviated as 2U, 4U, 4D, 3T, and 5T, respectively. The safety prediction models in Chapter 12 were based on the work by Harwood et al. (2007, 2008).

Safety Prediction Methodology

In the HSM Chapter 12 methodology, the overall safety of a highway segment or project is predicted by making separate safety predictions for individual constituent roadway segments and intersections (sites). Roadway segments are defined as continuous segments that are homogeneous with respect to the input variables considered in the safety prediction model. Safety prediction at intersections includes all crashes that occur within the curb limits of the intersection and those within 250 ft of the intersection that are intersection related (i.e., caused by the effect of the intersection). Safety prediction at roadway segments includes all crashes not attributable to specific intersections.

The safety prediction methodology in Chapter 12 follows the general 18 procedural steps described in Part C of the HSM (see HSM Figure C-2). For each individual roadway segment or intersection, predictions of safety performance are made separately for multiple-vehicle collisions, single-vehicle collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions. For roadway segments, multiple-vehicle collisions are further divided into nondriveway and driveway related, which are predicted separately.

In the HSM methodology, the expected crash frequency of a site (excluding vehicle-pedestrian and vehicle-bicycle collisions) is predicted as a combination of SPFs and CMFs. SPFs are regression models developed from data for a number of similar sites that estimate the predicted average crash frequency under specified base conditions for geometric design and traffic control features. CMFs are multiplicative factors that are used to account for differences between actual roadway characteristics and the presumed base conditions. As such, the structure of the crash prediction models for non-pedestrian and non-bicycle crashes are as follows:

$$N_x = N_{b_x} \times (CMF_{1x} \times CMF_{2x} \times ... \times CMF_{nx}) \qquad (1)$$

where,

N_x = predicted number of crashes per year (excluding vehicle-pedestrian and vehicle-bicycle crashes) for site type x (roadway segment or intersection).

N_{bx} = predicted number of crashes per year (excluding vehicle-pedestrian and vehicle-bicycle crashes) under base conditions for site type x (determined from the respective SPF).

$CMF_{1x}, CMF_{2x},\ldots, CMF_{nx}$ = CMFs for various features (1, 2, …, n) of site type x.

In HSM Chapter 12, the roadway segment and intersection SPFs (for non-pedestrian and non-bicycle crashes) are specified in the following forms, respectively:

$$N_{br} = a \times L \times AADT^{b} \quad (2)$$

$$N_{bi} = a \times AADT_{maj}^{b} \times AADT_{\min}^{c} \quad (3)$$

where,

N_{br} = predicted number of roadway segment crashes per year for base conditions.

$AADT$ = annual average daily traffic volume (veh/day) on roadway segment.

N_{bi} = predicted number of intersection-related crashes per year for base conditions.

$AADT_{maj}$ = annual average daily traffic volume (veh/day) for major road (both directions of travel combined).

$AADT_{min}$ = annual average daily traffic volume (veh/day) for minor road (both directions of travel combined).

The prediction methodology for vehicle-pedestrian collisions at signalized intersections includes base models (SPFs) for three- and four-legged signalized intersections and CMFs applied to both types of intersections. The SPFs accounts for total traffic volume (sum of major- and minor-road AADTs), ratio of minor-road AADT to major-road AADT, pedestrian volume, and maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection (considering presence of refuge islands).

Unlike at signalized intersections, the vehicle-pedestrian collisions at stop-controlled intersections are predicted as a proportion of the predicted crash frequency at the intersection excluding vehicle-pedestrian and vehicle-bicycle collisions (i.e., the total predicted frequency of single-vehicle and multiple-vehicle collisions multiplied by an adjustment factor provided by the HSM). The frequency of vehicle-bicycle collisions at signalized or stop-controlled intersections are predicted in a similar fashion. A similar methodology is also used to predict the frequency of vehicle-pedestrian and vehicle-bicycle collisions at roadway segments.

The specific collision-type predictions are combined to estimate the safety performance of individual sites, which are in turn combined to predict the overall safety of the entire facility of interest. In applying the algorithm to a jurisdiction or time period different from that for which the base model is estimated, a multiplicative calibration factor is applied to the model, calculated as the ratio of the observed number of crashes at a sample of sites to the predicted number of crashes at the sample sites using the safety prediction model prior to calibration.

Incorporating Crash History into Prediction

In the presence of crash history data, the HSM recommends using the Empirical Bayes (EB) method (Hauer, 1997) to combine the estimate using the predictive models and the observed crash frequencies to enhance the safety estimates for the existing sites. The EB method has a relatively simple structure and is expected to reduce the regression-to-the-mean bias.

Crash Severity and Collision Type

Separate models were developed in HSM Chapter 12 for total crashes (all crash severities), fatal-and-injury (FI) crashes, and property-damage-only (PDO) crashes. Since the models were developed separately, there is no assurance that the predicted crash frequencies for the two severity-level components will add up to the predicted total crash frequency. Therefore, the chapter recommends treating the predicted value of total crash frequency as the primary predicted value and using the relative predicted values for FI and PDO crashes to proportion the total crash frequency prediction into severity-level components. All pedestrian and bicycle collisions are, however, treated as FI crashes. The chapter does not provide proportions needed to further categorize the FI crashes into severity levels K, A, B, and C (as defined in the HSM, i.e., K = killed or fatal injury, A = incapacitating injury, B = non-incapacitating injury, C = possible injury).

The chapter also provides tables to break down multiple-vehicle crashes by collision type (i.e., manner of collision, including rear-end, head-on, angle, etc.) and single-vehicle crashes by the type of object struck. Separate proportions are provided for FI and PDO crashes.

Data for Model Development

HSM Chapter 12 safety prediction models for roadway segments were developed using data collected from the states of Minnesota and Michigan. The database consisted of 2,436 segments (blocks) with a total length of 303.9 mi from Minnesota and 1,819 segments with a total length of 294.4 mi from Michigan. The average block length was 0.12 mi in Minnesota and 0.14 mi in Michigan. The roadway segment safety prediction models were validated using a dataset from the Washington State Department of Transportation (DOT).

The safety prediction models for intersections were developed using data from 363 intersections, 182 in Minnesota and 181 in North Carolina. These models were validated using intersection data from the Florida DOT. The predictive models for vehicle-pedestrian collisions at signalized intersections were developed separately in Phase III of the NCHRP 17-26 project (Harwood et al., 2008) using data from 1,523 intersections in Toronto, Canada, and 351 intersections in Charlotte, North Carolina.

CMFs

Five CMFs in HSM Chapter 12 apply to the predicted average crash frequency for roadway segments. The CMFs are applicable to multiple-vehicle and single-vehicle collisions, but not to vehicle-pedestrian and vehicle-bicycle collisions. The key characteristics of these CMFs are as follows:

- *On-street parking CMF*: two parking types are considered (parallel and angle parking). The CMF value also depends on the land use classification: commercial/industrial/institutional or residential/other.
- *Roadside fixed-object CMF*: depends on the density of fixed objects (fixed objects/mi) and the average offset distance of the fixed objects. Point objects that are within 70 ft of one another longitudinally along the road are counted as a single object. If the computed CMF is less than 1.00, it is set equal to 1.00. This situation arises only for very low fixed-object densities.
- *Median width CMF*: applies only to traversable medians without traffic barriers; it is not applicable to medians serving as TWLTLs. The base condition for this CMF is a median width of 15 ft.
- *Lighting CMF*: assumes the absence of lighting as the base condition. The CMF depends on the proportion of crashes that occur at night and the proportion of total nighttime crashes by severity level (FI and PDO).
- *Automated speed enforcement CMF*: a CMF of 0.83 is suggested for FI crashes only; however, a CMF of 0.95 can be used by assuming that automated speed enforcement has no effect on non-injury crashes. The base condition for this CMF is the absence of automated speed enforcement.

Six CMFs in HSM Chapter 12 apply to the predicted average crash frequency (excluding vehicle-pedestrian and vehicle-bicycle collisions) for intersections. The key characteristics of these CMFs are as follows:

- *Left-turn-lane CMF*: applies to the installation of left-turn lanes on any approach of a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for the installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMFs for the installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes.
- *Left-turn signal phasing CMF*: assumes permissive left-turn phasing as the base condition. This CMF is limited to signalized intersections and takes different values for protected and protected/permissive left-turn signal phasing. If several approaches to a signalized intersection have left-turn phasing, the values of the CMF for each approach are multiplied together.
- *Right-turn-lane CMF*: similar to the left-turn-lane CMF, this CMF applies to the installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. This CMF applies only to right-turn lanes that are identified by marking or signing, but is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

- *Right-turn-on-red CMF*: applies to signalized intersections and depends on the number of approaches with right-turn-on-red prohibition. The base condition is right turn on red permitted at all approaches.
- *Lighting CMF*: assumes the absence of lighting as the base condition and depends on the proportion of total crashes for unlighted intersections that occur at night. Default values are provided for the aforementioned proportion based on the intersection type.
- *Red-light-camera CMF*: is based on the assumption that installation of a red-light camera would only affect right-angle collisions and rear-end collisions. Installation of a red-light camera is expected to reduce the frequency of right-angle collisions and increase the frequency of rear-end collisions. It is stated that there is no evidence that red-light camera installation influences other collision types. The CMF value depends on the proportions of crashes that are right-angle or rear-end collisions.

Finally, three CMFs in HSM Chapter 12 apply to the predicted average frequency of vehicle-pedestrian collisions. The CMFs address the safety effect of bus stops, schools, and alcohol sales establishments near the intersection. The base condition for these CMFs is the absence of these facilities near the intersection. The CMF values are determined based on the number of respective facilities located fully or partially within 1000 ft of the center of the intersection.

SAFETY PREDICTION FOR ARTERIALS WITH SIX OR MORE LANES

This section presents the findings from the review of literature related to safety prediction at urban and suburban arterials with six or more lanes. The existing safety prediction models in the literature were identified and compared to the HSM Chapter 12 methodology. The first part of this section covers safety prediction for roadway segments, while the second part focuses on intersections.

Safety Prediction at Roadway Segments

As described earlier, the existing safety prediction models in HSM Chapter 12 are limited to roadway segments with five or fewer lanes. The models provide sensitivity to the exposure variables of traffic volume and segment length in the formulation of the SPFs, and to geometric and environmental variables through the CMFs. Separate SPFs are provided for different cross-section configurations, where a configuration is described by the number of lanes and the median type (undivided, divided, or TWLTL).

The research team identified at least six sources in the literature that provide safety prediction models that apply to six-lane urban or suburban arterials. None of the safety prediction models found in the literature review were applicable to roadway segments with more than six lanes. Table 1 specifies the variables included in the HSM methodology and the safety prediction models for six-lane roadway segments that were found in the literature. These models provide sensitivity to a range of variables, some of which are common with the HSM models. Where separate models are provided for signalized or unsignalized intersections (such as in the HSM methodology), the safety effect of these facilities in the methodology is listed as "separate model." The variables that are included directly in the SPF equations are labeled as "SPF," whereas those that are addressed by CMFs are labeled as "CMF."

Table 1. Input variables of the safety prediction models for six-lane arterial segments and the HSM Chapter 12 methodology.

Variable	Safety Prediction Methodology						
	HSM Ch. 12 (AASHTO, 2010)	Petritsch et al. (2007)	Bonneson & Pratt (2009)	Sawalha & Sayed (2001)	Bonneson & McCoy (1997)	Hadi et al. (1995)	Squires & Parsonson (1989)
Number of lanes	2 or 4	6	6	6	4 or 6	6	6
Land use			SPF	CMF	CMF		
On-street parking	CMF		CMF		CMF		
Roadside fixed objects	CMF		CMF				
Lane width		CMF	CMF				
Curb presence						CMF	
Outside shoulder width		CMF	CMF				
Inside shoulder width		CMF					
Median width	CMF	CMF	CMF			CMF	
Median type	SPF		SPF			CMF	
Median opening presence							SPF
Lighting	CMF						
Speed limit	SPF[a]					CMF	
Automated speed enforcement	CMF						
Truck presence			CMF				
Horizontal curve radius or degree of curve		CMF	CMF				
Driveway presence	SPF	CMF	SPF	CMF	CMF		SPF
Driveway type (land use served)	SPF		SPF	CMF			
Signalized intersection presence	Separate model	CMF	Separate model				SPF
Unsignalized intersection presence	Separate model		Separate model	CMF	CMF		SPF
Crosswalk presence				CMF			

Note: Shaded cells: not available/no data (here and all other tables, except where otherwise noted).
[a] Applicable to SPFs for vehicle-pedestrian and vehicle-bicycle collisions only.

The variables listed in Table 1 can be characterized into the following general categories:

- Access control—driveway presence, median type (undivided, nonrestrictive median [including TWLTL, gravel, dirt, or grass], or restrictive median [raised curb]), and median opening presence.
- Land use and driveway type—residential, industrial, or commercial (which may be further subdivided into business or office).
- Cross-sectional attributes—lane width, outside shoulder width, inside shoulder width, median width, surface width, curb presence, and on-street parking presence.
- Alignment—horizontal curve radius or degree of curve.
- Traffic control—speed limit and automated speed enforcement.

- Intersection and crossing presence—signalized intersections, unsignalized intersections, and crosswalks.
- Roadside—lighting and roadside fixed objects (e.g., utility poles).

Some of the sources (Hadi et al., 1995; Squires and Parsonson, 1989) listed in Table 1 provide pairs of models, where one model provides an estimate of total crash frequency or rate for all crashes along a roadway of interest, and the other model provides an estimate of midblock crash frequency or rate for crashes not occurring near intersections. This approach allows for an indirect estimate of intersection-related crashes by subtracting the midblock crash frequency from the total crash frequency. Squires and Parsonson (1989) explained that they chose this modeling approach to account for the possibility that changing from a TWLTL median to a raised median may not improve overall safety because a shifting of conflicts from midblock locations to nearby intersections may occur.

As shown in Table 1, there is little agreement between the models in terms of the inclusion of input variables. The authors of the various sources described the processes that they used to develop their models. In all cases, additional variables were considered but excluded from the final model. Reasons for doing so included:

- The effect of the variable was found to be statistically insignificant. This finding may indicate that the variable truly does not affect safety performance, or it may indicate that the researchers' database did not contain a sufficient range in the variable values to allow its effect to be quantified.
- The researchers' data reduction resources were inadequate to allow the addition of the variable to their dataset.
- The variable was not of interest to the agency sponsoring the research. For example, an agency that is not interested in replacing TWLTL medians with raised-curb medians would not likely be interested in quantifying the difference in safety performance of these median types. The agency's decision not to consider installing raised-curb medians may be based on considerations other than safety (e.g., cost, right-of-way availability, community opposition, etc.).

Description of Models in the Literature

The six safety prediction models applicable to six-lane urban or suburban arterials are described below.

Petritsch et al. (2007). The safety prediction model calibrated for six-lane urban or suburban arterials is described by Equations 4–6:

$$C_{KA} = 3.65 \times 10^{-6} L\ AADT\ e^{\left(3.9026 + 0.0308 D_c + 0.0286 N_{sig} / L - 0.0216 W_{is} - 0.0156 W_s - 0.0017 W_m\right)} \quad (4)$$

$$C_{BC} = 3.65 \times 10^{-6} L\ AADT\ e^{\left(5.0665 - 0.0447 D_c + 0.0016 N_{dw} / L + 0.0509 N_{sig} / L - 0.0245 W_{is} - 0.0484 W_s\right)} \quad (5)$$

$$C_{PDO} = 3.65 \times 10^{-6} L\ AADT\ e^{\left(7.4675 - 0.0521 D_c + 0.0017 N_{dw} / L + 0.0492 N_{sig} / L - 0.0196 W_{is} - 0.0234 W_s - 0.0063 W_m - 0.0682 W_l N_l\right)} \quad (6)$$

where,

C_{KA}	=	fatal and incapacitating injury crash frequency, crash/year.
C_{BC}	=	non-incapacitating and possible injury crash frequency, crash/year.
C_{PDO}	=	PDO crash frequency, crash/year.
L	=	segment length, mi.
$AADT$	=	annual average daily traffic volume, veh/day.
D_c	=	horizontal degree of curve, degrees.
N_l	=	number of lanes (= 6).
N_{sig}	=	number of signalized intersections on the segment.
N_{dw}	=	number of driveways on the segment.
W_{is}	=	inside shoulder width, ft.
W_s	=	outside shoulder width, ft.
W_m	=	median width, ft.
W_l	=	lane width, ft.

It should be noted that Petritsch et al. (2007) reported the models in a different form, suggesting that crash rate is computed as the dependent variable and that none of the input variables are exponentiated in the crash prediction function (unlike the form shown by Equations 4–6). Analysis of the model development process, as documented by Petritsch et al., indicates that the models were likely calibrated using crash frequency, not crash rate, as the dependent variable, since the zero-inflated negative-binomial (NB) distribution was used. With this type of modeling approach, the input variable terms are typically exponentiated (i.e., the relationship between the number of crashes and the covariates of the model is log-linear). Hence, it is likely that the models were calibrated using crash frequency as the dependent variable and then algebraically manipulated to yield equations having crash rate as the dependent variable, and that the exponentiation of the terms was neglected in the drafting of the report.

The terms in the exponentiated portions of Equations 4–6 can be rewritten as CMFs, and the CMF for number of lanes can be computed for the case of six lanes to compare this model to the others presented in this section. Equations 4–6 can be reformulated as follows:

$$C = C_{KA} + C_{BC} \tag{7}$$

$$C_{KA} = 0.000181 L\ AADT\ CMF_{hc,KA} CMF_{sig,KA} CMF_{isw,KA} CMF_{sw,KA} CMF_{mw,KA} \tag{8}$$

$$C_{BC} = 0.000579 L\ AADT\ CMF_{hc,BC} CMF_{dw,BC} CMF_{sig,BC} CMF_{isw,BC} CMF_{sw,BC} \tag{9}$$

$$C_{PDO} = 0.006388 L\ AADT \begin{pmatrix} CMF_{hc,PDO} CMF_{dw,PDO} CMF_{sig,PDO} \\ CMF_{isw,PDO} CMF_{sw,PDO} CMF_{mw,PDO} CMF_{lw,PDO} \end{pmatrix} \tag{10}$$

$$CMF_{hc,KA} = e^{0.0308 D_c} \tag{11}$$

$$CMF_{hc,BC} = e^{-0.0447 D_c} \tag{12}$$

$$CMF_{hc,PDO} = e^{-0.0521 D_c} \tag{13}$$

$$CMF_{dw,BC} = e^{0.0016 N_{dw}/L} \tag{14}$$

$$CMF_{dw,PDO} = e^{0.0017 N_{dw}/L} \tag{15}$$

$$CMF_{sig,KA} = e^{0.0286 N_{sig}/L} \tag{16}$$

$$CMF_{sig,BC} = e^{0.0509 N_{sig}/L} \quad (17)$$

$$CMF_{sig,PDO} = e^{0.0492 N_{sig}/L} \quad (18)$$

$$CMF_{isw,KA} = e^{-0.0216 W_{is}} \quad (19)$$

$$CMF_{isw,BC} = e^{-0.0245 W_{is}} \quad (20)$$

$$CMF_{isw,PDO} = e^{-0.0196 W_{is}} \quad (21)$$

$$CMF_{sw,KA} = e^{-0.0156 W_{s}} \quad (22)$$

$$CMF_{sw,BC} = e^{-0.0484 W_{s}} \quad (23)$$

$$CMF_{sw,PDO} = e^{-0.0234 W_{s}} \quad (24)$$

$$CMF_{mw,KA} = e^{-0.0017 W_{m}} \quad (25)$$

$$CMF_{mw,PDO} = e^{-0.0063 W_{m}} \quad (26)$$

$$CMF_{lw,PDO} = e^{-0.2046 W_{l}} \quad (27)$$

where,

C	=	FI crash frequency, crash/year.
$CMF_{hc,i}$	=	horizontal curvature CMF for crashes of severity category *i* (*i* = KA, BC, or PDO).
$CMF_{dw,i}$	=	driveway presence CMF for crashes of severity category *i*.
$CMF_{sig,i}$	=	signalized intersection presence CMF for crashes of severity category *i*.
$CMF_{isw,i}$	=	inside shoulder width CMF for crashes of severity category *i*.
$CMF_{sw,i}$	=	outside shoulder width CMF for crashes of severity category *i*.
$CMF_{mw,i}$	=	median width CMF for crashes of severity category *i*.
$CMF_{lw,i}$	=	lane width CMF for crashes of severity category *i*.

The safety prediction models described by Equations 8–10 follow a multiplicative form, as the predicted crash frequencies can be expressed as the multiplication of SPFs for base conditions (including segment length and traffic variables) and the CMFs in Equations 11–27. Different CMFs are provided to reflect the different effects that the variables have on the frequency of crashes with different severities (K+A, B+C, and PDO). The models are not directly sensitive to median type (i.e., TWLTL versus raised curb), although they can be used to compare the expected crash frequency assuming the presence or absence of a median (by setting $Wm = 0$ or $Wm > 0$).

The base condition for the CMFs (i.e., the condition that yields a CMF value equal to 1.0) is a value of zero for the variable included in the CMF. For example, for horizontal curvature, Equations 11–13 yield CMF values of 1.0 if no horizontal curvature is present. In presence of horizontal curvature, the CMFs yield an increase in K+A crashes, but a reduction in B+C or PDO crashes, likely to reflect the change in severity distribution associated with horizontal curvature (i.e., greater frequency of more severe crashes). The base condition for the lane width CMF in Equation 27 is not attainable because it is not possible to have zero lane width.

Bonneson and Pratt (2009). The safety prediction model calibrated for six-lane urban and suburban arterials is described by Equations 28–40:

$$C_N = C_{b,N} \times (CMF_{cr} \times CMF_{lw} \times CMF_{sw} \times CMF_{mw,N} \times CMF_{pk} \times CMF_{pd} \times CMF_{tk}) \quad (28)$$

$$C_R = C_{b,R} \times (CMF_{cr} \times CMF_{lw} \times CMF_{sw} \times CMF_{mw,R} \times CMF_{pk} \times CMF_{pd} \times CMF_{tk}) \quad (29)$$

$$C_{b,N} = C_{mv,N} + C_{sv,N} + C_{dw,N} \quad (30)$$

$$C_{b,R} = C_{mv,R} + C_{sv,R} + C_{dw,R} \quad (31)$$

$$C_{mv,N} = 0.00527\, L\left(0.001\, AADT\right)^{1.82} F_{lu} \quad (32)$$

$$C_{sv,N} = 0.0609\, L\left(0.001\, AADT\right)^{0.63} F_{lu} \quad (33)$$

$$C_{dw,N} = 0.0734\left(\frac{AADT}{15000}\right)^{1.29} N_{dw,res} S_d^{\ 0.518} \quad (34)$$

$$C_{mv,R} = 0.0197 L\left(0.001\, AADT\right)^{1.38} F_{lu} \quad (35)$$

$$C_{sv,R} = 0.244 L\left(0.001\, AADT\right)^{0.201} F_{lu} \quad (36)$$

$$C_{dw,R} = 0.0657\left(\frac{AADT}{15000}\right)^{1.25} N_{dw,res} S_d^{\ 0.518} \quad (37)$$

$$N_{dw,res} = N_{res} + 1.32 N_{ind} + 4.11 N_{bus} + 2.91 N_{off} \quad (38)$$

$$F_{lu} = e^{\left(0.210 L_{ind} + .448 L_{bus} + 0.113 L_{off}\right)/L} \quad (39)$$

$$S_d = \frac{2L}{N_{res} + N_{ind} + N_{bus} + N_{off} + 1} \quad (40)$$

where,

C_N	=	expected FI crash frequency for segments with nonrestrictive medians, crash/year.
C_R	=	expected FI crash frequency for segments with restrictive medians, crash/year.
$C_{b,N}$	=	base FI crash frequency for segments with nonrestrictive medians, crash/year.
$C_{b,R}$	=	base FI crash frequency for segments with restrictive medians, crash/year.
CMF_{cr}	=	horizontal curve radius CMF.
CMF_{lw}	=	lane width CMF.
CMF_{sw}	=	shoulder width CMF.
$CMF_{mw,N}$	=	median width CMF for nonrestrictive medians.
$CMF_{mw,R}$	=	median width CMF for restrictive medians.
CMF_{pk}	=	curb parking CMF.
CMF_{pd}	=	utility pole offset CMF.
CMF_{tk}	=	truck presence CMF.
$C_{mv,N}$	=	multiple-vehicle FI crash frequency for segments with nonrestrictive medians, crash/year.
$C_{sv,N}$	=	single-vehicle FI crash frequency for segments with nonrestrictive medians, crash/year.

$C_{dw,N}$ = driveway-related FI crash frequency for segments with nonrestrictive medians, crash/year.

$C_{mv,R}$ = multiple-vehicle FI crash frequency for segments with restrictive medians, crash/year.

$C_{sv,R}$ = single-vehicle FI crash frequency for segments with restrictive medians, crash/year.

$C_{dw,R}$ = driveway-related FI crash frequency for segments with restrictive medians, crash/year.

F_{lu} = land use adjustment factor.

$N_{dw,res}$ = number of equivalent residential driveways on the segment.

S_d = driveway spacing, mi/driveway.

N_{res} = number of residential driveways on the segment.

N_{ind} = number of industrial driveways on the segment.

N_{bus} = number of business driveways on the segment.

N_{off} = number of office driveways on the segment.

L_{ind} = curb miles with industrial land use (two-way total), mi.

L_{bus} = curb miles with business land use (two-way total), mi.

L_{off} = curb miles with office land use (two-way total), mi.

These models represent a multiplicative form. Equations 32–34 (for nonrestrictive medians) and 35–37 (for restrictive medians) are used to obtain the crash frequency for segments with base conditions. The crash frequencies are then adjusted upward or downward by multiplying the base crash frequency by one or more CMFs, as listed above.

For both median types (nonrestrictive or restrictive), different equations are provided for the three crash types (multiple vehicle, single vehicle, and driveway related) to reflect the differing effect of median type on each crash type. Additionally, adjustments are applied in Equations 32–36 to capture the effect of land use on multi-vehicle and single-vehicle crash frequency. These adjustments allow the models to account for the fact that each of the land use categories (residential, industrial, business, and office) is associated with different traffic patterns, vehicle mixes, and driveway activity levels. The model structure also accommodates the possibility of having a mix of land uses on a given segment. This structure can help reduce the number of segments that need to be defined and allows the modeling of a segment that has different land uses on opposite sides of the street.

Sawalha and Sayed (2001). The model calibrated by Sawalha and Sayed is described by Equation 41:

$$C_{KABCO} = 0.1223\, L^{0.7631} AADT^{0.6459} e^{\left(0.09097 N_{unsig}/L + 0.08274 N_{cw}/L + 0.08515 N_l + 0.1553 I_u + 0.01683 I_{bus} N_{dw}/L\right)} \quad (41)$$

where,

C_{KABCO} = expected crash frequency with severity levels KABCO (all crashes), crash/year.

N_{unsig} = number of unsignalized intersections on the segment.

N_{cw} = number of crosswalks on the segment.

I_u = indicator variable for undivided cross-section (= 1 for undivided, 0 for divided).

I_{bus} = indicator variable for business land use (= 1 for business land use, 0 otherwise).

Equation 41 was calibrated to estimate the frequency of all crashes (fatal, injury, and PDO). To obtain an estimate of FI crash frequency, the equation can be multiplied by 0.278, which was the proportion of FI crashes in the dataset used to calibrate the equation. Additionally, the five terms in the exponentiated parenthetic expression can be rewritten as CMFs, and the CMF for number of lanes can be computed for the case of six lanes to compare this model to the others presented in this section. Hence, Equation 41 can be reformulated as follows:

$$C = 0.05667\, L^{0.7631} AADT^{0.6459} CMF_{unsig} CMF_{cw} CMF_u CMF_{dw} \tag{42}$$

$$CMF_{unsig} = e^{0.09097 N_{unsig}/L} \tag{43}$$

$$CMF_{cw} = e^{0.08274 N_{cw}/L} \tag{44}$$

$$CMF_u = e^{0.1553 I_u} = 1.168 \text{ for undivided cross-section, } 1.000 \text{ otherwise} \tag{45}$$

$$CMF_{dw} = e^{0.01683 I_{bus} N_{dw}/L} \tag{46}$$

where,

CMF_{unsig} = unsignalized intersection presence CMF.

CMF_{cw} = crosswalk presence CMF.

CMF_u = undivided cross-section CMF.

The model calibrated by Sawalha and Sayed (2001) is multiplicative in form. The CMFs described by Equations 43–46 are included to facilitate comparison with the other models presented in this section. The base conditions for these CMFs are no unsignalized intersections present, no crosswalks present, divided cross-section, and either no driveways present or no business land use present. If an estimate of segment-related crashes is desired (i.e., no intersection-related crashes included in the estimate), then the numbers of unsignalized intersections and crosswalks should both be set to zero.

Bonneson and McCoy (1997). The models calibrated by Bonneson and McCoy are described by Equations 47–49:

$$C_{r,KABCO} = L^{0.852} AADT^{0.91} e^{\left(-15.162 - 0.296 I_{b/o} - 0.596 I_{r/i} + 0.00478 [N_{dw} + N_{app}] I_{b/o}/L + 0.255 PDO\right)} \tag{47}$$

$$C_{n,KABCO} = L^{0.852} AADT^{0.91} e^{\left(-15.162 + 0.018 I_{b/o} + 0.093 I_{r/i} + 0.00478 [N_{dw} + N_{app}] I_{b/o}/L + 0.255 PDO\right)} \tag{48}$$

$$C_{u,KABCO} = L^{0.852} AADT^{(0.91 + 1.021 I_{r/i})} e^{\left(-15.162 - 10.504 I_{r/i} + 0.57 I_{Park} + 0.00478 [N_{dw} + N_{app}] I_{b/o}/L + 0.255 PDO\right)} \tag{49}$$

where,

$C_{r,KABCO}$ = expected crash frequency (all crash severity levels) for segments with raised-curb medians, crash/year.

$C_{n,KABCO}$ = expected crash frequency (all crash severity levels) for segments with TWLTL medians, crash/year.
$C_{u,KABCO}$ = expected crash frequency (all crash severity levels) for segments with undivided cross-sections, crash/year.
$I_{b/o}$ = indicator variable for business or office land uses (= 1 if present, 0 otherwise).
$I_{r/i}$ = indicator variable for residential or industrial land uses (= 1 if present, 0 otherwise).
I_{Park} = indicator variable for presence of parallel parking along the roadside (= 1 if present, 0 otherwise).
N_{app} = number of unsignalized public street approaches on the segment.
PDO = PDO crashes as a percentage of total crashes.

Equations 47–49 were calibrated to estimate the frequency of all crashes (fatal, injury, and PDO). To obtain an estimate of FI crash frequency, the equation can be multiplied by 0.321, which was the proportion of FI crashes in the dataset used to calibrate the equation. Additionally, the terms in the exponentiated parenthetic expression can be rewritten as CMFs or adjustment factors. Specifically, the constant term can be written as a model coefficient, and the PDO percentage term can be written as an adjustment factor (not a CMF since its intended purpose is to account for crash reporting thresholds, not site characteristics that influence safety performance). Hence, Equations 47–49 can be reformulated as follows:

$$C_d = 2.6 \times 10^{-7} L^{0.852} AADT^{0.91} CMF_{b/o} CMF_{r/i} CMF_{acc} e^{0.255 PDO} \quad (50)$$

$$C_u = 2.6 \times 10^{-7} L^{0.852} AADT^{(0.91+1.021 I_{r/i})} CMF_{r/i} CMF_{Park} CMF_{acc} e^{0.255 PDO} \quad (51)$$

$$CMF_{Park} = e^{0.57 I_{Park}} = 1.768 \text{ if roadside parallel parking is present, 1.000 otherwise} \quad (52)$$

$$CMF_{acc} = e^{0.00478 [N_{dw} + N_{app}] I_{b/o}} \quad (53)$$

where,

C_d = expected crash frequency (all crash severity levels) for segments with divided cross-sections, crash/year.
C_u = expected crash frequency (all crash severity levels) for segments with undivided cross-sections, crash/year.
$CMF_{b/o}$ = business and office land use CMF (see Table 2).
$CMF_{r/i}$ = residential and industrial land use CMF (see Table 2).
CMF_{Park} = parallel parking presence CMF.
CMF_{acc} = access point CMF.

The $CMF_{b/o}$ and $CMF_{r/i}$ values used in Equations 50 and 51 are provided in Table 2.

Table 2. CMF values for land use and parking presence (based on Bonneson and McCoy, 1997).

CMF	**CMF Value by Median Type**		
	Raised Curb	**TWLTL**	**Undivided**
$CMF_{b/o}$	0.744	1.018	Not applicable
$CMF_{r/i}$	0.551	1.097	2.74×10^{-5}

These models were calibrated as part of an effort to quantify the safety effects of midblock left-turn lane treatments. It should be noted that the database used to calibrate these models contained segments with four lanes as well as segments with six lanes. The models' lack of sensitivity to the number of lanes suggests that the effect of this variable on safety performance was found to be subtle compared to the variables described by the CMFs that were included.

Hadi et al. (1995). The models calibrated by Hadi et al. are described by Equations 54–59:

$$C_{mb,KABCO} = e^{\left(-12.04+0.8223\ln L+1.072\ln AADT-0.027V_{sl}+0.631\left[N_{sig}+N_{unsig}\right]-0.0412\sqrt{W_m}+0.1671I_{curb}\right)} \quad (54)$$

$$C_{tot,KABCO} = e^{\left(-8.766+0.6335\ln L+0.8152\ln AADT+0.1309\left[N_{sig}+N_{unsig}\right]-0.0026W_m+0.2819I_{curb}\right)} \quad (55)$$

$$C_{mb,ABC} = e^{\left(-14+0.8164\ln L+1.0934\ln AADT+0.0701\left[N_{sig}+N_{unsig}\right]-0.0501\sqrt{W_m}+0.2202I_{curb}\right)} \quad (56)$$

$$C_{tot,ABC} = e^{\left(-8.536+0.7022\ln L+0.8491\ln AADT-0.0278V_{sl}+0.113\left[N_{sig}+N_{unsig}\right]-0.05\sqrt{W_m}+0.1311I_{curb}\right)} \quad (57)$$

$$C_{mb,K} = e^{\left(-14.251+0.945\ln L+0.676\ln AADT\right)} \quad (58)$$

$$C_{tot,K} = e^{\left(-10.88+0.73\ln L+0.5376\ln AADT+0.0754\left[N_{sig}+N_{unsig}\right]\right)} \quad (59)$$

where,

$C_{mb,KABCO}$	=	expected midblock crash frequency for all crash severity levels, crash/year.
$C_{tot,KABCO}$	=	expected midblock plus intersection-related crash frequency for all crash severity levels, crash/year.
$C_{mb,ABC}$	=	expected midblock crash frequency for crash severity levels ABC, crash/year.
$C_{tot,ABC}$	=	expected midblock plus intersection-related crash frequency for crash severity levels ABC, crash/year.
$C_{mb,K}$	=	expected fatal midblock crash frequency, crash/year.
$C_{tot,K}$	=	expected fatal midblock plus intersection-related crash frequency, crash/year.
V_{sl}	=	posted speed limit, mph.
I_{curb}	=	indicator variable for presence of outside curb (= 1 if present, 0 otherwise).

Equations 54 and 56 apply to crashes that occur at midblock locations, while Equations 55 and 57 apply to all crashes along the street, including intersection-related crashes. These equations can be reformulated to yield multiplicative forms, as follows:

$$C_{mb} = C_{mb,K} + C_{mb,ABC} \quad (60)$$

$$C_{tot} = C_{tot,K} + C_{tot,ABC} \quad (61)$$

$$C_{mb,KABCO} = 5.9 \times 10^{-6} L^{0.8223} AADT^{1.072} CMF_{vsl,mb,KABCO} CMF_{i/s,mb,KABCO} CMF_{mw,mb,KABCO} CMF_{c,mb,KABCO} \quad (62)$$

$$C_{tot,KABCO} = 0.000156 L^{0.6335} AADT^{0.8152} CMF_{i/s,tot,KABCO} CMF_{mw,tot,KABCO} CMF_{c,tot,KABCO} \quad (63)$$

$$C_{mb,ABC} = 8.32 \times 10^{-7} L^{0.8164} AADT^{1.0934} CMF_{i/s,mb,ABC} CMF_{mw,mb,ABC} CMF_{c,mb,ABC} \quad (64)$$

$$C_{tot,ABC} = 0.000196 L^{0.7022} AADT^{0.8491} CMF_{vsl,tot,ABC} CMF_{i/s,tot,ABC} CMF_{mw,tot,ABC} CMF_{c,tot,ABC} \quad (65)$$

$$C_{mb,K} = 6.47 \times 10^{-7} L^{0.945} AADT^{0.676} \quad (66)$$

$$C_{tot,K} = 1.88 \times 10^{-5} L^{0.73} AADT^{0.5376} CMF_{i/s,tot,K} \quad (67)$$

$$CMF_{vsl,mb,KABCO} = e^{-0.027 V_{sl}} \quad (68)$$

$$CMF_{vsl,tot,ABC} = e^{-0.0278 V_{sl}} \quad (69)$$

$$CMF_{i/s,mb,KABCO} = e^{0.631 (N_{sig} + N_{unsig})} \quad (70)$$

$$CMF_{i/s,tot,KABCO} = e^{0.1309 (N_{sig} + N_{unsig})} \quad (71)$$

$$CMF_{i/s,mb,ABC} = e^{0.0701 (N_{sig} + N_{unsig})} \quad (72)$$

$$CMF_{i/s,tot,ABC} = e^{0.113 (N_{sig} + N_{unsig})} \quad (73)$$

$$CMF_{i/s,tot,K} = e^{0.0754 (N_{sig} + N_{unsig})} \quad (74)$$

$$CMF_{mw,mb,KABCO} = e^{-0.0412 \sqrt{W_m}} \quad (75)$$

$$CMF_{mw,tot,KABCO} = e^{-0.0026 W_m} \quad (76)$$

$$CMF_{mw,mb,ABC} = e^{-0.0501 \sqrt{W_m}} \quad (77)$$

$$CMF_{mw,tot,ABC} = e^{-0.05 \sqrt{W_m}} \quad (78)$$

where,

C_{mb} = midblock FI crash frequency, crash/year.
C_{tot} = midblock plus intersection-related FI crash frequency, crash/year.
$CMF_{vsl,i,j}$ = posted speed limit CMF for crash location *i* and severity *j*.
$CMF_{i/s,i,j}$ = intersection presence CMF for crash location *i* and severity *j*.
$CMF_{mw,i,j}$ = median width CMF for crash location *i* and severity *j*.
$CMF_{c,i,j}$ = outside curb presence CMF for crash location *i* and severity *j* (see Table 3).

The CMF_c values used in Equations 62–65 are provided in Table 3.

Table 3. CMF_c values (based on Hadi et al., 1995).

Crash Location	**CMF Value by Crash Severity**	
	KABCO	**KABC**
mb	1.182	1.246
tot	1.326	1.14

The most appropriate method to compare the models developed by Hadi et al. (1995) with those previously presented is to use the equations that apply to midblock crashes. To compare FI crash frequencies, Equation 60 should be used.

Squires and Parsonson (1989). The models calibrated by Squires and Parsonson are described by the following equations:

$$C_{mb,TWLTL} = \left(-60.87 + 0.00336 AADT\right) L \tag{79}$$

$$C_{tot,TWLTL} = \left(-73.91 + 0.00508 AADT - 0.895 N_{dw} / L + 32.372 N_{sig} / L + 6.482 N_{app} / L\right) L \tag{80}$$

$$C_{mb,Raised} = \left(-8.14 + 0.00097 AADT\right) L \tag{81}$$

$$C_{tot,Raised} = \left(-96.48 + 0.00455 AADT + 22.467 N_{sig} / L\right) L \tag{82}$$

where,

$C_{mb,TWLTL}$ = midblock crash frequency for segments with TWLTL median, crash/year.
$C_{tot,TWLTL}$ = midblock plus intersection-related crash frequency for segments with TWLTL median, crash/year.
$C_{mb,Raised}$ = midblock crash frequency for segments with raised-curb median, crash/year.
$C_{tot,Raised}$ = midblock plus intersection-related crash frequency for segments with raised-curb median, crash/year.

Equations 79–82 were calibrated to estimate the frequency of all crashes (fatal, injury, and PDO). To obtain an estimate of FI crash frequency, the equations can be multiplied by one minus the PDO proportions in Table 4. These proportions are derived from the dataset that was used to calibrate the equations.

Table 4. PDO proportions (based on Squires and Parsonson, 1989).

Crash Location	**PDO Proportion by Median Type**	
	TWLTL	**Raised Curb**
mb	0.734	0.773
tot	0.663	0.763

Unlike the models previously presented in this section, Equations 79–82 are of the linear form (without taking the log). They can still be compared to the previous models, and the most appropriate equations to use for this comparison are the midblock crash frequency models in Equations 79 and 81. It should be noted that Equations 79–82 do not apply to small AADT ranges because they do not bound to zero crashes for zero volume. The lowest AADT observed in the calibration dataset for these models was 20,360 veh/day.

Comparison of Models

With careful consideration of input variables, the aforementioned models can be compared. Input variable values used to generate model comparisons, along with the models' predicted crash rates, are listed in Table 5.

Table 5. Crash rates and input variables for six-lane roadway segment models in the literature.

Variable		Source					
		Petritsch et al. (2007)	**Bonneson & Pratt (2009)**	**Sawalha & Sayed (2001)**	**Bonneson & McCoy (1997)**	**Hadi et al. (1995)**	**Squires & Parsonson (1989)**
Equation number(s)		4, 5, 6	7, 8, 9	28, 29	41	47, 48, 49	54, 55
Number of lanes		6	6	6	4 or 6	6	6
Land use			Bus.	Bus.	Bus.		
Speed limit, mph						45	
Curvature		Tangent					
Driveways/mile (by median type)		30	30 (N), 15 (R)	30	30		30
Signalized intersections/mile		0				0	0
Unsignalized intersections/mile				0	0		0
Crosswalks/mile				0			
Inside shoulder width, ft		0					
Outside shoulder width, ft		1.5					
Median width, ft (by median type)		0 (U), 12 (N, R)				0 (U), 12 (N, R)	
Lane width, ft		12					
Curb presence						Yes	
Median openings/mile							0
On-street parallel parking					None		
PDO crash proportion (by median type)[a]	U						
	N			0.722	0.679		0.734
	R						0.773
Model functional form		Mult.	Mult.	Mult.	Mult.	Mult.	Linear
Model prediction basis		Seg.	Seg.	Seg.	Mid.	Mid.	Mid.
Calibration dataset AADT range, veh/day	Min.	14,900	3450	4232	3000	10,000	20,360
	Avg.	47,726	N.R.	N.R.	27,172	N.R.	32,242
	Max.	98,500	56,700	62,931	56,700	100,000	47,685
Crash rate at AADT = 60,000 veh/day, crash/mvm (by median type)	U	2.03		1.24	0.82	2.27	
	N	2.02	1.70	1.06	0.84	1.91	1.71
	R		0.87		0.61		0.52

Note: Bus. = business; U = undivided; N = nonrestrictive; R = restrictive; Mult. = multiplicative (e.g., with an SPF and one or more CMFs); Seg. = segment-related crashes; Mid. = midblock crashes; mvm = million vehicle-miles; N.R. = not reported.

[a] PDO crash proportion = PDO crash frequency ÷ total crash frequency. The numbers provided are based on the databases used to calibrate the models.

The crash rates in the bottom three rows of Table 5 show that considerable variation exists between the safety predictions provided by the models, even when the input variable values are carefully chosen to describe a similar facility; this is somewhat expected since the models were estimated in different geographical areas. However, comparisons of the model trends can still be made using the following categorization of median types:

- Undivided (i.e., no median).
- Nonrestrictive median (i.e., TWLTL, flush paved, dirt, gravel, or grass).
- Restrictive median (i.e., raised curb or positive barrier).
- Divided (i.e., all nonrestrictive and restrictive median types).

It can be seen that the model predictions consistently show lower crash rates for restrictive medians compared to nonrestrictive medians, and likewise for nonrestrictive medians compared to undivided segments.

A comparison of models that apply to undivided six-lane urban arterials is provided in Figure 1. The models calibrated by Petritsch et al. (2007) and by Hadi et al. (1995) seem to agree well across the range of traffic volumes. In contrast, the models calibrated by Sawalha and Sayed (2001) and by Bonneson and McCoy (1997) predict fewer crashes, particularly for higher volumes, though they have similar slopes to each other.

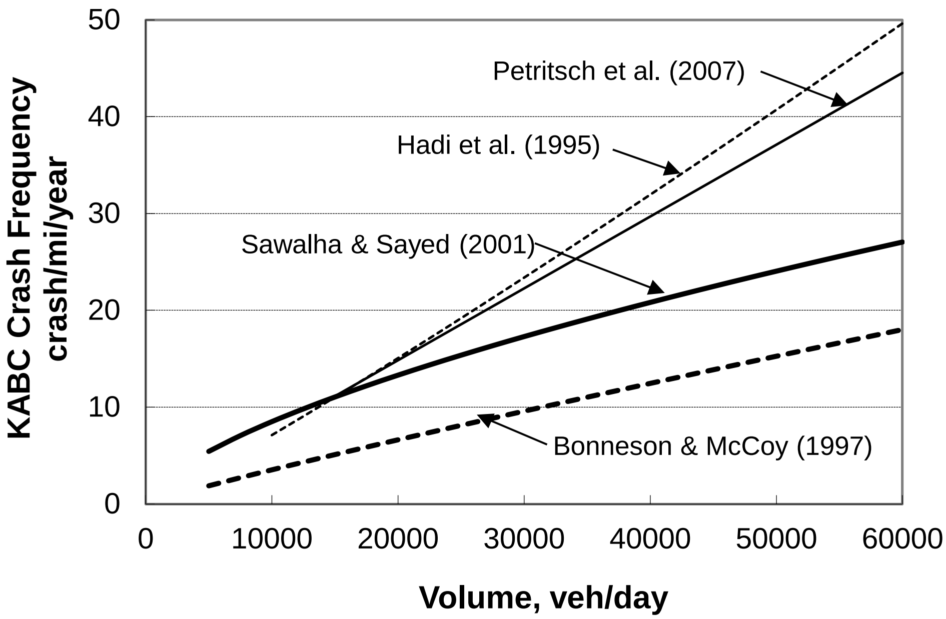

Figure 1. Models for six-lane undivided urban or suburban arterials.

A comparison of models that apply to six-lane urban or suburban arterials with nonrestrictive medians is provided in Figure 2. The model calibrated by Bonneson and Pratt (2009) agrees well with the model calibrated by Bonneson and McCoy (1997) for lower volumes (e.g., 20,000 veh/day or less) and with the model calibrated by Squires and Parsonson (1989) for higher volumes (e.g., 35,000 veh/day or more).

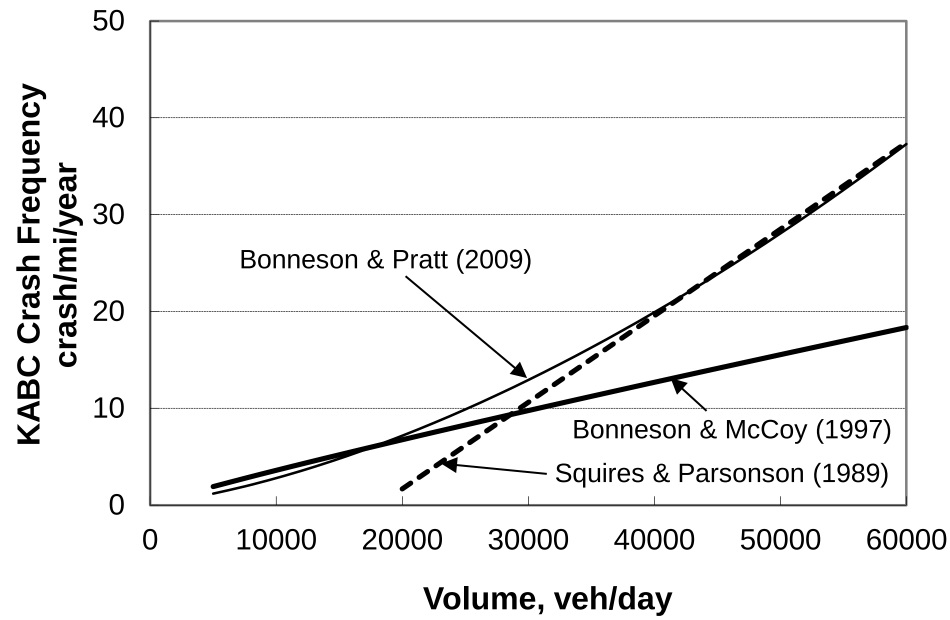

Figure 2. Models for six-lane urban or suburban arterials with nonrestrictive medians.

A comparison of models that apply to six-lane urban or suburban arterials with restrictive medians is provided in Figure 3. The models calibrated by Bonneson and McCoy (1997) and by Squires and Parsonson (1989) show similar slopes. Otherwise, there is not good agreement among these models, except at the lower range of volumes.

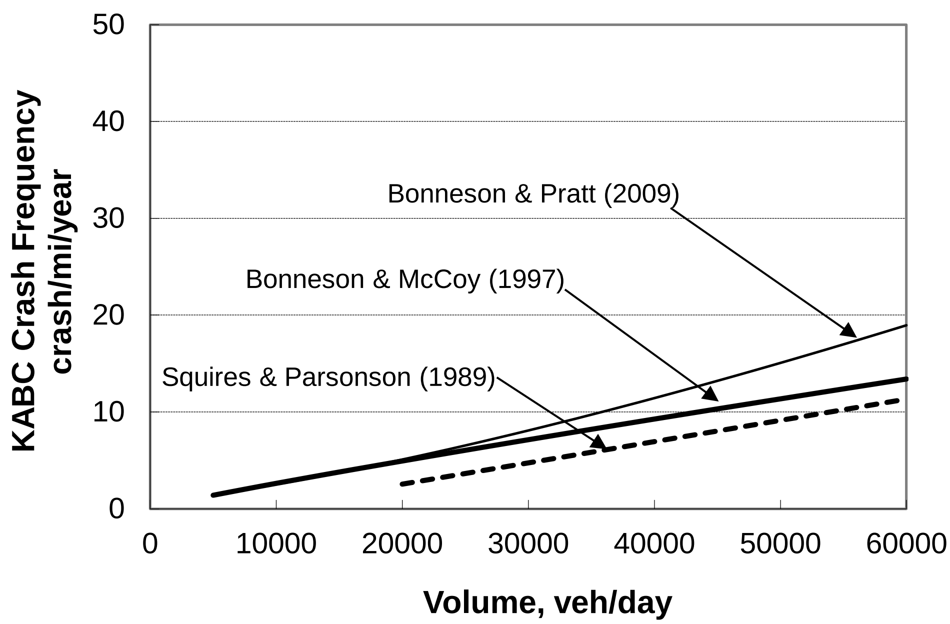

Figure 3. Models for six-lane urban or suburban arterials with restrictive medians.

A comparison of models that apply to divided six-lane urban arterials with no specification of median type (nonrestrictive versus restrictive) is provided in Figure 4. The models calibrated by Petritsch et al. (2007) and by Hadi et al. (1995) are shown to agree well across the range of traffic volumes. In contrast, the model calibrated by Sawalha and Sayed (2001) predicts fewer crashes at the higher range of volumes.

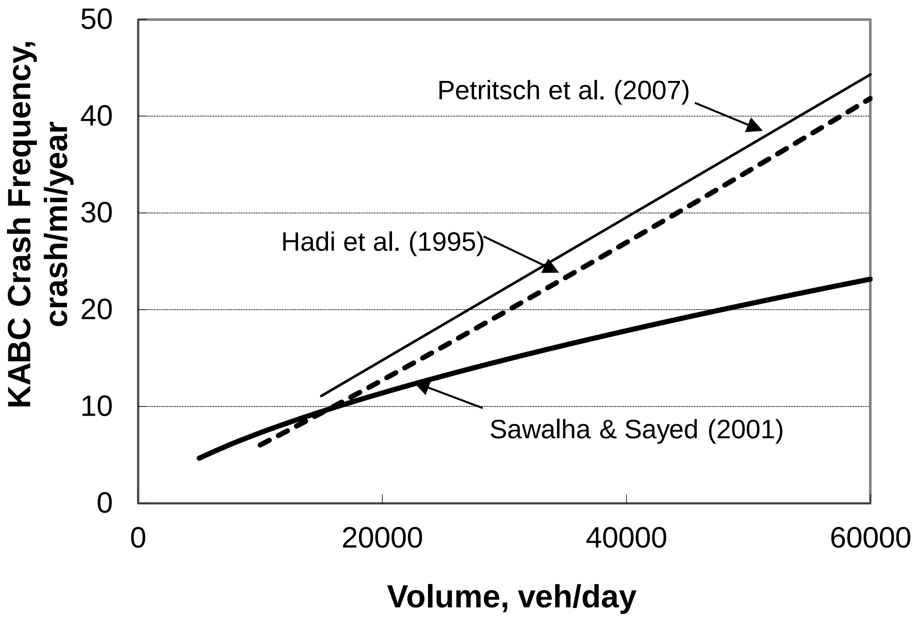

Figure 4. Models for six-lane divided urban or suburban arterials.

The variation in the preceding models' trends, combined with the inconsistent inclusion of input variables (as demonstrated in Table 1), suggests that the models may not be generalizable. Nevertheless, these models provide insight into the variables that should be included in a database needed to develop new models that would be more transferrable and include more input variables. Such models would allow designers and decision-makers to quantify the safety effects for a wide range of geometric and traffic control characteristics.

Comparison of CMFs

As was listed in Table 1, many CMFs are included in the preceding models. The trends of these CMFs are compared in the following paragraphs.

Land Use. CMF values for land use types are provided in Table 6. The CMF for business or office land uses derived by Sawalha and Sayed (2001) compares favorably to that derived by Bonneson and McCoy (1997) for business or office land uses on roadway segments with a TWLTL median.

Table 6. Land use CMF values.

Land Use Type	CMF Value by Median Type (Bonneson & McCoy, 1997)		CMF Value (Sawalha & Sayed, 2001)
	Raised	TWLTL	
Business or office	0.744	1.018	1.017
Residential or industrial	0.551	1.097	1.000

On-Street Parking. CMF values for the presence of on-street parking are provided in Table 7. The on-street parking CMF from HSM Chapter 12 was incorporated directly into the models developed by Bonneson and Pratt (2009). The CMF value for parallel parking from Bonneson and McCoy (1997) roughly agrees with that provided in HSM Chapter 12.

Table 7. On-street parking CMF values.

Road Type	CMF Value by Parking and Land Use Type			
	Parallel Parking		Angle Parking	
	Residential or Other	Commercial, Industrial, or Institutional	Residential or Other	Commercial, Industrial, or Institutional
2U, 3T (HSM Chapter 12)	1.465	2.074	3.428	4.853
4U, 4D, 5T (HSM Chapter 12)	1.100	1.709	2.574	3.999
4U, 4D, 5T, 6U, 6D, 7T (Bonneson & McCoy, 1997)	1.768		None provided	

Lane Width. The lane width CMF developed by Petritsch et al. (2007) is described by Equation 26. The lane width CMF developed by Bonneson and Pratt (2009) is described by Equation 83:

$$CMF_{lw} = \left(e^{-0.042[W_l - 12]} - 1.0\right)\frac{P_i}{0.26} + 1.0 \tag{83}$$

where,

CMF_{lw} = lane width CMF.
P_i = proportion of relevant crashes for the CMF (= 0.13 for nonrestrictive medians, 0.26 for restrictive medians).

The lane width CMFs are compared in Figure 5. The CMF developed by Petritsch et al. (2007) is shown to be more sensitive to lane width than that developed by Bonneson and Pratt (2009). The difference may be partially attributed to the different crash severities (KABC versus PDO) to which the CMFs apply.

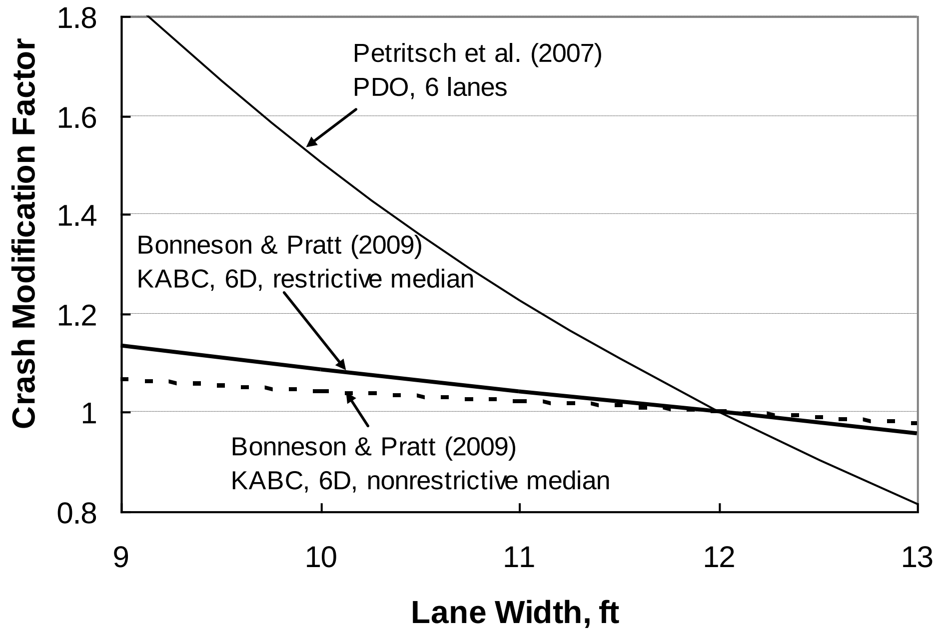

Figure 5. Lane width CMFs.

Outside Shoulder Width. Outside shoulder width CMFs developed by Petritsch et al. (2007) are described by Equations 22–24 for KA, BC, and PDO crashes, respectively. The outside shoulder width CMF developed by Bonneson and Pratt (2009) is described by Equation 84:

$$CMF_{sw} = \left(e^{-0.032[W_s - 1.5]} - 1.0\right)\frac{P_i}{0.11} + 1.0 \tag{84}$$

where,

CMF_{sw} = outside shoulder width CMF.
P_i = proportion of relevant crashes for the CMF (= 0.05 for nonrestrictive medians, 0.08 for restrictive medians).

The outside shoulder width CMFs are compared in Figure 6. The CMF for KA crashes developed by Petritsch et al. (2007) closely tracks the CMF for nonrestrictive median segments developed by Bonneson and Pratt (2009). Additionally, the CMF for PDO crashes developed by Petritsch et al. (2007) closely tracks the CMF for restrictive median segments developed by Bonneson and Pratt (2009).

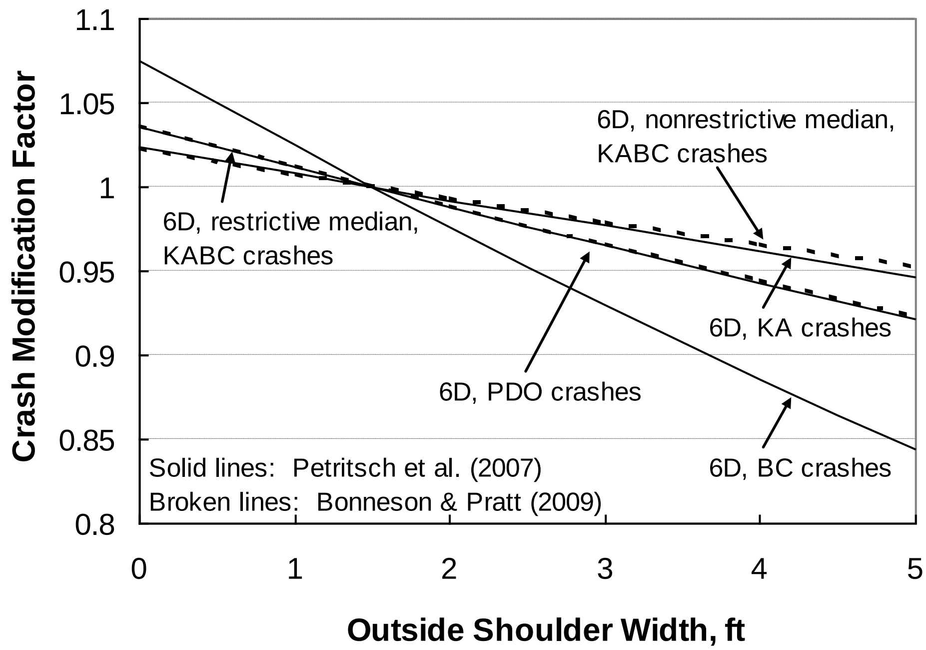

Figure 6. Outside shoulder width CMFs.

Inside Shoulder Width. Petritsch et al. (2007) developed inside shoulder width CMFs for KA, BC, and PDO crashes. These CMFs are described by Equations 19–21, respectively, and compared in Figure 7. The trends are similar to those seen for the outside shoulder width CMF and generally apply to the same range of values (i.e., approximately 0.92–1.04)

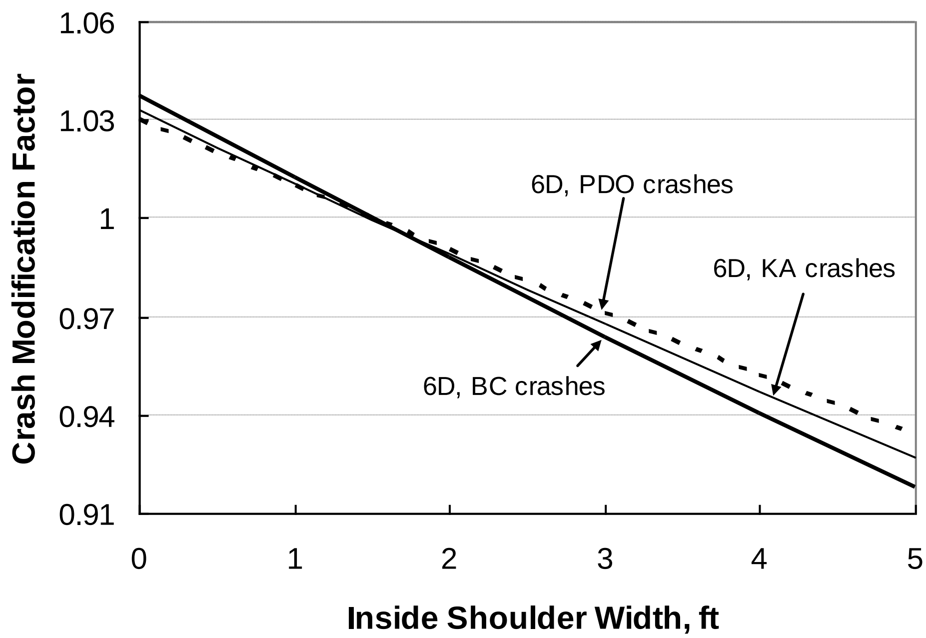

Figure 7. Inside shoulder width CMFs.

Median Width. CMFs for median width were developed by Petritsch et al. (2007) (see Equations 25–26), Bonneson and Pratt (2009), and Hadi et al. (1995) (see Equations 75–78). The CMFs developed by Bonneson and Pratt (2009) are described by Equations 85 and 86:

$$CMF_{mw,R} = e^{-0.041\left(\sqrt{W_m}-4\right)} \quad (85)$$

$$CMF_{mw,N} = e^{-0.0255\left(W_m-12\right)} \quad (86)$$

where,

$CMF_{mw,i}$ = median width CMF for median type *i* (restrictive or nonrestrictive).

These CMFs, along with that from HSM Chapter 12, are compared in Figure 8. The HSM Chapter 12 CMF applies only to traversable medians without traffic barriers, not including TWLTLs. As shown, there is considerable variation in the median width CMFs. This variation is likely due to other factors that are correlated with median type. For example, a restrictive median reduces the effective number of driveways by preventing through and left-turn movements into or out of driveways.

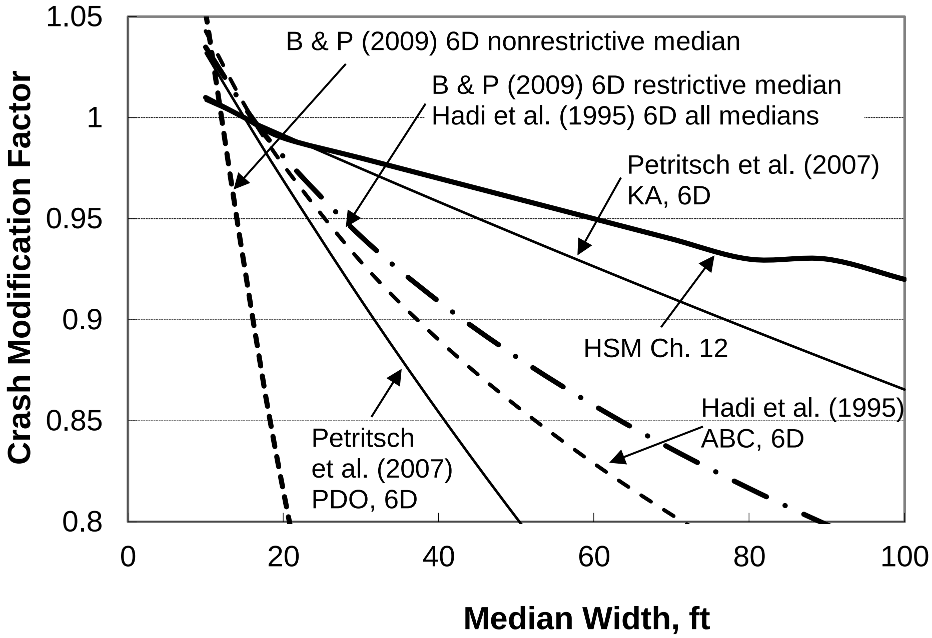

Figure 8. Median width CMFs.

Horizontal Curvature. CMFs for horizontal curvature were developed by Petritsch et al. (2007) (see Equations 11–13) and by Bonneson and Pratt (2009). The latter CMF is described by Equation 87:

$$CMF_{hc} = 1.0 + 0.97\left(0.147V_{sl}\right)^4 \frac{\left(1.47V_{sl}\right)^2}{32.2R^2} \quad (87)$$

where,

CMF_{hc} = horizontal curvature CMF.
R = curve radius, ft.

These CMFs are compared in Figure 9. For gradual and intermediate curves (e.g., $R \geq 1000$ ft), the CMF developed by Bonneson and Pratt (2009) compares favorably with the CMF developed by Petritsch et al. (2007) for KA crashes. The CMFs developed by Petritsch et al. for BC crashes and PDO crashes suggest that crashes of these severities decrease as horizontal curvature increases. When interpreted together, the three CMFs developed by Petritsch et al. suggest that the crash severity distribution changes when horizontal curvature is present. Specifically, more K and A crashes and fewer B, C, and PDO crashes occur.

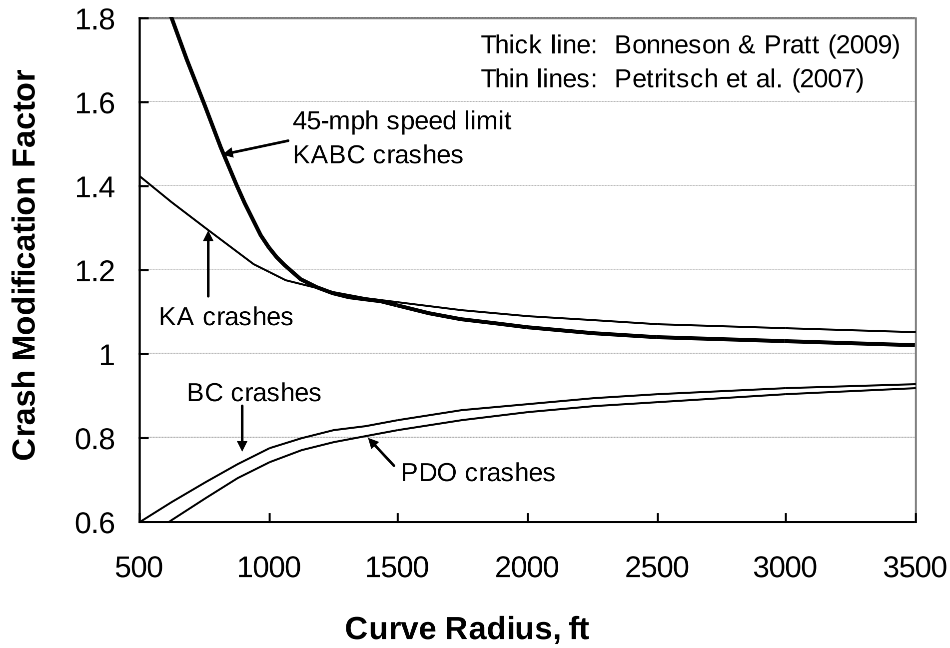

Figure 9. Horizontal curvature CMFs.

Access and Crossing Point Presence. Various CMFs have been developed to account for the safety influence of access and crossing point presence. Access points can take the form of driveways, signalized intersections, or unsignalized intersections. Crossing points can take the form of signalized intersections, unsignalized intersections, or crosswalks. For all of these CMFs, the base condition is no access or crossing points present.

Computed values for the various CMFs are provided in Table 8. The CMFs are compared in terms of the percentage increase in crashes associated with the presence of a single access or crossing point type on an example 1-mi urban street segment. That is, the CMF equation is evaluated with the number of points equal to 1, and 1.0 is subtracted from this value to obtain a percentage increase. These numbers can be used to compute the percentage increase in crashes due to more than one access or crossing point by raising the number to the power of the number of points. For example, the driveway density CMF by Petritsch et al. (2007) for BC crashes indicates that a 0.2 percent increase in BC crashes would occur due to the presence of one driveway on a 1-mi urban street segment. If three driveways were present, the predicted increase in crashes would be 0.6 percent (= $(1.002)^3 - 1$).

Table 8. Access or crossing point presence CMFs.

Access or Crossing Point Type	Source	Crash Severities	Equation Number	Percent Increase in Crashes per Point
Driveways	Petritsch et al. (2007)	BC	14	0.2
	Petritsch et al. (2007)	PDO	15	0.2
	Sawalha & Sayed (2001)	KABCO	46	1.7
	Bonneson & McCoy (1997)	KABCO	53	0.5
	Average	Not applicable		0.6
Signalized Intersections	Petritsch et al. (2007)	KA	16	2.9
	Petritsch et al. (2007)	BC	17	5.2
	Petritsch et al. (2007)	PDO	18	5.0
	Average	Not applicable		4.4
Unsignalized Intersections	Sawalha & Sayed (2001)	KABCO	43	9.5
	Bonneson & McCoy (1997)	KABCO	53	0.5
	Average	Not applicable		5.0
Crosswalks	Sawalha & Sayed (2001)	KABCO	44	8.6

The computed average values for percent increase in crashes suggest that intersections (either signalized or unsignalized) are associated with more crashes than driveways, which is intuitive. The percent increase in crashes for crosswalk presence is somewhat higher than expected and is likely correlated with pedestrian volumes at the sites included in the calibration dataset used to develop Equation 44.

Safety Prediction at Intersections

Different modeling methods have been used to account for intersection crashes. Earlier models were formulated in terms of total crashes and midblock crashes, such that intersection crashes could be obtained by subtracting the latter from the former. This approach was represented in Equations 54–59 and 79–82.

Some models for urban streets account for the presence of intersections (signalized and/or unsignalized) and crosswalks through the use of CMFs. This approach accounts for the presence of intersections, but not their geometric or traffic control characteristics. Equations 8, 10, 42, and 50–51 illustrate this approach. These equations can be used to infer the number of intersection-related crashes on an urban street facility by applying the equations twice—once with the CMF values computed based on the number of intersections and/or crosswalks present, and once with no intersections or crosswalks present.

The two aforementioned methods for predicting intersection-related crash frequency are flawed for two reasons. First, these approaches will yield the frequency of all crashes occurring near the intersection, regardless of whether they were truly intersection-related or just segment-related and occurring at or near the intersection. Second, these approaches will only include the crashes that occurred on the urban street being modeled (i.e., the major street) because only these crashes were included in the databases used to calibrate the urban street models. Crashes occurring on the minor-street approaches will not be included.

More recent efforts have yielded separate SPFs and CMFs for intersections, such that intersection geometric and traffic control characteristics could be directly modeled. This approach is represented in HSM Chapter 12 and was applied by Bonneson and Pratt (2009) and Bauer and Harwood (1998) using databases that included intersection-related crashes on all approaches. Table 9 summarizes the CMFs that are used with these SPFs, as well as the CMFs available in HSM Chapter 12 for intersections on two- and four-lane arterials.

Table 9. CMFs in intersection safety prediction models.

Variable	**CMFs by Source, Control Type, and Number of Legs**						
	HSM Chapter 12 (AASHTO, 2010)		**Bonneson & Pratt (2009)**		**Bauer & Harwood (1998)**		
	Stop	**Signal**	**Stop**	**Signal**	**Stop**		**Signal**
	3 or 4	**3 or 4**	**3 or 4**	**3 or 4**	**3**	**4**	**4**
Left-turn prohibition					Major	Major	
Left-turn lane	Major, minor	Major, minor	Major	Major, minor	Major		
Right-turn lane	Major, minor	Major, minor	Major	Major, minor			
Right turn on red		Major, minor					
Number of through lanes			Major, minor	Major, minor			Major, minor
Right-turn channelization			Major, minor	Major, minor	Minor	Minor	
Lane width			Major, minor	Major, minor	Major	Major	
Shoulder width			Major, minor			Major	
Median presence			Major		Major		
Access control						Major	Major
Functional class						Major	
Signal timing							Site
Signal phasing		Site					Site
Design speed							Major
Lighting	Site	Site			Site		
Red-light cameras		Site					
Bus stops[a]		Site					
Schools[a]		Site					
Alcohol sales establishments[a]		Site					

Note: Major = applicable to major street; Minor = applicable to minor street; Site = applicable to whole intersection.
[a] Applicable to vehicle-pedestrian crashes only.

The following subsections provide comparisons of the models that were developed by Bonneson and Pratt (2009) and Bauer and Harwood (1998), organized by control type (signal or stop controlled). The input variable values used with the CMFs are summarized in Table 10.

Table 10. Input variable values for intersection model comparisons.

Input Variable	Input Value by Source, Control Type, and Number of Legs				
	Bonneson & Pratt (2009)		Bauer & Harwood (1998)		
	Stop	Signal	Stop		Signal
	3 or 4	3 or 4	3	4	4
Left-turn prohibition			Turns permitted	Turns permitted	
Left-turn lane	Present on all legs	Present on all legs	Marked left-turn lanes		
Right-turn lane	None	None			
Number of through lanes	6 on major street; 2, 4, or 6 on minor street	6 on major street; 2, 4, or 6 on minor street		6 on major street	6 on major street; ≥ 4 or ≤ 3 on minor street
Right-turn channelization	None	None	None	None	
Lane width	12 ft	12 ft	12 ft	12 ft	
Shoulder width	1.5 ft			1.5 ft	
Median presence	None		Present or not present		
Access control				Partial	Partial
Functional class				Principal arterial	
Signal timing					Semiactuated
Signal phasing					Multiphase
Design speed					50 mph
Lighting			Present		

Signalized Intersections

The models calibrated by Bonneson and Pratt (2009) are described by Equations 88–94:

$$C_{3S} = 7.94 \times 10^{-7} AADT_{major}^{0.629} AADT_{minor}^{0.385} CMF_{lane} \quad (88)$$

$$C_{4S} = 5.88 \times 10^{-6} AADT_{major}^{0.459} AADT_{minor}^{0.397} CMF_{lane} \quad (89)$$

$$CMF_{lane} = CMF_{major} CMF_{minor} \quad (90)$$

$$CMF_{major} = e^{0.197(N_{major}-4)} P_{major} + 1.0(1 - P_{major}) \quad (91)$$

$$P_{major} = \frac{AADT_{major}}{AADT_{major} + AADT_{minor}} \quad (92)$$

$$CMF_{minor} = e^{0.197(N_{minor}-2)} P_{minor} + 1.0(1 - P_{minor}) \quad (93)$$

$$P_{minor} = \frac{AADT_{minor}}{AADT_{major} + AADT_{minor}} \quad (94)$$

where,

C_{3S} = KABC crash frequency at a three-leg signalized urban intersection, crash/year.

C_{4S} = KABC crash frequency at a four-leg signalized urban intersection, crash/year.

$AADT_{major}$ = major-street traffic volume, veh/day.
$AADT_{minor}$ = minor-street traffic volume, veh/day.
CMF_{lane} = number of lanes CMF.
N_{major} = number of lanes on the major street.
N_{minor} = number of lanes on the minor street.
P_{major} = proportion of traffic volume on the major street.
P_{minor} = proportion of traffic volume on the minor street.

The number of lanes CMF in Equation 90 can accommodate between two and six lanes on each of the two intersecting streets, with the constraint that the major street must have equal or more lanes than the minor street. Hence, with the use of this CMF, the SPFs described in Equations 88 and 89 can be applied to intersections on six-lane urban streets.

The model calibrated by Bauer and Harwood (1998) is described by Equations 95–98:

$$C_{4S} = 0.0032 AADT_{major}^{0.574} AADT_{minor}^{0.215} CMF_{lane} CMF_{speed} CMF_{phase} \quad (95)$$

$$CMF_{lane} = e^{-0.155 I_{lane}} \quad (96)$$

$$CMF_{speed} = e^{0.005 v_{des}} \quad (97)$$

$$CMF_{phase} = e^{-0.24 I_{2-phase}} = 0.787 \text{ for multiphase signal, } 1.000 \text{ for two-phase signal} \quad (98)$$

where:

I_{lane} = indicator variable for number of lanes on minor street (= 1 if three or fewer lanes, 0 if four or more lanes).
v_{des} = major-road design speed, mph.
$I_{2\text{-}phase}$ = indicator variable for two-phase signal operation (= 1 if multiphase signal, 0 if two-phase signal).

A comparison of Equations 89 (Bonneson and Pratt, 2009) and 95 (Bauer and Harwood, 1998) is provided in Figure 10. Two trends are evident. First, the models developed by Bonneson and Pratt predict notably more crashes than those developed by Bauer and Harwood. Second, the models developed by Bauer and Harwood show less sensitivity to the minor-street number of lanes compared to the models developed by Bonneson and Pratt.

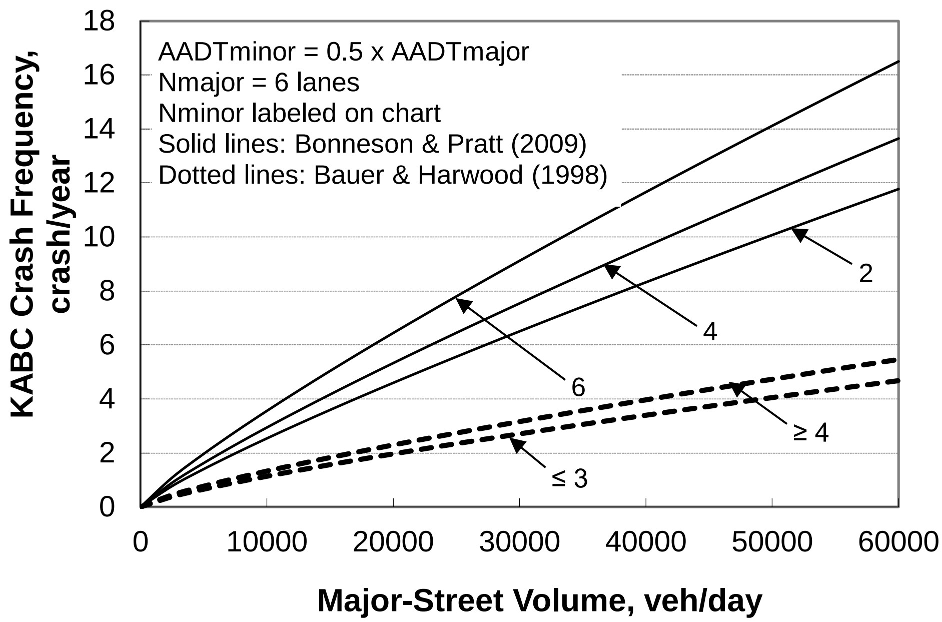

Figure 10. Models for urban four-leg signalized intersections.

As was listed in Table 9, several CMFs are included in the preceding models. The trends of these CMFs are compared in the following paragraphs. The CMFs from Bonneson and Pratt (2009) and from Bauer and Harwood (1998) apply to FI crashes. The CMFs from HSM Chapter 12 apply to all crashes.

Signal Timing Parameters. Bauer and Harwood (1998) provided CMFs to account for the safety effects of several different signal timing parameters. These CMFs are summarized in Table 11, along with the left-turn signal phasing CMF from HSM Chapter 12. The base condition inferred from the CMF values is the semi-actuated, two-phase signal operation. With both the Bauer and Harwood CMF for signal phasing and the HSM Chapter 12 CMF for left-turn signal phasing, the provision of protected left-turn phases is shown to reduce crashes.

Table 11. Signal timing parameters CMFs.

Source	CMF	Condition	Value
Bauer & Harwood (1998)	Signal timing	Pre-timed	0.95
		Semiactuated	1.00
		Fully actuated	1.49
	Signal phasing	Two-phase	1.00
		Multiphase	0.79
HSM Chapter 12	Left-turn signal phasing (per approach)	Protected	0.94
		Protected-permissive	0.99
		Permissive	1.00
	Left-turn signal phasing (four approaches)	Protected	0.78
		Protected-permissive	0.96
		Permissive	1.00

The left-turn signal phasing CMF as presented in HSM Chapter 12 is applied to each approach, such that the combined CMF value would be 0.78 (= 0.94^4) if protected left-turn phasing was provided on all four approaches. To facilitate comparison between this CMF and the signal phasing CMF developed by Bauer and Harwood (1998), the HSM Chapter 12 CMF was raised to the fourth power to represent cases where the given left-turn signal phasing was implemented on all four approaches. The HSM Chapter 12 CMF value for protected left-turn phasing at all four approaches (0.78) compares closely with the Bauer and Harwood (1998) CMF for multiphase signal phasing (0.79).

Left-Turn Lanes. CMFs for the presence of left-turn lanes were documented by Bonneson and Pratt (2009) and included in HSM Chapter 12. The CMFs in both sources are based on the work conducted by Harwood et al. (2002). A procedure was subsequently employed by Bonneson and Pratt (2008) to generalize the CMFs to multiple-approach applications and to add sensitivity to traffic volumes on each approach.

The left-turn lane CMF in HSM Chapter 12 is formulated based on a base condition of no left-turn lanes present, and it indicates that the addition of a left-turn lane on a single intersection approach results in a 7 percent reduction in crashes for a three-leg signalized intersection and a 10 percent reduction in crashes for a four-leg signalized intersection. The corresponding CMF values for these two cases are 0.93 and 0.90, respectively, and the CMFs are applied in a multiplicative manner if left-turn lanes are added to more than one intersection approach. For example, adding left-turn lanes to all four approaches of a signalized intersection would yield a combined left-turn lane CMF of 0.66 (= 0.90^4).

The left-turn lane CMF documented by Bonneson and Pratt (2009) is sensitive to traffic volumes on each approach. This CMF, unlike the HSM Chapter 12 left-turn lane CMF, is formulated for a base condition of left-turn lanes being present on all approaches, such that a crash increase would be observed if one or more left-turn lanes were removed. The reported values for the Bonneson and Pratt (2009) CMF can be inverted and compared with the HSM Chapter 12 CMF. This comparison is shown in Table 12 for all left-turn lane location cases at a four-leg intersection.

Table 12. Left-turn lane CMFs for four-leg signalized intersections.

Left-Turn Lane Location				CMF Value by Source	
Major Street		Minor Street		HSM Chapter 12	Bonneson & Pratt (2009)[a]
1 approach	2 approaches	1 approach	2 approaches		
X				0.90	0.85
		X		0.90	0.92
X	X			0.81	0.72
		X	X	0.81	0.84
X		X		0.81	0.78
X	X	X		0.73	0.66
X		X	X	0.73	0.71
X	X	X	X	0.66	0.60

[a] Minor-street volume = 0.5 × major-street volume.

For three-leg signalized intersections, the Bonneson and Pratt (2009) left-turn lane CMF applies only to the case of removing a left-turn lane from the major street. The CMF value for this case is 1.22 (or 0.82 for adding a left-turn lane).

Right-Turn Lanes. CMFs for the presence of right-turn lanes were documented by Bonneson and Pratt (2009) and included in HSM Chapter 12. The CMFs in both sources are based on work conducted by Harwood et al. (2002). A procedure was subsequently employed by Bonneson and Pratt (2008) to generalize the CMFs to multiple-approach applications and to add sensitivity to traffic volumes on each approach.

The right-turn lane CMF in HSM Chapter 12 is formulated based on a base condition of no right-turn lanes present, and it indicates that the addition of a right-turn lane on a single intersection approach results in a 4 percent reduction in crashes (or a corresponding CMF value of 0.96). The CMF is applied in a multiplicative manner if right-turn lanes are added to more than one intersection approach. For example, adding right-turn lanes to all four approaches of a signalized intersection would yield a combined right-turn lane CMF of 0.85 (= 0.96^4).

The right-turn lane CMF documented by Bonneson and Pratt (2009) is sensitive to traffic volumes on each approach. This CMF, such as the HSM Chapter 12 right-turn lane CMF, is formulated for a base condition of right-turn lanes not being present. A comparison of the right-turn lane CMFs from the two sources is shown in Table 13 for all right-turn lane location cases at a four-leg intersection.

Table 13. Right-turn lane CMFs for four-leg signalized intersections.

Right-Turn Lane Location				CMF Value by Source	
Major Street		Minor Street		HSM Chapter 12	Bonneson & Pratt (2009)[a]
1 approach	2 approaches	1 approach	2 approaches		
X				0.96	0.92
		X		0.96	0.96
X	X			0.92	0.85
		X	X	0.92	0.92
X		X		0.92	0.88
X	X	X		0.88	0.82
X		X	X	0.88	0.85
X	X	X	X	0.85	0.78

[a] Minor-street volume = 0.5 × major-street volume.

For three-leg signalized intersections, the Bonneson and Pratt (2009) right-turn lane CMF applies only to the case of adding a right-turn lane from the major street. The CMF value for this case is 0.90.

Right-Turn Channelization. A CMF for the presence of right-turn channelization (i.e., provision of free right-turn movements) was developed by Bonneson and Pratt (2009). It is formulated based on a base condition of no right-turn channelization present, and it is sensitive to traffic volumes on each approach. A listing of the right-turn channelization CMF values is shown in Table 14 for all right-turn channel location cases.

Table 14. Right-turn channelization CMFs for signalized intersections (based on Bonneson and Pratt, 2009).

Right-Turn Lane Location				CMF Value[a]	
Major Street		Minor Street		3-leg intersection	4-leg intersection
1 approach	2 approaches	1 approach	2 approaches		
X				1.11	1.09
		X		1.06	1.05
X	X			Not applicable	1.20
		X	X		1.10
X		X		1.18	1.14
X	X	X		Not applicable	1.26
X		X	X		1.20
X	X	X	X		1.32

[a] Minor-street volume = 0.5 × major-street volume.

The bottom row of Table 14 indicates that installation of right-turn channelization on all approaches of a four-leg signalized intersection would be associated with a 32 percent increase in FI crashes. Similarly, Bauer and Harwood (1998) derived a CMF value of 1.35, suggesting a 35 percent increase in crashes, for the provision of right-turn channelization at four-leg stop-controlled intersections. They stated that this finding seems counterintuitive, in that provision of right-turn channelization should be associated with a decrease in crashes. Bonneson and Pratt (2009) suggested that the increase in crashes may be due to the higher speeds associated with a free right-turn movement at a right-turn channel, compared to the slower speeds required to turn from a conventional right-turn lane. Another possible factor is the stopping of turning vehicles at the downstream portion of the right-turn channel while the drivers are waiting for a safe gap to merge into the receiving lane. Drivers waiting in this manner may become involved in rear-end crashes if other right-turning drivers do not have adequate sight distance to see them in the stopped position.

Other CMFs. The models developed by Bonneson and Pratt (2009) for urban signalized intersections included other CMFs. These additional CMFs include number of lanes and lane width. They are not presented here because they were taken from the report by Bauer and Harwood (1998) and adapted to include sensitivity to traffic volumes.

Unsignalized Intersections

The models calibrated by Bonneson and Pratt (2009) are described by Equations 99–105:

$$C_{3U} = 1.1\times10^{-7}\, AADT_{major}^{\;0.766} AADT_{minor}^{\;0.248} CMF_{lane} \qquad (99)$$

$$C_{4U} = 7.29\times10^{-7}\, AADT_{major}^{\;0.596} AADT_{minor}^{\;0.26} CMF_{lane} \qquad (100)$$

$$CMF_{lane} = CMF_{major} CMF_{minor} \qquad (101)$$

$$CMF_{major} = e^{-0.135(N_{major}-4)} P_{major} + 1.0(1 - P_{major}) \qquad (102)$$

$$P_{major} = \frac{AADT_{major}}{AADT_{major} + AADT_{minor}} \qquad (103)$$

$$CMF_{minor} = e^{-0.135(N_{minor}-2)} P_{minor} + 1.0(1 - P_{minor}) \qquad (104)$$

$$P_{minor} = \frac{AADT_{minor}}{AADT_{major} + AADT_{minor}} \quad (105)$$

where,

C_{3U}	=	KABC crash frequency at a three-leg unsignalized urban intersection, crash/year.
C_{4U}	=	KABC crash frequency at a four-leg unsignalized urban intersection, crash/year.

The number of lanes CMF in Equation 101 can accommodate between two and six lanes on each of the two intersecting streets, with the constraint that the major street must have equal or more lanes than the minor street. Hence, with the use of this CMF, the SPFs described in Equations 99 and 100 can be applied to intersections on six-lane urban streets.

The model calibrated by Bauer and Harwood (1998) is described by Equations 106–112:

$$C_{3U} = 0.0013 AADT_{major}^{0.696} AADT_{minor}^{0.238} CMF_{3,rtc} CMF_{lw} CMF_{div} \quad (106)$$

$$C_{4U} = 0.0092 AADT_{major}^{0.584} AADT_{minor}^{0.206} CMF_{4,rtc} CMF_{sw} \quad (107)$$

$CMF_{3,rtc} = e^{-0.581 I_{rtc}}$ = 0.559 if no right-turn channel is provided on minor-street approaches, 1.000 otherwise (108)

$CMF_{4,rtc} = e^{-0.3 I_{rtc}}$ = 0.741 if no right-turn channel is provided on minor-street approaches, 1.000 otherwise (109)

$$CMF_{lw} = e^{-0.048 W_l} \quad (110)$$

$CMF_{div} = e^{-0.182 I_{div}}$ = 0.834 for divided major street, 1.000 for undivided major street (111)

$$CMF_{sw} = e^{-0.02 W_s} \quad (112)$$

where,

$CMF_{3,rtc}$	=	right-turn channel presence CMF for three-leg stop-controlled intersections.
$CMF_{4,rtc}$	=	right-turn channel presence CMF for four-leg stop-controlled intersections.
CMF_{div}	=	major-street divided cross-section CMF.
I_{rtc}	=	indicator variable for right-turn channel presence (= 1 if channel is present on crossroad approaches, 0 otherwise).
I_{div}	=	indicator variable for divided cross-section (= 1 if major road is divided, 0 otherwise).

A comparison of Equations 100 (Bonneson and Pratt, 2009) and 107 (Bauer and Harwood, 1998) is provided in Figure 11. As shown, the model developed by Bonneson and Pratt predicts notably fewer crashes than the model developed by Bauer and Harwood.

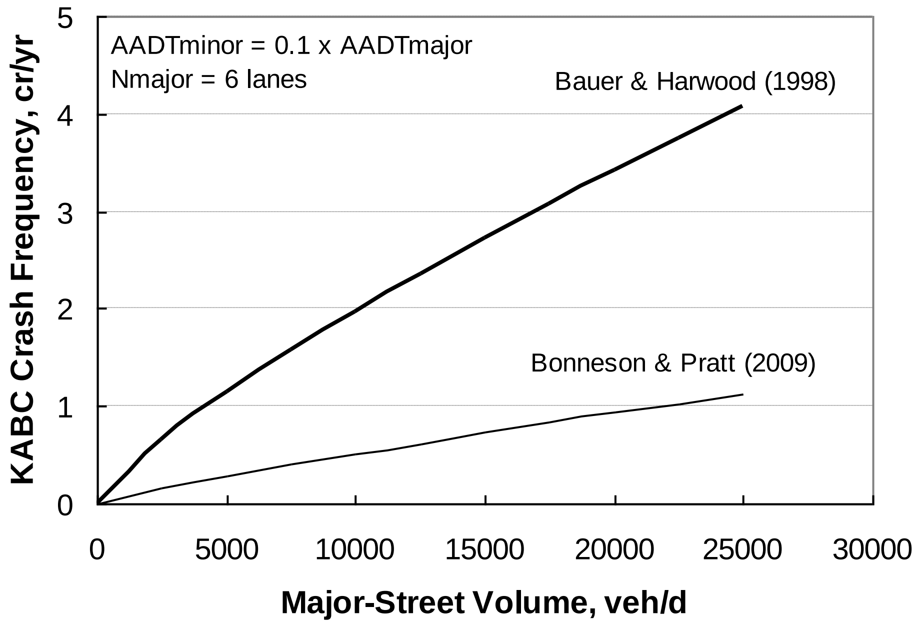

Figure 11. Models for urban four-leg stop-controlled intersections.

A comparison of Equations 99 (Bonneson and Pratt, 2009) and 106 (Bauer and Harwood, 1998) is provided in Figure 12. Two cases are shown for the Bauer and Harwood model—undivided cross-section on the major street, and divided cross-section on the major street. The model developed by Bonneson and Pratt predicts a crash frequency that is roughly the average of the two cases evaluated with the Bauer and Harwood model.

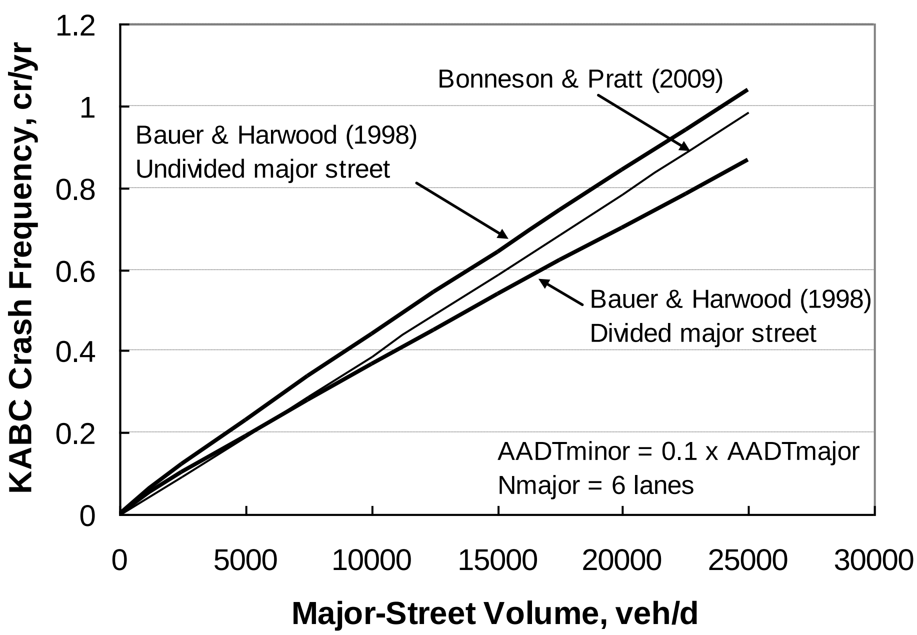

Figure 12. Models for urban three-leg stop-controlled intersections.

As was listed in Table 9, several CMFs are included in the preceding models. The trends of these CMFs are compared in the following paragraphs. The CMFs from Bonneson and Pratt (2009) and from Bauer and Harwood (1998) apply to FI crashes. The CMFs from HSM Chapter 12 apply to all crashes.

Left-Turn Lanes. CMFs for the presence of left-turn lanes on the major street were documented by Bonneson and Pratt (2009) and included in HSM Chapter 12. The CMFs in both sources are based on work conducted by Harwood et al. (2002). A procedure was subsequently employed by Bonneson and Pratt (2008) to generalize the CMFs to multiple-approach applications and to add sensitivity to traffic volumes on each approach.

The left-turn lane CMF in HSM Chapter 12 is formulated based on a base condition of no left-turn lanes present, and it indicates that the addition of a left-turn lane on a single intersection approach results in a 33 percent reduction in crashes for a three-leg unsignalized intersection and a 27 percent reduction in crashes for a four-leg unsignalized intersection. The corresponding CMF values for these two cases are 0.67 and 0.73, respectively, and the CMFs are applied in a multiplicative manner if left-turn lanes are added to more than one intersection approach. For example, adding left-turn lanes to both major-street approaches of an unsignalized intersection would yield a combined left-turn lane CMF of 0.45 (= 0.67^2).

The left-turn lane CMF documented by Bonneson and Pratt (2009) is sensitive to traffic volumes on each approach. This CMF, unlike the HSM Chapter 12 left-turn lane CMF, is formulated for a base condition of left-turn lanes being present on all approaches, such that a crash increase would be observed if one or more left-turn lanes were removed. The reported values for the Bonneson and Pratt CMF can be inverted and compared with the HSM Chapter 12 CMF. This comparison is shown in Table 15 for all left-turn location cases at a four-leg intersection.

Table 15. Left-turn lane CMFs for unsignalized intersections.

Major-Street Legs with Left-Turn Lanes	CMF Value by Source and Number of Legs			
	HSM Chapter 12		Bonneson & Pratt (2009)[a]	
	3-leg intersection	4-leg intersection	3-leg intersection	4-leg intersection
One leg	0.67	0.73	0.75	0.76
Both legs		0.53		0.58

Note: Shaded cell: forth leg of a three-leg intersection is not present.
[a] Minor-street volume = 0.1 × major-street volume.

Right-Turn Lanes. CMFs for the presence of right-turn lanes on the major street were documented by Bonneson and Pratt (2009) and included in HSM Chapter 12. The CMFs in both sources are based on work conducted by Harwood et al. (2002). A procedure was subsequently employed by Bonneson and Pratt (2008) to generalize the CMFs to multiple-approach applications and to add sensitivity to traffic volumes on each approach.

The right-turn lane CMF in HSM Chapter 12 is formulated based on a base condition of no right-turn lanes present, and it indicates that the addition of a right-turn lane on a single intersection approach results in a 14 percent reduction in crashes (or a corresponding CMF value of 0.86). The CMF is applied in a multiplicative manner if right-turn lanes are added to more than one intersection approach. For example, adding right-turn lanes to both approaches of an unsignalized intersection would yield a combined right-turn lane CMF of 0.74 (= 0.86^2).

The right-turn lane CMF documented by Bonneson and Pratt (2009) is sensitive to traffic volumes on each approach. This CMF, like the HSM Chapter 12 right-turn lane CMF, is formulated for a base condition of right-turn lanes not being present. A comparison of the right-turn lane CMFs from the two sources is shown in Table 16 for all right-turn location cases at a four-leg intersection.

Table 16. Right-turn lane CMFs for unsignalized intersections.

Major-Street Legs with Left-Turn Lanes	CMF Value by Source and Number of Legs			
	HSM Chapter 12		Bonneson & Pratt (2009)[a]	
	3-leg intersection	4-leg intersection	3-leg intersection	4-leg intersection
One leg	0.86	0.86	0.94	0.94
Both legs		0.74		0.89

[a] Minor-street volume = 0.1 × major-street volume.

Right-Turn Channelization. CMFs for the presence of right-turn channelization were developed by Bonneson and Pratt (2009) and Bauer and Harwood (1998). They are formulated based on a base condition of no right-turn channelization present. The CMF by Bonneson and Pratt is sensitive to traffic volumes on each approach. A listing of the right-turn channelization CMF values is shown in Table 17 for all right-turn channel location cases.

Table 17. Right-turn channelization CMFs for unsignalized intersections (based on Bonneson and Pratt, 2009).

Right-Turn Lane Location				CMF Value[a]	
Major Street		Minor Street		3-leg intersection	4-leg intersection
1 approach	2 approaches	1 approach	2 approaches		
X				1.74	1.70
		X		1.07	1.07
X	X			Not applicable	2.91
		X	X		1.15
X		X		1.86	1.82
X	X	X		Not applicable	3.11
X		X	X		1.96
X	X	X	X		3.35

[a] Minor-street volume = 0.1 × major-street volume.

Table 17 shows that installation of right-turn channelization is associated with an increase in FI crashes. Similarly, Bauer and Harwood (1998) derived a CMF value of 1.35 for the provision of right-turn channelization at four-leg unsignalized intersections and 1.24 for the provision of right-turn channelization at three-leg unsignalized intersections. They stated that this finding seems counterintuitive, in that provision of right-turn channelization should be associated with a decrease in crashes. Bonneson and Pratt (2009) suggested that the increase in crashes may be due to the higher speeds associated with a free right-turn movement at a right-turn channel, compared to the slower speeds required to turn from a conventional right-turn lane. Another possible factor is the stopping of turning vehicles at the downstream portion of the right-turn channel while the drivers are waiting for a safe gap to merge into the receiving lane. Drivers waiting in this manner may become involved in rear-end crashes if other right-turning drivers do not have adequate sight distance to see them in the stopped position.

Other CMFs. The models developed by Bonneson and Pratt (2009) for urban unsignalized intersections included other CMFs. These additional CMFs include number of lanes, lane width, shoulder width, and median type and width. As discussed above, they are not presented here because they were taken from the report by Bauer and Harwood (1998) and adapted to include sensitivity to traffic volumes.

SAFETY PREDICTION FOR ONE-WAY ARTERIALS

This section summarizes the literature on the safety performance of one-way arterials. The first subsection covers the segments, while the second subsection encompasses intersections with one or more legs that operate as one-way streets.

Safety Prediction at Roadway Segments

Safety prediction models have not yet been developed for one-way urban street segments. However, various reports and articles have been published about operational and safety performance changes that have been observed following the conversion of two-way urban street or frontage road segments to one-way operation. These sources provide some insight into the safety performance that would be expected on one-way urban street segments.

Eisele et al. (2011) conducted a before-after evaluation of freeway frontage roads that were converted from two-way operation to one-way operation. They proposed a CMF of 0.43 for KABC segment-related crashes for frontage road conversions, meaning that the average reduction in FI crashes on frontage road segments following a conversion is 57 percent (or 1.00 − 0.43, expressed as percent). Their study included 19.2 mi of frontage road segments that were converted and 22.1 mi of two-way frontage road segments that were used as comparison sites. However, they acknowledged that their results were affected by the crash reduction trends that were observed near freeway entrance or exit ramps that connected to the frontage road segments. They were unable to isolate the ramp-related crashes from other crashes occurring on the frontage road segments. Hence, a 57 percent crash reduction is likely greater than would occur on a converted urban street where ramp connections do not exist.

In an article about converting urban streets from two-way operation to one-way operation in New York City, Wiley (1959) reported that pedestrian crashes decreased by about 25 percent following the conversion. He did not specify whether these reductions applied to crossings at intersections, midblock crossings, or both, but he acknowledged that numerous midblock pedestrian crossings occur in New York City.

A comparison by Hocherman et al. (1990) of crash rates on one-way and two-way urban street segments in Jerusalem yielded mixed results. In their analysis, one-way streets were found to have lower crash rates in central business district areas, particularly for pedestrian crashes, while two-way streets were found to have lower crash rates in non-central business district areas. Their findings are provided in Table 18. Most of the computed relative risk values in the top portion of the table are greater than 1.00, indicating that two-way streets have lower crash rates. However, the relative risk values for pedestrian crashes and total crashes on one-way streets in the central business district are less than 1.00, suggesting that one-way streets are safer for pedestrians and in general (since pedestrian crashes represented over 76 percent of crashes in the central business district). However, Hocherman et al. acknowledged that their findings regarding trends in the central business district must be interpreted cautiously because of the limited number of crashes observed in that area.

Table 18. Midblock crash rates and counts on one-way and two-way streets (based on Hocherman et al., 1990).

Performance Measure	Area Type	Intersection Type	Pedestrian	Vehicle	Total
Midblock Crash Rate (crashes/mvm)	Central Business District	One-Way Streets	0.79	0.29	1.09
		Two-Way Streets	1.00	0.24	1.24
		Relative Risk	0.79	1.20	0.88
	Non-Central Business District	One-Way Streets	1.17	0.72	1.90
		Two-Way Streets	0.60	0.45	1.05
		Relative Risk	1.97	1.61	1.81
Midblock Crash Count	Central Business District	One-Way Streets	25	9	34
		Two-Way Streets	24	6	30
		Total	49	15	64
	Non-Central Business District	One-Way Streets	102	63	165
		Two-Way Streets	477	359	836
		Total	579	422	1001

In addition to the preceding trends, Hocherman et al. (1990) also observed a slight difference in crash severity when comparing one-way and two-way streets. In their crash dataset, 18 percent of midblock crashes on one-way streets were severe or fatal, while 22 percent of midblock crashes on two-way streets were severe or fatal. The difference was more noteworthy on streets that were classified as local (rather than arterial or collector). The percentage of severe or fatal midblock crashes on local streets was 16 percent for one-way and 27 percent for two-way streets. As a possible explanation for this trend, they noted that head-on crashes cannot occur on one-way streets unless one driver proceeds in the wrong direction.

Safety Prediction at Intersections

Safety prediction models have not yet been developed for intersections on one-way urban streets. However, reports and articles about operational and safety performance changes that have been observed following the conversion of two-way urban street or frontage road segments to one-way operation can yield insight into the safety performance that would be expected at intersections on one-way urban streets. A summary of the key issues is provided in the following paragraphs.

Underlying Principles. Stemley (1998) and Smith and Hart (1949) observed that there are fewer conflict points at four-leg intersections of one-way streets than intersections of two-way streets. The number of conflict points for three types of intersections is summarized in Table 19. Note that the number of conflict points decreases significantly when comparing an intersection of two two-way streets with an intersection of a two-way street and a one-way street, and the number of conflict points is even fewer for an intersection of two one-way streets.

Table 19. Conflict points at four-leg intersections (based on Smith and Hart, 1949).

Intersection Type	Conflict Point Count by Type		
	Crossing	Merge/Diverge	Pedestrian-Vehicle
Two-way/two-way	16	8	16
Two-way/one-way	5	6	10
One-way/one-way	1	4	6

Observations have also been made about human factors issues associated with one-way street traffic operations. Smith and Hart (1949) illustrated that a driver approaching an intersection of two two-way streets has three areas of concern where he or she needs to look for opposing traffic—to the left, to the right, and (if making a left turn) toward the opposing through vehicles. At an intersection of a two-way street and a one-way street, drivers have two areas of concern (to the left and to the right for drivers on the one-way street, and to one side and toward the opposing through vehicles for drivers on the two-way street). At an intersection of two one-way streets, drivers only need to look for opposing traffic from one direction of the intersecting street. It has been similarly observed that pedestrians crossing a one-way street only have to look for traffic in one direction instead of two (Stemley, 1998; Zegeer, 1983).

In an analysis of the operational and safety effects of pedestrian signalization alternatives, Zegeer et al. (1983) reported that intersections of one or more one-way streets experience significantly fewer pedestrian crashes than intersections of two two-way streets. In a branching analysis of mean pedestrian crash frequencies, they found that at intersections with entering volumes of fewer than 27,500 veh/day, the mean pedestrian crash frequency was 0.477 crash/year at intersections of two two-way streets or a two-way street and a one-way street, and 0.241 crash/year at intersections of two one-way streets. In other words, the pedestrian crash frequency at intersections of two one-way streets was roughly half of that at other intersections.

Experience with Two-Way to One-Way Frontage Road Conversion. Eisele et al. (2011) conducted a before-after evaluation of freeway frontage roads that were converted from two-way operation to one-way operation. All the frontage road conversions were located in an urban environment. They proposed the CMFs listed in Table 20 for different subsets of intersection-related KABC crashes. The CMFs show that intersection-related crashes are decreased significantly when two-way frontage roads are converted to one-way operation.

Table 20. Intersection CMFs for two-way to one-way frontage road conversion (based on Eisele et al., 2011).

Crash Category	CMF Value
Opposite-direction crashes	0.20
Opposite-direction crashes involving a left-turning vehicle	0.15
Angle and opposite-direction crashes involving a left-turning vehicle	0.23
Minor injury (C) crashes	0.14

Safety Prediction Model for Diamond Ramp Terminals. In terms of entering traffic movements, the intersection of a two-way street and a one-way street resembles that of a ramp terminal at a conventional diamond interchange, where diagonal entrance and exit ramps intersect a two-way crossroad. Hence, the safety prediction models developed by Bonneson et al. (2012) for this type of ramp terminal may be applicable to an intersection of a two-way urban street and a one-way urban street. These models are described by Equations 113 and 114:

$$C_{D4,sg} = e^{(-2.015+1.191\ln[AADT_{xrd}/1000]+0.131\ln[AADT_{ex}/1000+AADT_{en}/1000])} \quad (113)$$

$$C_{D4,st} = e^{(-3.064+1.008\ln[AADT_{xrd}/1000]+0.177\ln[AADT_{ex}/1000+AADT_{en}/1000])} \quad (114)$$

where,

$C_{D4,sg}$	=	KABC crash frequency at a signalized four-leg diamond ramp terminal, crash/year.
$C_{D4,st}$	=	KABC crash frequency at a one-way stop-controlled four-leg diamond ramp terminal, crash/year.
$AADT_{xrd}$	=	two-way traffic volume on the crossroad, veh/day.
$AADT_{ex}$	=	exit ramp traffic volume, veh/day.
$AADT_{en}$	=	entrance ramp traffic volume, veh/day.

For intersections with six lanes on the major street, Equations 113 and 114 can be reformulated as follows:

$$C_{D4,sg} = 1.44 \times 10^{-5} AADT_{xrd}^{1.191} AADT_{ex}^{0.131} AADT_{en}^{0.131} \quad (115)$$

$$C_{D4,st} = 1.3 \times 10^{-5} AADT_{xrd}^{1.008} AADT_{ex}^{0.177} AADT_{en}^{0.177} \quad (116)$$

The crash frequency trends predicted by Equations 115 and 116 are shown graphically in Figure 13 for the traffic volume ranges applicable to the models. When compared to the trends shown in Figure 10 (for signalized intersections of two two-way streets) and Figure 12 (for three-leg stop-controlled intersections of two two-way streets), the models for diamond interchange ramp terminals predict notably more crashes. This finding contrasts with the CMFs in Table 20 that suggest fewer crashes occur at an intersection of a two-way street and a one-way street. The comparison of a ramp terminal to an urban intersection must be made with caution because of the different nature of traffic patterns and the two facility types. Nonetheless, the model forms shown in Equations 115 and 116 are applicable to intersections of a two-way street and a one-way street.

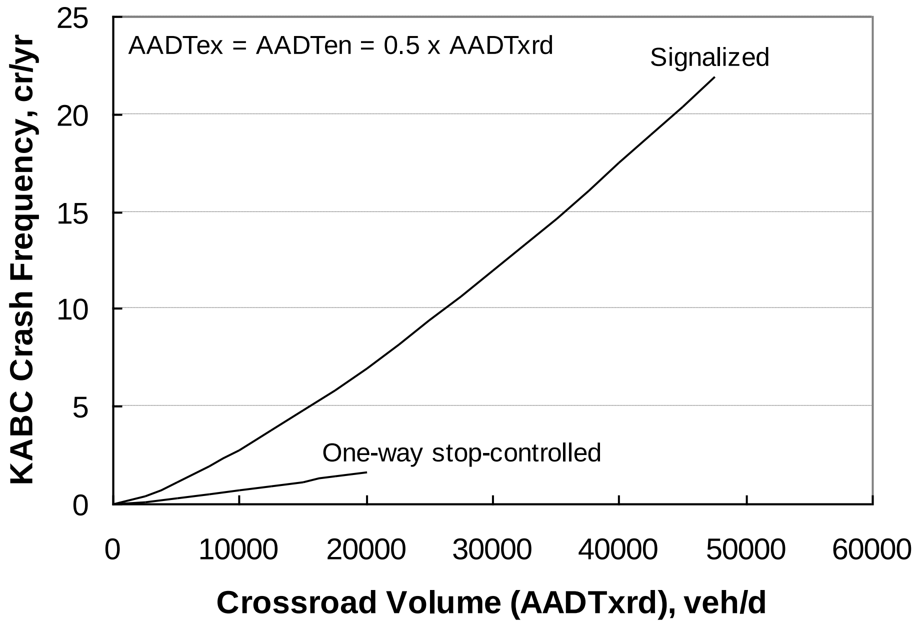

Figure 13. Models for four-leg diamond interchange ramp terminals (Bonneson et al., 2012).

CHAPTER 3. FRAMEWORK FOR SAFETY PREDICTION

This chapter describes the proposed methodology for estimating the safety performance of six or more lanes and one-way urban and suburban arterials. The chapter is divided into two sections. The first section presents the characteristics of models and methods that have been used for estimating the safety performance of different highway types in the HSM. The second section describes the methodology used for estimating the SPFs and CMFs for this project.

MODEL CALIBRATION METHODS

This section discusses important characteristics and issues related to the development of safety prediction methodologies. This section focuses on the methods most relevant to this research project.

Safety Prediction Method

Although there is a large body of predictive methods (see Lord and Mannering, 2010; Mannering and Bhat, 2014; Mannering et al., 2016), currently only two methods have been proposed for safety prediction model development for inclusion in the HSM. The first method consists of developing models for base conditions and adjusts the predicted values using CMFs, while the second method consists of using a full model to quantify the safety performance of various types of highway entities and develop CMFs from the cross-sectional model.

The models estimated for both methods are based on count data regression methodologies (Cameron and Trivedi, 1998; Winkelmann, 2008). The most basic count data models are the Poisson and Poisson-gamma (also known as NB). Both models belong to the family of generalized linear models. For the Poisson model to work, the mean has to equal the variance. However, in practice, it has been found that count data often exhibit overdispersion, meaning that the variance is larger than the mean (Lord, Washington, et al., 2005). On rare occasions, the data or modeling output may show characteristics of under-dispersion (Oh et al., 2006; Lord et al., 2010). To overcome the problem related to the overdispersion, the Poisson-gamma model has been proposed as a viable alternative to the Poisson model (Hilbe, 2011). The Poisson-gamma model has become very popular because it has a closed-form equation, and the mathematics to manipulate the relationship between the mean and the variance is relatively simple (Lord and Mannering, 2010). Furthermore, all statistical software packages have incorporated an NB function that simplifies the analysis of count data.

The Poisson-gamma model in highway safety applications has been shown to have the following probabilistic structure: the number of crashes at the *i*-th entity (road section, intersections, etc.) and *t*-th time period, Y_{it}, when conditional on its mean, θ_{it}, is assumed to be Poisson distributed and independent over all entities and time periods as follows (Miaou and Lord, 2003):

$$Y_{it} \mid \theta_{it} \sim Po(\theta_{it}) \qquad i = 1, 2, \ldots, I \text{ and } t = 1, 2, \ldots, T \tag{117}$$

The mean of the Poisson is structured as:

$$\theta_{it} = \mu_{it} \exp(\varepsilon_{it}) \quad (118)$$

where,

μ_{it} = a function of the covariates (X)
(e.g., $\mu_{it} = \exp\left(\beta_0 + \beta_1 X_{it1} + \beta_2 X_{it2} + \cdots + \beta_p X_{itp}\right)$ where p is the number of covariates).

β = a vector of unknown coefficients.

ε_{it} = the model error independent of all the covariates.

It is usually assumed that exp(ε_{it}) is independent and gamma distributed with a mean equal to 1 and a variance 1 / ϕ for all *i* and *t* (here ϕ is the inverse dispersion parameter, with ϕ > 0). With this characteristic, it can be shown that Y_{it}, conditional on μ_{it} and ϕ , is distributed as a Poisson-gamma random variable with a mean μ_{it} and a variance $\mu_{it}(1+\mu_{it}/\phi)$, respectively.

With the recent computational advancements in Bayesian statistics (Gelman et al., 2004), there has been a significant number of new models that have been proposed to analyze count data. In most cases, the error terms of these models are simply re-parameterized. These models include the Poisson-lognormal (Miaou et al., 2003), the Conway-Maxwell-Poisson (Lord et al., 2008), the Poisson-Weibull (Cheng et al., 2012), the NB-Lindley (Geedipally et al., 2012), and the Sichel model (Zou et al., 2013), among others. In some cases, these models offer similar statistical performances to the Poisson-gamma model, while others are more flexible to capture the overdispersion or handle under-dispersion. Although Bayesian models are more flexible to analyze complex modeling structures, they can take a long time for the model to converge.

To simplify the description and be consistent with the parameterization proposed in the HSM, the mean of the model (or predicted value), θ, is defined with the variable N.

Base Models + CMFs

The structure of the crash prediction algorithm proposed by Harwood et al. (2000) is as follows:

$$N_{rs} = N_{br} \times \left(CMF_{1r} \times CMF_{2r} \ldots CMF_{nr}\right) \quad (119)$$

$$N_{in} = N_{bi} \times \left(CMF_{1i} \times CMF_{2i} \ldots CMF_{ni}\right) \quad (120)$$

where,

N_{rs} = predicted number of total roadway segment crashes per year after application of CMFs.

N_{in} = predicted number of total intersection-related crashes per year after application of CMFs.

N_{br} = predicted number of total roadway segment crashes per year for base conditions.

N_{bi} = predicted number of total intersection-related crashes per year for base conditions.

$CMF_{1r}\ CMF_{2r}\ \ldots\ CMF_{nr}$ = CMFs for various road segment features (1, 2, …, *n*).

$CMF_{1i}\ CMF_{2i}\ \ldots\ CMF_{ni}$ = CMFs for various intersection features (1, 2, … , *n*).

The CMFs are multiplicative factors that are used to account for differences between actual roadway characteristics and those for which the base models apply. In applying the algorithm to a jurisdiction or time period different from that for which the base model is estimated, a calibration factor is applied to the model, calculated as the ratio of the observed number of crashes at a sample of sites to the predicted number of crashes prior to the calibration factor being applied. Harwood et al. (2000) recommended that the sample for estimating this calibration factor be such that the distribution of traffic volumes is similar to that in the data used for the original calibration.

The base condition model is calibrated using a database that is assembled to include only segments or intersections that have characteristics equal to base conditions, as specified in the HSM. The form of the model is as follows:

$$N_{br} = \beta_0 \times L \times AADT^{\beta_1} \tag{121}$$

$$N_{bi} = \beta_0 \times AADT_{maj}^{\beta_1} \times AADT_{\min}^{\beta_2} \tag{122}$$

This modeling structure was proposed for Chapters 10, 11, and 12 of the HSM. For this modeling structure, the base models and CMFs are estimated independently. Although base models are simple to use (i.e., for recalibration purposes), these models are most likely affected by omitted variable bias (Lord and Mannering, 2010). This bias can influence the predictability of regression models. It should be pointed out that CMFs can also be negatively influenced by data and methodological issues (Gross et al., 2010).

Full Model

The full model is calibrated using a database within which each safety-related variable (e.g., lane width, median width, etc.) has a representative range of values. Each variable is included in the model, and their coefficients are calibrated using regression analysis. The form of this model is shown as follows:

$$N_{rs} = \beta_0 \times L \times AADT^{\beta_1} \times e^{\beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n} \tag{123}$$

$$N_{bi} = \beta_0 \times AADT_{maj}^{\beta_1} \times AADT_{\min}^{\beta_2} \times e^{\beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n} \tag{124}$$

where,

X_{i} = site-related variable (e.g., lane width, median width, turning lane; i = 0, 1, 2….).

As performed by Bonneson et al. (2012) for the HSM chapters on freeways and interchanges, full models can be used for estimating base models and CMFs simultaneously. This modeling procedure also has the advantage of overcoming the regression-to-the-mean (RTM) bias since the models and CMFs are estimated using cross-sectional data; RTM only affects before-after studies or repeated measurements. This is even more important given recent research that showed that the EB method can still provide a biased estimate when it is used for developing CMFs using before-after data (Lord and Kuo, 2012). The full models and CMFs developed by Bonneson et al. (2012) are also based on an NB error distribution. It should be pointed out that the full model may not be able to capture nonlinear relationships between crashes and explanatory variables. Capturing these relationships is dependent on the modeling structure of the selected model. For instance, generalized additive models (Xie and Zhang, 2008) and Diritchlet-based models (Heydari et al., 2016; Shirazi et al., 2016), which are included in the family of semi-parametric models, can be used to this effect.

CRASH SEVERITY DISTRIBUTION

The predictive models in HSM Chapters 10, 11, and 12 differ from each other. In Chapter 10, only one single predictive model is provided. This model estimates the total number of crashes. To obtain the crash frequency by severity, the user needs to apply a severity distribution table provided in the chapter. Three different predictive models are provided in Chapter 11 for estimating the frequency for different severity levels: KABCO (total number of crashes), KABC, and KAB. HSM Chapter 12 includes models for predicting three severity levels (i.e., KABCO, KABC, and O or PDO) for each of three crash types (i.e., multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related collisions). Research by Milton et al. (2008) indicates that many traffic characteristics and geometric features influence the crash severity distribution. Wang et al. (2011) recommended the need to combine crash frequency predictions (i.e., SPFs) with crash SDFs. An SDF is represented by a discrete choice model. It is used to predict the proportion of crashes in each of the severity categories. The SDF can be used with the SPFs to estimate the expected crash frequency for each severity category. Such models could be calibrated using a common database. Bonneson et al. (2012) used this procedure and developed SPFs for KABC and PDO crashes separately, as well as SDFs to estimate the proportions of K, A, B, and C crashes. Savolainen et al. (2011) provided a good review of the issues and an intensive list of models that can be used for analyzing crash severity.

CRASH TYPE DISTRIBUTION

Given the differences observed in the characteristics associated with different collision types, some transportation safety analysts have recently proposed that distinct crash prediction models should be developed for different categories of crashes when the objective of the study consists of estimating the safety performance of highway segments (Geedipally and Lord, 2010; Jonsson et al., 2009; Lord, Manar, et al., 2005). For instance, Jonsson et al. (2009) compared models produced from the total number of crashes (aggregated data) and those estimated for different crash types. Using data collected for *NCHRP 17-29: Methodology to Predict the Safety Performance of Rural Multilane Highways* (i.e., HSM Chapter 11), the authors reported that models produced for different crash type provided a better fit than models estimated from aggregated data. Hence, Jonsson et al. recommended that using fixed proportions for estimating the number of crashes by collision type should be avoided.

Expanding on the work of Jonsson et al. (2009), Geedipally et al. (2010) developed models for different collision types by estimating the proportion using a discrete choice modeling framework (similar to the methodology used for developing SDFs above); this topic was also discussed in Geedipally and Lord (2010). These researchers noted that developing distinct models provided better predicting performance than developing models combining all crash categories together. However, the authors stated that it is not always possible to develop separate models for different collision types due to sample size issues and recommended the method that is based on the proportion estimated using a discrete choice modeling framework. In most cases, the motivation for separating models by the number of vehicles involved in the crash is based on the shape of the functional form linking crash types to the traffic flow variables, which have been found to be very different from one another. This work supported the analysis carried out by Lord, Manar, et al. (2005), who noted that the relationship between traffic flow rate and crash frequency varies by crash type. In sum, the use of tables for estimating crash type distribution proportions may not be adequate for some safety evaluations. A more accurate estimate of crash frequency is obtained when it can be estimated for each specific collision type separately. Again, developing this kind of model requires a very large dataset.

DISPERSION PARAMETER

Past research in highway safety has shown that the dispersion parameter can potentially be dependent upon the covariates of the model and could vary from one observation to another (Heydecker and Wu, 2001; Hauer, 2001; Miaou and Lord, 2003; Geedipally et al., 2009). This characteristic has been shown to be important, especially when the mean function is mis-specified, such as models that only incorporate entering traffic flows (Mitra and Washington, 2007). In previous studies, the varying dispersion parameter has been shown to influence EB estimates since the dispersion parameter plays an important role in the weight factors assigned to the predicted and observed values of this estimate (Geedipally et al., 2009). Others have reported that Poisson-gamma models with a varying dispersion parameter provide a better statistical fit and influence the computation of confidence intervals of the gamma mean and the predictive response compared to the fixed dispersion parameter.

A large number of different parameterizations have been proposed for estimating the dispersion parameter that varies across observations (Geedipally et al., 2009). One of them consists of modeling the dispersion parameter as a function of segment length. Using a hypothetical example, Hauer (2001) noted that shorter segments are subjected to greater variation than longer segments and unduly influence the long-term estimate of the segment (when estimated using the maximum-likelihood method). He suggested the following parameterization to model the variance function, in which the inverse dispersion parameter for observation i is equal to the length of the segment multiplied by a fixed constant, $\alpha = \delta \times L$. He also proposed a more generalized parameterization where $\alpha = \delta \times L^{\gamma}$, with $\gamma = [0, 1]$, but reported that this parameterization suffered from important limitations. The safety prediction methodologies developed for HSM Chapters 10 and 11 recognize the need for this sensitivity to segment length. SPFs in HSM Chapter 12 do not include this sensitivity. Rather, HSM Chapter 12 provides guidelines for identifying when the bias may be problematic and how it can be mitigated in the analysis. Bonneson et al. (2012) also utilized the parameterization proposed by Hauer (2001).

INTERACTION AMONG FACTOR EFFECTS

The safety prediction methods in Part C of the HSM are formulated using multiplicative CMFs. This formulation assumes that the CMFs are independent of each other. The HSM cautions that this assumption may not be true in all cases and cites cases where the effect of a change in lane width on safety may be influenced by the width of the adjacent shoulder width (or vice versa). In fact, recent research has confirmed this important characteristic (Gross et al., 2009; Gross et al., 2010).

PROPOSED METHODOLOGY

This section describes the predictive methodology for estimating the safety performance of six-or-more-lane and one-way urban and suburban arterials as well as the intersections located on these facilities. The research team used full predictive models for estimating baseline models (flow only for nominal base conditions) and CMFs. This category of models was selected to increase the number of CMFs that could be produced from this work. Although before-after studies are often preferred to estimate CMFs, there were not enough data to reliably estimate CMFs. CMFs estimated from cross-sectional studies can still be reliable (Bonneson et al., 2012; Wu et al., 2015).

This section is divided into two parts. The first part covers urban and suburban segments. The part describes the characteristics of the models for intersections.

Segments

The predicted average crash frequency for each road segment of a particular facility is computed as the sum of predicted average crash frequency of all crash types that occurred on the segment. The predicted average crash frequency is computed using the predictive model, where a model is the combination of an 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 a site is calculated as follows:

$$N_{rs} = N_{br} + N_{pedr} + N_{biker} \tag{125}$$

with,

$$N_{br} = N_{mvr} + N_{svr} \tag{126}$$

$$N_{mvr} = C_{mv} \times N_{spfmv} \times (CMF_{mv1} \times \ldots . \times CMF_{mvx}) \times (CMF_1 \times \ldots . \times CMF_p) \tag{127}$$

$$N_{svr} = C_{sv} \times N_{spfsv} \times (CMF_{sv1} \times \ldots . \times CMF_{svy}) \times (CMF_1 \times \ldots . \times CMF_p) \tag{128}$$

$$N_{pedr} = N_{br} \times f_{ped} \tag{129}$$

$$N_{biker} = N_{br} \times f_{bike} \tag{130}$$

where,

N_{rs} = predicted average crash frequency of an individual roadway segment for the selected year.

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions).

N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment.

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment.

N_{mvr} = predicted average crash frequency of multiple-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for an individual roadway segment.

N_{svr} = predicted average crash frequency of single-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for an individual roadway segment.

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

N_{spfsv} = predicted average crash frequency of single-vehicle crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for base conditions.

C_{mv} = local calibration factor for multiple-vehicle crashes.

C_{sv} = local calibration factor for single-vehicle crashes.

f_{ped} = adjustment factor for pedestrians.

f_{bike} = adjustment factor for bicyclists.

$CMF_{mv1} \times \ldots \times CMF_{mvx}$ = CMFs for multiple-vehicle crashes at a site with specific geometric design features *x*.

$CMF_{sv1} \times \ldots \times CMF_{svy}$ = CMFs for single-vehicle crashes at a site with specific geometric design features *y*.

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

SPFs and CMFs were estimated for the following four types of two-way and three types of one-way roadway segments on urban and suburban arterials:

- Six-lane two-way undivided arterials (6U).
- Six-lane two-way divided arterials (i.e., including a raised or depressed median) (6D).
- Seven-lane two-way arterials including a TWLTL (7T).
- Eight-lane two-way divided arterials (i.e., including a raised or depressed median) (8D).
- Two-lane one-way arterials (2O).
- Three-lane one-way arterials (3O).
- Four-lane one-way arterials (4O).

Intersections

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 an 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 follows.

$$N_{predicted\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \tag{131}$$

with,

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times \ldots . \times CMF_{xi}) \tag{132}$$

where,

N_{int} = predicted average crash frequency of an individual intersection for the selected year.
N_{bi} = predicted average crash frequency of an 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.
$N_{spf\ int}$ = predicted average crash frequency of intersection-related crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for base conditions.
C_i = calibration factor for intersections developed for use for a particular geographical area.
$CMF_{1i} \times \ldots . \times CMF_{xi}$ = CMFs at a site with specific geometric design features x.

SPFs and CMFs were estimated for the following intersection types for both two-way street intersections and one-way street intersections on urban and suburban arterials:

- Three-leg intersections with stop control on the minor-road approach (3ST).
- Three-leg signalized intersections (3SG).
- Four-leg intersections with stop control on the minor-road approaches (4ST).
- Four-leg signalized intersections (4SG).

Furthermore, the intersections were separated by the type of operational characteristics of each leg: two-way (x2), or one-way (x1). Hence, there were 12 different intersection types.

Standard Error of CMFs

The standard errors require the use of the delta method, are dependent on the functional form of the CMFs, and will change according to the range of the CMF. The standard errors can be used for estimating the confidence intervals of the CMFs and those estimated from the product of CMFs and predictive models (Lord, 2008). The equations were developed for the two most common functional forms used in this research. They are presented below. The coefficient β comes from the regression model, and $\hat{\beta}$ denotes an estimate of β.

Functional Form 1:

$$CMF_1 = g\left(\hat{\beta}\right) = AADT \times e^{\hat{\beta}}. \tag{133}$$

Then the derivative of $g\left(\hat{\beta}\right)$ is:

$$\mathrm{g}'\left(\hat{\beta}\right) = AADT \times e^{\hat{\beta}} \tag{134}$$

Let the standard error of $\hat{\beta}$ be $SE\left(\hat{\beta}\right)$. Then,

$$\begin{aligned} Var(CMF_1) &= Var\left(g\left(\hat{\beta}\right)\right) = g'\left(\hat{\beta}\right) \times \left(SE\left(\hat{\beta}\right)\right)^2 \times g'\left(\hat{\beta}\right) \\ &= \left(SE\left(\hat{\beta}\right)\right)^2 \times \left(AADT \times e^{\hat{\beta}}\right)^2 \end{aligned} \tag{135}$$

and

$$SE(CMF_1) = \sqrt{Var\left(g\left(\hat{\beta}\right)\right)} = SE\left(\hat{\beta}\right) \times \mathrm{g}'\left(\hat{\beta}\right) = SE\left(\hat{\beta}\right) \times AADT \times e^{\hat{\beta}} \tag{136}$$

Functional Form 2:

$$\mathrm{CMF}_2 = g(\hat{\beta}) = \exp\left(\left(X - Y\right)\hat{\beta}\right) \tag{137}$$

Then the derivative of $g\left(\hat{\beta}\right)$ is:

$$\mathrm{g}'\left(\hat{\beta}\right) = \left(X - Y\right) \times e^{\hat{\beta}(X-Y)} \tag{138}$$

Let the standard error of $\hat{\beta}$ be $SE\left(\hat{\beta}\right)$. Then,

$$\begin{aligned} Var(CMF_2) &= Var\left(g\left(\hat{\beta}\right)\right) = g'\left(\hat{\beta}\right) \times \left(SE\left(\hat{\beta}\right)\right)^2 \times g'\left(\hat{\beta}\right) \\ &= \left(SE\left(\hat{\beta}\right)\right)^2 \times (X - Y)^2 \times e^{2\hat{\beta}(X-Y)} \end{aligned} \tag{139}$$

and

$$\begin{aligned} SE(CMF_2) &= \sqrt{Var\left(g\left(\hat{\beta}\right)\right)} = SE\left(\hat{\beta}\right) \times \sqrt{(X-Y)2}\sqrt{\left(e^{\hat{\beta}(X-Y)}\right)} \\ &= SE\left(\hat{\beta}\right) \times \left|X - Y\right| \times e^{\hat{\beta}(X-Y)} \end{aligned} \tag{140}$$

CHAPTER 4. DEVELOPMENT OF PROJECT DATABASE

This chapter describes the development of the databases used for calibration of the safety prediction models in this project. The chapter is divided into six sections. The first section explains the sources of the data that were collected. The second and third sections describe the characteristics of the segments and intersections used for this project. The fourth section provides a description of the data collection procedures. The fifth section describes the characteristics of the crash data. The last section explains how data collection for pedestrians was accomplished.

DATA SOURCES

The project database was developed using data from five states: Texas, Illinois, California, Michigan, and Oregon. These states were selected based on the state-owned mileage of the two street categories of interest and the availability of crash data.

Crash and roadway data from California and Illinois were obtained from the HSIS, while data from Texas, Michigan, and Oregon were obtained directly from the state highway agencies. Table 21 summarizes the total mileage of roadway segments and number of intersections from each state that were used in model calibration. Data from Texas, Illinois, and California comprised the bulk of the project database. Data from Oregon were later added to increase the mileage of one-way streets, and data from Michigan were added to increase the number of intersections in the sample.

Table 21. Size of data from different states.

State	Total Mileage of Roadway Segments (mi)		Number of Intersections
	Two-Way Streets with Six or More Lanes	One-Way Streets	
Texas	376.5	88.1	372
Illinois	108.3	98.1	213
California	66.9	16.3	335
Oregon	0	48.5	0
Michigan	0	0	222
Total	551.7	251.0	1142

All segments and intersections used in this study were located in urban or suburban areas. The areas were classified as urban, suburban, or rural, according to HSM Chapter 12 definitions, which are based on FHWA (2008) guidelines: “urban” areas defined as places inside urban boundaries where the population is greater than 5,000 persons, “rural” areas defined as places outside urban areas where the population is less than 5,000 persons, and “suburban” areas defined as outlying portions of an urban area.

The most recent five-year period with available crash data was selected as the study period in each state, as follows:

- Illinois, California, and Oregon: 2006–2010.
- Texas and Michigan: 2008–2012.

Google Earth historical imagery was reviewed for every roadway segment and intersection in the database to ensure no construction activity occurred during the study periods. Roadway segments and intersections with a history of any significant construction or major change in the main site characteristics were discarded and not included in the final database.

SELECTION OF ROADWAY SEGMENT TYPES

Considering the project priorities and after reviewing the available data, the research team confined modeling efforts to the following four types of two-way and three types of one-way roadway segments:

- Divided two-way arterials with six lanes (including a raised or depressed median) (6D).
- Undivided two-way arterials with six lanes (6U).
- Two-way arterials with six lanes and a TWLTL in the middle (7T).
- Divided two-way arterials with eight lanes (including a raised or depressed median) (8D).
- One-way streets with two lanes (2O).
- One-way streets with three lanes (3O).
- One-way streets with four lanes (4O).

The state roadway databases included roadway segments with given traffic volume and other characteristics (such as lane width, shoulder width, etc.). Each state-defined segment was considered homogenous in terms of the main site traits. However, in Texas and Illinois, a large proportion of segments were relatively short. To increase the data collection efficiency, adjacent segments from these states were combined if they met the following criteria:

- Traffic volume did not change by more than 10 percent.
- Lane width did not change by more than 0.5 ft.
- Shoulder width did not change by more than 1 ft.
- Median type and width did not change appreciably.

By combining adjacent segments with nominal differences, the total number of homogeneous segments in Texas and Illinois was reduced by about half (without reducing the total mileage). Segments shorter than 0.01 mi were discarded due to the limited precision of crash location reporting and the potential modeling bias caused by segments that are too short. Table 22 presents the distribution of the available roadway segment data by segment type and state.

Table 22. Distribution of roadway segment data by segment type and state.

Segment Type	Number of Homogeneous Segments					Total Mileage (mi)				
	TX	IL	CA	OR	Total	TX	IL	CA	OR	Total
Two-Way Segments										
6D	529	1005	233		**1767**	217.0	95.5	40.1		**352.6**
6U	16	63	15		**94**	2.7	6.8	1.3		**10.8**
7T	201	24	41		**266**	141.5	2.0	9.1		**152.6**
8D	24	47	52		**123**	15.4	3.9	16.4		**35.7**
Total	**770**	**1139**	**341**		**2250**	**376.5**	**108.3**	**66.9**		**551.7**
One-Way Segments										
2O	258	489	42	760	**1549**	53.1	59.2	6.9	32.7	**151.9**
3O	96	262	81	324	**763**	22.1	29.0	9.3	13.3	**73.7**
4O	51	68	1	46	**166**	13.0	9.8	0.1	2.5	**25.4**
Total	**405**	**819**	**124**	**1130**	**2478**	**88.1**	**98.1**	**16.3**	**48.5**	**251.0**

Note: Shaded cell = data were not collected.

SELECTION OF INTERSECTION TYPES

Based on the project scope, safety prediction models had to be developed for intersections of two-way arterials with six or more lanes and intersections of one-way streets. Therefore, the intersections along the identified corridors (as discussed above) were included in the intersection database if the traffic volume was known for both intersecting streets. Consistent with HSM Chapter 12, the following types of intersections were selected for safety prediction modeling:

- Three-leg intersections with stop control on the minor-street approach (3ST).
- Three-leg signalized intersections (3SG).
- Four-leg intersections with stop control on the minor-street approaches (4ST).
- Four-leg signalized intersections (4SG).

Since the intersections in this project involved both two-way and one-way streets, the intersections were further subcategorized based on the number of travel directions in each intersecting street, as follows:

- 2×2 = A two-way street intersecting another two-way street.
- 1×2 = A one-way street intersecting a two-way street.
- 1×1 = A one-way street intersecting another one-way street.

Table 23 presents the breakdown of the number of intersections by state and intersection type.

Table 23. Distribution of intersection data by intersection type and state.

Intersection Type	Roadway Category	Number of Intersections				
		Texas	Illinois	California	Michigan	Total
3ST	2×2	23	2	26	5	56
	2×1	1	59	0	40	100
	1×1	2	4	0	1	7
	Total	26	65	26	46	163
3SG	2×2	18	2	28	10	58
	2×1	2	2	6	23	33
	1×1	2	2	0	3	7
	Total	22	6	34	36	98
4ST	2×2	12	3	12	9	36
	2×1	18	94	1	39	152
	1×1	2	0	0	1	3
	Total	32	97	13	49	191
4SG	2×2	126	21	228	27	402
	2×1	111	21	11	52	195
	1×1	55	3	23	12	93
	Total	292	45	262	91	690
Total		372	213	335	222	1142

Note: 2×2 = two-way street intersecting two-way street; 1×2 = one-way street intersecting two-way street; 1×1 = one-way street intersecting one-way street.

DATA COLLECTION

The state databases included crash data along with traffic volume and some other site characteristics for roadway segments and intersections. Additional data variables were collected for each segment and intersection mainly by using Google Earth aerial images and Street View. The description of data fields and the summary statistics of the collected data are presented below.

Site Characteristics Data for Roadway Segments

As specified earlier, this research used homogeneous segments as defined by the state databases. The state data provided the AADT volumes for each year during the study period. The average AADT over the five years of the study period was used as an input variable for modeling. In addition to AADT, every state database included data elements for lane, median, and right/left shoulder width. The research team deemed the quality of these data variables as satisfactory for modeling purposes and included them in the calibration database.

Additional data elements with potential influence on the safety of roadway segments were defined and collected for each segment in the database. **Table** 24 provides the complete list of variables collected from the roadway segments. The variables used in the HSM Chapter 12 models were all included in the data collection. As **Table** 24 indicates, the collected data included a wide range of geometric design and traffic control variables, many of which were not included in the final safety prediction models. Table 25 and Table 26 provide the summary statistics of the data collected for two-way and one-way roadway segments, respectively.

Table 24. List of data variables collected for roadway segments.

Data Variable	Description	Primary Source
AADT	Two-way annual average daily traffic volume (veh/day) during the study period.	State databases
Segment length	The length of the homogenous segment (mi) in the state database.	State databases
Lane width	Average width (ft) of the through lanes.	State databases
Left shoulder width (one-way segments)	Average width of the right shoulder (ft) along the segment.	State databases
Inside shoulder width (divided two-way segments)	Average width of the left shoulder (ft) in the two directions of travel.	State databases
Right shoulder width (one-way segments)	Average width of the right shoulder (ft) along the segment.	State databases
Outside shoulder width (two-way segments)	Average width of the left shoulder (ft) in the two directions of travel.	State databases
Median width (two-way segments)	Average median width (ft) along the segment.	State databases
Bus or high occupancy vehicle (HOV) lane presence	Presence of bus-only or HOV lanes.	Aerial and street-level photographs
Bicycle lane presence	Presence of bicycles lanes.	Aerial and street-level photographs
Sidewalks	Presence of sidewalks along each side of the roadway segment: 0: No sidewalk. 1: Sidewalk on one side of the roadway. 2: Sidewalks on both sides of the roadway.	Aerial and street-level photographs
Lighting	Presence of lighting along each side of the roadway segment: 0: No lighting. 1: Lighting on one side of the roadway. 2: Lighting on both sides of the roadway.	Street-level photographs
Parallel parking proportion	Proportion of the length of segment with parallel parking (considered in both directions of travel for two-way streets).	Aerial and street-level photographs
Angle parking proportion	Proportion of the length of segment with angle parking (considered in both directions of travel for two-way streets).	Aerial and street-level photographs
Speed limit	Posted speed limit (mph) as observed from speed limit signs.	Street-level photographs
Median barrier (two-way segments)	Presence of concrete barriers in the median.	Street-level photographs
Railroad crossings	Number of railroad-highway crossings within the limits of the roadway segment.	Aerial photographs

Table 24. List of data variables collected for roadway segments. (continued)

Data Variable	Description	Primary Source
Driveway density	Density of driveways along the length of the segment (driveways/mile), classified consistently with the HSM Chapter 12 driveway categories: • Major commercial driveways. • Minor commercial driveways. • Major industrial/institutional driveways. • Minor industrial/institutional driveways. • Major residential driveways. • Minor residential driveways. • Other driveways.	Aerial and street-level photographs
Roadside fixed-object density	Density of fixed roadside objects (objects/mile) within 30 ft of the edge of traveled way (in both directions of travel for two-way streets). In absence of marked edge lines, edge of traveled way was considered to be 2.0 ft from the face of curb. Fixed objects were counted using the same method as required for application of the HSM CMF for roadside fixed objects (described on pages 12–41 of the HSM).	Aerial and street-level photographs
Roadside fixed-object offset	Average distance from the edge of traveled way to the roadside fixed objects (as defined above).	Aerial photographs
Left curb proportion (one-way segments)	Proportion of the length of the segment with left-side curb present.	Aerial photographs
Right curb proportion (one-way segments)	Proportion of the length of the segment with right-side curb present.	Aerial photographs
Inside curb proportion (two-way segments)	Ratio of the two-way total length (ft) of curb present along the inside (median side) of the segment to twice the length of the segment.	Aerial photographs
Outside curb proportion (two-way segments)	Ratio of the two-way total length (ft) of curb present along the outside (right shoulder side) of the segment to twice the length of the segment.	Aerial photographs

Table 25. Descriptive statistics for two-way roadway segment variables.

Variable	Statistic	Segment Type			
		6U	6D	7T	8D
AADT (veh/day)	Minimum	8,700	2,750	4,100	14,700
	Maximum	78,000	118,000	94,000	152,000
	Mean	41,152	38,329	31,147	77,019
	Std. deviation	14,764	15,510	14,584	39,274
Segment length (mi)	Minimum	0.01	0.01	0.01	0.01
	Maximum	0.534	4.458	7.708	3.044
	Mean	0.118	0.2	0.576	0.294
	Std. deviation	0.104	0.38	0.783	0.444
Lane width (ft)	Minimum	10.0	9.0	10.0	10.0
	Maximum	18.5	27.0	20.5	16.0
	Mean	11.5	12.1	12.8	11.7
	Std. deviation	1.0	1.3	1.7	0.8
Inside shoulder width (ft)	Minimum		0		0
	Maximum		13.0		11.0
	Mean		0.5		0.9
	Std. deviation		1.7		2.2
Outside shoulder width (ft)	Minimum	0	0	0	0
	Maximum	10.0	14.0	14.0	12.0
	Mean	0.5	2.3	2.6	2.6
	Std. deviation	1.8	3.3	3.9	3.7
Median width (ft)	Minimum		0		0
	Maximum		240.0		60.0
	Mean		15.5		16.1
	Std. deviation		14.8		13.3
Bus or HOV lane presence (1=yes; 0=no)	Minimum	0	0	0	0
	Maximum	0	1	0	0
	Mean	0	0.002	0	0
	Std. deviation	0	0.05	0	0
Bicycle lane presence (1=yes; 0=no)	Minimum	0	0	0	0
	Maximum	1	1	1	0
	Mean	0.01	0.05	0.04	0
	Std. deviation	0.10	0.23	0.19	0
Sidewalks	Minimum	0	0	0	0
	Maximum	2	2	2	2
	Mean	1.5	0.94	0.91	1.13
	Std. deviation	0.8	0.92	0.93	0.95
Lighting	Minimum	0	0	0	0
	Maximum	2	2	2	2
	Mean	1.7	1.4	1.5	1.9
	Std. deviation	0.7	0.9	0.8	0.3
Parallel parking proportion	Minimum	0	0	0	0
	Maximum	0.74	1.0	1.0	0
	Mean	0.04	0.004	0.02	0
	Std. deviation	0.15	0.05	0.12	0
Angle parking proportion	Minimum	0	0	0	0
	Maximum	0	0	0.03	0
	Mean	0	0	0.0001	0
	Std. deviation	0	0	0.001	0

Table 25. Descriptive statistics for two-way roadway segment variables. (continued)

Variable	Statistic	Segment Type			
		6U	**6D**	**7T**	**8D**
Posted speed limit (mph)	Minimum	30	25	25	25
	Maximum	50	60	60	55
	Mean	36.9	42.8	43.8	41.8
	Std. deviation	5.8	6.5	7.3	4.8
Median barrier presence (1=yes; 0=no)	Minimum		0		0
	Maximum		1		1
	Mean		0.04		0.12
	Std. deviation		0.19		0.34
Railroad crossings	Minimum	0	0	0	0
	Maximum	1	3	2	1
	Mean	0.03	0.02	0.03	0.009
	Std. deviation	0.18	0.14	0.22	0.09
Major commercial driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	50.0	138.8	117.6	50.0
	Mean	3.1	2.7	7.0	3.5
	Std. deviation	7.5	7.6	13.2	7.3
Minor commercial driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	63.6	100.0	82.2	57.6
	Mean	12.5	5.6	18.8	5.8
	Std. deviation	15.9	11.1	19.5	9.5
Major industrial driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	27.3	100.0	36.4	6.8
	Mean	0.9	1.0	1.6	0.4
	Std. deviation	3.9	4.1	3.9	1.1
Minor industrial driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	25.0	75.0	81.6	16.1
	Mean	3.0	1.5	4.6	0.8
	Std. deviation	6.0	5.3	9.3	2.1
Major residential driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	0	27.8	100.0	5.4
	Mean	0	0.1	1.1	0.2
	Std. deviation	0	0.9	6.7	0.8
Minor residential driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	42.9	119.2	75.2	5.1
	Mean	0.5	1.1	3.6	0.2
	Std. deviation	4.5	5.7	10.3	0.8
Other driveway density[a] (driveways/mile)	Minimum	0	0	0	0
	Maximum	35.7	71.4	26.3	10.2
	Mean	0.5	0.4	1.4	0.3
	Std. deviation	3.8	2.7	3.9	1.2
Roadside fixed-object density (objects/mile)	Minimum	0	0	0	0
	Maximum	200.0	508.0	200.0	200.0
	Mean	89.3	60.9	57.2	66.1
	Std. deviation	46.3	44.8	35.1	35.1
Roadside fixed-object average offset (ft)	Minimum	0	0	0	0
	Maximum	23.3	30.0	30.0	26.0
	Mean	9.7	11.6	12.6	9. 9.6
	Std. deviation	4.3	7.2	6.4	5.4

Note: Shaded cell means not applicable.

[a] Equivalent number of full driveways where a partial driveway is given half the weight of a full driveway.

Table 26. Descriptive statistics for one-way roadway segment variables.

Variable	Statistic	2O	3O	4O
AADT (veh/day)	Minimum	316	2,220	200
	Maximum	33,960	29,000	29,000
	Mean	7,241	11,590	11,558
	Std. deviation	3,778	5,181	4,460
Segment length (mi)	Minimum	0.01	0.01	0.01
	Maximum	1.326	0.873	1.15
	Mean	0.15	0.137	0.194
	Std. deviation	0.16	0.130	0.204
Lane width (ft)	Minimum	9.0	9.0	9.0
	Maximum	27.0	25.0	20.0
	Mean	13.7	13.0	12.1
	Std. deviation	2.8	2.7	1.8
Left shoulder width (ft)	Minimum	0	0	0
	Maximum	20.0	19.0	9.0
	Mean	1.5	1.8	1.1
	Std. deviation	3.5	3.5	2.8
Right shoulder width (ft)	Minimum	0	0	0
	Maximum	20.0	20.0	20.0
	Mean	2.2	2.4	1.4
	Std. deviation	3.8	4.1	3.4
Bus or HOV lane presence (1=yes; 0=no)	Minimum	0	0	0
	Maximum	0	0	1
	Mean	0	0	0.03
	Std. deviation	0	0	0.18
Bicycle lane presence (1=yes; 0=no)	Minimum	0	0	0
	Maximum	1	0	1
	Mean	0.014	0	0.05
	Std. deviation	0.12	0	0.24
Sidewalks	Minimum	0	0	0
	Maximum	2	2	2
	Mean	1.45	1.64	1.66
	Std. deviation	0.8	0.73	0.67
Lighting	Minimum	0	0	0
	Maximum	2	2	2
	Mean	1.38	1.62	1.74
	Std. deviation	0.72	0.59	0.56
Parallel parking proportion	Minimum	0	0	0
	Maximum	1.0	0.8	0.6
	Mean	0.16	0.13	0.07
	Std. deviation	0.25	0.21	0.14
Angle parking proportion	Minimum	0	0	0
	Maximum	0.6	0.6	X
	Mean	0.01	0.01	X
	Std. deviation	0.05	0.04	X

Table 26. Descriptive statistics for one-way roadway segment variables. (continued)

Variable	Statistic	2O	3O	4O
Posted speed limit (mph)	Minimum	20	20	25
	Maximum	45	55	45
	Mean	32	32	33
	Std. deviation	5	5	4
Railroad crossings	Minimum	0	0	0
	Maximum	1	1	1
	Mean	0.04	0.04	0.05
	Std. deviation	0.19	0.20	0.22
Major commercial driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	58.3	25.0	23.4
	Mean	0.52	0.72	0.55
	Std. deviation	3.6	2.96	2.68
Minor commercial driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	83.3	75.0	52.6
	Mean	6.4	10.2	8.0
	Std. deviation	10.5	13.1	12.6
Major industrial driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	21.7	51.0	10.0
	Mean	0.5	0.5	0.9
	Std. deviation	2.4	3.1	2.2
Minor industrial driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	100.0	50.0	50.0
	Mean	4.1	4.5	5.7
	Std. deviation	8.1	7.2	9.6
Major residential driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	17.9	10.7	0
	Mean	0.05	0.03	0
	Std. deviation	0.8	0.54	0
Minor residential driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	58.8	76.3	88.5
	Mean	5.3	3.5	7.2
	Std. deviation	10.6	9.7	15.7
Other driveway density[a] (driveways/mile)	Minimum	0	0	0
	Maximum	50.0	33.3	14.3
	Mean	0.2	0.4	0.3
	Std. deviation	2.2	2.5	1.7
Roadside fixed-object density (objects/mile)	Minimum	0	0	0
	Maximum	300.0	240.0	300.0
	Mean	80.6	79.2	84.1
	Std. deviation	46.5	40.4	37.9
Roadside fixed-object average offset (ft)	Minimum	0	0	0
	Maximum	30.0	30.0	25.0
	Mean	10.4	9.0	8.0
	Std. deviation	5.2	4.9	3.7

[a] Equivalent number of full driveways where a partial driveway is given half the weight of a full driveway.

Site Characteristics Data for Intersections

An intersection database was created with intersections of six-or-more-lane arterials and one-way streets for which traffic volume data were available for both intersecting streets. In Illinois, California, and Michigan, the state database was the sole source for traffic volumes, and as such, only the intersections of two state-owned highways were included in the calibration dataset. In Texas, on the other hand, supplemental traffic volume data were obtained from the San Antonio, Austin, and Houston city databases available online (described further below). The traffic volumes were averaged over the five years of the study period to produce the AADT variable for modeling. In cases where the city-provided data did not include traffic volumes for every year, citywide traffic growth factors were calculated and used to project the traffic volume over the study period.

Additional data elements were collected using Google Earth images and Street View. Table 27 lists the data variables collected for each intersection in the database, and Table 28 shows the variables for the streets. The collected data included a wide range of geometric design and traffic control characteristics. As Table 28 indicates, most variables were specific to the individual intersecting streets. In 2×2 and 1×1 intersections, the major street was defined as the street with the greater traffic volume (AADT), regardless of the number of lanes, etc. In 1×2 intersections, however, the one-way street was always considered the major street and the two-way street was the minor street, regardless of the traffic volume.

Table 27. List of data variables collected for intersections as a whole.

Data Variable	Description	Primary Source
Intersection type	As defined by the HSM: 3ST: Three-leg stop-controlled 3SG: Three-leg signalized 4ST: Four-leg stop-controlled 4SG: Four-leg signalized	Aerial and street-level photographs
Roadway category	As defined below: 2×2 = two-way street intersecting two-way street 1×2 = one-way street intersecting two-way street 1×1 = one-way street intersecting one-way street	Aerial photographs
Lighting	Presence of lighting at the intersection	Aerial and street-level photographs
Skew angle	Absolute value of the difference between 90 degrees and the intersection angle (i.e., the acute or right angle between intersecting streets)	Aerial photographs
Area type	As defined below: Urban: If more than 50 percent of the land use within 250 ft of the center of intersection is commercial Suburban: If not urban	Aerial and street-level photographs

Table 28. List of data variables collected for individual streets (major and minor).

Data Variable	Description	Primary Source
AADT	Two-way annual average daily traffic volume (veh/day) during the 5-year study period	State or city databases
Left-turn phasing (signalized intersections)	Type of left-turn phasing: 0: Permitted 1: Protected/permitted 2: Protected only	Street-level photographs
Number of lanes	Two-way total number of traffic lanes (excluding the left-turn and right-turn lanes added at the intersection)	Aerial and street-level photographs
Presence of left-turn lanes	Number of approaches (0, 1, or 2) with exclusive left-turn lanes	Aerial and street-level photographs
Number of left-turn lanes	Two-way total number of exclusive left-turn lanes	Aerial and street-level photographs
Number of right-turn lanes	Two-way total number of exclusive right-turn lanes	Aerial and street-level photographs
Bicycle lanes	The number of approaches (0, 1, or 2) with bicycle lanes	Aerial and street-level photographs
Median type (two-way streets)	Type of median: No median or TWLTL Raised curb Depressed median	Aerial and street-level photographs
Right-turn channelization	Number of approaches with channelized right-turn lanes	Aerial photographs
Offset left-turn lanes	Number of approaches with offset left-turn lanes (i.e., left-turn lanes separated from through traffic via raised curb, etc.)	Aerial photographs
Left-turn prohibition	Number of approaches from which left turns are prohibited for reasons other than one-way cross street or three-leg intersection	Street-level photographs
RTOR prohibition (signalized intersections)	Number of approaches from which RTOR is prohibited	Street-level photographs
U-turn prohibition (two-way streets)	Number of approaches from which U-turns are prohibited via "No U-turn" signs	Street-level photographs

Summary statistics tables are provided separately for three categories of intersections:

- 2×2 intersections where both intersecting streets are two-way and at least one street has six or more through lanes at the intersection (Table 29 for continuous variables, Table 30 for categorical variables [intersection as a whole], Table 31 for categorical variables [major street], and Table 32 for categorical variables [minor street]).
- 1×2 intersections where a one-way (major) street intersects a two-way (minor) street (Table 33 for continuous variables, Table 34 for categorical variables [intersection as a whole or one-way street data], and Table 35 for categorical variables [two-way street data]).
- 1×1 intersections where both intersecting streets are one-way (Table 36 for continuous variables, Table 37 for categorical variables [intersection as a whole or one-way street data], and Table 38 for categorical variables [two-way street data]).

Table 29. Descriptive statistics for continuous variables for 2×2 intersections.

Variable	Statistic	3ST (n=56)[a]	3SG (n=58)[a]	4ST (n=36)[a]	4SG (n=402)[a]
Major-road AADT (veh/day)	Minimum	10,760	8755	12,668	7090
	Maximum	66,800	94,000	54,600	137,550
	Mean	37,072	38,791	33,249	44,658
	Std. deviation	12,707	17,224	12,098	17,593
Minor-road AADT (veh/day)	Minimum	100	98	118	86
	Maximum	8589	31,000	4600	68,343
	Mean	1247	5455	1245	14,188
	Std. deviation	1629	6117	1054	11,575
Skew angle (degrees)	Minimum	0	0	0	0
	Maximum	29.7	43.0	42.0	44.4
	Mean	7.0	7.1	8.1	7.1
	Std. deviation	9.1	11.3	12.5	10.8

[a] Number of intersections.

Table 30. Breakdown of the number of 2×2 intersections by categorical variables—data variables for intersection as a whole.

Variable	Value	3ST (n=56)	3SG (n=58)	4ST (n=36)	4SG (n=402)
Lighting	Lighted	54	58	35	393
	Not lighted	2	0	1	9
Area type	Urban	26	23	23	101
	Suburban	30	35	13	301

Table 31. Breakdown of the number of 2×2 intersections by categorical variables—major-street data variables.

Variable	Value	3ST (n=56)	3SG (n=58)	4ST (n=36)	4SG (n=402)
Left-turn phasing	Permitted		9		21
	Protected/permitted		8		50
	Protected only		39		300
	Not applicable	56[a]	2[b]	36[a]	31[b]
Number of lanes	2				1
	4				18
	6	53	52	36	313
	7		1		18
	8	3	4		50
	10		1		2
Presence of left-turn lanes	Neither approach	5	3	2	40
	One approach	41	43	9	26
	Both approaches	10	12	25	336
Number of left-turn lanes	0	5	3	2	39
	1	41	38	8	24
	2	10	16	26	261
	3		1		25
	4				53
Number of right-turn lanes	0	55	49	34	277
	1	1	9	1	63
	2			1	60
	3				2
Bicycle lanes	Neither approach	52	54	35	373
	One approach		2	1	3
	Both approaches	4	2		26
Median type	No median or TWLTL	27	22	21	89
	Raised curb	28	35	13	308
	Depressed median	1	1	2	5
Right-turn channelization	Neither approach	55	53	36	333
	One approach	1	5		30
	Both approaches				39
Offset left-turn lanes	Neither approach	55	58	36	395
	One approach				4
	Both approaches	1			3
Left-turn prohibition	Neither approach	49	51	35	362
	One approach	7	7	1	10
	Both approaches				30
RTOR prohibition	Neither approach		58		396
	One approach				5
	Both approach				1
	Not applicable	56		36	
U-turn prohibition	Neither approach	44	38	34	315
	One approach	10	14	2	37
	Both approaches	2	6		50

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left turn prohibited.

Table 32. Breakdown of the number of 2×2 intersections by categorical variables—minor-street data variables.

Variable	Value	3ST (n=56)	3SG (n=58)	4ST (n=36)	4SG (n=402)
Left-turn phasing	Permitted		24		129
	Protected/permitted		4		79
	Protected only		30		176
	Not applicable	56[a]	0	36[a]	18[b]
Number of lanes	0	23	21		
	1	7	17	3	2
	2	25	17	33	148
	3	1	2		28
	4		1		141
	5				20
	6, 7, 8				57, 2, 4
Presence of left-turn lanes	Neither approach	54	24	34	83
	One approach	2	33	1	70
	Both approaches		1	1	249
Number of left-turn lanes	0	54	24	34	83
	1	2	23	1	64
	2		11	1	186
	3				22
	4				46
	5				1
Number of right-turn lanes	0	54	27	31	188
	1	2	27	5	126
	2		4		86
	3				2
Bicycle lanes	Neither approach	56	56	36	370
	One approach				5
	Both approaches		2		27
Median type	No median or TWLTL	53	44	34	266
	Raised curb	3	14	2	136
Right-turn channelization	Neither approach	56	53	35	317
	One approach		5	1	44
	Both approaches				41
Offset left-turn lanes	Neither approach	56	58	36	394
	One approach				7
	Both approaches				1
Left-turn prohibition	Neither approach	54	58	35	374
	One approach	2		1	10
	Both approaches				18
RTOR prohibition	Neither approach		58		392
	One approach				7
	Both approaches				3
	Not applicable	56[a]		36[a]	
U-turn prohibition	Neither approach	56	45	36	301
	One approach		13		27
	Both approaches				74

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left turn prohibited.

Table 33. Descriptive statistics for continuous variables for 1×2 intersections.

Variable	**Statistic**	**3ST (n=100)[a]**	**3SG (n=33)[a]**	**4ST (n=152)[a]**	**4SG (n=195)[a]**
One-way road AADT (veh/day)	Minimum	98.4	896.8	345.4	103
	Maximum	42,630.6	43,733.2	23,364.6	77,000
	Mean	13,234	14,739	8718	10,538
	Std. deviation	7712	12,302	4485	8439
Two-way road AADT (veh/day)	Minimum	17	290	75	130
	Maximum	13,340	58,800	19,192	98,826
	Mean	1081	18,184	1413	16,993
	Std. deviation	2026	17,444	2498	15,843
Skew angle (degrees)	Minimum	0	0	0	0
	Maximum	28.2	44.0	35	41.0
	Mean	2.5	6.0	4.1	5.8
	Std. deviation	4.4	10.8	8.0	9.6

[a] Number of intersections.

Table 34. Breakdown of the number of 1×2 intersections by categorical variables—data variables for intersection as a whole or for one-way street data variables.

Variable	Value	3ST (n=100)	3SG (n=33)	4ST (n=152)	4SG (n=195)
Data Variables for Intersection as a Whole					
Lighting	Lighted	89	23	145	192
	Not lighted	11	10	7	3
Area type	Urban	62	26	99	65
	Suburban	38	7	53	130
One-Way Street Data Variables					
Left-turn phasing	Permitted		2		20
	Protected only		19		170
	Not applicable	100[a]	12[b]	152[a]	5[b]
Number of lanes	0	1	10	1	2
	1	1	4	7	9
	2	52	3	80	94
	3	28	7	54	67
	4	14	9	9	23
	5	4		1	
Presence of left-turn lanes	Neither approach	99	20	146	124
	One approach	1	11	6	71
	Both approaches		2		
Number of left-turn lanes	0	99	19	146	123
	1	1	9	6	68
	2		5		2
	3				2
Number of right-turn lanes	0	89	19	147	125
	1	11	14	5	70
Bicycle lanes	Neither approach	100	33	140	180
	One approach			12	14
	Both approaches				1
Right-turn channelization	Neither approach	100	32	150	161
	One approach		1	2	34
Left-turn prohibition	Neither approach	100	32	152	195
	One approach		1		
RTOR prohibition	Neither approach		32		194
	One approach				1
	Not applicable	100[a]	1[b]	152[a]	

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left/right turn prohibited.

Table 35. Breakdown of the number of 1×2 intersections by categorical variables—two-way street data variables.

Variable	Value	3ST (n=100)	3SG (n=33)	4ST (n=152)	4SG (n=195)
Left-turn phasing	Permitted		3		80
	Protected/permitted				69
	Protected only		4		38
	Not applicable	100[a]	26[b]	152[a]	8[b]
Number of lanes	0	26	13	1	
	1	13	4	2	6
	2	61		145	59
	3			1	6
	4		8	2	60
	5		1		4
	6		6	1	54
	7		1		4
	8				2
Presence of left-turn lanes	Neither approach	100	28	145	78
	One approach		5	7	111
	Both approaches				6
Number of left-turn lanes	0	99	27	145	78
	1	1	5	7	102
	2		1		15
Number of right-turn lanes	0	75	23	148	164
	1	25	8	4	29
	2		2		2
Bicycle lanes	Neither approach	100	32	151	187
	One approach		1	1	5
	Both approaches				3
Median type	No median or TWLTL	92	25	149	137
	Raised curb	8	8	3	58
Right-turn channelization	Neither approach	100	29	149	164
	One approach		1	3	31
	Both approaches		3		
Offset left-turn lanes	Neither approach	100	32	152	194
	One approach		1		1
Left-turn prohibition	Neither approach	100	33	152	190
	One approach				5
RTOR prohibition	Neither approach		30		194
	One approach		1		1
	Not applicable	100[a]	2[b]	152[a]	
U-turn prohibition	Neither approach	100	28	152	191
	One approach				3
	Both approaches		5		1

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left/right turn prohibited.

Table 36. Descriptive statistics for continuous variables for 1×1 intersections.

Variable	Statistic	3ST (n=7)[a]	3SG (n=7)[a]	4ST (n=3)[a]	4SG (n=93)[a]
Major-road AADT (veh/day)	Minimum	5700	5961	789	2244
	Maximum	16,814	20,058	10,993	24,225
	Mean	13,137	12,179	6937	11,840
	Std. deviation	3826	5393	5415	5398
Major-road AADT (veh/day)	Minimum	97	780	764	98
	Maximum	11,064	7479	6739	16,814
	Mean	2141	4314	3116	5776
	Std. deviation	3972	2724	3184	3613
Skew angle (degrees)	Minimum	0.4	0	0.3	0
	Maximum	43.3	11.4	39.0	39.0
	Mean	16.8	2.7	15.9	5.6
	Std. deviation	18.1	3.9	20.4	9.7

[a] Number of intersections.

Table 37. Breakdown of the number of 1×1 intersections by categorical variables—data variables for intersection as a whole or major-street data variables.

Variable	Value	3ST (n=7)	3SG (n=7)	4ST (n=3)	4SG (n=93)
Data Variables for Intersection as a Whole					
Lighting	Lighted	5	7	2	93
	Not lighted	2		1	
Area type	Urban	4	2	2	34
	Suburban	3	5	1	59
Major-Street Data Variables					
Left-turn phasing	Permitted				2
	Protected only				49
	Not applicable	7[a]	7[b]	3[a]	42[b]
Number of lanes	1			1	
	2	1	1	1	47
	3	4	1	1	35
	4	2	5		10
	5				1
Presence of left-turn lanes	Neither approach	7	7	3	75
	One approach				17
	Both approaches				1
Number of left-turn lanes	0	7	7	3	75
	1				16
	2				2
Number of right-turn lanes	0	7	7	3	82
	1				11
Bicycle lanes	Neither approach	7	6	3	93
	One approach		1		
Right-turn channelization	Neither approach	7	7	2	88
	One approach			1	5
Left-turn prohibition	Neither approach	7	7	3	92
	One approach				1
RTOR prohibition	Neither approach		4		62
	One approach		1		1
	Not applicable	7[a]	2[b]	3[a]	30[b]

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left/right turn prohibited.

Table 38. Breakdown of the number of 1×1 intersections by categorical variables—minor-street data variables.

Variable	Value	3ST (n=7)	3SG (n=7)	4ST (n=3)	4SG (n=93)
Left-turn phasing	Permitted		1		3
	Protected only		2		48
	Not applicable	7[a]	4[b]	3[a]	42[b]
Number of lanes	0	3	5		
	1	3	1		5
	2	1	1	3	51
	3				29
	4				8
Presence of left-turn lanes	Neither approach	7	4	3	77
	One approach		3		16
Number of left-turn lanes	0	6	4	3	77
	1	1			15
	2		3		1
Number of right-turn lanes	0	7	5	3	77
	1				16
	2		1		
	3		1		
Bicycle lanes	Neither approach	7	7	3	92
	One approach				1
Right-turn channelization	Neither approach	7	7	2	88
	One approach			1	5
Left-turn prohibition	Neither approach	7	7	3	92
	One approach				1
RTOR prohibition	Neither approach		4		62
	One approach		1		1
	Not applicable	7[a]	2[b]	3[a]	30[b]

Note: Shaded cell = not applicable.
[a] Unsignalized intersection.
[b] Left/right turn prohibited.

CRASH DATA

Crash data were obtained from Illinois, California, and Oregon for 2006–2010 and from Texas and Michigan for 2008–2012. The entire crash records from these states (and years) were obtained, which included data elements for crash type (single-vehicle, multi-vehicle, vehicle-pedestrian, vehicle-bicycle, etc.) and crash severity (K, A, B, C, or PDO) and the manner of collision (rear-end, head-on, angle, etc.).

Crashes were assigned to roadway segments if they occurred within the boundaries of the segment and were coded as non-intersection-related. Consistent with development of the existing safety prediction models in the HSM, the research team used the FHWA IHSDM (Harwood et al., 2000) and the HSM (AASHTO, 2010) criteria for assigning crashes to intersections. Crashes were assigned to intersections if they met at least one of the following conditions:

- The crash occurred within the curb limits of the intersection.
- The crash occurred within 250 ft of the center of the intersection and was coded as intersection-related.

A total of 76,134 crashes were included in the project database: 54,138 were assigned to roadway segments, and 22,176 were assigned to intersections. Table 39 presents the distribution of roadway segment crashes by jurisdiction and segment type. As described in Chapter 5, this project proposes an aggregate model for all multiple-vehicle crashes that accounts for presence of driveways with several input variables. Therefore, the multiple-vehicle crashes in Table 40 include both driveway-related and non-driveway-related collisions. Table 40 provides the distribution of crash types by different segment types and jurisdictions. Table 41, Table 42, Table 43, and Table 44 present similar distributions for intersections.

Table 39. Summary of crash frequency and exposure data for roadway segments.

Segment Type	Number of Roadway Segments	Total Length (mi)	Total Number of Crashes[a]	AADT (veh/day)	Total Exposure[a] (10^6 veh-mi)	Average Crash Rate[a] (per 10^6 veh-mi)
TEXAS						
6D	528	216.29	12,674	30,230	6.54	1.033
6U	15	2.67	77	23,869	0.06	0.622
7T	193	133.70	9261	25,760	3.44	1.400
8D	24	15.38	2367	48,522	0.75	1.426
2O	247	52.41	988	6602	0.35	1.448
3O	85	19.99	498	8847	0.18	2.008
4O	49	12.96	279	11,382	0.15	1.077
Total	1141	453.4	26,144			
ILLINOIS						
6D	1005	95.54	11,692	40,281	3.85	1.692
6U	63	6.81	1712	41,834	0.28	3.022
8D	47	3.91	2361	97,726	0.38	2.231
2O	488	59.11	2092	7267	0.43	2.703
3O	261	28.94	1662	11,145	0.32	2.730
4O	68	9.85	427	11,430	0.11	2.249
Total	1932	204.16	19,946			
CALIFORNIA						
6D	226	39.90	3131	47,873	1.91	1.505
6U	14	1.34	150	56,596	0.08	1.406
7T	32	6.96	682	40,265	0.28	1.811
8D	45	14.79	2744	70,591	1.04	1.663
2O	42	6.93	153	10,990	0.08	1.289
3O	81	9.30	591	15,976	0.15	2.308
4O	1	0.09	10	29,000	0.00	2.032
Total	441	79.31	7461			
OREGON						
2O	260	14.67	283	14,236	0.21	1.267
3O	109	6.37	244	20,789	0.13	1.662
4O	18	1.02	60	17,037	0.02	3.670
Total	387	22.06	587			
COMBINED						
6D	1759	351.73	27,497	38,240	13.45	1.470
6U	92	10.81	1939	41,152	0.44	2.385
7T	225	140.67	9943	27,822	3.91	1.459
8D	116	34.08	7472	77,019	2.62	1.844
2O	1037	133.11	3516	9007	1.20	1.987
3O	536	64.59	2995	13,472	0.87	2.335
4O	136	23.92	776	12,284	0.29	2.013
Total	3901	758.91	54,138			

Note: Shaded cell = not applicable.
[a] In the five years of the study period.

Table 40. Summary of crash type data for roadway segments.

Segment Type	Number (Percentage) of Crashes in Five Years									
	Multiple-Vehicle Collisions		Single-Vehicle Collisions		Vehicle-Pedestrian Collisions		Vehicle-Bicycle Collisions		Total	
	Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
TEXAS										
6D	10,789	85.1	1632	12.9	188	1.5	65	0.5	12,674	(100)
6U	56	72.7	20	26.0	1	1.3	0	0.0	77	(100)
7T	8421	90.9	686	7.4	119	1.3	35	0.4	9261	(100)
8D	2135	90.2	159	6.7	56	2.4	17	0.7	2367	(100)
2O	733	74.2	233	23.6	18	1.8	4	0.4	988	(100)
3O	407	81.7	87	17.5	3	0.6	1	0.2	498	(100)
4O	207	74.2	63	22.6	8	2.9	1	0.4	279	(100)
ILLINOIS										
6D	10,300	88.1	1245	10.6	104	0.9	43	0.4	11,692	(100)
6U	1591	92.9	87	5.1	19	1.1	15	0.9	1712	(100)
8D	1616	68.4	735	31.1	6	0.3	4	0.2	2361	(100)
2O	1720	82.2	343	16.4	17	0.8	12	0.6	2092	(100)
3O	1420	85.4	212	12.8	21	1.3	9	0.5	1662	(100)
4O	352	82.4	62	14.5	9	2.1	4	0.9	427	(100)
CALIFORNIA										
6D	2537	81.0	333	10.6	152	4.9	109	3.5	3131	(100)
6U	121	80.7	18	12.0	8	5.3	3	2.0	150	(100)
7T	578	84.8	68	10.0	20	2.9	16	2.3	682	(100)
8D	2381	86.8	186	6.8	94	3.4	83	3.0	2744	(100)
2O	124	81.0	18	11.8	4	2.6	7	4.6	153	(100)
3O	531	89.8	32	5.4	14	2.4	14	2.4	591	(100)
4O	9	90.0	1	10.0	0	0.0	0	0.0	10	(100)
OREGON										
2O	223	78.8	21	7.4	20	7.1	19	6.7	283	(100)
3O	197	80.7	13	5.3	25	10.2	9	3.7	244	(100)
4O	51	85.0	2	3.3	2	3.3	5	8.3	60	(100)
COMBINED										
6D	23,626	85.9	3210	11.7	444	1.6	217	0.8	27,497	(100)
6U	1768	91.2	125	6.4	28	1.4	18	0.9	1939	(100)
7T	8999	90.5	754	7.6	139	1.4	51	0.5	9943	(100)
8D	6132	82.1	1080	14.5	156	2.1	104	1.4	7472	(100)
2O	2800	79.6	615	17.5	59	1.7	42	1.2	3516	(100)
3O	2555	85.3	344	11.5	63	2.1	33	1.1	2995	(100)
4O	619	79.8	128	16.5	19	2.4	10	1.3	776	(100)

Table 41. Summary of crash frequency and exposure data for intersections—Texas and Illinois.

Int. Type	Roadway Category	Number of Intersections	Major-Street AADT (veh/day)	Minor-Street AADT (veh/day)	Total Exposure[a] (10^6 veh)	Total Number of Crashes[a]	Average Crash Rate[a] (per 10^6 veh)
TEXAS							
3ST	2×2	23	32,215	1203	1403	171	0.122
	1×2	1	559	2832	6	0	0.000
	1×1	2	16,138	6193	82	8	0.098
	Combined	26	29,761	1650	1490	179	0.120
3SG	2×2	18	38,656	6552	1485	433	0.292
	1×2	2	9637	7217	62	52	0.845
	1×1	2	6202	4816	40	6	0.149
	Combined	22	33,067	6454	1587	491	0.309
4ST	2×2	12	35,073	1095	792	100	0.126
	1×2	18	8575	2730	371	27	0.073
	1×1	2	5891	1304	26	3	0.114
	Combined	32	18,344	2028	1190	130	0.109
4SG	2×2	126	37,373	19,207	13,010	7380	0.567
	1×2	111	8226	17,907	5294	2489	0.470
	1×1	55	9487	4891	1443	709	0.491
	Combined	292	21,041	16,016	19,748	10,578	0.536
ILLINOIS							
3ST	2×2	2	37,030	320	136	8	0.059
	1×2	59	11,572	1144	1369	227	0.166
	1×1	4	11,512	626	89	4	0.045
	Combined	65	12,351	1086	1594	239	0.150
3SG	2×2	2	41,755	857	156	68	0.437
	1×2	2	13,020	615	50	6	0.121
	1×1	2	12,780	1095	51	35	0.691
	Combined	6	22,518	855	256	109	0.426
4ST	2×2	3	42,976	1320	243	30	0.124
	1×2	94	8460	791	1587	442	0.278
	Combined	97	9528	808	1830	472	0.258
4SG	2×2	21	46,859	8197	2110	846	0.401
	1×2	21	11,854	3755	598	267	0.446
	1×1	3	6210	634	37	16	0.427
	Combined	45	27,814	5620	2746	1129	0.411

[a] In the five years of the study period.

Table 42. Summary of crash frequency and exposure data for intersections—California and Michigan.

Int. Type	Roadway Category	Number of Intersections	Major-Street AADT (veh/day)	Minor-Street AADT (veh/day)	Total Exposure[a] (10^6 veh)	Total Number of Crashes[a]	Average Crash Rate[a] (per 10^6 veh)
CALIFORNIA							
3ST	2×2	26	42,468	1118	2068	148	0.072
3SG	2×2	28	43,344	5744	2508	207	0.083
	1×2	6	8707	44,151	579	79	0.136
	Combined	34	37,232	12,521	3087	286	0.093
4ST	2×2	12	37,173	1582	849	66	0.078
	1×2	1	8760	910	18	1	0.057
	Combined	13	34,988	1530	866	67	0.077
4SG	2×2	228	49,119	11,599	25,265	3572	0.141
	1×2	11	19,924	38,926	1181	123	0.104
	1×1	23	16,423	7926	1022	266	0.260
	Combined	262	45,023	12,424	27,468	3961	0.144
MICHIGAN							
3ST	2×2	5	31,371	2487	309	16	0.052
	1×2	40	16,001	944	1237	114	0.092
	1×1	1	13,629	97	25	0	0.000
	Combined	46	17,620	1094	1571	130	0.083
3SG	2×2	10	25,693	3590	534	101	0.189
	1×2	23	16,905	13,890	1293	339	0.262
	1×1	3	15,762	6125	120	13	0.108
	Combined	36	19,251	10382	1947	453	0.233
4ST	2×2	9	22,343	970.2	383	27	0.071
	1×2	39	9405	2316	834	241	0.289
	1×1	1	9030	6739	29	2	0.069
	Combined	49	11,774	2159	1246	270	0.217
4SG	2×2	27	39,277	17,292	2787	1792	0.643
	1×2	52	12,953	15,747	2724	1415	0.519
	1×1	12	15,252	6992	487	475	0.975
	Combined	91	21,067	15,051	5998	3682	0.614

[a] In the five years of the study period.

Table 43. Summary of crash type data for intersection—Texas and Illinois.

Int. Type	Roadway Category	Number (Percentage) of Crashes in Five Years									
		Multiple-Vehicle Collisions		Single-Vehicle Collisions		Vehicle-Pedestrian Collisions		Vehicle-Bicycle Collisions		Total	
TEXAS											
3ST	2×2	157	(92)	7	(4)	4	(2)	3	(2)	171	(100)
	2×1	0	-	0	-	0	-	0	-	0	-
	1×1	5	(63)	3	(38)	0	(0)	0	(0)	8	(100)
	Combined	162	(91)	10	(6)	4	(2)	3	(2)	179	(100)
3SG	2×2	398	(92)	30	(7)	4	(1)	1	(0.2)	433	(100)
	2×1	47	(90)	3	(6)	2	(4)	0	(0)	52	(100)
	1×1	2	(33)	3	(50)	1	(17)	0	(0)	6	(100)
	Combined	447	(91)	36	(7)	7	(1)	1	(0.2)	491	(100)
4ST	2×2	90	(90)	6	(6)	2	(2)	2	(2)	100	(100)
	2×1	24	(89)	2	(7)	1	(4)	0	(0)	27	(100)
	1×1	1	(33)	1	(33)	1	(33)	0	(0)	3	(100)
	Combined	115	(88)	9	(7)	4	(3)	2	(2)	130	(100)
4SG	2×2	7041	(95)	211	(3)	88	(1)	40	(1)	7380	(100)
	2×1	2350	(94)	86	(3)	33	(1)	20	(1)	2489	(100)
	1×1	644	(91)	30	(4)	31	(4)	4	(1)	709	(100)
	Combined	9658	(95)	314	(3)	146	(1)	64	(1)	10182	(100)
ILLINOIS											
3ST	2×2	5	(63)	2	(25)	1	(13)	0	(0)	8	(100)
	2×1	208	(92)	13	(6)	3	(1)	3	(1)	227	(100)
	1×1	3	(75)	0	(0)	0	(0)	1	(25)	4	(100)
	Combined	216	(90)	15	(6)	4	(2)	4	(2)	239	(100)
3SG	2×2	65	(96)	3	(4)	0	(0)	0	(0)	68	(100)
	2×1	5	(83)	0	(0)	0	(0)	1	(17)	6	(100)
	1×1	34	(97)	1	(3)	0	(0)	0	(0)	35	(100)
	Combined	104	(95)	4	(4)	0	(0)	1	(1)	109	(100)
4ST	2×2	28	(93)	2	(7)	0	(0)	0	(0)	30	(100)
	2×1	406	(92)	20	(5)	8	(2)	8	(2)	442	(100)
	Combined	434	(92)	22	(5)	8	(2)	8	(2)	472	(100)
4SG	2×2	811	(96)	29	(4)	2	(0.3)	4	(0.6)	846	(100)
	2×1	253	(95)	4	(1)	7	(3)	3	(1)	267	(100)
	1×1	16	(100)	0	(0)	0	(0)	0	(0)	16	(100)
	Combined	1110	(96)	34	(3)	9	(1)	7	(1)	1160	(100)

Table 44. Summary of crash type data for intersection—California and Michigan.

Int. Type	Roadway Category	Number (Percentage) of Crashes in Five Years: Multiple-Vehicle Collisions		Single-Vehicle Collisions		Vehicle-Pedestrian Collisions		Vehicle-Bicycle Collisions		Total	
CALIFORNIA											
3ST	2×2	118	(80)	7	(5)	11	(7)	12	(8)	148	(100)
3SG	2×2	160	(77)	13	(6)	14	(7)	20	(10)	207	(100)
	2×1	75	(95)	3	(4)	0	(0)	1	(1)	79	(100)
	Combined	235	(82)	16	(6)	14	(5)	21	(7)	286	(100)
4ST	2×2	51	(77)	4	(6)	6	(9)	5	(8)	66	(100)
	2×1	1	(100)	0	(0)	0	(0)	0	(0)	1	(100)
	Combined	52	(78)	4	(6)	6	(9)	5	(7)	67	(100)
4SG	2×2	2993	(84)	200	(6)	195	(5)	183	(5)	3571	(100)
	2×1	93	(76)	5	(4)	15	(12)	10	(8)	123	(100)
	1×1	253	(95)	3	(1)	5	(2)	5	(2)	266	(100)
	Combined	3339	(84)	208	(5)	215	(5)	198	(5)	3960	(100)
MICHIGAN											
3ST	2×2	15	(94)	1	(6)	0	(0)	0	(0)	16	(100)
	2×1	104	(91)	6	(5)	2	(2)	2	(2)	114	(100)
	1×1	0	-	0	-	0	-	0	-	0	-
	Combined	119	(92)	7	(5)	2	(2)	2	(2)	130	(100)
3SG	2×2	91	(90)	5	(5)	4	(4)	1	(1)	101	(100)
	2×1	312	(92)	18	(5)	3	(1)	6	(2)	339	(100)
	1×1	11	(85)	0	(0)	2	(15)	0	(0)	13	(100)
	Combined	414	(91)	23	(5)	9	(2)	7	(2)	453	(100)
4ST	2×2	20	(74)	4	(15)	2	(7)	1	(4)	27	(100)
	2×1	221	(92)	9	(4)	4	(2)	7	(3)	241	(100)
	1×1	2	(100)	0	(0)	0	(0)	0	(0)	2	(100)
	Combined	243	(90)	13	(5)	6	(2)	8	(3)	270	(100)
4SG	2×2	1728	(96)	31	(2)	17	(1)	16	(1)	1792	(100)
	2×1	1334	(94)	39	(3)	27	(2)	15	(1)	1415	(100)
	1×1	454	(96)	7	(1)	6	(1)	8	(2)	475	(100)
	Combined	3516	(95)	77	(2)	50	(1)	39	(1)	3682	(100)

SUPPLEMENTAL DATA COLLECTION—PEDESTRIAN DATA

Since pedestrian exposure data were not available in the electronic databases that were assembled for this project, on-site data collection activities were done to supplement the data already collected. A sample of 40 intersections in California and 24 intersections in San Antonio, Texas, were therefore selected for data collection for the pedestrian evaluation. The sites in California were selected along three corridors with six through lanes—CA-82 and US-101 in the San Francisco Bay Area and CA-187 in Los Angeles—and a one-way street pair—CA-32 in Chico. The 24 intersections in San Antonio were all located downtown or the area near downtown. All the intersections in San Antonio involved one-way streets. Table 45 shows the distribution of the intersections in the sample based on the number of traffic directions on the intersection approaches (2×2, 2×1, and 1×1) and intersection type (3SG or 4SG).

Table 45. Sample size based on intersection type and location.

Intersection Type	California		San Antonio, Texas	
	3SG	4SG	3SG	4SG
2×2	5	25	0	0
2×1	0	4	0	18
1×1	0	6	0	6

Note: 2×2 = two-way street intersecting two-way street; 2×1 = two-way street intersecting one-way street; 1×1 = one-way street intersecting one-way street; 3SG = three-leg signalized intersection; 4SG = four-leg signalized intersection.

Table 46 presents a summary of the collected data used for validation of the HSM model for vehicle-pedestrian collisions at signalized intersections. Eighteen-hour (6:00 AM to 12:00 AM) pedestrian counts were collected at five sites, one along each of the corridors in California and one in downtown San Antonio. Two-hour pedestrian counts were collected at the remaining intersections. The 18-hour counts were used to compute adjustment factors needed to convert two-hour counts to daily pedestrian volumes. It was assumed that pedestrian activity during the remaining six hours (between 12:00 AM and 6:00 AM) was negligible.

The major- and minor-street AADTs were determined using California HSIS data and City of San Antonio traffic volume data. The variable n_{lanesx} was determined using Google Earth aerial imagery. The presence of schools and number of bus stops and alcohol sales establishments within 1,000 ft of the intersection were recorded for each site using Google Earth aerial imagery and Street View. The team followed the HSM instructions to determine these variables. The CMFs were determined using the respective tables in the HSM.

The observed number of vehicle-pedestrian collisions at the selected intersections was determined using HSIS data for California and the Crash Records Information System (CRIS) database for Texas. A vehicle-pedestrian collision was assigned to an intersection if it occurred within 250 ft of the intersection center or was coded as intersection-related. Where a collision occurred between two adjacent intersections that were less than 500 ft apart, the collision was assigned to the nearest intersection. Only fatal or injury collisions were considered in the analysis (consistent with the HSM).

Table 46. Descriptive statistics for collected data at signalized intersections in California and San Antonio, Texas.

Variable		3SG Intersections				4SG Intersections			
		Min. value	Max. value	Average (SD)	Frequency	Min. value	Max. value	Average (SD)	Frequency
CALIFORNIA									
Major-road AADT (veh/day)		35,582	44,588	40,186 (3769.5)	5	12,060	61,815	39,979 (12,646.6)	35
Minor-road AADT (veh/day)		800	2480	1374 (668.8)	5	2600	28,100	11,451 (6956.8)	35
Total pedestrian volume crossing all intersection legs (ped/day)		390	1172	669 (316.4)	5	66	16,445	3364 (4120.97)	35
Maximum number of lanes crossed by pedestrian at intersection considering presence of refuge islands		6	7	6.8 (0.44)	5	2	10	6.7 (2.30)	35
Number of bus stops within 1000 ft of the intersection	0 1 or 2 ≥ 3				0 4 1				0 9 26
School presence	0 (no) 1 (yes)				3 2				30 5
Number of alcohol sales establishments within 1000 ft of the intersection	0 1–8 ≥ 9				3 2 0				7 28 0
SAN ANTONIO, TX									
Major-road AADT (veh/day)					0	4046	18,592	10,780 (4298.2)	24
Minor-road AADT (veh/day)					0	462	12,727	5134 (3497.6)	24
Total pedestrian volume crossing all intersection legs (ped/day)					0	33	12,985	4096 (4239.2)	24
Maximum number of lanes crossed by pedestrian at intersection considering presence of refuge islands					0	3	4	3.2 (0.44)	24
Number of bus stops within 1000 ft of the intersection	0 1 or 2 ≥ 3								0 1 23
School presence	0 (no) 1 (yes)								23 1
Number of alcohol sales establishments within 1000 ft of the intersection	0 1–8 ≥ 9								5 17 2

Note: Shaded cell = data not collected or not applicable.

CHAPTER 5. PREDICTIVE MODELS FOR URBAN AND SUBURBAN ROADWAY SEGMENTS WITH SIX OR MORE LANES

This chapter describes the activities undertaken to calibrate safety predictive models for urban and suburban roadway segments with six or more lanes. Each model consists of an SPF and a family of CMFs. The SPF is derived to estimate the crash frequency with specified design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from those that are specified.

The calibrated safety predictive models were used to develop the two-way arterial roadway segment safety predictive method. This method describes how to use the models to evaluate the safety of two-way six-or-more-lane arterials, as may be influenced by road geometry, roadside features, and traffic volume. Collectively, the predictive models for roadway segments in this chapter address the following facilities.

- Divided two-way arterials with six lanes (including a raised or depressed median) (6D).
- Undivided two-way arterials with six lanes (6U).
- Two-way arterials with six lanes and a TWLTL in the middle (7T).
- Divided two-way arterials with eight lanes (including a raised or depressed median) (8D).

This chapter is divided into four sections. The first section provides a brief background related to segmentation, database development, and modeling approach. The second section summarizes the details of calibration data. The third section describes the calibration of the models to predict FI, PDO, vehicle-pedestrian, and vehicle-bicycle crash frequency. The fourth section provides a list of CMFs.

BACKGROUND

The road segment boundaries are typically defined by intersections or by a change in the cross-section. Each segment is homogenous with respect to characteristics such as traffic volumes and key roadway design characteristics and traffic control features. Figure 14 shows the segment length, *L*, for a single homogenous roadway segment occurring between two intersections. However, several homogenous roadway segments can occur between two intersections.

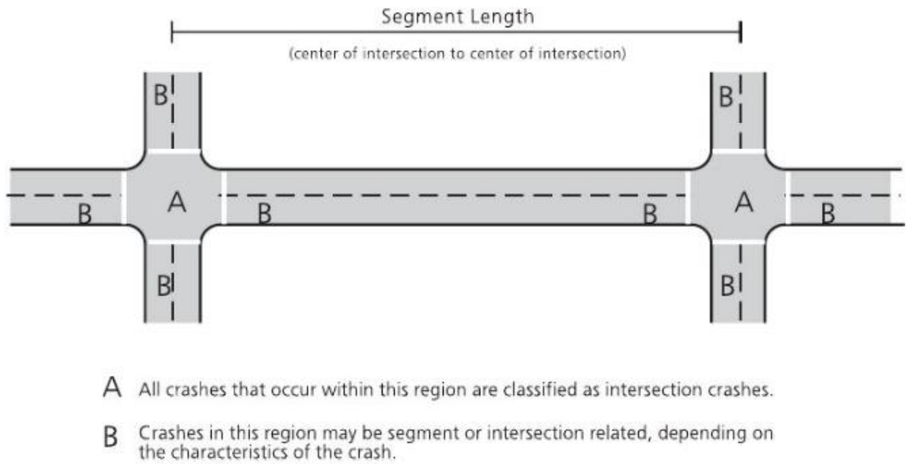

Figure 14. Definition of roadway segments and intersections (AASHTO, 2010).

A new (unique) homogenous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

- AADT (vehicles per day).
- Number of through lanes.
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL).
- Lane width.
- Outside shoulder width.
- Median width.
- Speed category.

A cross-sectional (as opposed to panel) database was created for developing the regression models. The database includes a five-year study period for all observations. Study duration in years is represented as an offset variable in the regression model. One reason for using cross-sectional data for model calibration relates to the accuracy of the AADT values in most highway safety databases. Segment AADT is frequently extrapolated by a state DOT from partial-year counts taken at temporary count stations located several miles from the subject segment. Thus, there are accuracy implications associated with this temporal and spatial extrapolation (Bonneson et al., 2012). Moreover, state DOT practice when a current count is not available for a segment is sometimes used to adjust the AADT from the last year it was counted (which could be several years previous); other times, the practice is to leave the variable as missing. Thus, averaging each segment's AADT over years minimizes the variability in AADT, which, based on the aforementioned observations, is considered largely random. More generally, cross-sectional data provide a more robust predictive model than panel data when the year-to-year variability in the independent variables is largely random.

A second reason for using cross-sectional data for model calibration is to minimize the problems associated with overrepresentation of segments or intersections with zero crashes. Statistical methods have been developed to improve the fit of a model to these zero-inflated or excess zero data. However, Lord et al. (2005) and Geedipally et al. (2012) indicate that when these methods have been applied to highway crash data, they have (a) an inherent tendency to over-fit the data, (b) a theoretic explanation of dual state highway safety that is problematic with one of the two states that has a long-term mean equal to zero (i.e., the mean of the Poisson distribution is always equal to zero), and (c) the potential to obfuscate the interpretation of predictive model trend and coefficient meaning. Thus, summing each segment's crashes over years minimizes the proportion of segments or intersections with zero crashes in the database and precludes the need for a dual state distribution.

Separate models were developed for FI and PDO crashes. Experience with regression-based calibration of SPFs and CMFs using total crashes and using only FI crashes indicates that the calibration coefficients often vary among model types for common variables. Some of this variation is likely due to the fact that geometric elements often have a different effect on FI crashes than on PDO crashes. As a result, the search for correlation and possible causation is challenged when using total crash data to build total crash prediction models because total crashes combine FI and PDO crashes. It is widely recognized that PDO crash counts vary widely on a regional basis due to significant variation in the reporting threshold. When crash frequency varies systematically from county to county, district to district, and state to state because of formal and informal differences in the reporting threshold, the use of PDO crash data to build PDO crash prediction models is problematic. This observation suggests that PDO-based and total crash models are likely to include regional biases and added uncertainty due to variation in reporting thresholds.

Based on these issues, the following model-building process was developed. Researchers rationalized that (a) FI crash data are likely to provide the most accurate insight into regression model structure and factors influencing safety, and (b) PDO-based models are preferred to total crash models. However, because of under-reporting, the development of PDO regression models is problematic and the variable effect provided by these models may not be accurate. Therefore, the FI regression model structure was developed first and then used as a starting point for the development of the PDO regression model. By doing this, the research team could estimate the PDO crashes at the same base conditions. Some geometric variables that were significant in the FI model were less significant in the PDO model. Specifically, the standard error was increased for those geometric variables that varied more among counties than within counties. Unfortunately, it is not known whether the among-county variation is due to differences in reporting threshold (as may be informally applied at different levels within a state) or because of differences in geometry. This approach often resulted in the PDO model having fewer geometric variables than the FI model. Since FI models were more accurate than PDO models, the CMFs were developed from FI crash data only but were used for both FI and PDO crashes.

CALIBRATION DATA

The database assembly for these types of facilities focused on Texas and two HSIS states: California and Illinois. Although a general description of all the data collected was provided in the previous chapter, the descriptions provided here and the subsequent chapters are tailored specifically for the models documented in the corresponding chapter and include only the variables that were considered in the final models. The data are summarized in Table 47 and Table 48 for electronic and supplemental variables, respectively.

Table 47. Variables acquired from state databases for six-or-more-lane arterials.

Data Variable	Description
AADT	Two-way annual average daily traffic volume (veh/day) during the study period
Segment length	Length of the homogenous segment (mi) in the state database
Lane width	Average width (ft) of the through lanes
Inside shoulder width (divided segments)	Average width of the inside shoulder (ft) in the two directions of travel
Outside shoulder width	Average width of the outside shoulder (ft) in the two directions of travel
Median width	Average median width (ft) along the segment

Table 48. Supplemental data collected for six-or-more-lane arterials.

Data Variable	Description
Bus or HOV lane presence	Presence of bus-only or HOV lanes.
Bicycle lane presence	Presence of bicycles lanes.
Sidewalks	Presence of sidewalks along each side of the roadway segment: 0: No sidewalk. 1: Sidewalk on one side of the roadway. 2: Sidewalks on both sides of the roadway.
Lighting	Presence of lighting along each side of the roadway segment: 0: No lighting. 1: Lighting on one side of the roadway. 2: Lighting on both sides of the roadway.
Parallel parking proportion	Proportion of the length of segment with parallel parking (considered in both directions of travel for two-way streets).
Angle parking proportion	Proportion of the length of segment with angle parking (considered in both directions of travel for two-way streets).
Speed limit	Posted speed limit (mph) as observed from speed limit signs.
Median barrier	Presence of concrete barriers in the median.
Railroad crossings	Number of railroad-highway crossings within the limits of the roadway segment.
Driveway density	Density of driveways along the length of the segment (driveways/mile), classified consistently with the HSM Chapter 12 driveway categories: Major commercial driveways. Minor commercial driveways. Major industrial/institutional driveways. Minor industrial/institutional driveways. Major residential driveways. Minor residential driveways. Other driveways.
Roadside fixed-object density	Density of fixed roadside objects (objects/mile) within 30 ft of the edge of traveled way (in both directions of travel for two-way streets). In absence of marked edge lines, edge of traveled way was considered to be 2.0 ft from the face of the curb. Fixed objects were counted using the same method as required for application of the HSM CMF for roadside fixed objects (described on pages 12–41 of the HSM).
Roadside fixed-object offset	Average distance from the edge of traveled way to the roadside fixed objects (as defined above).
Inside curb proportion	Ratio of the two-way total length (ft) of curb present along the inside (median side) of the segment to twice the length of the segment.
Outside curb proportion	Ratio of the two-way total length (ft) of curb present along the outside (right shoulder side) of the segment to twice the length of the segment.

MODEL DEVELOPMENT—SIX-OR-MORE-LANE ARTERIALS

The regression model form that was used to predict the average crash frequency on an individual roadway segment is as follows:

$$N_j = (N_{mv} I_{mv} + N_{sv} I_{sv}) \times CMF_{lw} \times CMF_{osw} \times CMF_{mw} \times CMF_{rhx} \quad (141)$$

with,

$$N_{mv} = N_{spfmv} \times CMF_{dwc\_mj} \times CMF_{dwi\_mj} \times CMF_{dw\_mn} \times CMF_{bar,mv} \quad (142)$$

$$N_{sv} = N_{spfsv} \times CMF_{fo} \times CMF_{bar,sv} \quad (143)$$

$$N_{spfmv} = L \times n \times e^{b_{mv}+b_{mv1}\ln(AADT)+b_{ca}I_{ca}+b_{il}I_{il}} \quad (144)$$

$$N_{spfsv} = L \times n \times e^{b_{sv}+b_{sv1}\ln(AADT)+b_{ca}I_{ca}+b_{il}I_{il}} \quad (145)$$

$$CMF_{lw} = e^{b_{lw}(W_l-12)} \quad (146)$$

$$CMF_{osw} = e^{b_{osw}(W_{os}-1.5)} \quad (147)$$

$$CMF_{mw} = e^{b_{mw}(W_m-15)} \quad (148)$$

$$CMF_{rhx} = e^{b_{rhx}n_{rhx/L}} \quad (149)$$

$$CMF_{dwc\_mj} = e^{b_{dwc\_mj}(n_{dwc\_mj}-2)} \quad (150)$$

$$CMF_{dwi\_mj} = e^{b_{dwi\_mj}(n_{dwi\_mj}-1)} \quad (151)$$

$$CMF_{dw\_mn} = e^{b_{dw\_mn}(n_{dw\_mn}-10)} \quad (152)$$

$$CMF_{bar,j} = e^{b_{bar,j}I_{bar}};\ j = mv,\ sv \quad (153)$$

$$CMF_{fo} = 1.0 + \frac{0.01D_{fo}}{e^{b_{fo}(O_{fo})}} \quad (154)$$

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} = crash indicator variable (= 1.0 if multiple-vehicle crash data, 0.0 otherwise).
I_{sv} = crash indicator variable (= 1.0 if single-vehicle crash data, 0.0 otherwise).
L = segment length, mi.
n = number of years of crash data.
$AADT$ = average annual daily traffic, veh/day.
I_{ca} = California state indicator variable (= 1.0 if site is in California, 0.0 if not).
I_{il} = Illinois state indicator variable (= 1.0 if site is in Illinois, 0.0 if not).
CMF_{lw} = lane width CMF.
CMF_{osw} = shoulder width CMF.
CMF_{mw} = median width CMF.
CMF_{rhx} = railroad crossing CMF.
CMF_{dwc_mj} = major commercial driveways CMF.
CMF_{dwi_mj} = major industrial driveways CMF.
CMF_{dw_mn} = minor driveways CMF.
$CMF_{bar,j}$ = median barrier CMF.
CMF_{fo} = roadside fixed objects CMF.
W_l = average lane width, ft.
W_{os} = average outside shoulder width, ft.
W_m = median width, ft.
n_{rhx} = number of railroad crossings on the segment.
n_{dwc_mj} = major commercial driveway density, driveways/mile.
n_{dwi_mj} = major industrial driveway density, driveways/mile.
n_{dw_mn} = minor driveway density, driveways/mile.
I_{bar} = median barrier presence indicator variable (= 1.0 if present, 0.0 if absent).

O_{fo} = roadside fixed-object offset, ft.
D_{fo} = roadside fixed-object density, fixed objects/mile.
p_{fo} = roadside fixed-object collisions as a proportion of total crashes.
b_i = calibration coefficient for variable i.

The inverse dispersion parameter, K (which is the inverse of the overdispersion parameter k), is allowed to vary with the segment length. The inverse dispersion parameter is calculated using Equation 155:

$$K = L \times e^{\delta,j};\ j = mv, sv \quad (155)$$

where,

K = inverse dispersion parameter.
δ = calibration coefficient for inverse dispersion parameter.

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 the equations above. The simultaneous calibration approach was needed because several 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.

Table 49 and Table 50 summarize the modeling results for two-way arterial segments for FI and PDO crashes, respectively. The variables with the corresponding p-values less than 0.05 can be considered statistically significant (at the significance level $\alpha = 0.05$). For those few variables where the p-value was greater than 0.05, 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 when applied to this database).

Table 49. Calibrated coefficients for FI crashes on six-or-more-lane arterials.

Coefficient	Variable	Facility	Estimate	Std. Error	t-statistic	p-value
b_{mv}	Intercept for MV crashes	6U	−15.4189	2.7868	−5.53	<0.0001
		6D	−11.5649	0.5438	−21.27	<0.0001
		7T	−11.4439	0.5362	−21.34	<0.0001
		8D	−11.3817	0.5805	−19.61	<0.0001
b_{mv1}	AADT on MV crashes	6U	1.6329	0.2625	6.22	<0.0001
		6D	1.2399	0.0526	23.59	<0.0001
		7T	1.2399	0.0526	23.59	<0.0001
		8D	1.2399	0.0526	23.59	<0.0001
b_{sv}	Intercept for SV crashes	6U	−4.5419	1.3489	−3.37	0.0008
		6D	−5.2579	0.8626	−6.10	<0.0001
		7T	−4.5419	1.3489	−3.37	0.0008
		8D	−5.3556	0.9281	−5.77	<0.0001
b_{sv1}	AADT on SV crashes	6U	0.3694	0.1309	2.82	0.0048
		6D	0.4631	0.0835	5.55	<0.0001
		7T	0.3694	0.1309	2.82	0.0048
		8D	0.4631	0.0835	5.55	<0.0001
b_{lw}	Lane width	All	−0.0219	0.0138	−1.58	0.1144
b_{osw}	Outside shoulder width	All	−0.0285	0.0045	−6.30	<0.0001
b_{mw}	Median width	6D/8D	−0.0057	0.0012	−4.65	<0.0001
$b_{mb,mv}$	Median barrier on MV crashes	6D/8D	−0.5106	0.1550	−3.29	0.0010
$b_{mb,sv}$	Median barrier on SV crashes	6D/8D	0.6766	0.2099	3.22	0.0013
b_{rhx}	Railroad crossing presence	All	0.0388	0.0218	1.78	0.0747
b_{dwc_mj}	Major commercial driveway density on MV crashes	All	0.0350	0.0038	9.20	<0.0001
b_{dwi_mj}	Major industrial driveway density on MV crashes	All	0.0107	0.0085	1.25	0.2105
b_{dw_mn}	Minor driveway density on MV crashes	All	0.0054	0.0015	3.72	0.0002
b_{fo}	Roadside fixed-object density on SV crashes	All	0.1310	0.0366	3.58	0.0004
b_{il}	Added effect of Illinois	All	−0.3808	0.0475	−8.02	<0.0001
δ_{mv}	Inverse dispersion parameter for MV crashes	6U	2.8668	0.2825	10.15	<0.0001
		6D	2.0469	0.0586	34.96	<0.0001
		7T	1.2993	0.1198	10.84	<0.0001
		8D	2.4932	0.1738	14.35	<0.0001
δ_{sv}	Inverse dispersion parameter for SV crashes	6U	3.0797	0.9312	3.31	0.0010
		6D	1.4992	0.1316	11.39	<0.0001
		7T	3.0797	0.9312	3.31	0.0010
		8D	2.0078	0.3753	5.35	<0.0001
	Observations	2229 segments (6U=92; 6D=1759; 7T=222; 8D=113)				

Note: MV = multiple vehicle; SV = single vehicle.

Table 50. Calibrated coefficients for PDO crashes on six-or-more-lane arterials.

Coefficient	Variable	Facility	Estimate	Std. Error	t-statistic	p-value
b_{mv}	Intercept for MV crashes	6U	−15.6792	2.2895	−6.85	<0.0001
		6D	−9.2080	0.5054	−18.22	<0.0001
		7T	−9.1980	0.4998	−18.40	<0.0001
		8D	−8.8445	0.5459	−16.20	<0.0001
b_{mv1}	AADT on MV crashes	6U	1.6966	0.2160	7.85	<0.0001
		6D	1.0611	0.0490	21.68	<0.0001
		7T	1.0611	0.0490	21.68	<0.0001
		8D	1.0611	0.0490	21.68	<0.0001
b_{sv}	Intercept for SV crashes	6U	−3.9795	1.3071	−3.04	0.0023
		6D	−4.7118	0.6937	−6.79	<0.0001
		7T	−3.9795	1.3071	−3.04	0.0023
		8D	−4.3443	0.7476	−5.81	<0.0001
b_{sv1}	AADT on SV crashes	6U	0.3429	0.1269	2.70	0.0068
		6D	0.4341	0.0671	6.47	<0.0001
		7T	0.3429	0.1269	2.70	0.0068
		8D	0.4341	0.0671	6.47	<0.0001
b_{lw}	Lane width	All	−0.0516	0.0138	−3.75	0.0002
b_{osw}	Outside shoulder width	All	−0.0278	0.0044	−6.26	<0.0001
b_{mw}	Median width	6D/8D	−0.0035	0.0011	−3.11	0.0019
$b_{mw,mv}$	Median barrier on MV crashes	6D/8D	−0.7651	0.1517	−5.04	<0.0001
$b_{mw,sv}$	Median barrier on SV crashes	6D/8D	0.5723	0.1545	3.70	0.0002
b_{rhx}	Railroad crossing presence	All	0.0420	0.0187	2.25	0.0255
b_{dwc_mj}	Major commercial driveway density on MV crashes	All	0.0479	0.0040	11.89	<0.0001
b_{dwi_mj}	Major industrial driveway density on MV crashes	All	0.0091	0.0083	1.09	0.2709
b_{dw_mn}	Minor driveway density on MV crashes	All	0.0069	0.0015	4.48	<0.0001
b_{fo}	Roadside fixed-object density on SV crashes	All	0.1461	0.0305	4.79	<0.0001
b_{il}	Added effect of Illinois	All	0.7871	0.0420	18.73	<0.0001
δ_{mv}	Inverse dispersion parameter for MV crashes	6U	2.9953	0.1894	15.82	<0.0001
		6D	1.9099	0.0412	46.41	<0.0001
		7T	1.0820	0.1077	10.04	<0.0001
		8D	1.6689	0.1367	12.20	<0.0001
δ_{sv}	Inverse dispersion parameter for SV crashes	6U	1.9732	0.2607	7.57	<0.0001
		6D	1.9997	0.0888	22.52	<0.0001
		7T	1.9732	0.2607	7.57	<0.0001
		8D	1.8385	0.2282	8.06	<0.0001
	Observations	2229 segments (6U=92; 6D=1759; 7T=222; 8D=113)				

Indicator variables were included for the states of California and Illinois. However, only the coefficient for Illinois was statistically significant. This means that the magnitude of the crashes between Texas and California are about the same, but Illinois experiences fewer FI crashes and more PDO crashes for the same conditions and exposure. The trend could not be explained by difference in road design among the states. It is likely that the differences between states are due to unobserved variables such as vertical grade, signing, pavement condition, weather, reporting accuracy, and speed limit.

The mixed nonlinear regression procedure (NLMIXED) in the Statistical Analysis System (SAS) software was used to estimate the proposed model coefficients. This procedure was used because the proposed predictive model is both nonlinear and discontinuous. The log-likelihood function for the NB distribution was used to determine the best-fit model coefficients.

Figure 15 and Figure 16 show the relationship between the number of FI crashes and traffic flow for six-or-more-lane segments for multi-vehicle and single-vehicle crashes, respectively. Figure 15 shows that divided facilities experience fewer multi-vehicle crashes than undivided facilities. Figure 16 shows that six-lane divided facilities experience slightly more single-vehicle FI crashes than do eight-lane divided and six-lane undivided arterials.

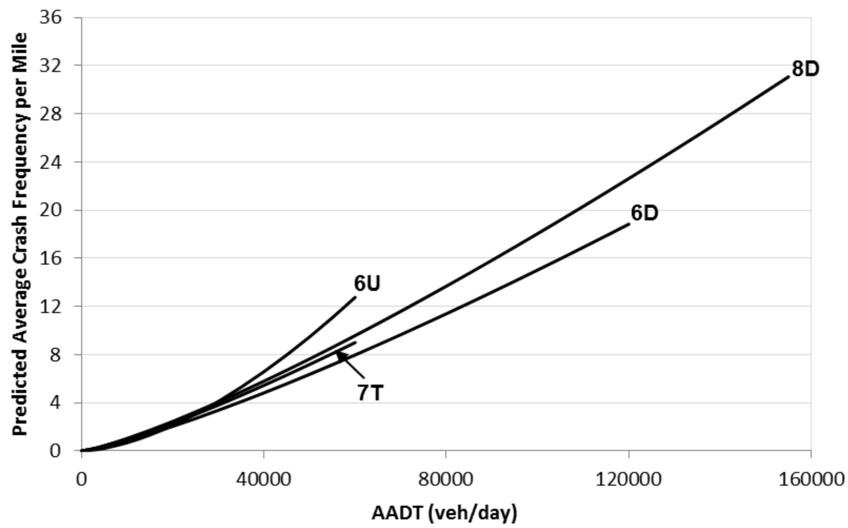

Figure 15. Graphical form of the SPF for FI multiple-vehicle collisions, six-or-more-lane arterials.

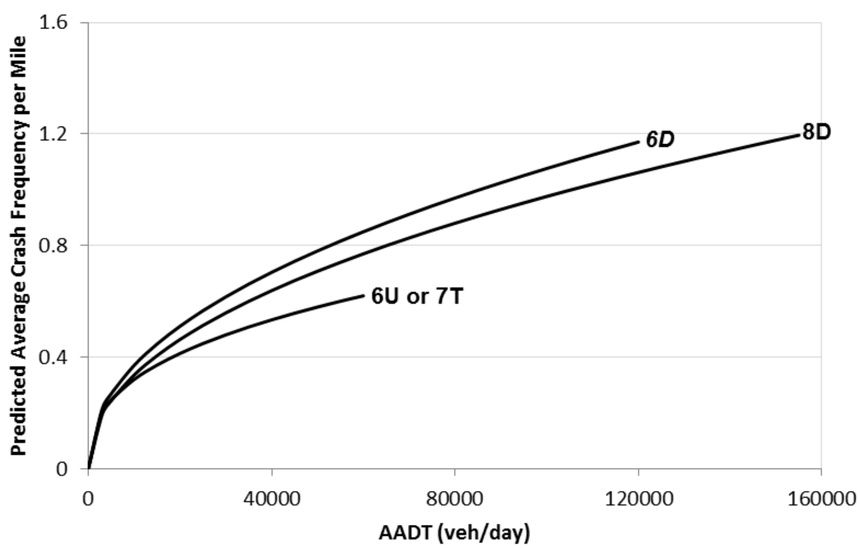

Figure 16. Graphical form of the SPF for FI single-vehicle collisions, six-or-more-lane arterials.

Figure 17 and Figure 18 show the relationship between the number of PDO crashes and traffic flow for six or more lanes for multi-vehicle and single-vehicle crashes, respectively. Figure 17 shows that eight-lane divided facilities experience more multi-vehicle PDO crashes than do six-lane undivided and divided facilities. Figure 18 shows that eight-lane divided facilities experience more single-vehicle PDO crashes than do six-lane divided and six-lane undivided facilities.

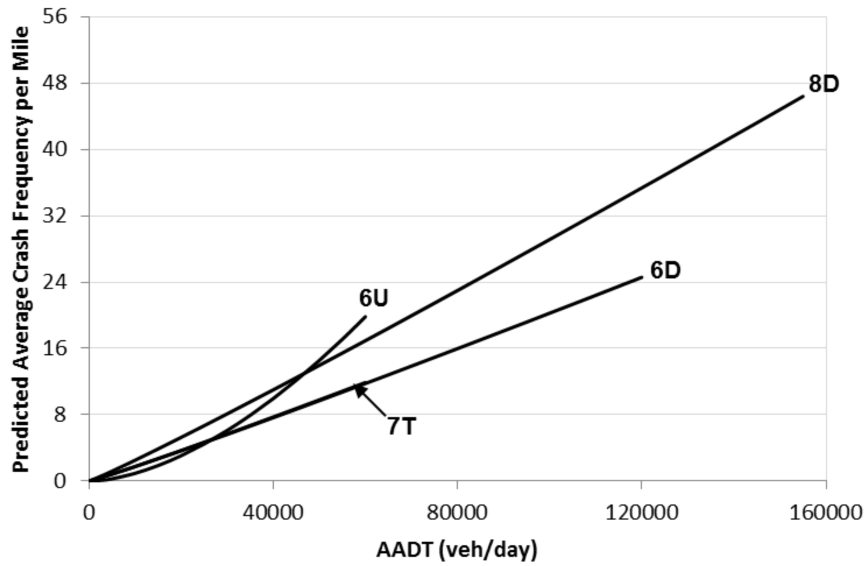

Figure 17. Graphical form of the SPF for PDO multiple-vehicle collisions, six-or-more-lane arterials.

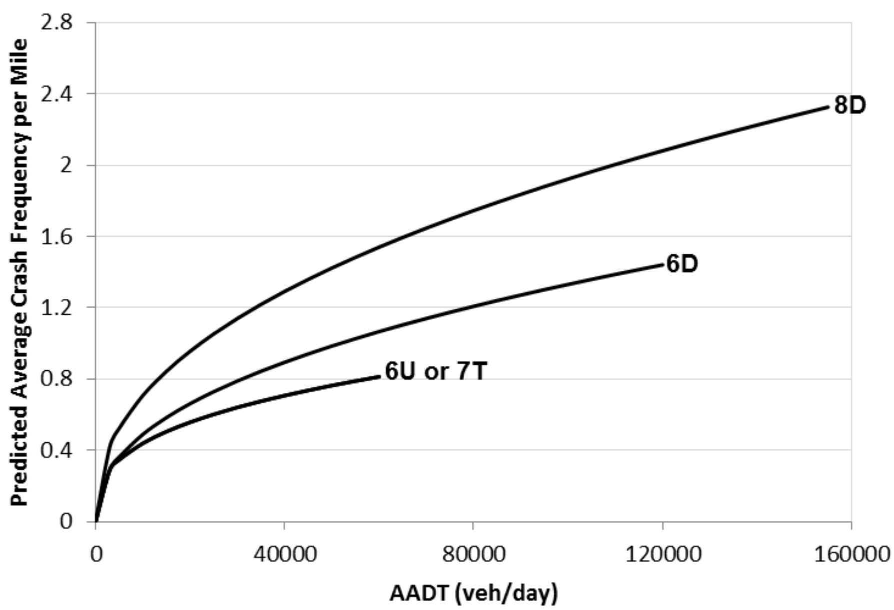

Figure 18. Graphical form of the SPF for PDO single-vehicle collisions, six-or-more-lane arterials.

The proportions in Table 51 are used to separate multiple-vehicle crashes into components by collision type for arterials with six or more lanes.

Table 51. Distribution of multiple-vehicle collisions for roadway segments by manner of collision type.

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types							
	6U		6D		7T		8D	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.752	0.586	0.769	0.591	0.694	0.588	0.746	0.647
Head-on collision	0.037	0.008	0.012	0.012	0.034	0.012	0.006	0.000
Angle collision	0.064	0.052	0.091	0.081	0.148	0.092	0.147	0.093
Sideswipe, same direction	0.083	0.302	0.087	0.262	0.072	0.255	0.073	0.236
Sideswipe, opposite direction	0.028	0.005	0.011	0.020	0.020	0.024	0.011	0.012
Other multiple-vehicle collisions	0.037	0.046	0.030	0.033	0.031	0.029	0.017	0.012

Source: HSIS data for California (2006–2010).

The proportions in Table 52 are used to separate single-vehicle crashes into components by crash type for arterials with six or more lanes.

Table 52. Distribution of single-vehicle crashes for roadway segments by collision type for arterials with six or more lanes.

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types							
	6U		6D		7T		8D	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with fixed object—left	0.100	0.174	0.296	0.353	0.158	0.248	0.167	0.273
Collision with fixed object—right	0.350	0.413	0.332	0.397	0.495	0.481	0.611	0.591
Collision with other object	0.050	0.130	0.032	0.073	0.011	0.037	0.000	0.045
Other single-vehicle collision	0.500	0.283	0.339	0.177	0.337	0.234	0.222	0.091

Source: HSIS data for California (2006–2010).

VEHICLE-PEDESTRIAN COLLISIONS

The number of vehicle-pedestrian crashes per year for a roadway segment is estimated using Equation 156.

$$N_{pedr} = N_{br} \times f_{pedr} \quad (156)$$

where,

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions).
N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for a roadway segment.
f_{pedr} = pedestrian crash adjustment factor.

The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the total segment crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for each segment type. Table 53 presents the values of f_{pedr}. All vehicle-pedestrian collisions are considered FI crashes. The HSM adjustment factors (from the original Table 12-16 in HSM Chapter 12) are also displayed for comparison.

Pedestrian crash adjustment factors are developed using Equation 157.

$$f_{pedr} = \frac{N_{pedr}}{N_{br}} \tag{157}$$

where,

N_{pedr} = crash frequency of vehicle-pedestrian collisions for an individual roadway segment.
N_{br} = crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions).

Table 53. Pedestrian crash adjustment factor for two-way roadway segments.

Source	Road Type	Pedestrian Crash Adjustment Factor (f_{pedr})							
		Posted Speed 30 mph or Lower				Posted Speed Greater Than 30 mph			
		Number of Segments	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{pedr}	Number of Segments	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{pedr}
HSM Ch. 12	2U				0.036				0.005
	3T				0.041				0.013
	4U				0.022				0.009
	4D				0.067				0.019
	5T				0.030				0.023
Proposed	6U	22	10	549	0.018	72	18	1359	0.013
	6D	106	69	2377	0.029	1661	369	24720	0.015
	7T	16	11	324	0.034	250	138	10016	0.014
	8D	1	1	612		122	150	6623	0.023

Note: Shaded cell = data not available.
[a] Excludes pedestrian and bicycle crashes.

VEHICLE-BICYCLE COLLISIONS

The number of vehicle-bicycle collisions per year for an intersection is estimated using Equation 158.

$$N_{biker} = N_{br} \times f_{biker} \tag{158}$$

where,

N_{br} = predicted average crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions).

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an intersection.
f_{biker} = 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 54 presents the values of f_{biker}. All vehicle-bicycle collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-17) are also displayed for comparison.

The adjustment factors are developed using Equation 159.

$$f_{biker} = \frac{N_{biker}}{N_{br}} \tag{159}$$

where,

N_{br} = crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions).
N_{biker} = crash frequency of vehicle-bicycle collisions for an individual roadway segment.

Table 54. Bicycle crash adjustment factor for two-way roadway segments.

Source	Road Type	Bicycle Crash Adjustment Factor (f_{biker})							
		Posted Speed 30 mph or Lower				Posted Speed Greater Than 30 mph			
		Number of Segments	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{biker}	Number of Segments	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{biker}
HSM Ch. 12	2U				0.018				0.004
HSM Ch. 12	3T				0.027				0.007
HSM Ch. 12	4U				0.011				0.002
HSM Ch. 12	4D				0.013				0.005
HSM Ch. 12	5T				0.050				0.012
Proposed	6U	22	7	549	0.013	72	9	1359	0.007
Proposed	6D	106	16	2377	0.007	1661	190	24720	0.008
Proposed	7T	16	8	324	0.025	250	46	10016	0.001
Proposed	8D	1	0	612		122	92	6623	0.014

Note: Shaded cell = data not available.
[a] Excludes pedestrian and bicycle crashes.

CMFS FOR SIX-OR-MORE-LANE ARTERIALS

Several CMFs were calibrated in conjunction with the SPFs. All of them were calibrated using the FI crash data. Collectively, they describe the relationship between various geometric factors and crash frequency. These CMFs are described in this section and, where possible, compared with the findings from previous research as a means of model validation. Many of the CMFs found in the literature are typically derived from (and applied to) the combination of multiple-vehicle and single-vehicle crashes. That is, one CMF is used to indicate the influence of a specified geometric feature on total crashes. In contrast, the models developed for this project include several CMFs that are calibrated for a specific crash type. If the standard errors of the CMFs are desired, then Equations 133–140 can be used to compute them.

This section shows figures of the CMFs developed from the regression models described above for six-or-more-lane arterials. Where available, other CMFs from the literature are used for comparison purposes.

Lane Width CMF

The lane width CMF is described using Equation 160:

$$CMF_{lw} = e^{-0.0219(W_l - 12)} \tag{160}$$

The base condition for this CMF is a 12-ft lane width. The lane width used in this CMF is an average for all through lanes on the segment. The lane width CMF is shown in Figure 19 using a thick, solid trend line. The lane widths used to calibrate this CMF range from 9 to 16 ft. This CMF is applicable to both multi-vehicle and single-vehicle crashes. Also shown in Figure 19 are CMFs developed by other researchers. Broken lines are used to differentiate these CMFs from the one proposed in this research project. The proposed CMF closely tracks the CMFs developed by Bonneson and Pratt (2009) for nonrestrictive median segments. The CMF developed by Petritsch et al. (2007) is shown to be more sensitive to lane width than the proposed CMF or the CMF developed by Bonneson and Pratt (2009).

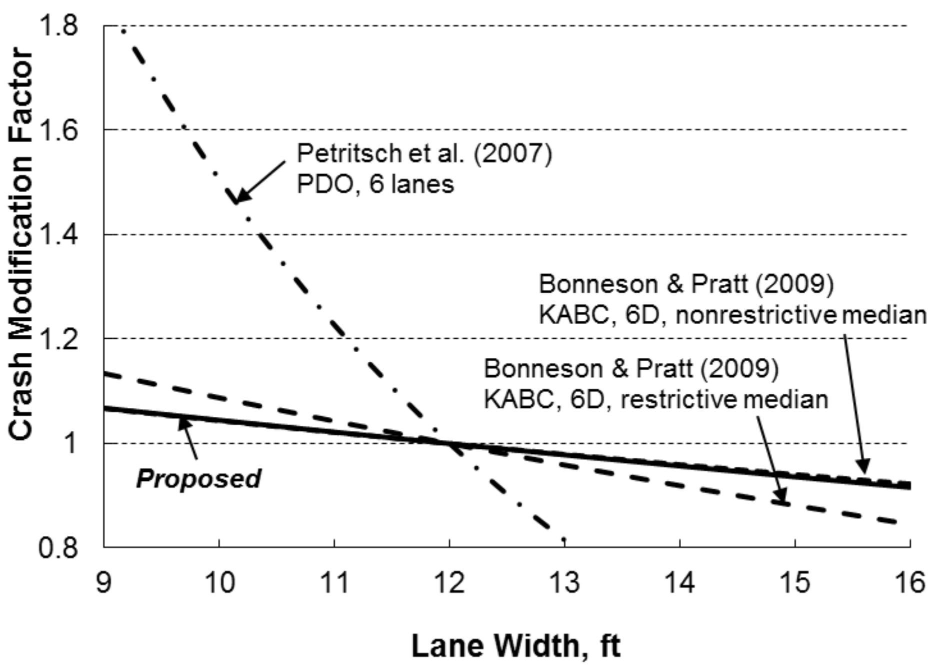

Figure 19. Lane width CMF, six-or-more-lane arterials.

Outside Shoulder Width CMF

The outside shoulder width CMF is described using Equation 161.

$$CMF_{osw} = e^{-0.0285(W_{os}-1.5)} \quad (161)$$

The base condition for this CMF is a 1.5-ft outside shoulder width. The shoulder width used in this CMF is an average of two roadbeds on the segment. The outside shoulder width CMF is shown in Figure 20 using a thick, solid trend line. The outside shoulder widths used to calibrate this CMF range from 0 to 14 ft. This CMF is applicable to both multi-vehicle and single-vehicle crashes. The outside shoulder width CMFs developed in different studies are compared in Figure 6. Thin lines or broken lines are used to differentiate these CMFs from the one developed for this research project. The CMF proposed in this research closely tracks the CMF for restrictive median segments developed by Bonneson and Pratt (2009) and for PDO crashes developed by Petritsch et al. (2007).

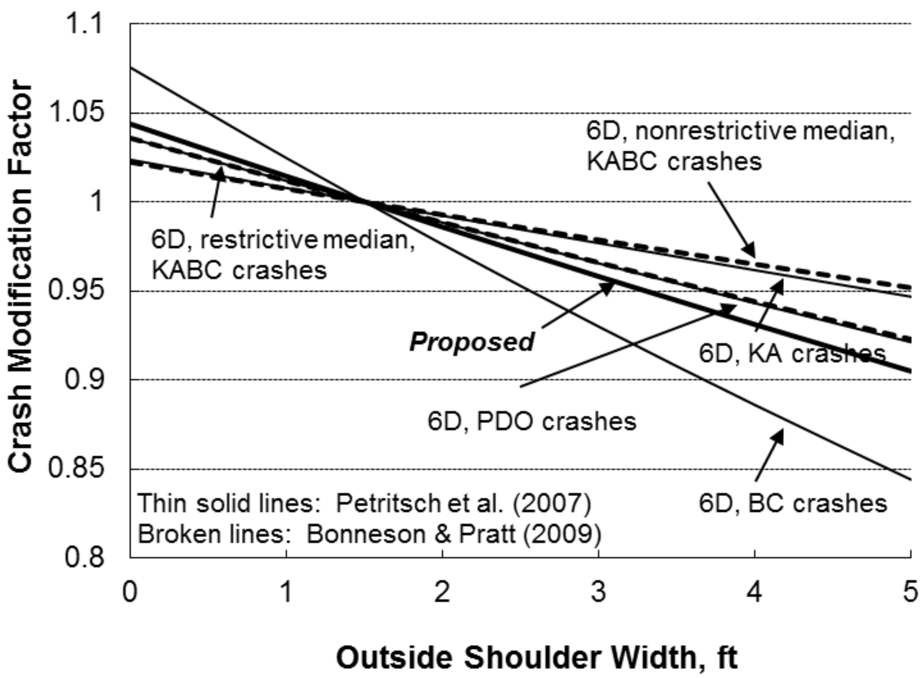

Figure 20. Outside shoulder width CMF, six-or-more-lane arterials.

Median Width CMF

The median width CMF is described using Equation 162.

$$CMF_{mw} = e^{-0.0057(W_m-15)} \quad (162)$$

The base condition for this CMF is a 15-ft median width. The median width CMF is shown in Figure 21 using a thick, solid trend line. The median widths used to calibrate this CMF range from 0 to 60 ft. This CMF is applicable to both multi-vehicle and single-vehicle crashes. The

CMF proposed in this research is compared with the CMF in HSM Chapter 12 and CMFs developed by other researchers in Figure 21. The HSM Chapter 12 CMF applies only to traversable medians without traffic barriers, not including TWLTLs. As shown, there is considerable variation in the median width CMFs. This variation is likely due to other factors that are correlated with median type. For example, a restrictive median reduces the effective number of driveways by preventing through and left-turn movements into or out of driveways.

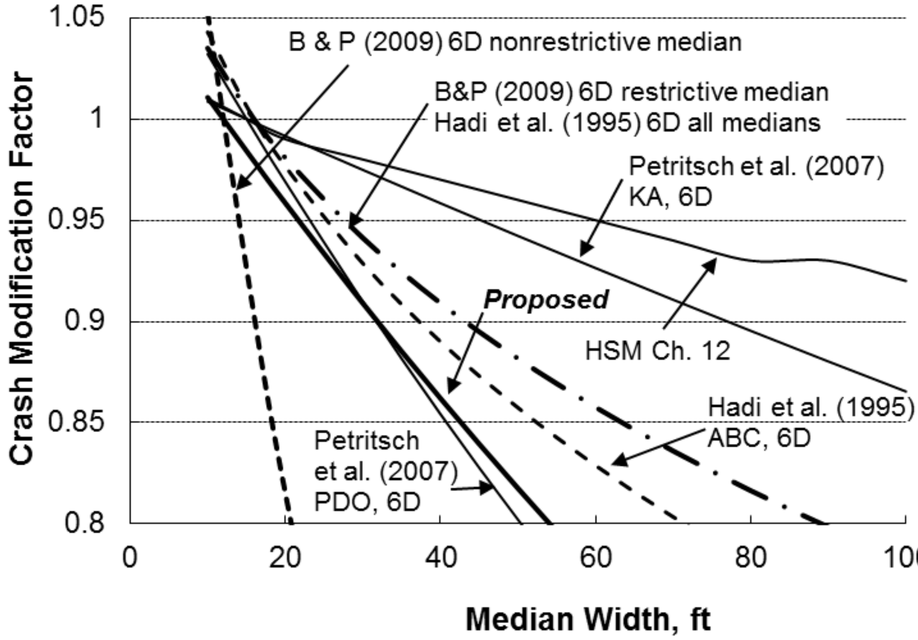

Figure 21. Median width CMF, six-or-more-lane arterials.

Median Barrier CMF

The median barrier CMF is applicable to cable barriers and concrete barriers on roadway segments. The base condition is a median with no barrier. The calibrated median barrier CMF has two forms, depending on which component model is being used. The median barrier CMF for multiple-vehicle crashes is described using Equation 163.

$$CMF_{bar,mv} = e^{-0.5106 \times I_{bar}} \qquad (163)$$

Figure 22 shows the change in the median barrier CMF value for multiple-vehicle crashes with the presence of a median barrier. The results suggest that the presence of a median barrier reduces multiple-vehicle crash frequency. In general, a median barrier prevents vehicles from entering into opposing traffic on the other roadbed and thus reduces the number of crashes.

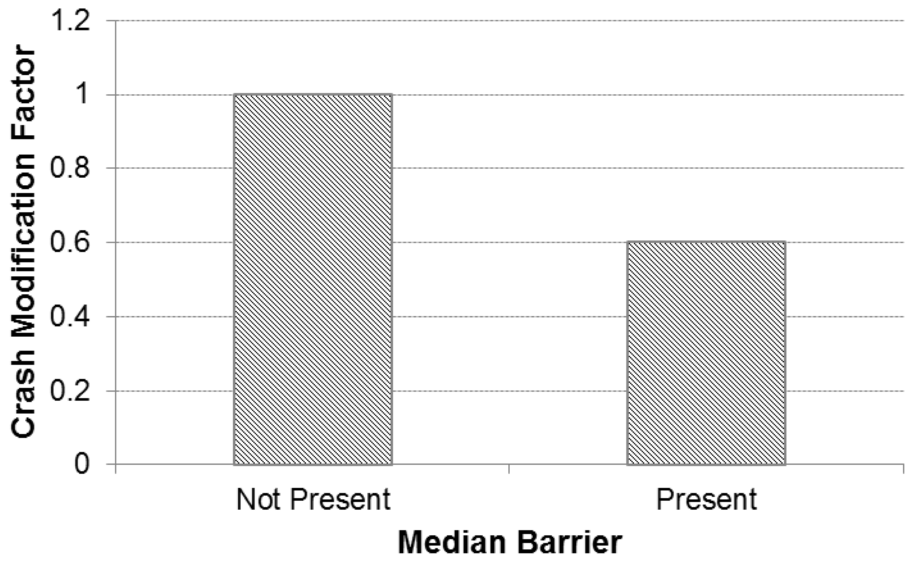

Figure 22. Median barrier CMF for multiple-vehicle crashes, six-or-more-lane arterials.

The median barrier CMF for single-vehicle crashes is described using Equation 164.

$$CMF_{bar,sv} = e^{0.6766 \times I_{bar}} \tag{164}$$

Figure 23 shows the change in the median barrier CMF value for single-vehicle crashes with the presence of a median barrier. The results suggest that the presence of a median barrier increases single-vehicle crash frequency. Although a median barrier prevents a vehicle from entering into opposing traffic on the other roadbed, the vehicle will still be involved in a collision with the barrier.

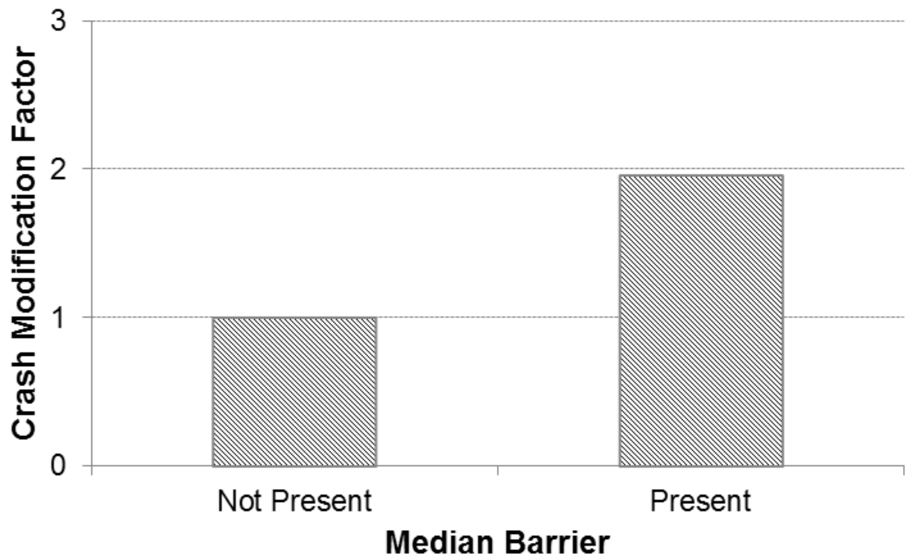

Figure 23. Median barrier CMF for single-vehicle crashes, six-or-more-lane arterials.

Railroad Crossing Presence CMF

The railroad crossing presence CMF is described using Equation 165.

$$CMF_{mw} = e^{0.0388 \times n_{rhx}/L} \tag{165}$$

The base condition for this CMF is the absence of a railroad crossing on the segment. This CMF is applicable to both multi-vehicle and single-vehicle crashes. The change in the CMF with the increase in railroad crossings is shown in Figure 24. The crashes increase by 4 percent with each railroad crossing on the segment.

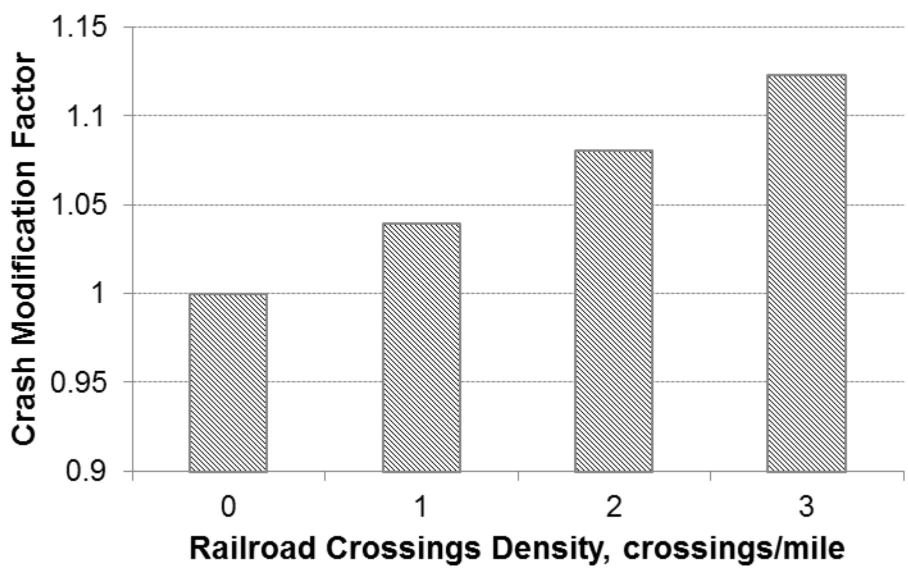

Figure 24. Railroad crossing CMF, six-or-more-lane arterials.

Driveway CMF

The driveway CMF is applicable to multiple-vehicle crashes only. Major commercial, major industrial, and minor driveways are found to be significant in influencing crashes. Minor driveways include all driveway types. Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with fewer than 50 parking spaces. Commercial driveways provide access to establishments that serve retail customers. Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Residential driveways serve single- and multiple-family dwellings.

The major commercial driveway CMF is described using Equation 166.

$$CMF_{dwc\_mj} = e^{0.0350(n_{dwc\_mj}-2)} \tag{166}$$

The major industrial driveway CMF is described using Equation 167.

$$CMF_{dwi\_mj} = e^{0.0107(n_{dwi\_mj}-1)} \tag{167}$$

The base condition for the commercial driveway CMF is two driveways per mile, whereas it is one driveway per mile for the industrial driveway CMF. The comparison of CMFs is shown in Figure 25. It can be seen that commercial driveways are associated with more multiple-vehicle crashes than are industrial driveways.

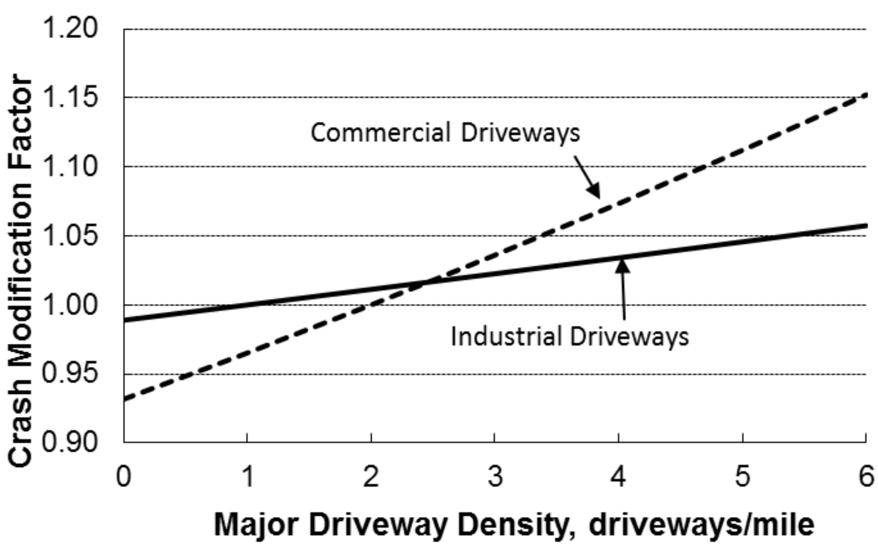

Figure 25. Major driveway CMF, six-or-more-lane arterials.

The minor driveway CMF is described using Equation 168.

$$CMF_{dw\_mn} = e^{0.0054(n_{dw\_mn}-10)} \tag{168}$$

The base condition for the minor driveway CMF is 10 driveways per mile. The change in CMF with the increase in the driveways is shown in Figure 26.

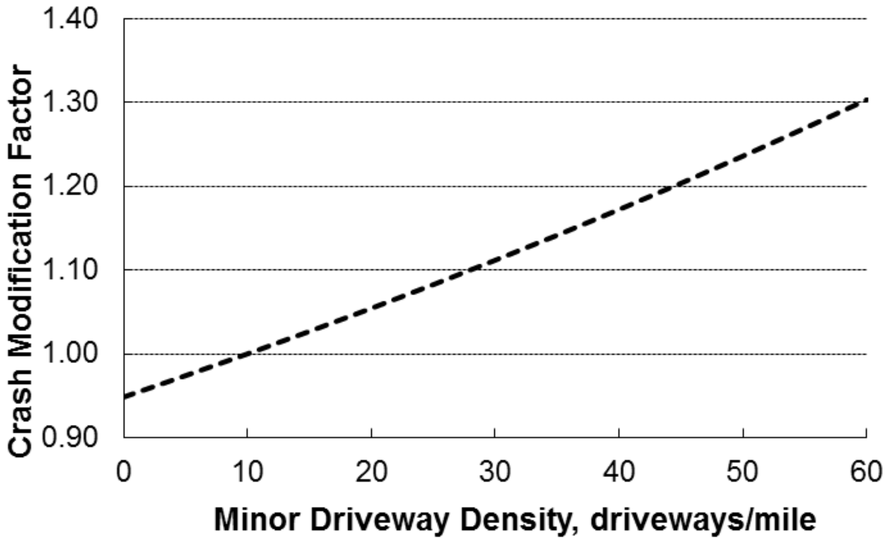

Figure 26. Minor driveway CMF, six-or-more-lane arterials.

Table 55 shows the comparison of percentage increase in crashes associated with the presence of a driveway on an example 1-mi urban street segment. The related percentage crash increase found in this research is similar to the increase found by other various researchers.

Table 55. Increase in crashes with driveways.

Source	Crash Severities	Percent Increase in Crashes per Driveway
Petritsch et al. (2007)	BC	0.2
Petritsch et al. (2007)	PDO	0.2
Sawalha & Sayed (2001)	KABCO	1.7
Bonneson & McCoy (1997)	KABCO	0.5
Proposed, major commercial	KABCO	4.0
Proposed, major industrial	KABCO	1.0
Proposed, minor	KABCO	0.5

Roadside Fixed-Object CMF

The roadside fixed-object CMF is applicable to single-vehicle crashes only. It is described using Equation 169.

$$CMF_{fo} = 1.0 + \frac{0.01 D_{fo}}{e^{0.131(O_{fo})}} \quad (169)$$

The base condition for the roadside fixed-object CMF is absence of roadside objects. The change in the roadside fixed-object CMF with the increase in the offset distance for a segment with 50 roadside objects per mile is shown in Table 56.

Table 56. Roadside fixed-object CMF, six-or-more-lane arterials.

Offset to Fixed Objects (O_{fo}) (ft)	CMF (Proposed)
0	1.50
2	1.38
5	1.26
10	1.13
15	1.07
20	1.04
25	1.02
30	1.01

CHAPTER 6. PREDICTIVE MODELS FOR INTERSECTIONS OF URBAN AND SUBURBAN ARTERIALS WITH SIX OR MORE LANES

This chapter describes the activities undertaken to calibrate safety predictive models for both signalized and stop-controlled intersections of urban and suburban roadway arterials with six or more lanes. Each model consists of an SPF and a family of CMFs. The SPF is derived to estimate the crash frequency with specified design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from those that are specified.

The calibrated safety predictive models were used to develop a safety predictive method for intersections of urban and suburban roadway arterials with six or more lanes. This method describes how to use the models to evaluate intersection safety, which may be influenced by road geometry, roadside features, and traffic volume. Collectively, the predictive models for intersections in this chapter address the following traffic control modes.

- Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST).
- Signalized three-leg intersection (3SG).
- Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST).
- Signalized four-leg intersection (4SG).

This chapter is divided into three sections. The first section provides details about the calibration data. The second section describes the calibration of the models to predict FI, PDO, vehicle-pedestrian, and vehicle-bicycle crash frequency. The third section provides a list of CMFs.

CALIBRATION DATA

The database assembly for these facility types focused on Texas, Michigan, and HSIS states California and Illinois. All crashes that were within 250 ft from the center of an intersection and coded as intersection or intersection-related were assigned to their respective intersection. If a particular crash was within 250 ft from more than one intersection, then it was assigned to the nearest intersection. The variables collected during database assembly are listed in Table 57 and Table 58.

Table 57. Supplemental data collected for intersections as a whole.

Data Variable	Description
Intersection type	As defined by the HSM: 3ST: Three-leg stop-controlled 3SG: Three-leg signalized 4ST: Four-leg stop-controlled 4SG: Four-leg signalized
Roadway category	As defined below: 2×2 = two-way street intersecting two-way street 1×2 = one-way street intersecting two-way street 1×1 = one-way street intersecting one-way street
Lighting	Presence of lighting at the intersection
Skew angle	Absolute value of the difference between 90 degrees and the intersection angle (i.e., the acute or right angle between intersecting streets)
Area type	As defined below: Urban: If more than 50 percent of the land use within 250 ft of the center of intersection is commercial Suburban: If not urban

Table 58. Supplemental data collected for individual streets (major and minor).

Data Variable	Description
Left-turn phasing (signalized intersections)	Type of left-turn phasing: 0: Permitted 1: Protected/permitted 2: Protected only
Number of lanes	Two-way total number of traffic lanes (excluding left-turn and right-turn lanes added at the intersection)
Presence of left-turn lanes	Number of approaches (0,1, or 2) with exclusive left-turn lanes
Number of left-turn lanes	Two-way total number of exclusive left-turn lanes
Number of right-turn lanes	Two-way total number of exclusive right-turn lanes
Bicycle lanes	Number of approaches (0, 1, or 2) with bicycle lanes
Median type	Type of median: No median or TWLTL Raised curb Depressed median
Right-turn channelization	Number of approaches with channelized right-turn lanes
Offset left-turn lanes	Number of approaches with offset left-turn lanes (i.e., left-turn lanes separated from through traffic via raised curb, etc.)
Left-turn prohibition	Number of approaches from which left turns are prohibited for reasons other than one-way cross street or three-leg intersection
RTOR prohibition (signalized intersections)	Number of approaches from which RTOR is prohibited
U-turn prohibition	Number of approaches from which U-turns are prohibited via “No U-turn” signs

MODEL DEVELOPMENT—TWO-WAY STREET INTERSECTIONS

A two-way street intersection is defined as an intersection with traffic flow in both directions on the major and minor streets. The major street is defined as the intersecting street with the higher traffic volume, irrespective of the other geometric characteristics. The predicted average crash frequency for each site was computed using a predictive model. Each model represented the combination of an SPF and several CMFs. The SPF was used to estimate the average crash frequency for a generic site whose attributes were consistent with the SPF’s stated base conditions. The CMFs were used to adjust the SPF estimate when the attributes of the subject site were not consistent with the base conditions.

Given the small sample size of single-vehicle crashes at intersections, separate models could not be developed for these crash types. The single-vehicle crashes were combined with multiple-vehicle crashes, and a model was developed for total crashes. The following regression model form was used to predict the average crash frequency at an individual two-way street intersection.

Signalized Intersections:

$$N_{bi} = N_{spf\ int} \times CMF_{lg} \times CMF_{ltph} \times CMF_{rtor} \times CMF_{ut} \times CMF_{ch} \times CMF_{lanes} \quad (170)$$

Unsignalized Intersections:

$$N_{bi} = N_{spf\ int} \times CMF_{lg} \quad (171)$$

with,

$$N_{spf\ int} = n \times e^{b_0 + b_1 \ln(AADT_{Maj}) + b_2 \ln(AADT_{Min}) + b_{ca} I_{ca} + b_{il} I_{il} + b_{mi} I_{mi}} \quad (172)$$

$$CMF_{lg} = 1 - e^{b_{lg}} \times p_{ni} \quad (173)$$

$$CMF_{ltph} = e^{b_{pp} \times I_{pp} + b_{pt} \times I_{pt}} \quad (174)$$

$$CMF_{rtor} = (e^{b_{rtor}})^{n_{rtor}} \quad (175)$$

$$CMF_{ut} = (e^{b_{ut}})^{n_{ut}} \quad (176)$$

$$CMF_{ch} = e^{b_{ch} \times n_{ch}} \quad (177)$$

$$CMF_{lanes} = CMF_{lanes1} \times CMF_{lanes2} = \left[e^{b_{lanes}(N_{maj}-6)} P_{maj} + (1 - P_{maj})\right] \times \left[e^{b_{lanes}(N_{min}-2)} P_{min} + (1 - P_{min})\right] \quad (178)$$

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj} + AADT_{min}} \quad (179)$$

$$P_{min} = \frac{AADT_{min}}{AADT_{maj} + AADT_{min}} \quad (180)$$

where,

N_{bi}	=	predicted annual average crash frequency.
n	=	number of years of crash data.
$AADT_{Maj}$	=	average annual daily traffic on the major street, veh/day.
$AADT_{Min}$	=	average annual daily traffic on the minor street, veh/day.
I_{ca}	=	California state indicator variable (= 1.0 if site is in California, 0.0 if not).
I_{il}	=	Illinois state indicator variable (= 1.0 if site is in Illinois, 0.0 if not).
I_{mi}	=	Michigan state indicator variable (= 1.0 if site is in Michigan, 0.0 if not).
CMF_{lg}	=	lighting CMF.
CMF_{ltph}	=	left-turn signal phasing CMF.
CMF_{rtor}	=	right-turn-on-red prohibition CMF.

CMF_{ut} = U-turn prohibition CMF.
CMF_{ch} = right-turn channelization CMF.
CMF_{lanes} = number of lanes CMF.
p_{ni} = proportion of total crashes for unlighted intersections that occur at night.
I_{pp} = major-street protected/permissive signal phasing indicator variable (= 1.0 if both approaches are protected/permissive, 0.0 otherwise).
I_{pt} = major-street protected signal phasing indicator variable (= 1.0 if both approaches are protected, 0.0 otherwise).
n_{rtor} = number of signalized intersection approaches for which right turn on red is prohibited.
n_{uturn} = number of signalized intersection approaches for which U-turn movements are prohibited.
n_{ch} = number of major-street approaches with right-turn channelization.
N_{maj} = number of lanes on the major street (excluding left-turn and right-turn lanes added at the intersection).
P_{maj} = proportion of annual average daily traffic volume on the major street.
N_{min} = number of lanes on the minor street (excluding left-turn and right-turn lanes added at the intersection).
P_{min} = proportion of annual average daily traffic volume on the minor street.
b_i = calibration coefficient for variable *i*.

The predictive model calibration process consisted of the simultaneous calibration of total crash models for various intersection types. The simultaneous calibration approach was needed because several CMFs were common to three-leg and four-leg intersections.

Table 59 and Table 60 summarize the multivariate regression modeling results for two-way street intersections for FI and PDO crashes, respectively. Variables with corresponding p-values less than 0.05 can be considered statistically significant (at the significance level $\alpha = 0.05$). For those few variables where the p-value was greater than 0.05, 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 when applied to this database).

Table 59. Calibrated coefficients for FI crashes at two-way street intersections.

Coefficient	Variable	Int. Control	Estimate	Std. Error	t-statistic	p-value
b_0	Intercept	3ST	−15.033	4.353	−3.45	0.0006
		3SG	−7.107	2.816	−2.52	0.0119
		4ST	−10.078	5.064	−1.99	0.0471
		4SG	−4.631	1.278	−3.62	0.0003
b_1	Major AADT	3ST	1.087	0.416	2.62	0.0092
		3SG	0.650	0.259	2.51	0.0124
		4ST	0.579	0.480	1.20	0.2288
		4SG	0.358	0.114	3.13	0.0018
b_2	Minor AADT	3ST	0.532	0.176	3.03	0.0026
		3SG	0.156	0.104	1.50	0.1330
		4ST	0.603	0.209	2.89	0.0040
		4SG	0.273	0.055	4.95	<0.0001
b_{lg}	Lighting	All	−0.043	0.699	−0.06	0.9507
b_{pt}	Protected signal phasing	3SG/4SG	−0.285	0.106	−2.69	0.0074
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	−0.077	0.491	−0.16	0.8758
b_{ut}	U-turn prohibition	3SG/4SG	−0.038	0.064	−0.60	0.5486
b_{ch}	Right-turn channelization	3SG/4SG	0.218	0.069	3.16	0.0017
b_{lanes}	Number of lanes	3SG/4SG	0.194	0.056	3.45	0.0006
b_{ca}	Added effect of California	All	−1.335	0.099	−13.54	<0.0001
b_{il}	Added effect of Illinois	All	−0.737	0.188	−3.92	<0.0001
b_{mi}	Added effect of Michigan	All	−0.746	0.164	−4.54	<0.0001
k	Inverse dispersion parameter	3ST	1.536	0.586	2.62	0.0091
		3SG	1.927	0.612	3.15	0.0017
		4ST	1.667	0.652	2.56	0.0108
		4SG	1.771	0.166	10.69	<0.0001
	Observations	549 intersections (3ST=55; 3SG=57; 4ST=36; 4SG=401)				

Table 60. Calibrated coefficients for PDO crashes at two-way street intersections.

Coefficient	Variable	Int. Control	Estimate	Std. Error	t-statistic	p-value
b_0	Intercept	3ST	−14.973	4.113	−3.64	0.0003
		3SG	−5.073	3.662	−1.39	0.1665
		4ST	−12.011	5.666	−2.12	0.0345
		4SG	−3.772	1.591	−2.37	0.0181
b_1	Major AADT	3ST	1.349	0.393	3.43	0.0006
		3SG	0.472	0.337	1.40	0.1612
		4ST	0.672	0.541	1.24	0.2146
		4SG	0.268	0.143	1.88	0.0608
b_2	Minor AADT	3ST	0.153	0.156	0.98	0.3287
		3SG	0.135	0.119	1.14	0.2561
		4ST	0.747	0.268	2.78	0.0056
		4SG	0.271	0.064	4.24	<0.0001
b_{lg}	Lighting	All	−0.064	0.824	−0.08	0.9383
b_{pt}	Protected signal phasing	3SG/4SG	0.081	0.131	0.62	0.5385
b_{rtor}	Right-turn-on-red prohibition	3SG/4SG	−0.032	0.614	−0.05	0.9590
b_{ut}	U-turn prohibition	3SG/4SG	−0.033	0.077	−0.42	0.6726
b_{ch}	Right-turn channelization	3SG/4SG	0.269	0.089	3.04	0.0025
b_{lanes}	Number of lanes	3SG/4SG	0.296	0.064	4.64	<0.0001
b_{ca}	Added effect of California	All	−1.242	0.118	−10.57	<0.0001
b_{il}	Added effect of Illinois	All	0.558	0.235	2.38	0.0179
b_{mi}	Added effect of Michigan	All	0.000	0.000	0.00	0.0000
k	Inverse dispersion parameter	3ST	1.342	0.449	2.99	0.0029
		3SG	1.004	0.258	3.89	0.0001
		4ST	0.879	0.294	2.99	0.0029
		4SG	1.009	0.083	12.11	<0.0001
	Observations	549 intersections (3ST=55; 3SG=57; 4ST=36; 4SG=401)				

Indicator variables were included for the states of California, Illinois, and Michigan. All the coefficients were found to be statistically significant but with different magnitude and signs. The negative coefficient for all three states means that these states experience fewer FI crashes than Texas for the same conditions and exposure. The trend could not be explained by difference in intersection design among the states. It is likely that the differences between states are due to unobserved variables such as vertical grade, signing, pavement condition, weather, reporting accuracy, and speed limit.

The NLMIXED procedure in the SAS software was used to estimate the proposed model coefficients. This procedure was used because the proposed predictive model is both nonlinear and discontinuous. The log-likelihood function for the NB distribution was used to determine the best-fit model coefficients.

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 27 for three-leg stop-controlled intersections.

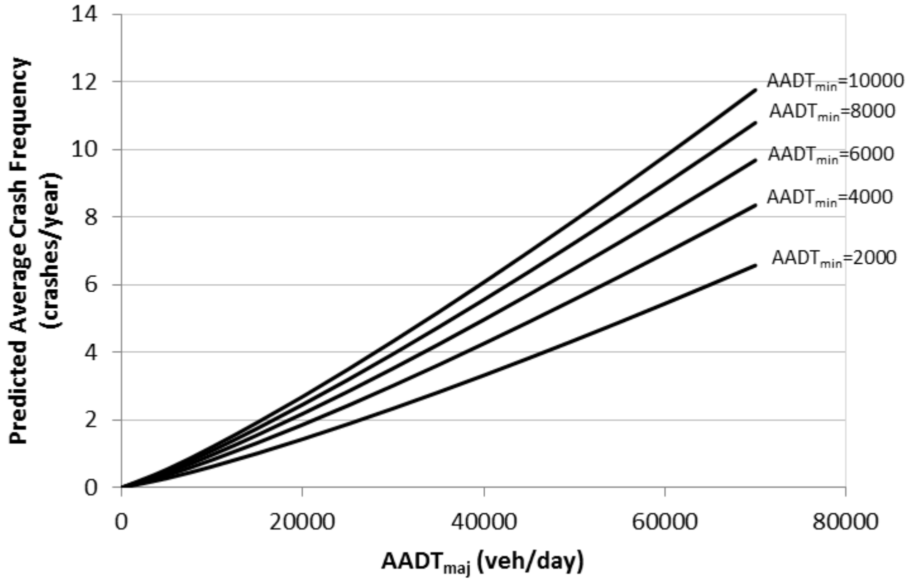

Figure 27. Graphical form of the intersection SPF for crashes on three-leg stop-controlled intersections (3ST).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 28 for three-leg signalized intersections.

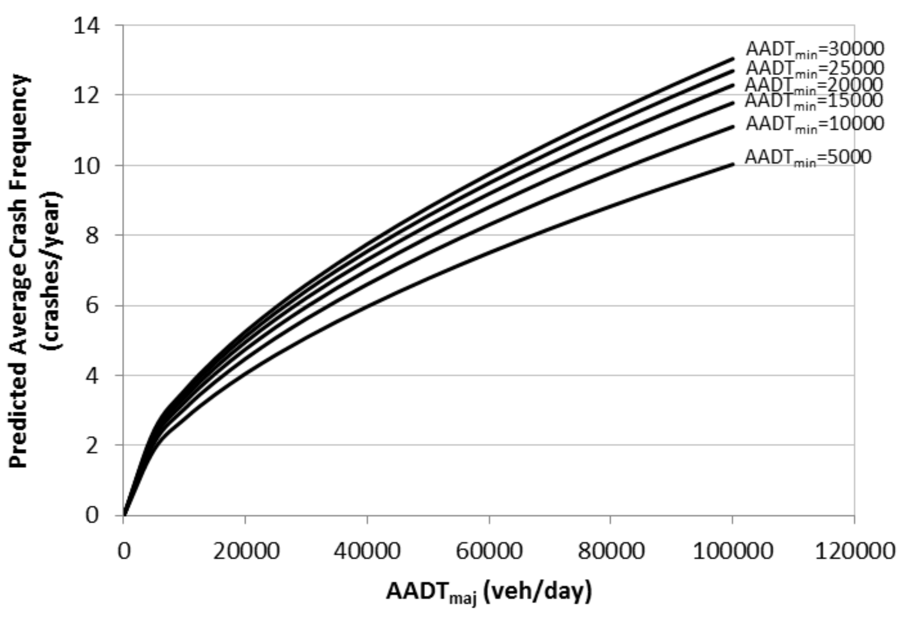

Figure 28. Graphical form of the intersection SPF for crashes on three-leg signalized intersections (3SG).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 29 for four-leg stop-controlled intersections.

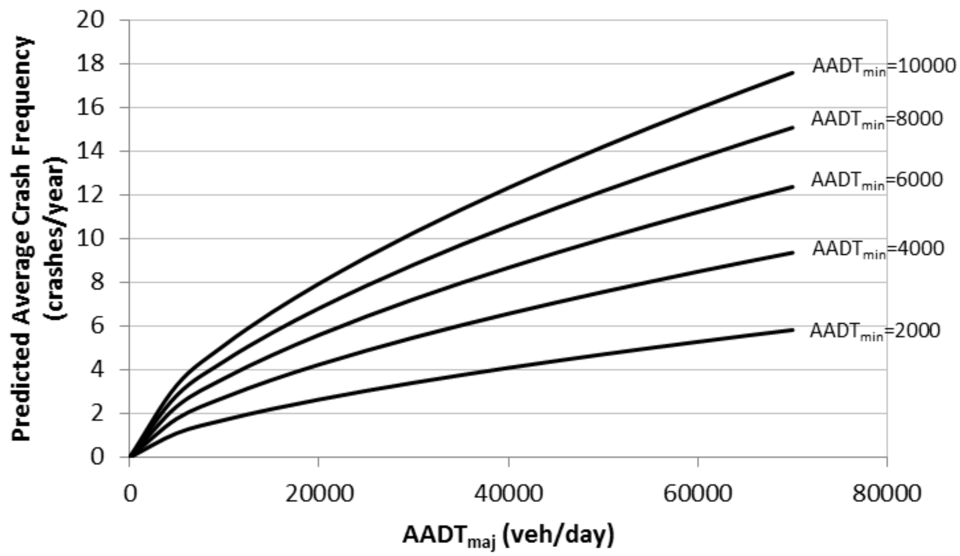

Figure 29. Graphical form of the intersection SPF for crashes on four-leg stop-controlled intersections (4ST).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 30 for four-leg signalized intersections.

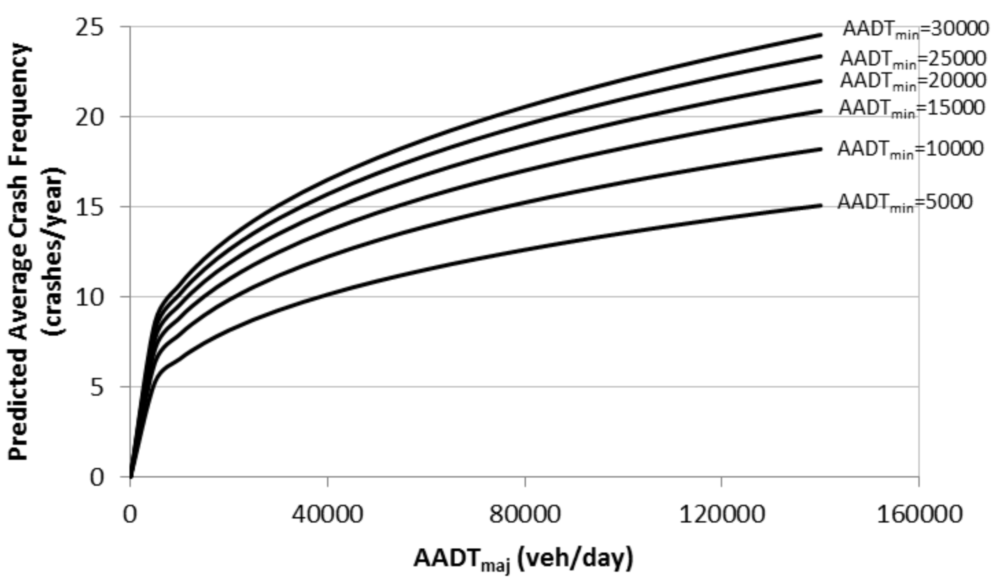

Figure 30. Graphical form of the intersection SPF for crashes on four-leg signalized intersections (4SG).

The proportions in Table 61 are used to separate total crashes into components by crash type for intersections with six-or-more-lane streets.

Table 61. Distribution of total vehicle collisions for intersections with six or more lanes by collision type.

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3ST		3SG		4ST		4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Head-on collision	0.043	0.023	0.056	0.034	0.030	0.012	0.093	0.046
Angle collision	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552
Sideswipe	0.052	0.120	0.063	0.149	0.055	0.122	0.038	0.171
Other multiple-vehicle	0.021	0.012	0.028	0.000	0.024	0.024	0.029	0.022
Single-vehicle crashes	0.026	0.062	0.056	0.074	0.006	0.037	0.012	0.061

Source: HSIS data for California (2006–2010).

VEHICLE-PEDESTRIAN COLLISIONS

The HSM provides a model to estimate the number of vehicle-pedestrian crashes at signalized intersections (i.e., 3SG and 4SG), which is described using the Equations 181 and 182 (Equations 12–28 and 12–29, respectively, in the HSM).

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p} \qquad (181)$$

$$N_{pedbase} = \exp\left(a + b \times \ln(AADT_{total}) + c \times \ln\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d \times \ln(PedVol) + e \times n_{lanesx}\right) \qquad (182)$$

where,

$N_{pedbase}$ = predicted number of vehicle-pedestrian collisions per year for base conditions at signalized intersections.

$AADT_{total}$ = sum of the average daily volumes (veh/day) for the major and minor roads (= $AADT_{maj} + AADT_{min}$).

$PedVol$ = sum of daily pedestrian volumes (ped/day) crossing all intersection legs.

n_{lanesx} = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands.

CMF_{1p} = CMF for bus stops (HSM Table 12-28).

CMF_{2p} = CMF for schools (HSM Table 12-29).

CMF_{3p} = CMF for alcohol sales establishment (HSM Table 12-30).

a, b, c, d, e = regression coefficients (HSM Table 12-14).

According to *NCHRP 129: Phase III* (Harwood et al., 2008), the above model was developed using data from a total of 1,883 signalized intersections—1,532 in Toronto and 351 in Charlotte, North Carolina—which did not include any one-way leg. The HSM model accounts for the vehicular and pedestrian traffic as well as the maximum length that a pedestrian may be exposed to the vehicular traffic (through n_{lanesx}). Based on the summary statistics in Table 13 of *NCHRP 129: Phase III*, the data used for development of the HSM model included intersections with number of lanes (n_{lanesx}) of up to nine, indicating that the application of the model may not be limited to intersections of arterials with fewer than six lanes (as is the case in the current HSM

Chapter 12). Nonetheless, due to unavailability of the original data for development of the HSM model, the research team wanted to verify the applicability of the HSM model for intersections of six-or-more-lane arterials using field data.

A sample of 30 signalized intersections in California was selected for data collection. Out of those 30, five intersections are three-leg and 25 intersections are four-leg. The sites were selected along three corridors with six through lanes: CA-82 and US-101 in the San Francisco Bay Area and CA-187 in Los Angeles. Chapter 3 of Harwood et al. (2008) presents a summary of the collected data used for validation of the HSM model for vehicle-pedestrian collisions at signalized intersections. Two-hour pedestrian counts were collected at the selected intersections by Traffic Research & Analysis Inc. (TRA Inc.). Eighteen-hour (6:00 AM to 12:00 AM) pedestrian counts were collected at five sites, one along each of the corridors in California. The 18-hour counts were used to compute adjustments factors needed to convert two-hour counts to daily pedestrian volumes. It was assumed that pedestrian activity during the remaining six hours (between 12:00 AM and 6:00 AM) was negligible.

The major- and minor-street AADTs were determined using California HSIS data traffic volume data. The variable n_{lanesx} was determined using Google Earth aerial imagery. The presence of schools and number of bus stops and alcohol sales establishments within 1000 ft of the intersection were recorded for each site using Google Earth aerial imagery and Street View. The team followed the HSM instructions to determine these variables. The CMFs were determined using the respective tables in the HSM.

The observed number of vehicle-pedestrian collisions at the selected intersections was determined using the HSIS data for California. A vehicle-pedestrian collision was assigned to an intersection if it occurred within 250 ft of the intersection center and was coded as intersection-related. Where a collision occurred between two adjacent intersections that were less than 500 ft apart, the collision was assigned to the nearest intersection. Only fatal or injury collisions were considered in the analysis (consistent with the HSM).

Unfortunately, the small number of crashes observed at these sites (only 24 crashes) hindered the research team from performing a meaningful test of hypotheses for applicability of the HSM model because only four groups of observations with an expected crash frequency greater than 5 could be created. With this insufficient sample size, the chi-squared test that was used to perform the model validation might yield an inaccurate inference. Nonetheless, the research team concluded that the HSM model for vehicle-pedestrian collisions is applicable because of the following reasons:

- The HSM model controls for the significant traffic and exposure variables.
- The HSM model has been developed using a large sample from intersections with a wide range of lane counts that includes intersections of streets with six or more lanes as a subset.

For 3ST and 4ST, the number of vehicle-pedestrian collisions per year for an intersection is estimated using Equation 183.

$$N_{pedi} = N_{bi} \times f_{pedi} \tag{183}$$

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.

f_{pedi} = pedestrian crash adjustment factor.

The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the total intersection crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for each intersection type. Table 62 presents the values of f_{pedi}. All vehicle-pedestrian collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-16) are also displayed for comparison.

The adjustment factors are developed using Equation 184.

$$f_{pedi} = \frac{N_{pedi}}{N_{bi}} \quad (184)$$

where,

N_{pedi} = crash frequency of vehicle-pedestrian collisions for an individual intersection.

N_{bi} = crash frequency of an individual intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions).

Table 62. Pedestrian crash adjustment factors: two-way street intersections.

Intersection Type	Number of Intersections	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{pedi} (proposed)	f_{pedi} (HSM)
3ST	55	16	312	0.051	0.021
4ST	36	10	205	0.049	0.022

[a] Excludes pedestrian and bicycle crashes.

VEHICLE-BICYCLE COLLISIONS

The number of vehicle-bicycle collisions per year for an intersection is estimated using Equation 185.

$$N_{bikei} = N_{bi} \times f_{bikei} \quad (185)$$

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.

f_{bikei} = 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 63 presents the values of f_{bikei}. All vehicle-bicycle collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-17) are also displayed for comparison.

The adjustment factors are developed using Equation 186.

$$f_{bikei} = \frac{N_{bikei}}{N_{bi}} \quad (186)$$

where,

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

Table 63. Bicycle crash adjustment factors: two-way street intersections.

Intersection Type	Number of Intersections	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{bikei} (proposed)	f_{bikei} (HSM)
3ST	56	15	312	0.048	0.016
3SG	58	22	765	0.029	0.011
4ST	36	8	205	0.039	0.018
4SG	402	243	13,044	0.019	0.015

[a] Excludes pedestrian and bicycle crashes.

CMFS FOR 2×2 INTERSECTIONS

Several CMFs were calibrated in conjunction with the SPFs. All of them were calibrated using FI crash data. Collectively, they describe the relationship between various geometric factors and crash frequency. These CMFs are described in this section and, where possible, compared with the findings from previous research for model validation. Equations 133–140 can be used to compute the standard errors of the CMFs.

Lighting CMF

The base condition for lighting is the absence of intersection lighting. The lighting CMF is described using Equation 187.

$$CMF_{lg} = 1 - e^{-0.0432} \times p_{ni} = 1 - 0.96 \times p_{ni} \quad (187)$$

This CMF is similar to the CMF presented in the HSM ($CMF_{lg} = 1 - 0.38 \times p_{ni}$). However, the proposed coefficient in this research is highly insignificant, and thus the research team recommends using the CMF in the HSM. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes) and is applicable to both signalized and stop-controlled intersections. Table 64 presents default values for the nighttime crash proportion, p_{ni}.

Table 64. Nighttime crash proportions for unlighted intersections.

Intersection Type	**Proportion of Crashes That Occur at Night, p_{ni}**
3ST	0.238
4ST	0.229
3SG and 4SG	0.235

Intersection Left-Turn Signal Phasing CMF

Types of left-turn signal phasing considered include permissive, protected, protected/permissive, and permissive/protected. Protected/permissive operation is also referred to as a leading left-turn signal phase; permissive/protected operation is also referred to as a lagging left-turn signal phase. Initially, an attempt was made to capture the safety effect of left-turn signal phasing by individual approach. However, the coefficient was highly insignificant, so an indicator variable was created to state if both approaches on the major street have the same phasing. That is, this variable takes the value of 1 if both approaches are protected/permitted or protected only, and 0 otherwise. The CMF values are presented in Table 65. The CMFs in the HSM are also provided for comparison. Note that the CMF is a function of number of approaches in the HSM. The base condition for this CMF is permissive left-turn signal phasing. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. The CMF is determined using Equation 188.

$$CMF_{ltph} = e^{0 \times I_{pp} - 0.285 \times I_{pt}} \quad (188)$$

Table 65. CMF for major-street left-turn signal phasing.

Type of Left-Turn Signal Phasing	**CMF**	
	HSM Ch. 12 (both major approaches)	**Proposed**
Permissive	$1.00^2 = 1.00$	1.00
Protected/Permissive	$0.99^2 = 0.98$	1.00
Protected	$0.94^2 = 0.88$	0.74

RTOR CMF

The base condition for the RTOR CMF is permitting an RTOR at all approaches to a signalized intersection. The CMF is determined using Equation 189.

$$CMF_{rtor} = (e^{-0.0768})^{n_{rtor}} = (0.93)^{n_{rtor}} \quad (189)$$

This CMF is closer to the CMF presented in the HSM ($CMF_{rtor} = 0.98^{(n_{rtor})}$). However, the proposed coefficient in this research is highly insignificant, and thus the research team recommends using the CMF in the HSM. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections.

U-turn Prohibition CMF

The base condition for the U-turn prohibition CMF is permitting a U-turn movement at both approaches on the major street of an intersection. The CMF is determined using Equation 190.

$$CMF_{ut} = (e^{-0.0385})^{n_{ut}} = 0.96^{(n_{ut})} \quad (190)$$

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. When a U-turn is prohibited at one approach, a reduction of crashes by 4 percent can be observed. If a U-turn is prohibited at both approaches on the major street of a four-leg intersection, then an 8 percent reduction in crashes can be expected. This is mainly because the conflict between the U-turning vehicles and vehicles coming straight or turning right from other streets will be reduced.

Right-Turn Channelization CMF

The base condition for CMF_{ut} is absence of right-turn channelization at both approaches on the major street of an intersection. The CMF is determined using Equation 191.

$$CMF_{ch} = e^{(0.2175 * n_{ch})} \quad (191)$$

This CMF applies to the total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. The proposed CMF suggests that the right-turn channelization at both approaches on the major street of an intersection would be associated with a 24 percent increase in crashes. Bonneson and Pratt (2009) developed a CMF and found that installation of right-turn channelization on both approaches on the major street of a four-leg signalized intersection would be associated with a 20 percent increase in FI crashes. Bauer and Harwood (1998) derived a CMF value of 1.35, suggesting a 35 percent increase in crashes, for the provision of right-turn channelization at all approaches of a four-leg stop-controlled intersections. They stated that this finding seems counterintuitive, in that provision of right-turn channelization should be associated with a decrease in crashes. Bonneson and Pratt (2009) suggested that the increase in crashes may be due to the higher speeds associated with a free right-turn movement at a right-turn channel, compared to the slower speeds required to turn from a conventional right-turn lane. Another possible factor is the stopping of turning vehicles at the downstream portion of the right-turn channel while the drivers are waiting for a safe gap to merge into the receiving lane. Drivers waiting in this manner may become involved in rear-end crashes if other right-turning drivers do not have adequate sight distance to see them in the stopped position.

Number of Lanes CMF

The number of lanes CMF is determined using Equation 192.

$$CMF_{lanes} = \left[e^{0.194(N_{maj}-6)} P_{maj} + (1 - P_{maj})\right] \times \left[e^{0.194(N_{min}-2)} P_{min} + (1 - P_{min})\right] \quad (192)$$

with,

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj} + AADT_{\min}} \quad (193)$$

$$P_{\min} = \frac{AADT_{\min}}{AADT_{maj} + AADT_{\min}} \quad (194)$$

The base condition for the number of lanes CMF is six lanes on the major street and two lanes on the minor street (excluding left-turn and right-turn lanes added at the intersection). Table 66 presents the relationship between number of lanes and FI crash frequency at signalized intersections when the volume on the minor street is equal to one-half the volume on the major street. This CMF applies to all intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. The CMF indicates that the increase in the number of lanes at a signalized intersection is associated with an increase in the frequency of crashes. The number of lanes in the cross-section tends to increase the size of the intersection conflict area, which could increase the exposure of vehicles to conflict with crossing movements.

Table 66. CMF for number of lanes at a signalized intersection.

Number of Major-Street Lanes	CMF Based on Number of Minor-Street Lanes				
	2	**3**	**4**	**5**	**6**
6	1.00	1.07	1.16	1.26	1.39
7	1.14	1.22	1.32	1.44	1.59
8	1.32	1.41	1.52	1.66	1.83

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

CHAPTER 7. PREDICTIVE MODELS FOR URBAN AND SUBURBAN ONE-WAY ARTERIAL ROADWAY SEGMENTS

This chapter describes the activities undertaken to calibrate safety predictive models for urban and suburban one-way arterial roadway segments. Each model consists of an SPF and a family of CMFs. The SPF is derived to estimate the crash frequency with specified design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from those that are specified.

The calibrated safety predictive models were used to develop a one-way arterial roadway segment safety predictive method. This method describes how to use the models to evaluate safety of one-way arterials, which may be influenced by road geometry, roadside features, and traffic volume. Collectively, the predictive models for roadway segments in this chapter address the following facilities:

- Two-lane one-way arterials (2O).
- Three-lane one-way arterials (3O).
- Four-lane one-way arterials (4O).

This chapter is divided into three sections. The first section provides details about the calibration data. The second section describes the calibration of the models to predict FI, PDO, vehicle-pedestrian, and vehicle-bicycle crash frequency. The third section provides a list of CMFs.

CALIBRATION DATA

For one-way arterial segments, a new (unique) homogenous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

- AADT (vehicles per day).
- Number of through lanes.
- Right shoulder width.
- Speed category.

The database assembly for these type of arterials focused on Texas, Oregon, and two HSIS states: California and Illinois. The data acquired from these databases are summarized in Table 67 and Table 68 for the electronic and supplemental data, respectively.

Table 67. Variables acquired from state databases for one-way arterials.

Data Variable	Description
AADT	Annual average daily traffic volume (veh/day) during the study period
Segment length	Length of the homogenous segment (mi) in the state database
Lane width	Average width (ft) of the through lanes
Left shoulder width	Average width of the left shoulder (ft) along the segment
Right shoulder width	Average width of the right shoulder (ft) along the segment

Table 68. Supplemental data collected for one-way arterials.

Data Variable	Description
Bus or HOV lane presence	Presence of bus-only or HOV lanes.
Bicycle lane presence	Presence of bicycles lanes.
Sidewalks	Presence of sidewalks along each side of the roadway segment: 0: No sidewalk. 1: Sidewalk on one side of the roadway. 2: Sidewalks on both sides of the roadway.
Lighting	Presence of lighting along each side of the roadway segment: 0: No lighting. 1: Lighting on one side of the roadway. 2: Lighting on both sides of the roadway.
Parallel parking proportion	Proportion of the length of segment with parallel parking (considered in both directions of travel for two-way streets).
Angle parking proportion	Proportion of the length of segment with angle parking (considered in both directions of travel for two-way streets).
Speed limit	Posted speed limit (mph) as observed from speed limit signs.
Railroad crossings	Number of railroad-highway crossings within the limits of the roadway segment.
Driveway density	Density of driveways along the length of the segment (driveways/mile), classified consistently with the HSM Chapter 12 driveway categories: Major commercial driveways. Minor commercial driveways. Major industrial/institutional driveways. Minor industrial/institutional driveways. Major residential driveways. Minor residential driveways. Other driveways.
Roadside fixed-object density	Density of fixed roadside objects (objects/mile) within 30 ft of the edge of traveled way (in both directions of travel for two-way streets). In absence of marked edge lines, edge of traveled way was considered to be 2.0 ft from the face of the curb. Fixed objects were counted using the same method as required for application of the HSM CMF for roadside fixed objects (described on pages 12–41 of the HSM).
Roadside fixed-object offset	Average distance from the edge of the traveled way to the roadside fixed objects (as defined above).
Left curb proportion	Proportion of the length of the segment with left-side curb present.
Right curb proportion	Proportion of the length of the segment with right-side curb present.

MODEL DEVELOPMENT—ONE-WAY ARTERIALS

The following regression model form was used to predict the average crash frequency on an individual one-way roadway segment.

$$N_j = (N_{mv}I_{mv} + N_{sv}I_{sv}) \times CMF_{rsw} \quad (195)$$

with,

$$N_{mv} = N_{spfmv} \times CMF_{pk\_par} \times CMF_{pk\_ang} \times CMF_{dwc\_mj} \times CMF_{dw\_mn} \quad (196)$$

$$N_{sv} = N_{spfsv} \times CMF_{fo} \quad (197)$$

$$N_{spfmv} = L \times n \times e^{b_{mv}+b_{mv1}\ln(AADT)+b_{ca}I_{ca}+b_{il}I_{il}+b_{or}I_{or}} \quad (198)$$

$$N_{spfsv} = L \times n \times e^{b_{sv}+b_{sv1}\ln(AADT)+b_{ca}I_{ca}+b_{il}I_{il}+b_{or}I_{or}} \quad (199)$$

$$CMF_{rsw} = e^{b_{rsw}(W_{rs}-4)} \quad (200)$$

$$CMF_{pk\_par} = 1 + p_{pk\_par} \times (b_{pk\_par} - 1.0) \quad (201)$$
$$CMF_{pk\_ang} = 1 + p_{pk\_ang} \times (b_{pk\_ang} - 1.0) \quad (202)$$
$$CMF_{dwc\_mj} = e^{b_{dwc\_mj}(n_{dwc\_mj} - 2)} \quad (203)$$
$$CMF_{dw\_mn} = e^{b_{dw\_mn}(n_{dw\_mn} - 10)} \quad (204)$$
$$CMF_{fo} = 1.0 + \frac{0.01 D_{fo}}{e^{b_{fo}(O_{fo})}} \quad (205)$$

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}	=	crash indicator variable (= 1.0 if multiple-vehicle crash data, 0.0 otherwise).
I_{sv}	=	crash indicator variable (= 1.0 if single-vehicle crash data, 0.0 otherwise).
L	=	segment length, mi.
n	=	number of years of crash data.
$AADT$	=	average annual daily traffic, veh/day.
I_{ca}	=	California state indicator variable (= 1.0 if site is in California, 0.0 if not).
I_{il}	=	Illinois state indicator variable (= 1.0 if site is in Illinois, 0.0 if not).
I_{or}	=	Oregon state indicator variable (= 1.0 if site is in Oregon, 0.0 if not).
CMF_{rsw}	=	right shoulder width CMF.
CMF_{pk_par}	=	on-street parallel parking CMF.
CMF_{pk_ang}	=	on-street angle parking CMF.
CMF_{dwc_mj}	=	major commercial driveways CMF.
CMF_{dwi_mj}	=	major industrial driveways CMF.
CMF_{dw_mn}	=	minor driveways CMF.
CMF_{bar}	=	median barrier CMF.
CMF_{fo}	=	roadside fixed-object CMF.
W_{rs}	=	right shoulder width, ft.
p_{pk_par}	=	proportion of curb length with on-street parallel parking = (0.5 L_{pk_par}/L).
p_{pk_ang}	=	proportion of curb length with on-street angle parking = (0.5 L_{pk_ang}/L).
L_{pk_par}	=	sum of curb length with on-street parallel parking for both sides of road combined, mi.
L_{pk_ang}	=	sum of curb length with on-street angle parking for both sides of road combined, mi.
n_{dwc_mj}	=	major commercial driveway density, driveways/mile.
n_{dw_mn}	=	minor driveway density, driveways/mile.
O_{fo}	=	roadside fixed-object offset, ft.
D_{fo}	=	roadside fixed-object density, fixed objects/mile.
p_{fo}	=	roadside fixed-object collisions as a proportion of total crashes.
b_i	=	calibration coefficient for variable *i*.

The inverse dispersion parameter K (which is the inverse of the overdispersion parameter k) is allowed to vary with the segment length. The inverse dispersion parameter is calculated using Equation 206.

$$K = L \times e^{\delta,j};\ j = \ mv, sv \qquad (206)$$

where,

K	=	inverse dispersion parameter.
δ	=	calibration coefficient for inverse dispersion parameter.

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 the equations above. The simultaneous calibration approach was needed because the right shoulder CMF was 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.

Table 69 and Table 70 summarize the modeling results for one-way arterial segments for FI and PDO, respectively. The variables with the corresponding p-values less than 0.05 can be considered statistically significant (at the significance level $\alpha = 0.05$). For those few variables where the p-value was greater than 0.05, 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 when applied to this database).

Table 69. Calibrated coefficients for FI crashes on one-way arterials.

Coefficient	Variable	Facility	Estimate	Std. Error	t-statistic	p-value
b_{mv}	Intercept for MV crashes	2O	−11.4766	0.7694	−14.92	<0.0001
		3O	−11.4871	0.7999	−14.36	<0.0001
		4O	−11.7375	0.8067	−14.55	<0.0001
b_{mv1}	AADT on MV crashes	All	1.2559	0.0839	14.98	<0.0001
b_{sv}	Intercept for SV crashes	2O	−5.3153	1.1314	−4.70	<0.0001
		3O	−4.9291	1.1859	−4.16	<0.0001
		4O	−4.9291	1.1859	−4.16	<0.0001
b_{sv1}	AADT on SV crashes	All	0.4179	0.1259	3.32	0.0009
b_{rsw}	Right shoulder width	All	−0.0201	0.0098	−2.05	0.0403
b_{pk_par}	On-street parallel parking on MV crashes	2O	1.1116	0.2515	4.42	<0.0001
		3O/4O	1.3586	0.3087	4.40	<0.0001
b_{pk_ang}	On-street angle parking on MV crashes	2O/3O	4.3644	2.4706	1.77	0.0774
b_{dwc_mj}	Major commercial driveway density on MV crashes	2O/3O	0.0177	0.0113	1.56	0.1186
b_{dw_mn}	Minor driveway density on MV crashes	2O/3O	0.0046	0.0026	1.76	0.0793
b_{fo}	Roadside fixed-object density on SV crashes	All	0.0938	0.0838	1.12	0.2629
b_{il}	Added effect of Illinois	All	−0.1732	0.0803	−2.16	0.0311
δ_{mv}	Inverse dispersion parameter for MV crashes	2O	2.1203	0.1659	12.78	<0.0001
		3O	2.5670	0.1931	13.29	<0.0001
		4O	2.4619	0.4102	6.00	<0.0001
δ_{sv}	Inverse dispersion parameter for SV crashes	2O	1.1900	0.3160	3.77	0.0002
		3O	1.9423	0.4244	4.58	<0.0001
		4O	1.9423	0.4244	4.58	<0.0001
	Observations	1709 segments (2O=1037; 3O=536; 4O=136)				

Table 70. Calibrated coefficients for PDO crashes on one-way arterials.

Coefficient	Variable	Facility	Estimate	Std. Error	t-statistic	p-value
b_{mv}	Intercept for MV crashes	2O	−8.2598	0.5140	−16.07	<0.0001
		3O	−8.2735	0.5376	−15.39	<0.0001
		4O	−8.6803	0.5443	−15.95	<0.0001
b_{mv1}	AADT on MV crashes	All	1.0194	0.0569	17.92	<0.0001
b_{sv}	Intercept for SV crashes	2O	−4.7133	0.7891	−5.97	<0.0001
		3O	−4.7189	0.8323	−5.67	<0.0001
		4O	−4.7189	0.8323	−5.67	<0.0001
b_{sv1}	AADT on SV crashes	All	0.4269	0.0885	4.82	<0.0001
b_{rsw}	Right shoulder width	All	−0.0047	0.0076	−0.61	0.5390
b_{pk_par}	On-street parallel parking on MV crashes	2O	1.2587	0.1695	7.42	<0.0001
		3O/4O	1.9568	0.3013	6.49	<0.0001
b_{pk_ang}	On-street angle parking on MV crashes	2O/3O	4.2811	1.5850	2.70	0.0069
b_{dwc_mj}	Major commercial driveway density on MV crashes	2O/3O	0.0303	0.0100	3.02	0.0025
b_{dw_mn}	Minor driveway density on MV crashes	2O/3O	0.0015	0.0019	0.76	0.4450
b_{fo}	Roadside fixed-object density on SV crashes	All	0.2545	0.1436	1.77	0.0764
b_{il}	Added effect of Illinois	All	0.7450	0.0580	12.85	<0.0001
δ_{mv}	Inverse dispersion parameter for MV crashes	2O	2.4635	0.0955	25.80	<0.0001
		3O	2.4531	0.0952	25.77	<0.0001
		4O	2.5184	0.2164	11.64	<0.0001
δ_{sv}	Inverse dispersion parameter for SV crashes	2O	2.1203	0.2287	9.27	<0.0001
		3O	1.9771	0.2265	8.73	<0.0001
		4O	1.9771	0.2265	8.73	<0.0001
	Observations	1709 segments (2O=1037; 3O=536; 4O=136)				

Indicator variables were included for the states of California, Oregon, and Illinois. However, only the coefficient for Illinois was statistically significant. This means that the magnitude of the crashes between Texas, Oregon, and California are about the same, but Illinois experiences fewer FI crashes and more PDO crashes for the same conditions and exposure. It is likely that the differences between states are due to unobserved variables such as vertical grade, signing, pavement condition, weather, reporting accuracy, and speed limit.

The NLMIXED procedure in the SAS software was used to estimate the proposed model coefficients. This procedure was used because the proposed predictive model is both nonlinear and discontinuous. The log-likelihood function for the NB distribution was used to determine the best-fit model coefficients.

Figure 31 and Figure 32 show the relationship between the number of FI crashes and traffic flow for two, three, and four lanes for multi-vehicle and single-vehicle crashes on one-way arterials, respectively. Figure 31 shows that four-lane one-way arterials experience fewer multi-vehicle crashes than two- and three-lane arterials. On the other hand, Figure 32 shows that four-lane and three-lane one-way arterials experience more single-vehicle crashes than two-lane one-way arterials.

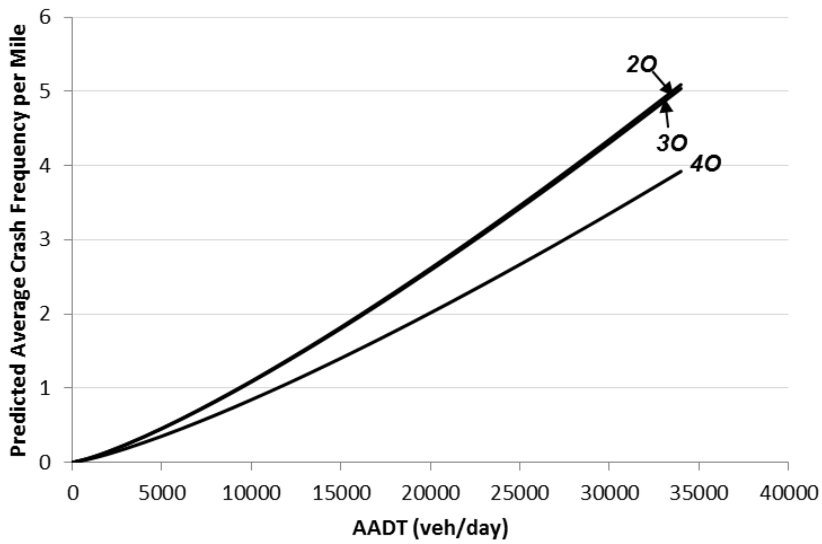

Figure 31. Graphical form of the SPF for FI multiple-vehicle collisions, one-way arterials.

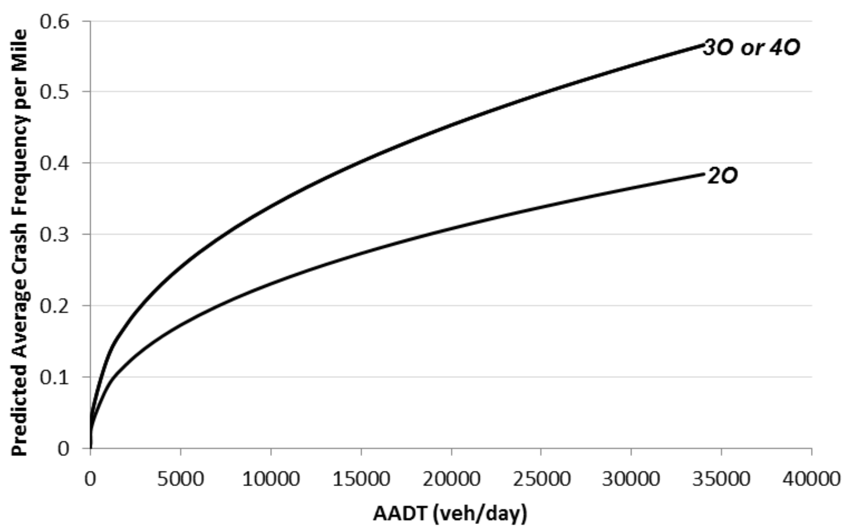

Figure 32. Graphical form of the SPF for FI single-vehicle collisions, one-way arterials.

Figure 33 and Figure 34 show the relationship between the number of PDO crashes and traffic flow for two, three, and four lanes for multi-vehicle and single-vehicle crashes on one-way arterials, respectively. Figure 33 shows that four-lane one-way arterials experience fewer multi-vehicle PDO crashes than two- and three-lane arterials. On the other hand, Figure 34 shows that four-lane one-way arterials experience more single-vehicle PDO crashes than two- or three-lane one-way arterials.

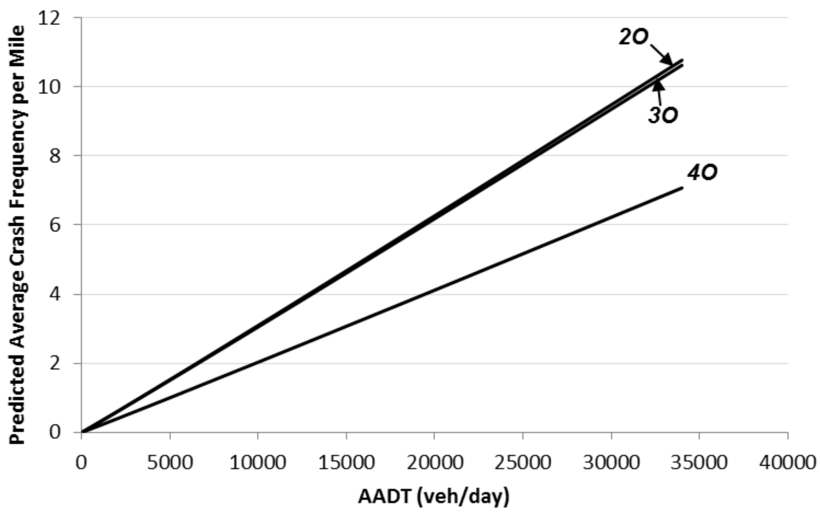

Figure 33. Graphical form of the SPF for PDO multiple-vehicle collisions, one-way arterials.

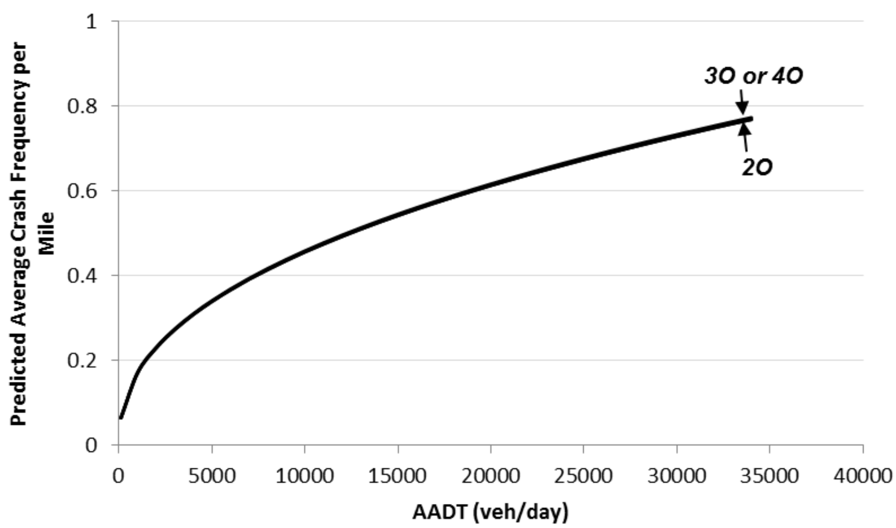

Figure 34. Graphical form of the SPF for PDO single-vehicle collisions, one-way arterials.

The proportions in Table 71 are used to separate multiple-vehicle crashes into components by collision type for one-way arterial roadway segments.

Table 71. Distribution of multiple-vehicle collisions for roadway segments by manner of collision type.

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types					
	2O		3O		4O	
	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.617	0.445	0.671	0.435	0.714	0.400
Head-on collision	0.021	0.017	0.013	0.013	0.000	0.067
Angle collision	0.128	0.076	0.133	0.115	0.000	0.000
Sideswipe, same direction	0.170	0.336	0.133	0.384	0.143	0.467
Sideswipe, opposite direction	0.043	0.042	0.013	0.017	0.000	0.000
Other multiple-vehicle collisions	0.021	0.084	0.038	0.036	0.143	0.067

Source: HSIS data for California (2006–2010).

The proportions in Table 72 are used to separate single-vehicle crashes into components by crash type for arterials with six or more lanes.

Table 72. Distribution of single-vehicle crashes for roadway segments by collision type for arterials with six or more lanes.

Collision Type	Proportion of Crashes by Severity Level for Specific Road Types					
	2O		3O		4O	
	FI	PDO	FI	PDO	FI	PDO
Collision with fixed object—left	0.400	0.261	0.182	0.489	0.286	0.167
Collision with fixed object—right	0.100	0.435	0.182	0.289	0.429	0.667
Collision with other object	0.000	0.130	0.091	0.044	0.000	0.000
Other single-vehicle collision	0.500	0.174	0.545	0.178	0.286	0.167

Source: HSIS data for California (2006–2010).

VEHICLE-PEDESTRIAN COLLISIONS

The number of vehicle-pedestrian crashes per year for a roadway segment is estimated using Equation 156. The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the total segment crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for each segment type. Table 73 presents the values of f_{pedr}. All vehicle-pedestrian collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-16) are also displayed for comparison. The adjustment factors are developed using Equation 157.

Table 73. Pedestrian crash adjustment factor for one-way roadway segments.

Source	Road Type	Pedestrian Crash Adjustment Factor (f_{pedr})							
		Posted Speed 30 mph or Lower				Posted Speed Greater Than 30 mph			
		Number of Segments	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{ped}	Number of Segments	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{ped}
Proposed	2O	774	48	2767	0.017	276	12	676	0.018
	3O	395	52	2217	0.024	162	15	911	0.017
	4O	81	7	342	0.021	57	12	405	0.030

[a] Excludes pedestrian and bicycle crashes.

VEHICLE-BICYCLE COLLISIONS

The number of vehicle-bicycle collisions per year for an intersection is estimated using Equation 158. 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 segment type. Table 74 presents the values of f_{biker}. All vehicle-bicycle collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-17) are also displayed for comparison. The adjustment factors are developed using Equation 159.

Table 74. Bicycle crash adjustment factor for one-way roadway segments.

Source	Road Type	Bicycle Crash Adjustment Factor (f_{biker})							
		Posted Speed 30 mph or Lower				Posted Speed Greater Than 30 mph			
		Number of Segments	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{ped}	Number of Segments	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{ped}
Proposed	2O	774	29	2767	0.011	276	11	676	0.016
	3O	395	24	2217	0.011	162	11	911	0.012
	4O	81	7	342	0.021	57	3	405	0.007

[a] Excludes pedestrian and bicycle crashes.

CMFS FOR ONE-WAY ARTERIALS

Several CMFs were calibrated in conjunction with the SPFs. All of them were calibrated using FI crash data. Collectively, they describe the relationship between various geometric factors and crash frequency. The models developed for this project include several CMFs that are calibrated for a specific crash type. If the standard errors of the CMFs are desired, then Equations 133–140 can be used to compute them.

This section presents the CMFs developed from the regression models described above for one-way arterials. The CMFs for one-way arterials are compared with the CMFs for two-way arterials because there are no CMFs available in the literature for one-way arterials.

Right Shoulder Width CMF

The right shoulder width CMF is described using Equation 207.

$$CMF_{osw} = e^{-0.0201(W_{os}-4)} \tag{207}$$

The base condition for this CMF is a 4-ft outside shoulder width. The shoulder width used in this CMF is measured at places where parking is not present. For places with parking, the shoulder width is 0 ft. The right shoulder width CMF is shown in Figure 35 using a thick, solid trend line. The right shoulder widths used to calibrate this CMF range from 0 to 20 ft. This CMF is applicable to both multi-vehicle and single-vehicle crashes. The right shoulder width CMF is compared with the outside shoulder width CMF for two-way arterials with six or more lanes in Figure 35. A dotted line is used to differentiate this CMF from the one developed for one-way arterials. The CMF values suggest that the right shoulder on one-way streets has a more significant effect on crashes than the outside shoulder width on two-lane streets.

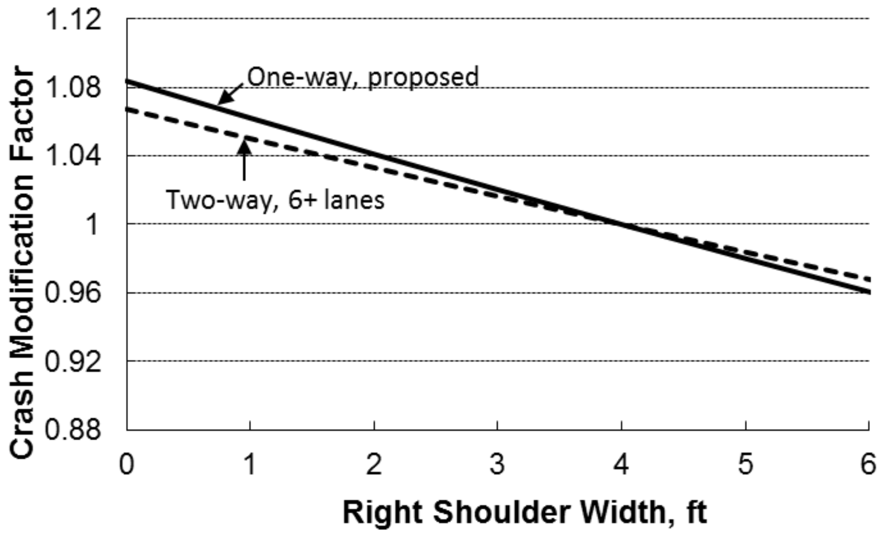

Figure 35. Right shoulder width CMF, one-way arterials.

On-Street Parking CMF

The on-street parking CMF is determined using Equations 208 and 209.

$$CMF_{pk\_par} = 1 + \left(0.5\, L_{pk\_par}/L\right) \times (b_{pk\_par} - 1.0) \quad (208)$$

$$CMF_{pk\_ang} = 1 + \left(0.5\, L_{pk\_ang}/L\right) \times (b_{pk\_ang} - 1.0) \quad (209)$$

The base condition is the absence of on-street parking on a roadway segment. This CMF is applicable to multi-vehicle crashes only. The on-street parking CMF is compared with the CMFs for two-way arterials with five or fewer lanes in Table 75. A CMF could not be developed in this research by different land use type due to the small sample size. The CMF values developed in this research are in agreement with the CMFs presented in the HSM.

Table 75. Values of b_{pk} used in determining the CMF for on-street parking.

	Type of Parking and Land Use			
	Parallel Parking (b_{pk_par})		Angle Parking (b_{pk_ang})	
Road Type	**Residential/Other**	**Commercial or Industrial/Institutional**	**Residential/Other**	**Commercial or Industrial/Institutional**
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999
2O	1.112		4.364	
3O	1.359		4.364	
4O	1.359		4.364	

Driveway CMF

This CMF is applicable to multiple-vehicle crashes only. Major commercial and minor driveways are found to be significant in influencing the crashes. Minor driveways include all driveway types. Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with fewer than 50 parking spaces. Commercial driveways provide access to establishments that serve retail customers. Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Residential driveways serve single- and multiple-family dwellings.

The major commercial driveway CMF is described using Equation 210.

$$CMF_{dwc\_mj} = e^{0.0177(n_{dwc\_mj}-2)} \tag{210}$$

The base condition for commercial driveway CMF is two driveways per mile. The CMF is compared with the commercial driveway CMF for two-way arterials and is shown in Figure 36. It can be seen that commercial driveways on two-way arterials are associated with more multiple-vehicle crashes than on one-way arterials. On one-way arterials, there are fewer conflict points with the vehicles entering or exiting the driveways than on the two-way arterials.

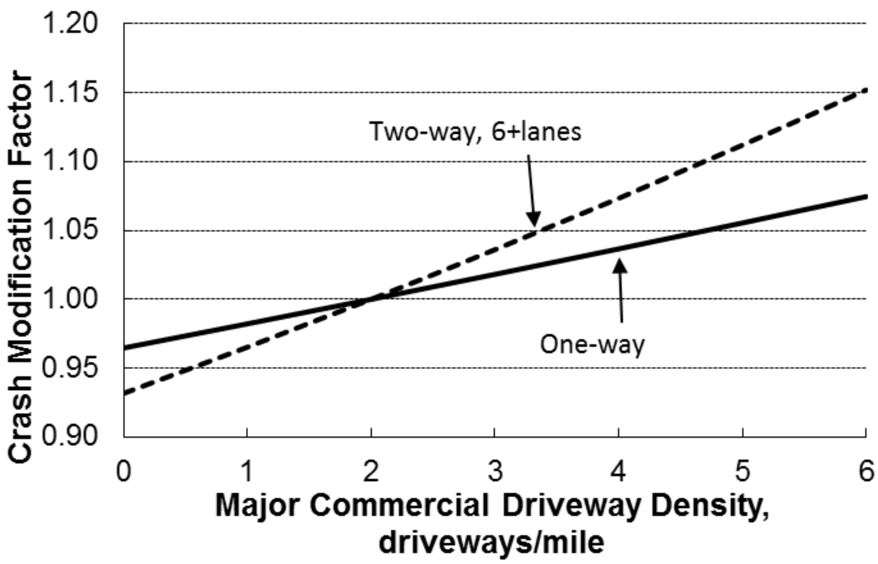

Figure 36. Major commercial driveway CMF, one-way arterials.

The minor driveway CMF is described using Equation 211.

$$CMF_{dw\_mn} = e^{0.0046(n_{dw\_mn}-10)} \tag{211}$$

The base condition for the minor driveway CMF is 10 driveways per mile. The CMF is compared with the minor driveways CMF for two-way arterials and is shown in Figure 37. It can be seen that minor driveways on two-way arterials are associated with more multiple-vehicle crashes than on one-way arterials. On one-way arterials, there are fewer conflict points with the vehicles entering or exiting the driveways than on the two-way arterials.

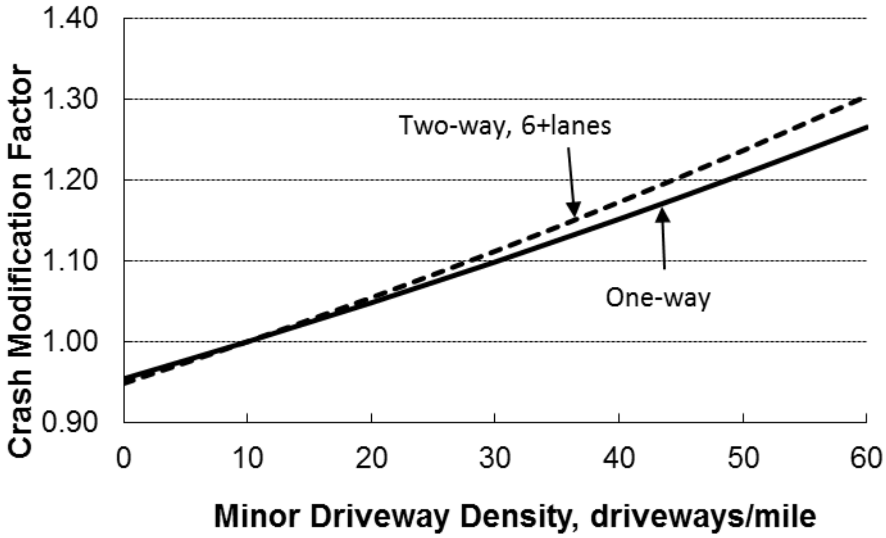

Figure 37. Minor driveway CMF, one-way arterials.

Roadside Fixed-Object CMF

The roadside fixed-object CMF is applicable to single-vehicle crashes only and is described by Equation 212:

$$CMF_{fo} = 1.0 + \frac{0.01 D_{fo}}{e^{0.0938(O_{fo})}} \qquad (212)$$

The base condition for the roadside fixed-object CMF is the absence of roadside objects. The change in the CMF with the increase in the offset distance for a segment with 50 roadside objects per mile is shown in Table 76.

Table 76. Roadside fixed-object CMF, one-way arterials.

Offset to Fixed Objects (O_{fo}) (ft)	CMF (Proposed)
0	1.50
2	1.41
5	1.31
10	1.20
15	1.12
20	1.08
25	1.05
30	1.03

CHAPTER 8. PREDICTIVE MODELS FOR INTERSECTIONS OF URBAN AND SUBURBAN ONE-WAY ARTERIALS

This chapter describes the activities undertaken to calibrate safety predictive models for both signalized and stop-controlled intersections of urban and suburban one-way arterials. Each model consists of an SPF and a family of CMFs. The SPF is derived to estimate the crash frequency with specified design elements and operating conditions. The CMFs are used to adjust the SPF estimate whenever one or more elements or conditions deviate from those that are specified.

The calibrated safety predictive models were used to develop a safety predictive method for intersections of urban and suburban roadway one-way arterials. This method describes how to use the models to evaluate intersection safety, which may be influenced by road geometry, roadside features, and traffic volume. Collectively, the predictive models for intersections in this chapter address the following traffic control modes.

- Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST).
- Signalized three-leg intersection (3SG).
- Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST).
- Signalized four-leg intersection (4SG).

This chapter is divided into three sections. The first section provides details about the calibration data. The second section describes the calibration of the models to predict FI, PDO, vehicle-pedestrian, and vehicle-bicycle crash frequency. The third section provides a list of CMFs.

CALIBRATION DATA

The database assembly for these facility types focused on Texas, Michigan, and HSIS states California and Illinois. As described above, all crashes that were within 250 ft from the center of an intersection and coded as intersection or intersection-related were assigned to their respective intersection. If a particular crash was within 250 ft from more than one intersection, then it was assigned to the nearest intersection. The final variables used for the models are listed in Table 57 and Table 58 in Chapter 6.

MODEL DEVELOPMENT—ONE-WAY STREET INTERSECTIONS

A one-way street intersection is defined as an intersection that has only one-way traffic flow on the major street and has either two-way or one-way traffic on the minor street. The major street is always a one-way street and may or may not have traffic volume higher than the minor street. The predicted average crash frequency for each site was computed using a predictive model. Each model represented the combination of an SPF and several CMFs. The SPF was used to estimate the average crash frequency for a generic site whose attributes were consistent with the SPF's stated base conditions. The CMFs were used to adjust the SPF estimate when the attributes of the subject site were not consistent with the base conditions.

Given the small sample size of single-vehicle crashes at intersections, separate models could not be developed for these crash types. The single-vehicle crashes were combined with multiple-vehicle crashes, and a model was developed for total crashes. The following regression model form was used to predict the average crash frequency at an individual one-way street intersection.

Signalized Intersections:

$$N_{bi} = N_{spf} \times CMF_{lg} \times CMF_{lanes} \tag{213}$$

Unsignalized Intersections:

$$N_{bi} = N_{spf} \times CMF_{lg} \tag{214}$$

with,

$$N_{spf} = n \times e^{b_0 + b_1 \ln(AADT_{Maj}) + b_2 \ln(AADT_{Min}) + b_{I11} I_{I11} + b_{ca} I_{ca} + b_{il} I_{il} + b_{mi} I_{mi}} \tag{215}$$

$$CMF_{lg} = 1 - e^{b_{lg}} \times p_{ni} \tag{216}$$

$$\begin{aligned} CMF_{lanes} &= CMF_{lanes1} \times CMF_{lanes2} \\ &= \left[e^{b_{lanes}(N_{maj}-2)} P_{maj} + (1 - P_{maj})\right] \times \left[e^{b_{lanes}(N_{min}-2)} P_{min} + (1 - P_{min})\right] \end{aligned} \tag{217}$$

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj} + AADT_{min}} \tag{218}$$

$$P_{min} = \frac{AADT_{min}}{AADT_{maj} + AADT_{min}} \tag{219}$$

where,

N_j	=	predicted annual average crash frequency.
n	=	number of years of crash data.
$AADT_{Maj}$	=	average annual daily traffic on the major street, veh/day.
$AADT_{Min}$	=	average annual daily traffic on the minor street, veh/day.
I_{I11}	=	one-way on minor-street indicator variable (= 1.0 if minor street is one-way, 0.0 if not).
I_{ca}	=	California state indicator variable (= 1.0 if site is in California, 0.0 if not).
I_{il}	=	Illinois state indicator variable (= 1.0 if site is in Illinois, 0.0 if not).
I_{mi}	=	Michigan state indicator variable (= 1.0 if site is in Michigan, 0.0 if not).
CMF_{lg}	=	lighting CMF.
CMF_{lanes}	=	number of lanes CMF.
p_{ni}	=	proportion of total crashes for unlighted intersections that occur at night.
b_i	=	calibration coefficient for variable *i*.

The predictive model calibration process consisted of the simultaneous calibration of total crash models for various intersection types. The simultaneous calibration approach was needed because several CMFs were common to three-leg and four-leg intersections. The results of the multivariate regression model calibration are presented in Table 77 and Table 78 for one-way street intersections for FI and PDO crashes, respectively.

Variables with corresponding p-values less than 0.05 can be considered statistically significant (at the significance level α = 0.05). For those few variables where the p-value was greater than 0.05, 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 when applied to this database).

Table 77. Calibrated coefficients for FI crashes at one-way street intersections.

Coefficient	Variable	Int. Control	Estimate	Std. Error	t-statistic	p-value
b_0	Intercept	3ST	−9.117	3.808	−2.39	0.0170
		3SG	−11.206	3.128	−3.58	0.0004
		4ST	−10.829	1.927	−5.62	<0.0001
		4SG	−5.468	1.098	−4.98	<0.0001
b_1	Major AADT	3ST	0.646	0.383	1.69	0.0918
		3SG	0.594	0.238	2.50	0.0127
		4ST	0.672	0.193	3.48	0.0005
		4SG	0.184	0.111	1.65	0.0996
b_2	Minor AADT	3ST	0.105	0.192	0.55	0.5848
		3SG	0.560	0.155	3.61	0.0003
		4ST	0.414	0.108	3.85	0.0001
		4SG	0.372	0.089	4.19	<0.0001
b_{I11}	Added effect for one-way traffic on minor street	All	−0.104	0.170	−0.61	0.5401
b_{lanes}	Number of lanes	3SG/4SG	0.242	0.078	3.12	0.0019
b_{lg}	Lighting	All	−1.484	18.00	−0.08	0.9343
b_{il}	Added effect of Illinois	All	0.414	0.182	2.28	0.0232
k	Inverse dispersion parameter	3ST	0.495	0.193	2.57	0.0104
		3SG	1.049	0.368	2.85	0.0045
		4ST	1.881	0.794	2.37	0.0182
		4SG	0.751	0.080	9.43	<0.0001
	Observations	586 intersections (3ST=107; 3SG=40; 4ST=155; 4SG=284)				

Table 78. Calibrated coefficients for PDO crashes at one-way street intersections.

Coefficient	Variable	Int. Control	Estimate	Std. Error	t-statistic	p-value
b_0	Intercept	3ST	−17.602	2.588	−6.80	<0.0001
		3SG	−7.069	2.787	−2.54	0.0115
		4ST	−12.064	1.611	−7.49	<0.0001
		4SG	−5.917	1.199	−4.94	<0.0001
b_1	Major AADT	3ST	1.531	0.263	5.83	<0.0001
		3SG	0.485	0.220	2.20	0.0281
		4ST	0.855	0.167	5.13	<0.0001
		4SG	0.381	0.124	3.08	0.0021
b_2	Minor AADT	3ST	0.306	0.105	2.91	0.0037
		3SG	0.348	0.133	2.61	0.0093
		4ST	0.512	0.101	5.07	<0.0001
		4SG	0.362	0.093	3.88	0.0001
b_{I11}	Added effect for one-way traffic on minor street	All	−0.392	0.176	−2.23	0.0264
b_{lanes}	Number of lanes	3SG/4SG	0.069	0.094	0.73	0.4640
b_{il}	Added effect of Illinois	All	0.726	0.158	4.61	<0.0001
k	Inverse dispersion parameter	3ST	0.966	0.220	4.38	<0.0001
		3SG	1.113	0.268	4.15	<0.0001
		4ST	1.039	0.188	5.52	<0.0001
		4SG	0.496	0.045	11.00	<0.0001
	Observations	586 intersections (3ST=107; 3SG=40; 4ST=155; 4SG=284)				

Indicator variables were included for the states of California, Illinois, and Michigan. However, only the coefficient for Illinois was statistically significant. This means that the magnitude of the crashes between Texas, Michigan, and California are about the same, but Illinois experiences fewer crashes for the same conditions and exposure. The trend could not be explained by difference in road design among the states. It is likely that the differences between states are due to unobserved variables such as vertical grade, signing, pavement condition, weather, reporting accuracy, and speed limit, as well as reportability criteria.

The NLMIXED procedure in the SAS software was used to estimate the proposed model coefficients. This procedure was used because the proposed predictive model is both nonlinear and discontinuous. The log-likelihood function for the NB distribution was used to determine the best-fit model coefficients.

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 38 for one-way street three-leg stop-controlled intersections, with one-way direction on the major street only.

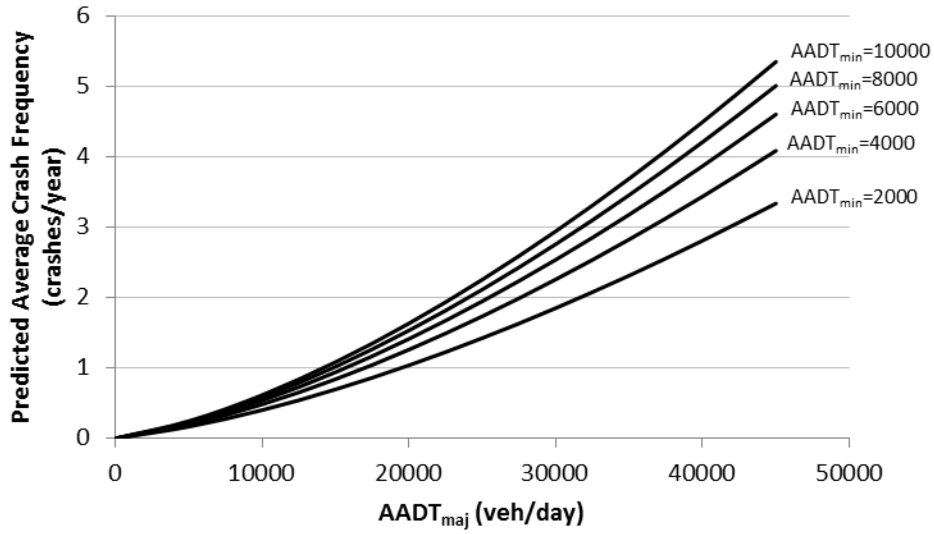

Figure 38. Graphical form of the intersection SPF for crashes on one-way street three-leg stop-controlled intersections (3ST).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 39 for one-way street three-leg signalized intersections, with one-way direction on the major street only.

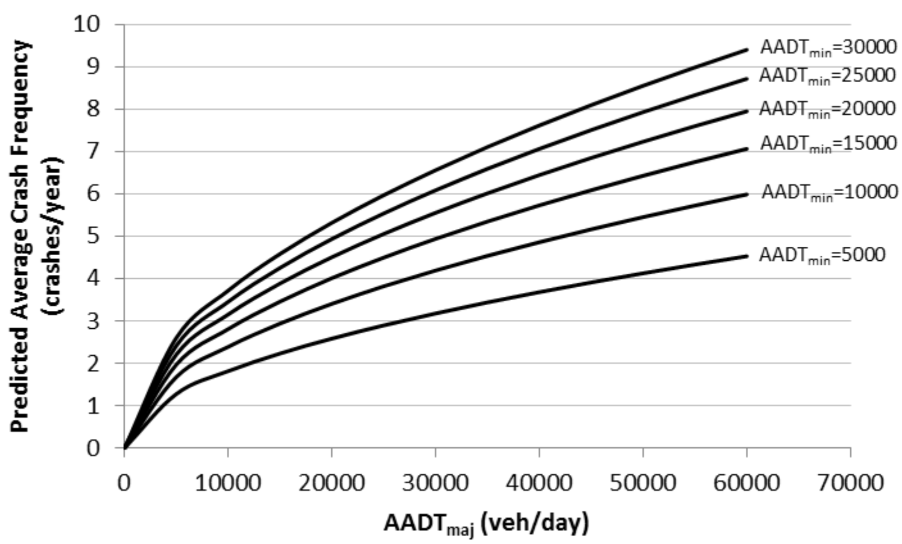

Figure 39. Graphical form of the intersection SPF for crashes on one-way street three-leg signalized intersections (3SG).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 40 for one-way street four-leg stop-controlled intersections, with one-way direction on the major street only.

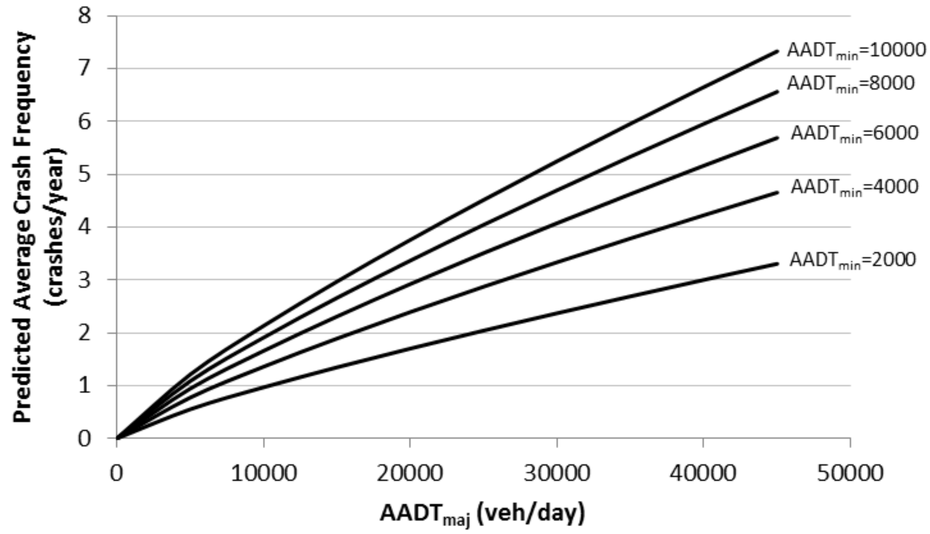

Figure 40. Graphical form of the intersection SPF for crashes on one-way street four-leg stop-controlled intersections (4ST).

The relationship between crash frequency (FI and PDO crashes) and traffic demand for base conditions, as obtained from the calibrated models, is illustrated in Figure 41 for one-way street four-leg signalized intersections, with one-way direction on the major street only.

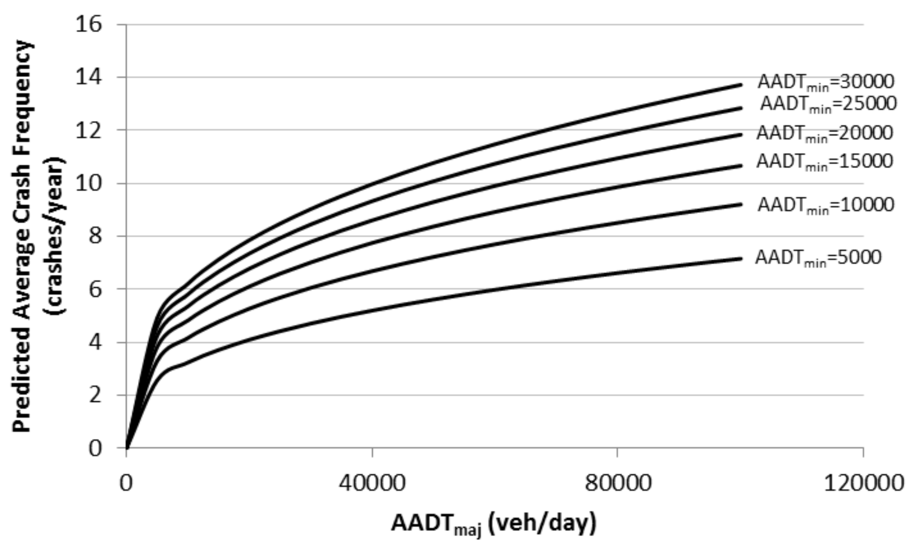

Figure 41. Graphical form of the intersection SPF for crashes on one-way street four-leg signalized intersections (4SG).

The comparison of crash frequency (FI and PDO crashes) between intersection categories, as obtained from the calibrated models, is illustrated in Figure 42 for one-way street four-leg signalized intersections. The intersection with two one-way streets would experience about 30 percent fewer crashes than the intersection with one-way direction on the major street only.

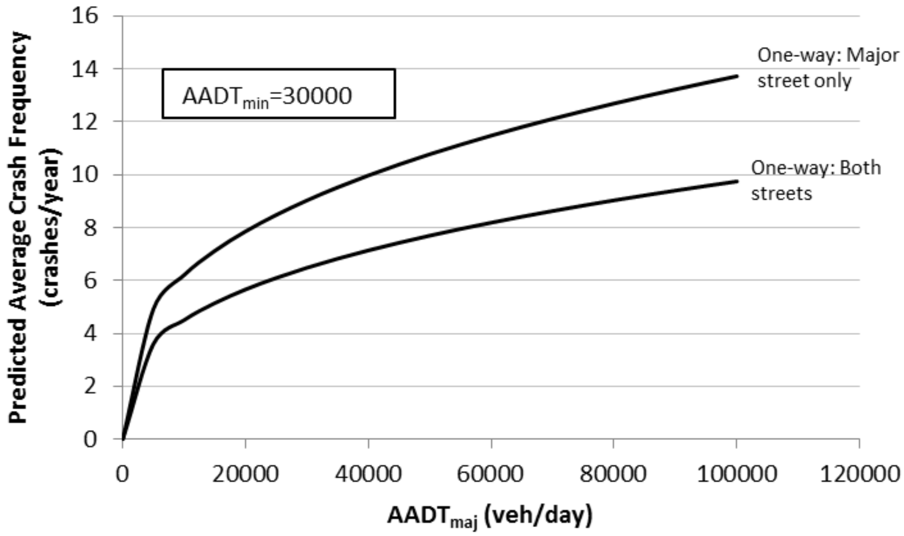

Figure 42. Comparison of the SPF by intersection category for crashes on one-way street four-leg signalized intersections (4SG).

The proportions in Table 79 are used to separate total crashes into components by crash type for 1×2 and 1×1 intersections.

Table 79. Distribution of total vehicle collisions for 1×2 or 1×1 intersections by collision type.

Manner of Collision	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3ST		3SG		4ST		4SG	
	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Head-on collision	0.000	0.000	0.000	0.000	0.028	0.020	0.039	0.030
Angle collision	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733
Sideswipe	0.400	0.350	0.000	0.214	0.075	0.157	0.059	0.145
Other multiple-vehicle	0.100	0.050	0.000	0.071	0.009	0.013	0.030	0.012
Single-vehicle crashes	0.100	0.250	0.000	0.000	0.019	0.039	0.006	0.021

Source: HSIS data for California (2006–2010).

Vehicle-Pedestrian Collisions

The HSM provides a model to estimate the number of vehicle-pedestrian crashes at signalized intersections (i.e., 3SG and 4SG), which is described in Equations 181 and 182 of Chapter 6.

According to *NCHRP 129: Phase III* (Harwood et al., 2008), the model was developed using data from a total of 1,883 signalized intersections—1,532 in Toronto and 351 in Charlotte, North Carolina—which did not include any one-way leg. Since the HSM model accounts for the vehicular and pedestrian traffic as well as the maximum length that a pedestrian may be exposed to the vehicular traffic (through n_{lanesx}), the research team hypothesized that the same model would be valid for intersections of one-way streets. This hypothesis was tested using field data, and the results are presented in this section.

A sample of 10 intersections in California and 24 intersections in San Antonio, Texas, were selected for data collection. All the intersections involved one-way streets. The sites in California were selected along a one-way street pair: CA-32 in Chico. The 24 intersections in San Antonio were all located downtown or the area near downtown.

Two-hour pedestrian counts were collected at the selected intersections by TRA Inc. in California and TTI research team members in San Antonio. Eighteen-hour (6:00 AM to 12:00 AM) pedestrian counts were collected at five sites, one along each of the corridors in California and one in downtown San Antonio. The 18-hour counts were used to compute adjustments factors needed to convert two-hour counts to daily pedestrian volumes. It was assumed that pedestrian activity during the remaining six hours (between 12:00 AM and 6:00 AM) was negligible.

The major- and minor-street AADTs were determined using California HSIS data and City of San Antonio traffic volume data. The variable n_{lanesx} was determined using Google Earth aerial imagery. The presence of schools and number of bus stops and alcohol sales establishments within 1000 ft of the intersection were recorded for each site using Google Earth aerial imagery and Street View. The team followed the HSM instructions to determine these variables. The CMFs were determined using the respective tables in the HSM.

The observed number of vehicle-pedestrian collisions at the selected intersections was determined using HSIS data for California and the CRIS database for Texas. A vehicle-pedestrian collision was assigned to an intersection if it occurred within 250 ft of the intersection center or was coded as intersection-related. Where a collision occurred between two adjacent intersections that were less than 500 ft apart, the collision was assigned to the nearest intersection. Only fatal or injury collisions were considered in the analysis (consistent with the HSM).

The HSM model for vehicle-pedestrian collisions at signalized intersections was used to predict the crash frequency. The objective was to validate the applicability of the HSM model for crash frequency prediction at signalized intersections where at least one of the approaches was a one-way street.

The model validation consisted of several tasks. The first task was to quantify the local calibration factor (C_i), which would be the first step for any agency using the HSM methodology:

$$C_i = \frac{\sum_{all\ sites} observed\ crashes}{\sum_{all\ sites} predicted\ crashes} \tag{220}$$

The local calibration factor was determined to be 0.51 and 0.23 for San Antonio and California, respectively. Since the estimated calibrated coefficient for California was too low, it was not considered in further analysis. The second task was to apply the recalibrated model to compute the expected crash frequency at each intersection and compare it with the reported crash frequency for each site.

The third task was to perform a goodness-of-fit evaluation to assess the applicability of the HSM model to signalized intersections of one-way streets. The Pearson's chi-squared test was used for this purpose. To meet the requirements of this test, observations (intersections) had to be grouped so that each group had an expected crash frequency greater than 5 (Yates et al., 1999). The observations were sorted by $AADT_{total}$ and combined into seven groups with expected crash frequencies greater than 5.

The Pearson χ^2 statistic was determined to be 8.62, which is less than $\chi^2_{0.05}$ with n − 1 = 6 degrees of freedom (12.59), so the hypothesis that the model fits the validation data from San Antonio could not be rejected at significance level (α) = 0.05. Therefore, the HSM model for vehicle-pedestrian collisions at signalized intersections is applicable to intersections of one-way streets.

For 3ST and 4ST, the number of vehicle-pedestrian collisions per year for an intersection is estimated using Equation 183. The pedestrian crash adjustment factor is estimated by dividing the vehicle-pedestrian crashes by the total intersection crashes (excluding vehicle-pedestrian and vehicle-bicycle collisions) for each intersection type. Table 80 presents the values of f_{pedi}. All vehicle-pedestrian collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-16) are also displayed for comparison. The adjustment factors are developed using Equation 184.

Table 80. Pedestrian crash adjustment factors: one-way street intersections.

Intersection Type	Number of Intersections	Total Pedestrian Crashes	Total MV and SV Crashes[a]	f_{pedi} (proposed)	f_{pedi} (HSM)
3ST	107	5	342	0.015	0.021
4ST	155	14	687	0.020	0.022

[a] Excludes pedestrian and bicycle crashes.

Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for an intersection is estimated using Equation 185. 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 81 presents the values of f_{bike}. All vehicle-bicycle collisions are considered FI crashes. The HSM adjustment factors (from HSM Table 12-17) are also displayed for comparison. The adjustment factors are developed using Equation 186.

Table 81. Bicycle crash adjustment factors: one-way street intersections.

Intersection Type	Number of Intersections	Total Bicycle Crashes	Total MV and SV Crashes[a]	f_{bikei} (proposed)	f_{bikei} (HSM)
3ST	107	6	342	0.018	0.016
3SG	40	8	514	0.016	0.011
4ST	155	15	687	0.022	0.018
4SG	288	65	5571	0.012	0.015

[a] Excludes pedestrian and bicycle crashes.

CMFS FOR 1×2 OR 1×1 INTERSECTIONS

CMFs were calibrated in conjunction with the SPFs. All of them were calibrated using FI crash data. Collectively, they describe the relationship between various geometric factors and crash frequency. This section shows figures of the CMFs developed from the regression models described above for one-way street intersections. If the standard errors of the CMFs are desired, then Equations 133–140 can be used to compute them.

Lighting CMF

The base condition for lighting is the absence of intersection lighting. The lighting CMF is described using Equation 221.

$$CMF_{lg} = 1 - e^{-1.484} \times p_{ni} = 1 - 0.23 \times p_{ni} \quad (221)$$

This CMF is similar to the CMF presented in the HSM ($CMF_{lg} = 1 - 0.38 \times p_{ni}$). However, the proposed coefficient in this research is highly insignificant, and thus the research team recommends using the CMF in the HSM. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle crashes) and is applicable to both signalized and unsignalized intersections. Table 82 presents default values for the nighttime crash proportion, p_{ni}.

Table 82. Nighttime crash proportions for unlighted intersections.

Intersection Type	Proportion of Crashes That Occur at Night, p_{ni}
3ST	0.238
4ST	0.229
3SG and 4SG	0.235

Number of Lanes CMF

The number of lanes CMF is determined using Equation 222.

$$CMF_{lanes} = \left[e^{0.242(N_{maj}-6)} P_{maj} + (1 - P_{maj})\right] \times \left[e^{0.242(N_{min}-2)} P_{min} + (1 - P_{min})\right] \quad (222)$$

with,

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj} + AADT_{\min}} \quad (223)$$

$$P_{\min} = \frac{AADT_{\min}}{AADT_{maj} + AADT_{\min}} \quad (224)$$

The base condition for the number of lanes CMF is two lanes on the major street and two lanes on the minor street. Table 83 presents the relationship between number of lanes and FI crash frequency at signalized intersections when the volume on the minor street is equal to one-half the volume on the major street. This CMF applies to all intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. The CMF indicates that the increase in the number of lanes at a signalized intersection is associated with an increase in the frequency of crashes. The number of lanes in the cross-section tends to increase the size of the intersection conflict area, which could increase the exposure of vehicles to conflict with crossing movements.

Table 83. CMF for number of lanes at a signalized intersection.

Number of Major-Street Lanes	CMF Based on Number of Minor-Street Lanes				
	2	**3**	**4**	**5**	**6**
2	1.00	1.09	1.21	1.36	1.54
3	1.18	1.29	1.43	1.60	1.83
4	1.42	1.54	1.71	1.92	2.19

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

CHAPTER 9. SEVERITY DISTRIBUTION FUNCTIONS

This chapter describes the activities undertaken to calibrate SDFs for various components of the urban and suburban arterial system. An SDF is a discrete choice model that includes variables describing a site's geometric design, traffic control features, and traffic characteristics, along with a calibration factor. It is used to predict for each site the proportion of crashes associated with each of the following severity levels:

- Fatal (K).
- Incapacitating injury (A).
- Non-incapacitating injury (B).
- Possible injury (C).

The SDFs were developed to be used with a predictive model to estimate the expected crash frequency for each severity level. They were calibrated using a highway safety database that combines crash data with road inventory data. The database assembled for calibration included crash severity level as a dependent variable and the geometric variables of each site as independent variables. From the database described in Chapter 4, each row (site characteristics) is repeated to the frequency of each severity level. Thus, a segment with *n* crashes will be repeated *n* number of times. It should be noted that the segments with no injury crashes are not included in the database. The total sample size of the final dataset for model calibration will be equal to the total number of injury (and fatal) crashes in the original dataset. During the model calibration, the "possible injury" category is set as the base scenario, with coefficients restricted at zero.

This chapter is divided into five sections. The first section describes the development of an SDF for six-or-more-lane arterial segments. The second section describes the development of an SDF for one-way arterial segments. The third section describes the development of an SDF for signalized intersections of six-or-more-lane arterials. The fourth section describes the development of an SDF for signalized intersections of one-way streets. The last section describes the development of an SDF for unsignalized intersections of either six-or-more-lane arterials or one-way streets.

METHODOLOGY

The multinomial logit (MNL) model was used to predict the probability of crash severities. An individual crash severity among the given severities was considered to be predicted if the crash severity likelihood function was maximum for that particular severity. Each crash severity likelihood function, which is a dimensionless measure of the crash likelihood, was considered to have a deterministic component and an error/random component. While the deterministic part is assumed to contain variables that can be measured, the random part corresponds to the unaccounted factors that impact injury severity. The deterministic part of the crash severity likelihood was designated as a linear function of the driver, roadway, vehicle, and weather characteristics, as shown in Equation 225:

$$V_j = ASC_j + \sum_{k=1}^{K} b_{k,j} X_k \quad (225)$$

where,

V_j	=	systematic component of crash severity likelihood for severity *j*.
ASC_j	=	alternative specific constant for crash severity *j*.
$b_{k,j}$	=	regression coefficient for crash severity *j* and variable *k*, *k* =1,...,K.
X_{ki}	=	independent variable *k*.
K	=	total number of independent variables included in the model.

The logit model was derived assuming that the error components are extreme value (or Gumbel) distributed (McFadden, 1981), and the probability for each crash severity is given by Equation 226:

$$P_j = \frac{e^{V_j}}{\sum_{j=1}^{J} e^{V_j}} \quad (226)$$

where,

P_j	=	probability of the occurrence of crash severity *j*.
J	=	total number of crash severities to be modeled.

To adjust for the local conditions, Equation 226 is modified by considering the local calibration factor. The adjusted probability for each severity category is given as follows.

$$P_K = \frac{e^{V_K}}{\frac{1}{C} + e^{V_K} + e^{V_A} + e^{V_B}} \quad (227)$$

$$P_A = \frac{e^{V_A}}{\frac{1}{C} + e^{V_K} + e^{V_A} + e^{V_B}} \quad (228)$$

$$P_B = \frac{e^{V_B}}{\frac{1}{C} + e^{V_K} + e^{V_A} + e^{V_B}} \quad (229)$$

$$P_C = 1 - (P_K + P_A + P_B) \quad (230)$$

where,

C = local calibration factor.

The NLMIXED procedure in the SAS software was used for model calibration.

On a few facilities, fatal crashes rarely occur due to lower speeds. When a small number of fatal crashes are reported, the calibrated model may provide unreliable and insignificant estimates (Ye and Lord, 2014). In those cases, the fatal and incapacitating injury crashes can be combined into one category during the final model calibration. The probabilities in those situations are given as follows.

$$P_{K+A} = \frac{e^{V_{K+A}}}{\frac{1}{C} + e^{V_{K+A}} + e^{V_B}} \tag{231}$$

$$P_B = \frac{e^{V_B}}{\frac{1}{C} + e^{V_{K+A}} + e^{V_B}} \tag{232}$$

$$P_C = 1 - (P_{K+A} + P_B) \tag{233}$$

SIX-OR-MORE-LANE ARTERIAL SEGMENTS

The database included 15,172 FI crashes reported in California, Illinois, and Texas. Table 84 summarizes the estimation results of model calibration. Although many variables were considered, the results presented in Table 84 show the variables that are significant in influencing crash severities. 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 84 are logical and consistent with previous research findings. The t-statistic for each coefficient in Table 84 indicates a test of the hypothesis that the coefficient value is equal to 0.0. Those t-statistics with an absolute value 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 was smaller than 2.0, it was decided that the variable was important to the model, and its trend was found to be intuitive and, where available, consistent with previous research findings (even if the specific value was not known with a great deal of certainty when applied to this database).

Table 84. Crash SDF: six-or-more-lane arterials.

Variable	Fatality (K)		Incapacitating Injury (A)		Non-incapacitating Injury (B)	
	Value	t-statistic	Value	t-statistic	Value	t-statistic
Alternative specific constant	−5.1142	−9.77	−1.7347	−23.58	−0.5751	−12.62
Area type (urban=1)	−0.4714	−3.33	−0.2505	−5.86	−0.2505	−6.25
Posted speed limit	0.0442	4.19				
Indicator for 6D	−0.3327	−2.32	−0.2923	−4.06	−0.0938	−2.17
Indicator for 8D	−0.2296	−1.07	−0.5230	−4.71	−0.2373	−3.83
Added effect of Illinois	0.6748	14.84	0.6748	14.84	0.6748	14.84
Added effect of California	−0.2884	−6.12	−0.2884	−6.12	−0.2884	−6.12
Observations	15,172 crashes (K=247; A=1086; B=4407; C=9432)					

Note: Possible injury is the base scenario with coefficients restricted at zero. Shaded cell means coefficient is highly insignificant.

Indicator variables were included for the states of California and Illinois. The state-specific variables were included to improve the accuracy of the model in order to account for differences between states that could not be explained with the other variables in the model. There may be differences between states, such as weather and driver behavior, that were not included in the model. The definition of a reportable crash also varied per state. In the final model, state-specific variables were not included, but this effect was captured through the calibration process. The coefficients for both California and Illinois were statistically significant. The coefficients for these variables are shown in the last two rows of Table 84. Their values indicate that a crash on a six-or-more-lane segment in Illinois is likely to be more severe, and a crash in California is likely to be less severe than a crash on a segment in Texas. The differences may be caused by different highway design practices (e.g., use of different roadside design features, etc.), terrain, weather pattern, driver behavior, and reporting accuracy.

The coefficients in Table 84 were combined with Equation 225 to obtain the deterministic component of each crash severity level for crashes on six-or-more-lane segments. The form of each model is described by Equations 234–236.

$$V_K = -5.1142 + (-0.4714 \times I_{urban}) + (0.0442 \times PSL) + (-0.3327 \times I_{6D}) + (-0.2296 \times I_{8D}) \quad (234)$$

$$V_A = -1.7347 + (-0.2505 \times I_{urban}) + (0.0000 \times PSL) + (-0.2923 \times I_{6D}) + (-0.5230 \times I_{8D}) \quad (235)$$

$$V_B = -0.5751 + (-0.2505 \times I_{urban}) + (0.0000 \times PSL) + (-0.0938 \times I_{6D}) + (-0.2373 \times I_{8D}) \quad (236)$$

where,

I_{urban} = area type indicator variable (= 1.0 if urban, 0.0 if suburban).
PSL = posted speed limit (mph).
I_{6D} = indicator variable for six-lane divided highway (= 1.0 if six-lane divided, 0.0 otherwise).
I_{8D} = indicator variable for eight-lane divided highway (= 1.0 if eight-lane divided, 0.0

otherwise).

The probability of each severity level is obtained by combining Equations 234 to 236 with Equations 227–230.

Predicted Probabilities

The below subsections provide the influence of variables on crash severities for six-or-more-lane arterials.

Area Type

The sites considered in the project were located in both urban and suburban area types. About 68 percent of crashes occurred in urban areas. The negative coefficient for the area type shown in Table 84 indicates that a crash occurring in an urban area is generally less severe than a crash in a suburban area. As seen in Table 85, the likelihood of fatal and severe injury crashes (i.e., K, A, and B) changes from 33.9 percent in urban areas to 40.7 percent in suburban areas. The trend with area type can be attributed to higher operating speeds in suburban areas. A crash that occurs at a higher speed typically has higher severity than a crash at a lower speed.

Table 85. Crash severity distribution of six-or-more-lane segments based on area type.

Area Type	**Crash Severity**			
	K	**A**	**B**	**C**
Urban	1.3%	6.1%	26.5%	66.1%
Suburban	1.9%	8.2%	30.6%	59.3%

Speed Limit

The speed limit variable indicates the posted speed limit on a particular segment. The speed limit of all segments considered in the SDF model calibration ranged from 25 mph to 60 mph. The average speed limit was 42 mph. The positive sign for posted speed limit in Table 84 shows that as speed limit increases, the likelihood of a fatal injury also increases. As seen in Table 86, the likelihood of a fatal crash increases from 0.7 percent at 25 mph to 3.1 percent at 60 mph. This is not unexpected because speed limit is highly correlated to crash severity.

Table 86. Crash severity distribution of six-or-more-lane segments based on posted speed limit.

Posted Speed Limit (mph)	**Crash Severity**			
	K	**A**	**B**	**C**
25	0.7%	6.8%	28.0%	64.5%
30	0.8%	6.8%	27.9%	64.4%
35	1.1%	6.8%	27.9%	64.3%
40	1.3%	6.8%	27.8%	64.1%
45	1.6%	6.7%	27.7%	63.9%
50	2.0%	6.7%	27.6%	63.7%
55	2.5%	6.7%	27.5%	63.3%
60	3.1%	6.6%	27.3%	62.9%

Road Type

The effect of road type on crash severity was also considered in the calibrated model. About 55 percent of crashes occurred on six-lane divided roads, 16 percent occurred on eight-lane divided roads, and the remaining 29 percent occurred on six-lane undivided or six-lane with TWLTL segments. The model coefficients in Table 84 indicate that a crash on a six-lane or eight-lane divided road segment is less severe than a crash on a six-lane undivided or six-lane with TWLTL segment. As seen in Table 87, the likelihood of fatal and severe injury crashes (i.e., K, A, and B) is about 39 percent on six-lane undivided or six-lane with TWLTL segments, about 36 percent on six-lane divided segments, and about 32 percent on eight-lane divided segments. Overall, the chance of high severe crashes is lower on eight-lane divided segments. These road types are generally located in downtown areas, which typically have lower speeds. A crash that occurs at a lower speed has less severity than a crash at a higher speed.

Table 87. Crash severity distribution of six-or-more-lane segments based on road type.

Road Type	Crash Severity			
	K	A	B	C
6U or 7T	1.8%	8.2%	29.0%	61.1%
6D	1.3%	6.5%	27.8%	64.4%
8D	1.6%	5.4%	25.3%	67.7%

ONE-WAY ARTERIAL SEGMENTS

The database included 1,615 FI crashes reported in California, Illinois, Oregon, and Texas. Initially, a model was developed to predict the proportion of crashes in each severity category (i.e., K, A, B, and C). However, due to a small number of reported fatal crashes, the model provided unreliable and insignificant estimates. Thus, the fatal and incapacitating injury crashes were combined into one category during the final model calibration. The results of crash severity models are summarized in Table 88 for one-way arterials. Although many variables were considered, the results presented in Table 88 show the variables that are significant in influencing crash severities. 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 88 are logical and consistent with previous research findings.

Table 88. Crash SDF: one-way roadways.

Variable	Fatality (K)+Incapacitating Injury (A)		Non-incapacitating Injury (B)	
	Coefficient	t-value	Coefficient	t-value
Alternative specific constant	0.2933	0.54	−0.381	−3.8
Lane width	−0.1226	−3.01		
Right shoulder width	−0.126	−4.53	−0.05755	−3.7
Area type (urban=1)	−0.3994	−2.38		
Bike lanes (yes =1)	0.9969	2.19	0.8691	3.01
Illinois	0.5035	4.03	0.5035	4.03
Observations	1615 crashes (K=17; A=154; B=611; C=833)			

Note: Possible injury is the base scenario, with coefficients restricted at zero. Shaded cell means coefficient is highly insignificant.

In addition to the variables included in the calibrated model, there may be differences between states, such as weather and driver behavior, that were not included in the model. Thus, indicator variables for the states of California, Oregon, and Illinois were included in the calibrated model to account for the overall differences between the states, which could not be explained with the variables included in the model. The coefficients for Oregon and California were very small and not statistically significant, suggesting that the state effects are very similar among Texas, Oregon, and California. The positive coefficient for Illinois in Table 88 shows that a crash occurring on roads in Illinois is likely to be more severe than a crash in other states, when all other variables are controlled. The differences may be explained by different highway design practices (e.g., use of different roadside design features, etc.), terrain, weather pattern, driver behavior, and reporting accuracy or criteria.

The coefficients in Table 88 were combined with Equation 225 to obtain the deterministic component of each crash severity level for crashes on six-or-more-lane segments. The form of each model is described by Equations 237 and 238.

$$V_{K+A} = 0.2933 + (-0.1226 \times W_l) + (-0.126 \times W_{rs}) + (-0.3994 \times I_{urban}) + (-0.9969 \times I_{bike}) \quad (237)$$

$$V_B = -0.381 + (0.0000 \times W_l) + (-0.05755 \times W_{rs}) + (0.0000 \times I_{urban}) + (0.8691 \times I_{bike}) \quad (238)$$

where,

W_l = lane width (ft).
W_{rs} = shoulder width on the right side (ft).
I_{urban} = area type indicator variable (= 1.0 if urban, 0.0 if suburban).
I_{bike} = bike lane presence indicator variable (= 1.0 if present, 0.0 otherwise).

The probability of each severity level is obtained by combining Equations 237 and 238 with Equations 231–233.

Predicted Probabilities

The subsections below provide the influence of variables on crash severities for one-way arterials.

Lane Width

The lane width used in this research was an average for all through lanes on the segment. The average lane width in the dataset was 13 ft. The negative coefficients for the lane width variable for fatal and non-incapacitating crashes in Table 88 suggests that as the lane width increases, the likelihood of these severity levels decreases. As seen in Table 89, the likelihood of fatal and incapacitating injury crashes (i.e., K and A) changes from 18.2 percent for 10-ft lanes to 9.6 percent for 16-ft lanes. For every 1-ft increase in lane width, an average reduction of 1.4 percent in K and A crashes can be expected. The relative effect of lane width reduces at the higher widths. Generally, the lane width is positively correlated with safety because it allows drivers more room to maneuver within the lane.

Table 89. Crash severity distribution of one-way segments based on lane width.

Lane Width (ft)	Crash Severity		
	K+A	B	C
10	18.2%	30.5%	51.3%
11	16.4%	31.2%	52.4%
12	14.8%	31.8%	53.4%
13	13.3%	32.4%	54.3%
14	12.0%	32.9%	55.1%
15	10.8%	33.3%	55.9%
16	9.6%	33.7%	56.6%

Right Shoulder Width

The effect of both left and right shoulders on crash severity was initially considered in the calibrated model. However, only the right shoulder width was statistically significant. The average right shoulder width in the dataset was 3 ft. The negative model coefficients in Table 88 indicate that as right shoulder width increases, probability of fatal and incapacitating injury crashes decreases. As seen in Table 90, the likelihood of fatal and incapacitating injury crashes (i.e., K and A) changes from 17.1 percent with no right shoulder to 6.7 percent with 10-ft right shoulder. For every 1-ft increase in right shoulder width, an average reduction of 1.0 percent in K+A crashes can be expected. The relative effect of right shoulder width reduces at the higher widths. Generally, the right width is positively correlated with safety because it prevents drivers from hitting the roadside fixed objects.

Table 90. Crash severity distribution of one-way segments based on right shoulder width.

Right Shoulder Width (ft)	Crash Severity		
	K+A	B	C
0	17.1%	34.3%	48.6%
2	14.4%	33.0%	52.5%
4	12.0%	31.6%	56.4%
6	9.9%	30.0%	60.1%
8	8.2%	28.3%	63.5%
10	6.7%	26.5%	66.8%

Area Type

The sites considered in the project were located in both urban and suburban areas. About 68 percent of crashes occurred in urban areas. The negative coefficient for the area type shown in Table 88 indicates that a crash occurring in an urban area is generally less severe than a crash in a suburban area. The possible reason for this influence could be due to higher speeds on roads located in suburban areas. As seen in Table 91, the likelihood of a fatal and incapacitating injury changes from 11.9 percent in urban areas to 16.7 percent in suburban areas. The trend with area type can be attributed to higher operating speeds in suburban areas. A crash that occurs at a higher speed typically has higher severity than a crash at a lower speed.

Table 91. Crash severity distribution of one-way segments based on area type.

Area Type	Crash Severity		
	K+A	B	C
Urban	11.9%	32.9%	55.2%
Suburban	16.7%	31.1%	52.2%

Bike Lanes

The effect of bike lane presence on crash severity was also considered in the calibrated model. About 4 percent of crashes occurred on segments with bike lanes. The positive coefficients for high severe crashes in Table 88 indicate that a crash on a road with bike lanes is generally more severe than on a road without bike lanes. As seen in Table 92, the likelihood of a fatal and incapacitating injury changes from 13.0 percent on segments without bike lanes to 21.1 percent on segments with bike lanes. It is important to note that this result does not suggest that the bike lanes increase the crash severity. It is a proxy for the presence of more bicycle volume. If the bike lanes are not physically separated from the vehicular lanes, then the chances of vehicle-bicycle collisions increase and are much more severe than vehicle-vehicle crashes.

Table 92. Crash severity distribution of one-way segments based on bike lane presence.

Presence of Bike Lanes	Crash Severity		
	K+A	B	C
No	13.0%	31.8%	55.2%
Yes	21.1%	45.7%	33.2%

TWO-WAY STREET SIGNALIZED INTERSECTIONS

The database included 5,850 FI crashes reported in California, Illinois, Michigan, and Texas. Initially, a model was developed to predict the proportion of crashes in each severity category (i.e., K, A, B, and C). However, due to a small number of reported fatal crashes, the model provided unreliable and insignificant estimates. Thus, the fatal and incapacitating injury crashes were combined into one category during the final model calibration. The results of crash severity models are summarized in Table 93 for two-way street signalized intersections. Although many variables were considered, the results presented in Table 93 show the variables that are significant in influencing crash severities. 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 93 are logical and consistent with previous research findings.

Table 93. Crash SDF: two-way street signalized intersections.

Variable	Fatality (K)+ Incapacitating Injury (A)		Non-incapacitating Injury (B)	
	Coefficient	t-value	Coefficient	t-value
Alternative specific constant	−1.7673	−5.15	−0.7250	−5.95
Area type (1=urban, 0=suburban)	−0.1161	−1.66	−0.1161	−1.66
Right-turn-on-red prohibition (1=prohibited, 0=allowed)	−1.1661	−1.13	−1.0743	−2.19
U-turn prohibition (1=prohibited, 0=allowed)	−0.1415	−1.23	−0.0693	−1.17
Presence of major-street left lanes (2=both approaches, 1=one approach, 0=none)	−0.1784	−1.55	−0.1075	−1.66
Lighting presence (1=present, 0=absent)	−0.3310	−1.11		
Added effect of Illinois (1=Illinois, 0=other)	0.7363	5.10	0.7363	5.10
Observations	5850 crashes (K=31; A=300; B=1488; C=4031)			

Note: Possible injury is the base scenario, with coefficients restricted at zero. Shaded cell means coefficient is highly insignificant.

In addition to the variables included in the calibrated model, there may be differences between states, such as weather and driver behavior, that were not included in the model. The definition of a reportable crash also varied per state. Thus, an indicator variable for each state was included in the calibrated model to account for the overall differences between the states, which could not be explained with the variables included in the model. However, the coefficients for Michigan and California were very small and not statistically significant. This finding suggests that the state effects are very similar among Texas, Michigan, and California. The Michigan and California indicator variables were removed as a result.

The coefficient for Illinois was relatively large and statistically significant. Its positive sign in Table 93 indicates that a crash at two-way street signalized intersections in Illinois is likely to be more severe than a crash in Texas, Michigan, or California, when all other variables are controlled. This difference may be explained by different highway design practices (e.g., use of different roadside design features, etc.), terrain, weather pattern, driver behavior, and reporting accuracy for the various states.

The coefficients in Table 93 were combined with Equation 225 to obtain the deterministic component of each crash severity level for crashes at two-way street intersections. The form of each model is described by Equations 239 and 240.

$$V_{K+A} = -1.7673 + (-0.1161 \times I_{urban}) + (-1.1661 \times I_{rtor}) + (-0.1415 \times I_{uturn}) + (-0.1784 \times n_{lt}) + (-0.331 \times I_{light}) \quad (239)$$

$$V_B = 0.725 + (-0.1161 \times I_{urban}) + (-1.0743 \times I_{rtor}) + (-0.0693 \times I_{uturn}) + (-0.1075 \times n_{lt}) + (0.000 \times I_{light}) \quad (240)$$

where,

I_{urban} = area type indicator variable (= 1.0 if urban, 0.0 if suburban).

I_{rtor} = right-turn-on-red prohibition indicator variable (= 1.0 if prohibited, 0.0 if allowed).

I_{uturn} = U-turn prohibition indicator variable (= 1.0 if prohibited, 0.0 if allowed).

n_{lt} = number of major-street approaches with exclusive left-turn lanes (= 2.0 if both approaches, 1.0 if one approach, 0.0 if none).

I_{light} = lighting presence indicator variable (= 1.0 if present, 0.0 otherwise).

The probability of each severity level is obtained by combining Equations 239 and 240 with Equations 231–233.

Predicted Probabilities

The subsections below provide the influence of variables on crash severities at two-way signalized intersections.

Area Type

The sites considered in the project were located in both urban and suburban areas. About 75 percent of the crashes occurred in urban areas. The negative coefficient for the area type shown in Table 93 indicates that a crash occurring in an urban area is generally less severe than a crash in a suburban area. As seen in Table 94, the likelihood of K, A, and B crashes changes from 30.3 percent in urban areas to 32.8 percent in suburban areas. The trend with area type can be attributed to higher operating speeds in suburban areas. A crash that occurs at a higher speed typically has higher severity than a crash at a lower speed.

Table 94. Two-way street signalized intersection severity distribution based on area type.

Area Type	Crash Severity		
	K+A	B	C
Urban	5.5%	24.8%	69.7%
Suburban	5.9%	26.9%	67.2%

Right Turn on Red

The RTOR prohibition variable indicates the right-turn movement at a signalized intersection. Less than 1 percent of crashes occurred at intersections with RTOR prohibition. The negative sign for the RTOR prohibition variable in Table 93 indicates that K and A crash severity decreases when RTOR is prohibited. Table 95 suggests that the probability of K and A crashes decreases from 5.6 percent when RTOR is allowed to 2.2 percent when RTOR is prohibited. Since a collision during an RTOR involves at least two vehicles or roadway users, the likelihood that one road user gets injured increases. A similar trend is seen for non-incapacitating injury crashes.

Table 95. Two-way street signalized intersection severity distribution based on RTOR.

RTOR	Crash Severity		
	K+A	B	C
Allowed	5.6%	25.5%	68.9%
Prohibited	2.2%	11.0%	86.8%

U-turn

The U-turn prohibition variable indicates U-turn movement presence on the major street of a signalized intersection. About 27 percent of crashes occurred at intersections with U-turn prohibition. The negative sign for the U-turn prohibition variable in Table 93 indicates that K and A crash severity decreases when the U-turn movement is prohibited. Similar to RTOR, U-turns involve more than one vehicle, which increases the likelihood of injuries.
Table 96 suggests that the probability of K, A, and B crashes decreases from 31.4 percent when U-turns are allowed to 29.7 percent when they are prohibited.

Table 96. Two-way street signalized intersection severity distribution based on U-turn prohibition.

U-turn	Crash Severity		
	K+A	B	C
Allowed	5.8%	25.6%	68.6%
Prohibited	5.2%	24.5%	70.3%

Left-Turn Lanes

The left-turn lane variable indicates the presence of a left-turn lane on each approach of the major street. About 84 percent of crashes occurred at intersections with left-turn lanes on both approaches of the major street. Crashes occurring at intersections with left-turn lanes on only one approach of the major street accounted for 8 percent of all crashes. The remaining 8 percent of crashes occurred at intersections without left-turn lanes on both major-street approaches. The negative sign for the left-turn lane variable in Table 93 indicates that the chance of high severity crashes decreases when a left-turn lane is present. Table 97 suggests that the probability of K, A, and B crashes decreases from 35.6 percent when no left-turn lane is present to 30.3 percent when a left-turn lane is present on both approaches. Providing a left-turn lane may reduce the speed of the turning vehicle since the driver has more flexibility to find a gap in the approaching traffic.

Table 97. Two-way street signalized intersection severity distribution based on major-street left-turn lane.

Left-Turn Lane on Major Street	Crash Severity		
	K+A	B	C
Not present	7.1%	28.5%	64.3%
One approach only	6.2%	26.7%	67.1%
Both approaches	5.4%	24.9%	69.7%

Lighting

About 97 percent of intersections where crashes occurred had the presence of lighting. The relationship between lighting presence and severity level is shown in Table 98. The negative value of the associated coefficient (in Table 93) indicates that a crash occurring at an unlighted intersection is more severe than a crash at an intersection with lighting presence, when all other variables are controlled. The percentages in Table 98 indicate that the fatal and severe injury crash percentage at an unlighted intersection is 31.4 percent, and it is 29.7 percent when lighting is present. At unlighted intersections, a driver’s perception might be obscured and reaction time might be longer, which could result in hitting the other vehicle, road user, or object at a higher rate of speed.

Table 98. Two-way street signalized intersection severity distribution based on lighting presence.

Lighting	Crash Severity		
	K+A	B	C
Not present	5.8%	25.6%	68.6%
Present	5.2%	24.5%	70.3%

ONE-WAY STREET SIGNALIZED INTERSECTIONS

The database included 2,056 FI crashes reported in California, Illinois, Michigan, and Texas. Initially, a model was developed to predict the proportion of crashes in each severity category (i.e., K, A, B, and C). However, due to a small number of reported fatal crashes, the model provided unreliable and insignificant estimates. Thus, the FI crashes were combined into one category during the final model calibration. The results of crash severity models are summarized in Table 99 for one-way street signalized intersections. Although many variables were considered, the results presented in Table 99 show the variables that are significant in influencing crash severities. 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 99 are logical and consistent with previous research findings.

Table 99. Crash SDF: one-way street signalized intersections.

Variable	Fatality (K)+ Incapacitating Injury (A)		Non-incapacitating Injury (B)	
	Coefficient	t-value	Coefficient	t-value
Alternative specific constant	−2.0416	−10.74	−0.7406	−6.27
Area type (1=urban, 0=suburban)	−0.4074	−1.94	−0.0992	−0.85
Presence of major-street left lanes (1=present, 0=absent)	−0.2956	−1.20	−0.2551	−1.97
Channelization on major street (1=present, 0=absent)			0.5566	3.09
Channelization on minor street (1=present, 0=absent)	−0.3057	−0.97	−0.5040	−2.79
Added effect of Michigan (1=Michigan, 0=other)	−0.4251	−3.31	−0.4251	−3.31
Added effect of Illinois (1=Illinois, 0=other)	0.5425	2.28	0.5425	2.28
Observations	2056 crashes (K=5; A=104; B=530; C=1417)			

Note: Possible injury is the base scenario, with coefficients restricted at zero. Shaded cell means coefficient is highly insignificant.

In addition to the variables included in the calibrated model, there may be differences between states, such as weather and driver behavior, that were not included in the model. The definition of a reportable crash also varied per state. Thus, an indicator variable for each state was included in the calibrated model to account for the overall differences between the states, which could not be explained with the variables included in the model. However, the coefficient for California was very small and not statistically significant. This finding suggests that the state effects are very similar between Texas and California. The California indicator variable was removed as a result.

The coefficients for Michigan and Illinois were relatively large and statistically significant. The negative sign of the coefficient for Michigan indicates that a crash at one-way street signalized intersections in Michigan is less likely to be classified as severe than a similar crash in Texas or California, when all other variables are controlled. However, a similar crash in Illinois is likely to be categorized as severe than in Texas or California. This difference may be explained by different highway design practices (e.g., use of different roadside design features, etc.), terrain, weather pattern, driver behavior, and reporting accuracy for the various states.

The coefficients in Table 99 were combined with Equation 225 to obtain the deterministic component of each crash severity level for crashes at two-way street intersections. The form of each model is described by Equations 241 and 242.

$$V_{K+A} = -2.0416 + (-0.4074 \times I_{urban}) + (-0.2956 \times I_{lt}) + (0.000 \times I_{mjch}) + (-0.3057 \times I_{mnch}) \quad (241)$$

$$V_B = -0.7406 + (-0.0992 \times I_{urban}) + (-0.2551 \times I_{lt}) + (0.5566 \times I_{mjch}) + (-0.5040 \times I_{mnch}) \quad (242)$$

where,

I_{urban} = area type indicator variable (= 1.0 if urban, 0.0 if suburban).
I_{lt} = presence of exclusive left-turn lane on the major-street indicator variable (= 1.0 if present, 0.0 if absent).
I_{mjch} = presence of right-turn channelization on the major-street indicator variable (= 1.0 if present, 0.0 if absent).
I_{mnch} = presence of right-turn channelization on the minor-street indicator variable (= 1.0 if present, 0.0 if absent).

The probability of each severity level is obtained by combining Equations 241 and 242 with Equations 231–233.

Predicted Probabilities

The subsections below provide the influence of variables on crash severities at one-way signalized intersections.

Area Type

The sites considered in the project were located in both urban and suburban areas. About 66 percent of the crashes occurred at intersections in urban areas. The relationship between area type and severity level is shown in Table 100. The negative value of the associated coefficient (in Table 99) indicates that a crash in an urban area is likely to be less severe than a crash in a suburban area, when all other variables are controlled. The percentages in Table 100 indicate that the likelihood of fatal and severe injury crashes (i.e., K, A, and B) changes from 29.6 percent in urban areas to 32.9 percent in suburban areas. The trend with area type can be attributed to higher operating speeds in suburban areas. A crash that occurs at a higher speed typically has higher severity than a crash at a lower speed.

Table 100. One-way street signalized intersection severity distribution based on area type.

Area Type	Crash Severity		
	K+A	**B**	**C**
Urban	4.6%	25.0%	70.4%
Suburban	6.6%	26.3%	67.1%

Left-Turn Lane

The left-turn lane variable indicates the presence of left-turn lanes on the major street. It should be noted that the left-turn lane is possible on one approach only because the major street always serves one-way traffic. About 44 percent of crashes occurred at intersections with a left-turn lane on the major street. The negative sign for the left-turn lane variable in Table 99 indicates that the chance of high severity crashes decreases when a left-turn lane is present. Table 101 suggests that the probability of fatal and severe injury crashes decreases from 33.2 percent when a left-turn lane is not present to 27.7 percent when one is present. Providing a left-turn lane helps maintain free flow of the through traffic and thus reduces the chance of rear-end crashes at higher speeds.

Table 101. One-way street signalized intersection severity distribution based on major-street left-turn lane.

Left-Turn Lane on Major Street	Crash Severity		
	K+A	**B**	**C**
Not present	5.7%	27.5%	66.8%
Present	4.6%	23.1%	72.3%

Channelization

The channelization variable indicates the presence of right-turn channelization at an intersection. Separate variables representing channelization on major and minor streets were included in the calibrated model. About 20 percent of intersections where crashes occurred had right-turn channelization on the major street. Similarly, 22 percent of intersections had right-turn channelization on the minor street. The negative sign for the right-turn channelization variable on the minor street in Table 99 indicates that the chance of high severity crashes decreases when channelization is present. In contrast, the positive sign for major-street channelization indicates that the chance of non-incapacitating injury crashes increases when channelization is present. The coefficient for fatal and incapacitating injury was very small and not statistically significant. Even though insignificant, there will be a small change in fatal and incapacitating injury crash proportion because the sum of all crash severity proportions must equal 1. Table 102 suggests that the probability of fatal and severe injury crashes decreases from 33 percent when right-turn channelization on the minor street is not present to 23.5 percent when it is present. At the same time, the presence of channelization on the major street increases the likelihood of non-incapacitating injury from 23.4 percent to 34.8 percent.

Table 102. One-way street signalized intersection severity distribution based on channelization.

Street	Channelization	Crash Severity		
		K+A	B	C
Minor	Not present	5.4%	27.6%	67.0%
	Present	4.5%	19.0%	76.4%
Major	Not present	5.3%	23.4%	71.2%
	Present	4.5%	34.8%	60.7%

STOP-CONTROLLED INTERSECTIONS

The database included 503 FI crashes reported in California, Illinois, Michigan, and Texas. Initially, a model was developed to predict the proportion of crashes in each severity category (i.e., K, A, B, and C). However, due to a small number of reported fatal crashes, the model provided unreliable and insignificant estimates. Thus, the fatal and incapacitating injury crashes were combined into one category during the final model calibration. The results of crash severity models are summarized in Table 103 for stop-controlled intersections. Although many variables were considered, the results presented in Table 103 show the variables that are significant in influencing crash severities. 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 103 are logical and consistent with previous research findings.

Table 103. Crash SDF: stop-controlled intersections.

Variable	Fatality (K)+ Incapacitating Injury (A)		Non-incapacitating Injury (B)	
	Coefficient	t-value	Coefficient	t-value
Alternative specific constant	−1.1062	−2.46	−0.3610	−1.02
Area type (1=urban, 0=suburban)	−0.3823	−1.16	−0.2775	−1.34
Lighting presence (1=present, 0=absent)	−0.9178	−1.88	−0.3972	−1.07
Presence of minor-street left lanes (1=present, 0=absent)			−0.4343	−0.91
Added effect of Illinois (1=Illinois, 0=other)	0.8174	4.13	0.8174	4.13
Observations	503 crashes (K=2; A=45; B=161; C=295)			

Note: Possible injury is the base scenario, with coefficients restricted at zero. Shaded cell means coefficient is highly insignificant.

In addition to the variables included in the calibrated model, there may be differences between states, such as weather and driver behavior, that were not included in the model. The definition of a reportable crash also varied per state. Thus, an indicator variable for each state was included in the calibrated model to account for the overall differences between the states, which could not be explained with the variables included in the model. However, the coefficients for Michigan and California were very small and not statistically significant. This finding suggests that the state effects are very similar among Texas, Michigan, and California. The Michigan and California indicator variables were removed as a result.

The coefficient for Illinois was relatively large and statistically significant. Its positive sign in Table 103 indicates that a crash at stop-controlled intersections in Illinois is likely to be more severe than a crash in Texas, Michigan, or California, when all other variables are controlled. This difference may be explained by different highway design practices (e.g., use of different roadside design features, etc.), terrain, weather pattern, driver behavior, and reporting accuracy for the various states.

The coefficients in Table 103 were combined with Equation 225 to obtain the deterministic component of each crash severity level for crashes at stop-controlled intersections. The form of each model is described by Equations 243 and 244.

$$V_{K+A} = -1.1062 + (-0.3823 \times I_{urban}) + (-0.9178 \times I_{light}) + (0.0000 \times I_{ltmn}) \quad (243)$$

$$V_{B} = -0.3610 + (-0.2775 \times I_{urban}) + (-0.3972 \times I_{light}) + (-0.4343 \times I_{ltmn}) \quad (244)$$

where,

I_{urban} = area type indicator variable (= 1.0 if urban, 0.0 if suburban).

I_{light} = lighting presence indicator variable (= 1.0 if present, 0.0 otherwise).

I_{ltmn} = presence of exclusive left-turn lanes on the minor-street indicator variable (= 1.0 if present, 0.0 if absent).

The probability of each severity level is obtained by combining Equations 243 and 244 with Equations 231–233.

Predicted Probabilities

The subsections below provide the influence of variables on crash severities at stop-controlled intersections.

Area Type

The sites considered in the project were located in both urban and suburban areas. About 48 percent of the crashes occurred at intersections in urban areas. The relationship between area type and severity level is shown in Table 104. The negative value of the associated coefficient (in Table 103) indicates that a crash in an urban area is likely to be less severe than a crash in a suburban area, when all other variables are controlled. The percentages in Table 104 indicate that the likelihood of fatal and severe injury crashes (i.e., K, A, and B) changes from 37.2 percent in urban areas to 44.5 percent in suburban areas. The trend with area type can be attributed to higher operating speeds in suburban areas. A crash that occurs at a higher speed typically has higher severity than a crash at a lower speed.

Table 104. Stop-controlled intersection severity distribution based on area type.

Area Type	Crash Severity		
	K+A	B	C
Urban	7.9%	29.3%	62.8%
Suburban	10.3%	34.2%	55.5%

Lighting

About 92 percent of intersections where crashes occurred had the presence of lighting. The relationship between lighting presence and severity level is shown in Table 105. The negative value of the associated coefficient (in Table 103) indicates that a crash occurring at a lighted intersection is likely to be less severe than a crash at an unlighted intersection, when all other variables are controlled. The percentages in Table 105 indicate that the fatal and severe injury crash percentage at an unlighted intersection is 53.2 percent, and it is 40.0 percent when lighting is present. At unlighted intersections, a driver's perception might be obscured and reaction time might be longer, which could result in hitting the other vehicle, road user, or object at a higher rate of speed.

Table 105. Stop-controlled intersection severity distribution based on lighting presence.

Lighting	Crash Severity		
	K+A	B	C
Not present	16.8%	36.4%	46.8%
Present	8.6%	31.4%	60.0%

Left-Turn Lanes

The left-turn lane variable indicates the presence of a left-turn lane on one or both approaches of the minor street. Only about 5 percent of intersections where crashes occurred had left-turn lane presence on the minor street. The negative sign of the associated coefficient (in Table 103) indicates that the chance of non-incapacitating injury crashes decreases when a left-turn lane is present. The coefficient for fatal and incapacitating injury was very small and not statistically significant. Even though insignificant, there will be a small change in fatal and incapacitating injury crash proportion because the sum of all crash severity proportions must equal 1. Table 106 suggests that the probability of non-incapacitating injury crashes decreases from 32.3 percent when a left-turn lane is not present to 23.6 percent when one is present.

Table 106. Stop-controlled intersection severity distribution based on minor-street left-turn lane.

Left-Turn Lane on Minor Street	Crash Severity		
	K+A	B	C
Not present	9.0%	32.3%	58.7%
Present	10.2%	23.6%	66.2%

CHAPTER 10. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The following summary and conclusions have been developed based on the research conducted for this project:

- Crash and roadway data from California and Illinois were obtained from the HSIS, while data from Texas, Michigan, and Oregon were obtained directly from the state highway agencies. Data for the five states were combined for model calibration and the development of CMFs. These data were enriched through the inclusion of additional road inventory data extracted from Google Earth and Street View. The enhanced database was then combined with the crash data to form the highway safety database needed for model and CMF development and calibration.
- Since pedestrian exposure data were not available in the electronic databases that were assembled for this project, on-site data collection activities were done to supplement the data already collected. A sample of 40 intersections in California and 24 intersections in San Antonio, Texas, were therefore selected for data collection for the pedestrian evaluation. The data for pedestrians were used to assess and recalibrate the existing predictive method for estimating pedestrian safety in HSM Chapter 12.
- SPFs and CMFs were estimated for the following four types of two-way and three types of one-way roadway segments on urban and suburban arterials:
    - Six-lane two-way undivided arterials (6U).
    - Six-lane two-way divided arterials (i.e., including a raised or depressed median) (6D).
    - Seven-lane two-way arterials including a center TWLTL (7T).
    - Eight-lane two-way divided arterials (i.e., including a raised or depressed median) (8D).
    - Two-lane one-way arterials (2O).
    - Three-lane one-way arterials (3O).
    - Four-lane one-way arterials (4O).
- SPFs and CMFs were estimated for the following intersection types for both two-way street intersections and one-way street intersections on urban and suburban arterials:
    - Three-leg intersections with stop control on the minor-road approach (3ST).
    - Three-leg signalized intersections (3SG).
    - Four-leg intersections with stop control on the minor-road approaches (4ST).
    - Four-leg signalized intersections (4SG).
- The intersections were separated by the type of operational characteristics of each leg: two-way (x2), or one-way (x1). Hence, the models and CMFs were estimated for 12 different intersection types: 2×2, 1×2, and 1×1 for all four categories of intersections.
- A safety prediction method for six-or-more-lane and one-way urban and suburban arterials as well as intersections located on these facilities that is suitable for incorporation in the HSM was documented. It included CMFs that describe the observed relationship between crash frequency and on-street parking, roadside fixed objects, median width, lighting, automated speed enforcement, lane width, outside shoulder width, rail-highway crossing, median barriers, major industrial driveways, major

commercial driveways, minor driveways, and right shoulder width for six-or-more-lane and one-way segments. For intersections, the CMFs influencing crash counts included those related to intersection left-turn lanes, intersection left-turn signal phasing, intersection right-turn lanes, right turn on red, lighting, red-light cameras, number of lanes, intersection right-turn channelization, and U-turn prohibition. Finally, the CMFs influencing vehicle-pedestrian crashes included those associated with bus stops, schools, and alcohol sales establishments.
- A safety prediction method for estimating the proportion of crashes by severity levels was also documented. The SDFs are available for urban and suburban six-or-more-lane arterials; one-way streets; 2×2 signalized intersections with six or more lanes; 1×2 and 1×1 signalized intersections; and 2×2 (with six or more lanes), 1×2, and 1×1 stop-controlled intersections. Various factors influence the severity of collisions. They include lane width, right shoulder width, the presence of an exclusive left-turn lane on the major road, the presence of right-turn channelization on the major road, the presence of right-turn channelization on the minor road, and street lighting, among others.

The following recommendations have been developed based on the research conducted for this project:

- Although not very common, facilities such as eight-lane undivided, eight-lane with two-way left-turn lane, and 10-lane divided arterials do exist. Predictive models could not be estimated for these facilities due to the small sample size. Further research may be needed to include such facilities in safety prediction methodologies.
- Similarly, a small number of one-way segments with one lane or five lanes do exist. Similar to the previous point, the sample size was too small. Hence, additional research is needed to include such facilities in safety prediction methodologies.
- Frontage roads mostly serve one-way traffic. One-way frontage roads were included in this research for developing models for 1×2/1×1 intersections. However, the safety performance of these intersections may differ from a typical one-way street intersection. Additional research is needed to quantify the difference.
- Since speed limits are higher in suburban areas, the geometric variables may have a different effect in suburban areas than in urban areas. Although the SDFs capture the overall safety performance difference, more research is needed to capture the performance of each geometric feature by area type. This is applicable to the proposed new material for HSM Chapter 12 as well as the existing HSM Chapter 12 material.

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Draft Version of the Revised HSM Chapter 12—Predictive Method for Urban and Suburban Arterials

12.1. INTRODUCTION

This chapter presents the predictive method for urban and suburban arterial facilities. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in the Part C---Introduction and Applications Guidance.

The predictive method for urban or suburban arterial facilities provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for facilities with known characteristics. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the Safety Performance Functions (SPFs) in Chapter 12 is documented by Harwood et al.(8) (9), and Lord et al. (11). The Crash Modification Factors (CMFs) used in this chapter have been reviewed and updated by Harkey et al. (6) and in related work by Srinivasan et al. (14) and Lord et al. (11). The SPF coefficients, default collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (15) and Lord et al. (11).

This chapter presents the following information about the predictive method for urban and suburban arterial facilities:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 12, and site types for which predictive models have been developed for Chapter 12.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing an urban or suburban arterial facility into individual sites, consisting of intersections and roadway segments.
- SPFs for urban and suburban arterials. Note that the SPFs are grouped separately for arterials with five or fewer lanes and either arterials with six or more lanes or one-way arterials, since they were developed under two different projects.
- CMFs applicable to the SPFs in Chapter 12.
- Guidance for applying the Chapter 12 predictive method, and limitations of the predictive method specific to Chapter 12.
- Sample problems illustrating the application of the Chapter 12 predictive method for urban and suburban arterials.

12.2 OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the "expected average crash frequency," $N_{expected}$ (by total crashes, crash severity, or collision type) of a roadway network, facility, or site. In the predictive method, the roadway is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments referred to as "sites." Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type, a number of different site types may exist, such as divided and undivided roadway segments and signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities.

The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The estimate relies on estimates made using predictive models which may be combined with observed crash data using the Empirical Bayes (EB) Method.

The predictive models used within Chapter 12 predictive method are described in detail in Section 12.3.

The predictive models used in Chapter 12 to predict average crash frequency, $N_{predicted}$, are of the general form shown in Equations 12-1 and 12-2.

$$N_{\text{predicted } x} = \left(\sum_{z} N_{bxz} + N_{pedx} + N_{bikex}\right) \times C_x \tag{12-1}$$

$$N_{bxz} = N_{spf\,x\,z} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \tag{12-2}$$

Where:

$N_{\text{predicted } x}$ = predicted average crash frequency for a specific year for site type x;

N_{bxz} = predicted average crash frequency of collision type z (multiple-vehicle, single-vehicle, or driveway-related) per year for site type x;

N_{pedx} = predicted average crash frequency of vehicle-pedestrian collisions per year for site type x;

N_{bikex} = predicted average crash frequency of vehicle-bicycle collisions per year for site type x;

C_x = calibration factor to adjust SPF for local conditions for site type x;

$N_{spf\,x\,z}$ = predicted average crash frequency of collision type z (multiple-vehicle, single-vehicle, or driveway-related) per year for site type x for base conditions; and

CMF_{yx} = crash modification factors specific to site type x and specific geometric design or traffic control feature y.

The predictive models in Chapter 12 provide estimates of the crash severity and collision type distributions for roadway segments and intersections. The SPFs in Chapter 12 address two general crash severity levels: fatal-and-injury (FI) and property-damage-only (PDO) crashes. FI crashes include crashes involving all levels of injury severity including fatalities, incapacitating injuries, nonincapacitating injuries, and possible injuries. The relative proportions of crashes for the two severity levels are determined from separate SPFs for each severity level. For arterials with five or fewer lanes, the default estimates of the crash severity and crash type distributions are both provided with the SPFs for roadway segments and intersections in Section 12.6. For arterials with six or more lanes and one-way arterials, the default estimates of the crash type distributions are provided with the SPFs for roadway segments and intersections in Section 12.6 whereas the default estimates of the crash severity distributions are determined via the severity distribution functions (SDFs) provided in Section 12.8.

12.3 URBAN AND SUBURBAN ARTERIALS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 12

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 12. These predictive models are applied following the steps of the predictive method presented in Section 12.4

12.3.1. Definition of Chapter 12 Facility Types

The predictive method in Chapter 12 addresses the following urban and suburban arterial facilities: two-, four- and six-lane undivided facilities, four-, six- and eight-lane divided facilities, three-, five- and seven-lane facilities with a center two-way left-turn lane (TWLTL), and one-way arterials with two, three and four lanes. Divided arterials are nonfreeway facilities (i.e., facilities without full control of access) that have lanes in the two directions of travel separated by a raised or depressed median. Such facilities may have occasional grade-separated interchanges, but these are not the primary form of access. The predictive models do not apply to any section of an arterial within the limits of an interchange which has free-flow ramp terminals on the arterial of interest. Arterials with a flush separator (i.e., a painted median) between the lanes in the two directions of travel are considered undivided facilities, not divided facilities. Separate prediction models are provided for arterials with flush separator that serves as a center two-way left-turn lane.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all urban and suburban arterials independent of official state or local highway designation.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas is based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas where the population is less than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area. The term “arterial” refers to facilities that meet the FHWA definition of “roads serving major traffic movements (high-speed, high volume) for travel between major points” (5).

Table 12-1 identifies the specific site types on urban and suburban arterial highways that have predictive models. For roadway segments with five or fewer lanes, separate SPFs are used for each individual site to predict multiple-vehicle nondriveway collisions, driveway-related collisions, single-vehicle collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions. A similar set of SPFs is used for roadway segments with six or more lanes and one-way roadway segments, except that multiple-vehicle nondriveway collisions and driveway-related collisions are combined with a single SPF for all multiple-vehicle collisions (nondriveway or driveway-related). For intersections of arterial highways with five or fewer lanes, separate SPFs are used for each individual site to predict multiple-vehicle collisions, single-vehicle collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions. A similar set of SPFs is used for intersections of arterials with six or more lanes and intersections of one-way arterials, except that multiple-vehicle and single-vehicle collisions are combined with a single SPF for all multiple- or single-vehicle collisions. The predictions from SPFs are combined to predict the total average crash frequency at an individual site.

Table 12-1. Urban and Suburban Arterial Site Type SPFs included in Chapter 12

Site Type	Site Types with SPFs in Chapter 12
Roadway Segments	Two-lane undivided arterials (2U)
	Three-lane arterials including a center TWLTL (3T)
	Four-lane undivided arterials (4U)
	Four-lane divided arterials (including a raised or depressed median) (4D)
	Five-lane arterials including a center TWLTL (5T)
	Six-lane undivided arterials (6U)
	Six-lane divided arterials (including a raised or depressed median) (6D)
	Seven-lane arterials including a center TWLTL (7T)
	Eight-lane divided arterials (including a raised or depressed median) (8D)
	Two-lane one-way arterials (2O)
	Three-lane one-way arterials (3O)
	Four-lane one-way arterials (4O)
Intersections	Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST)
	Signalized three-leg intersection (3SG)
	Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST)
	Signalized four-leg intersection (4SG)

These specific site types are defined as follows:

- *Two-lane undivided arterial (2U)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Three-lane arterials including a center TWLTL (3T)*—a roadway consisting of three lanes with a continuous cross-section providing two directions of travel in which center lane is a TWLTL.
- *Four-lane undivided arterials (4U)*—a roadway consisting of four lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Four-lane divided arterials (including a raised or depressed median) (4D)*—a roadway consisting of four lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Five-lane arterials including a center TWLTL (5T)*—a roadway consisting of five lanes with a continuous cross-section providing two directions of travel in which the center lane is a TWLTL.
- *Six-lane undivided arterial (6U)*—a roadway consisting of six lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Six-lane divided arterials (including a raised or depressed median) (6D)*—a roadway consisting of six lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Seven-lane arterials including a center TWLTL (7T)*—a roadway consisting of seven lanes with a continuous cross-section providing two directions of travel in which the center lane is a TWLTL.
- *Eight-lane divided arterials (including a raised or depressed median) (8D)*—a roadway consisting of eight lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Two-lane one-way arterial (2O)*—a roadway consisting of two lanes with a continuous cross-section providing one direction of travel in which the lanes are not physically separated by either distance or a barrier.

- *Three-lane one-way arterial (3O)*—a roadway consisting of three lanes with a continuous cross-section providing one direction of travel in which the lanes are not physically separated by either distance or a barrier.
- *Four-lane one-way arterial (4O)*—a roadway consisting of four lanes with a continuous cross-section providing one direction of travel in which the lanes are not physically separated by either distance or a barrier.
- *Three-leg intersection with stop control (3ST)*—an intersection of an urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection only.
- *Three-leg signalized intersection (3SG)*—an intersection of an urban or suburban arterial and one minor road. Signalized control is provided at the intersection by traffic signalss.
- *Four-leg intersection with stop control (4ST)*—an intersection of an urban or suburban arterial and two minor roads. A stop sign is provided on both the minor road approaches to the intersection.
- *Four-leg signalized intersection (4SG)*—an intersection of an urban or suburban arterial and two minor roads. Signalized control is provided at the intersection by traffic signals.

12.3.2. Predictive Models for Urban and Suburban Arterial Roadway Segments

The predictive models can be used to estimate total average crashes (i.e., all crash severities and collision types) or can be used to predict average frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines the SPFs, CMFs, and a calibration factor. Chapter 12 contains separate predictive models for roadway segments and for intersections.

The predictive models for roadway segments estimate the predicted average frequency of crashes occurring outside the limits of intersections that are non-intersection-related. The roadway segment predictive models estimate crashes that would occur regardless of the presence of the intersection.

The predictive models for roadway segments are presented in Equations 12-3 and 12-4.

$$N_{\text{predicted}\ rs} = C_r \times (N_{br} + N_{pedr} + N_{biker}) \tag{12-3}$$

$$N_{br} = N_{brmv} + N_{brsv} \tag{12-4}$$

Where:

$N_{\text{predicted}\ rs}$ = predicted average crash frequency of an individual roadway segment for the selected year;

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions);

N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment;

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment;

N_{brmv} = predicted average crash frequency of multiple-vehicle collisions for an individual roadway segment;

N_{brsv} = predicted average crash frequency of single-vehicle crashes for an individual roadway segment; and

C_r = calibration factor for roadway segments of a specific type developed for use for a particular geographical area.

Equation 12-3 shows that roadway segment crash frequency is estimated as the sum of three components: N_{br}, N_{pedr}, and N_{biker}. Equation 12-3 shows that N_{br} is further separated into two components by collision type: multiple-vehicle collisions and single-vehicle crashes. Only for arterial roadway segments with five or fewer lanes, multiple-vehicle collisions, N_{brmv}, are further separated into two components as shown in Equation12-5. For two-way arterial roadway segments with six or more lanes or one-way arterial segments, driveway-related and nondriveway collisions are combined.

$$N_{brmv} = N_{brnondwy} + N_{brdwy} \tag{12-5}$$

Where:

$N_{brnondwy}$ = predicted average crash frequency of multiple-vehicle nondriveway collisions for an individual roadway segment; and

N_{brdwy} = predicted average crash frequency of multiple-vehicle driveway-related collisions for an individual roadway segment.

The components of N_{br} are noted as N_{brz} where z indicates the collision type: "mv" for multiple-vehicle collisions, "sv" for single-vehicle collisions, "nondwy" for multiple-vehicle nondriveway collisions, and "dwy" for multiple-vehicle driveway-related collisions. The predictive models used to predict each component of N_{br} are of the general form shown in Equation 12-6.

$$N_{brz} = N_{spf\,rs\,z} \times (CMF_{1r} \times CMF_{2r} \times ... \times CMF_{nr}) \tag{12-6}$$

Where:

N_{brz} = predicted average crash frequency of collision type z ($z = mv$, sv, $nondwy$, or dwy) for an individual roadway segment;

$N_{spf\,rs\,z}$ = predicted average crash frequency of collision type z ($z = mv$, sv, $nondwy$, or dwy) for an individual roadway segment for base conditions; and

$CMF_{1r}...CMF_{nr}$ = crash modification factors for roadway segments.

Some of the CMFs in Equation 12-6 only apply to specitic categories of roadway segments (two-way roadway segments with 5 or fewer lanes, two-way roadway segments with 6 or more lanes, and one-way roadway segments). Also, some CMFs only apply to a particular collision type (i.e., multiple-vehicle or single-vehicle). Therefore, there is a distinct set of applicable CMFs for each category of roadway segments and collision type. The detailed information regarding the application of each CMF is presented in Section 12-7.

Thus, the SPFs, adjustment factors, and CMFs are applied to determine the components of the total average crash frequency: N_{brmv} (sum of $N_{brnondwy}$ and N_{brdwy} for roadway segments with five or fewer lanes), N_{brsv}, N_{pedr}, and N_{biker}, which together provide a prediction of total average crash frequency for a roadway segment.

Equation 12-3 through 12-6 are applied to estimate roadway segment crash frequencies for all crash severity levels combined (i.e., total crashes) or for FI or PDO crashes.

12.3.3. Predictive Models for Urban and Suburban Arterials Intersections

The predictive models for intersections estimate the predicted total average crash frequency for crashes that occur within the limits of an intersection and those that occur on the intersection legs that are intersection-related (i.e., occurring as a result of the presence of the intersection). The predictive model for intersections is presented in Equation 12-7.

$$N_{\text{predicted}\,int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \tag{12-7}$$

Where:

$N_{\text{predicted } int}$ = 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 individual intersection;

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

C_i = calibration factor for intersections developed for use for a particular geographical area.

Equation 12-7 shows that the intersection crash frequency is estimated as the sum of three components: N_{bi}, N_{pedi}, and N_{bikei}. Only for intersections with five or fewer lanes (on all intersection legs), N_{bi} is further separated into two components by collision type shown in Equation 12-8.

$$N_{bi} = N_{bimv} + N_{bisv} \tag{12-8}$$

Where:

N_{bimv} = predicted average crash frequency of multiple-vehicle collisions for an individual intersection; and

N_{bisv} = predicted average crash frequency of single-vehicle crashes for an individual intersection.

The predictive models used to predict N_{bi} or its components N_{bimv} and N_{bisv} (for intersections of two-way arterials with five or fewer lanes) are of the general form shown in Equation 12-9.

$$N_{biz} = N_{spf\ \text{int}\ z} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{ni}) \tag{12-9}$$

Where:

N_{brz} = predicted average crash frequency of collision type z ($z = mv$ or sv for intersections of two-way arterials with five or fewer lanes) for an individual intersection;

$N_{spf\ int\ z}$ = predicted average crash frequency of collision type z ($z = mv$ or sv for intersections of two-way arterials with five or fewer lanes) for an individual intersection for base conditions; and

$CMF_{1i} \ldots CMF_{ni}$ = crash modification factors for intersections.

Some of the CMFs in Equation 12-9 only apply to certain categories of intersections (intersections of two-way arterials with five or fewer lanes, intersections of two-way arterials with six or more lanes, or intersections of one-way arterials). The CMFs shown in Equation 12-9 do not apply to vehicle-pedestrian and vehicle-bicycle collisions. A separate set of CMFs that apply to vehicle-pedestrian collisions at signalized intersections is presented in Section 12.7.3. The detailed information regarding the application of each CMF is presented in Section 12-7.

Thus, the SPFs and adjustment factors are applied to determine the components of the total average crash frequency: N_{bi} (sum of N_{bimv} and N_{bisv} for intersections of arterials with five or fewer lanes), N_{pedi}, and N_{bikei}, which together provide a prediction of total average crash frequency for an intersection.

Equation 12-7 through 12-9 are applied to estimate intersection crash frequencies for all crash severity levels combined (i.e., total crashes) or for FI or PDO crashes.

The SPFs for urban and suburban arterial highways are presented in Section 12.6. The associated CMFs for each of the SPFs are presented in Section 12.7 and summarized in Table 12-31. Only specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors, C_r, and C_i, can be determined using the procedures in Part C, Appendix A.1.1. Due to continual change in the crash frequency and severity distributions with time, the value of the calibration factors may change for the selected year of the study period.

12.4. PREDICTIVE METHOD STEPS FOR URBAN AND SUBURBAN ARTERIALS

The predictive method for urban and suburban arterials is shown in Figure 12-1. Applying the predictive method yields an estimate of the expected average crash frequency and distribution of crash severity and collision type for an urban or suburban arterial facility. The components of the predictive models in Chapter 12 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Part C, Appendix A. In some situations, certain steps will not require any action. For example, a new facility will not have observed crash data and therefore steps relating to the EB Method require no action.

There are 18 steps in the predictive method. In some situations, certain steps will not be needed because data are not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario, or proposed treatment option (within the same period to allow for comparison).

The following explains the details of each step of the method as applied to urban and suburban arterials.

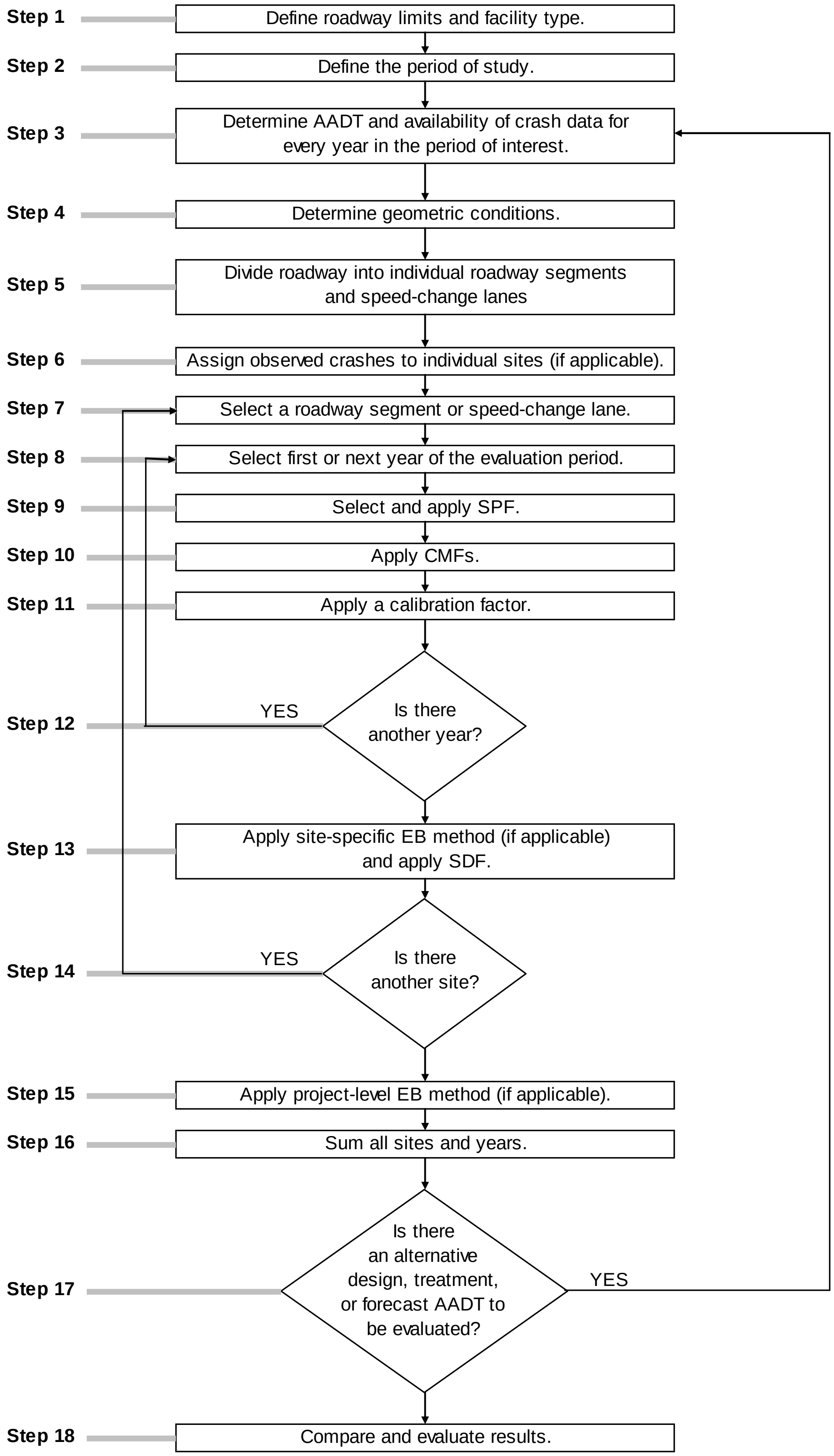

Figure 12-1. The HSM Predictive Method

Step 1—Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated.
The predictive method can be undertaken for a roadway network, a facility, or an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and unsignalized intersections. The definitions of urban and suburban arterials, intersections, and roadway segments and the specific site types included in Chapter 12 are provided in Section 12.3.

The predictive method can be undertaken for an existing roadway, a design alternative for an existing roadway or a new roadway (which may be either unconstructed or yet to experience enough traffic to have observed crash data).

The limits of the roadway of interest will depend on the nature of the study. The study may be limited to only one specific site or group of contiguous sites. Alternatively, the predictive method can be applied to a very long corridor for the purpose of network screening which is discussed in Chapter 4.

Step 2—Define the period of interest.
The predictive method can be undertaken for either a past period or a future period. All periods are measured in years. Years of interest will be determined by the availability of observed or forecast average annual daily traffic (AADT) volumes, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

- A past period (based on observed AADTs) for:
  - An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features and traffic volumes are known.
  - An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).
- A future period (based on forecast AADTs) for:
  - An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
  - An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
  - A new roadway network, facility, or site that does not currently exist but is proposed for construction during some future period.

Step 3—For the study period, determine the availability of AADT, pedestrian crossing volumes, and, for an existing roadway network, the availability of observed crash data (to determine whether the EB Method is applicable).

Determining Traffic Volumes
The SPFs used in Step 9 include AADT volumes (vehicles per day) as a variable. For a past period, the AADT may be determined by an automated recording or estimated by a sample survey. For a future period, the AADT may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models or based on the assumption that current traffic volumes will remain relatively constant.

For each roadway segment, the AADT is the average daily two-way 24-hour traffic volume on that roadway segment in each year of the period to be evaluated selected in Step 8.

For each intersection, the two-way AADT of both intersecting roads are required in each predictive model. The two intersecting roads are designated as major and minor as follows: if both of the intersecting roads have two-way or one-way traffic, the major and minor roads are defined as the road with the higher and lower AADT, respectively. However, if one of the intersecting roads has two-way traffic and the other has one-way traffic, the major road is defined as the one-way road (and the minor road as the two-way road) regardless of the AADTs. The AADT of the major and minor roads are denoted as $AADT_{maj}$ and $AADT_{min}$, respectively.

For intersections of two-way arterials with five or fewer lanes, if the AADTs on the two legs of an intersecting road differ, the larger of the two AADT values is used. For intersections of two-way arterials with six or more lanes and intersections of one-way arterials, if the AADTs on the two legs of an intersecting road differ, the average of the two AADT values is used.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated, as appropriate. If there is not an established procedure for doing this, the following may be applied within the predictive method to estimate the AADTs for years for which data are not available.

- If AADT data are available for only a single year, that same value is assumed to apply to all years of the before period.
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation.
- The AADTs for years before the first year for which data are available are assumed to be equal to the AADT for the first year.
- The AADTs for years after the last year for which data are available are assumed to be equal to the last year.

If the EB Method is used (discussed below), AADT data are needed for each year of the period for which observed crash frequency data are available. If the EB Method will not be used, AADT data for the appropriate time period—past, present, or future—determined in Step 2 are used.

For signalized intersections, the pedestrian volumes crossing each intersection leg are determined for each year of the period to be evaluated. The pedestrian crossing volumes for each leg of the intersection are then summed to determine the total pedestrian crossing volume for the intersection. Where pedestrian volume counts are not available, they may be estimated using the guidance presented in Table 12-28. Where pedestrian volume counts are not available for each year, they may be interpolated or extrapolated in the same manner as explained above for AADT data.

Determining Availability of Observed Crash Data

Where an existing site or alternative conditions for an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable observed crash data are available for the specific study roadway network, facility, or site. Observed data may be obtained directly from the jurisdiction's crash report system. At least two years of observed crash frequency data are desirable to apply the EB Method. The EB Method and criteria to determine whether the EB Method is applicable are presented in Part C, Appendix A.2.1.

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but cannot be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash frequency data are not available, then Steps 6, 13, and 15 of the predictive method are not conducted. In this case the estimate of expected average crash frequency is limited to using a predictive model (i.e., the predictive average crash frequency).

Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the study network.

The following geometric design and traffic control features are used to apply the SPFs and CMFs in Step 9 and Step 10 and estimate the expected average crash frequency of roadway segments and intersections:

<u>*For Two-Way Arterials with Five or Fewer Lanes*</u>

- Length of roadway segment (miles)

- AADT (vehicles per day)
- Number of through lanes
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
- Width of median, if present (feet)
- Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of the street)
- Number of driveways for each driveway type (major commercial, minor commercial; major industrial/institutional; minor industrial/institutional; major residential; minor residential; other)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Presence/absence of roadway lighting
- Speed category (based on actual traffic speed or posted speed limit)
- Presence of automated speed enforcement

For Two-Way Arterials with Six or More Lanes

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Number of through lanes
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
- Widths of traffic lanes, outside shoulders and median, (if present (feet)
- Presence of median barriers
- Density of railroad crossing (crossing/mile)
- Driveway density for the following driveway types: major commercial, major industrial/institutional, and all minor driveways (for any land use)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Speed category (based on actual traffic speed or posted speed limit)
- Presence of automated speed enforcement

For One-Way Arterials

- Length of roadway segment (miles)

- AADT (vehicles per day)
- Number of through lanes
- Width of right shoulder (feet)
- Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of the street)
- Driveway density for the following driveway types: major commercial, and all minor driveways (of any type)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Speed category (based on actual traffic speed or posted speed limit)
- Presence of automated speed enforcement

For Intersections of Two-Way Arterials with Five or Fewer Lanes

For all intersections within the study area, the following geometric and traffic control features are identified:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road stop or signal)
- AADT of each intersecting road
- Number of approaches with aleft-turn lane (all approaches, 0,1, 2, 3, or 4 for signalized intersections; only major approaches, 0, 1, or 2, for stop-controlled intersections)
- Number of major-road approaches with left-turn signal phasing (0, 1, or 2) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, or protected)
- Number of approaches with a right turn lane (all approaches, 0, 1, 2, 3, or 4 for signalized intersections; only major approaches, 0 ,1, or 2, for stop-controlled intersections)
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Presence/absence of intersection lighting
- Presence of red light camera (signalized intersections only)
- Proportion of nighttime crashes for unlighted intersections

For Intersections of Two-Way Arterials with Six or More Lanes:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road stop or signal)
- AADT of each intersecting road
- Number of lanes on each intersecting road

- Number of major-road approaches with left-turn signal phasing (0, 1, or 2) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, or protected)
- Number of major-road approaches with channelized right turn lane
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Number of approaches from which U-turn operation is prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Presence/absence of intersection lighting
- Presence of red light camera (signalized intersections only)
- Proportion of nighttime crashes for unlighted intersections

For Intersections of One-Way Arterials:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road stop or signal)
- AADT of the intersecting roads
- Number of lanes on the intersecting roads
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Presence/absence of intersection lighting
- Presence of red light camera (signalized intersections only)
- Proportion of nighttime crashes for unlighted intersections

In addition, for signalized intersections, the following land use and demographic data are needed to estimate the expected average crash frequency of vehicle-pedestrian collisions:

- Daily pedestrian volumes crossing the intersection legs
- Maximum number of traffic lanes to be crossed by a pedestrian from corner to corner in any crossing maneuver at the intersection considering the presence of refuge islands
- Number of bus stops within 1,000 feet of the intersection
- Presence of schools within 1,000 feet of the intersection
- Number of alcohol sales establishments within 1,000 feet of the intersection

Step 5—Divide the roadway network or facility into individual homogenous roadway segments and intersections which are referred to as sites.
Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 12 predictive models are provided in Section 12.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will decrease data collection and management efforts.

Step 6—Assign observed crashes to the individual sites (if applicable).
Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, proceed to Step 7. In Step 3, the availability of observed data and whether the data could be assigned to specific locations was determined. The specific criteria for assigning crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

All crashes that occur within the limits of an intersection and intersection-related crashes (i.e., crashes related to the presence of an intersection) that occur on an intersection leg, are assigned to the intersection and to be used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections, and are not related to the presence of an intersection, are assigned to the roadway segment on which they occur. Such crashes are used in the EB Method together with the predicted average crash frequency for the roadway segment.

Step 7—Select the first or next individual site in the study network.
In Step 5, the roadway network within the study limits has been divided into a number of individual homogenous sites (intersections and roadway segments).

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, which is the sum of the all of the individual sites, for each year in the study. Note that this value will be the total number of crashes expected to occur over all sites during the period of interest. If a crash frequency is desired, the total can be divided by the number of years in the period of interest.

The estimation for each site (roadway segments or intersection) is conducted one at a time. Steps 8 through 13 are repeated for each site.

Step 8—For the selected site, select the first or next year in the period of interest.
The individual years of the evaluation period may have to be analyzed one year at a time for any particular roadway segment or intersection because SPFs are dependent on AADT, which may change from year to year.

For each site, steps 9 through 11 are repeated for each year in the study period.

Step 9—For the selected site, determine and apply the appropriate SPFs for the site's facility type and traffic control features.
Steps 9 through 13 are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 12 follow the general form shown in Equations 12-1 and 12-2. Other than vehicle-pedestrian and vehicle-bicycle collisions, the predicted average crash frequency of each collision type is determined using an SPF, which is adjusted to site specific conditions using a set of CMFs (in Step 10). The total predicted average crash frequency (including all collision types) for each site is adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, and calibration factor attained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site.

The SPFs (which are regression models based on observed crash data for a set of similar sites) determine the predicted average crash frequency (of each collision type) for a site with the base conditions (i.e., a specific set of geometric design and traffic control features). The SPFs are calculated using the AADT determined in Step 3 ($AADT_{maj}$ and $AADT_{min}$ for intersections) for the selected year. A detailed explanation and overview of the SPFs are provided in Section C.6.3.

The SPFs developed for Chapter 12 are presented in Section 12.6 and summarized in Table 12-2. For the selected site, the appropriate set of SPFs for the site type (intersection or roadway segment) and the geometric and traffic control features (undivided roadway, divided roadway, stop-controlled intersection, signalized intersection, etc.) should be selected. Different sets of SPFs apply to arterial roadway segments with five or fewer lanes (provided in Section 12.6.1.1) and roadway segment with six or more lanes or one-way arterial roadway segments (provided in Section 12.6.1.2). Similarly, different sets of SPFs apply to intersections of arterials with five or fewer lanes (provided in Section 12.6.2.1) and intersection of arterials with six or more lanes or intersections of one-way arterials.

Each SPF determined in Step 9 is provided with default distributions of crash severity and manner of collision (presented in Section 12.6). These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
In order to account for differences between the base conditions and the specific conditions of the site, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Chapter 12 have the same base conditions as the SPFs used in Chapter 12 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 12.7 may be used as part of the Chapter 12 predictive method. Table 12-31 indicates which CMFs are applicable to the SPFs in Section 12.6.

The CMFs for roadway segments are those described in Section 12.7.1. These CMFs are applied as shown in Equation 12-6.The CMFs for intersections are those described in Section 12.7.2, which apply to both signalized and stop-controlled intersections, and in Section 12.7.3, which apply to vehicle-pedestrian collisions at signalized intersections only. These CMFs are applied as shown in Equation 12-9 and Equation 12-35.

In Chapter 12, the multiple- and single-vehicle base crashes determined in Step 9 and the CMF values calculated in Step 10 are then used to estimate the vehicle-pedestrian and vehicle-bicycle base crashes for roadway segments and intersections (present in Sections 12.6.1 and 12.6.2 respectively).

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor
The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods. Calibration to local conditions will account for these differences. A calibration factor (C_r for roadway segments or C_i for intersections) is applied to the total predicted average crash frequency (including all collision types) for each site. An overview of the use of calibration factors is provided in Section C.6.5. Detailed guidance for the development of calibration factors is included in Part C, Appendix A.1.1.

Steps 9, 10, and 11 together implement the predictive models in Equation 12-3 through Equation 12-9 to determine the predicted average crash frequency for each site within the facility.

Step 12—If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

Step 13—Apply site-specific EB Method (if applicable).
Whether the site-specific EB Method is applicable is determined in Step 3. The site-specific EB Method combines the Chapter 12 predictive model estimate of predicted average crash frequency, $N_{predicted}$, with the observed crash frequency of the specific site, $N_{observed}$. This provides a more statistically reliable estimate of the expected average crash frequency of the selected site.

In order to apply the site-specific EB Method, the overdispersion parameter, k, for the SPF is also used. This is in addition to the material in Part C, Appendix A.2.4. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to $N_{predicted}$ and $N_{observed}$.

If appropriate, the site-specific EB Method should be applied to a future time period. The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period to a future time period. In doing this, consideration is given to significant changes in geometric or roadway characteristics caused by the treatments considered for future time period.

Step 14—If there is another site to be evaluated, return to Step 7. Otherwise, proceed to Step 15.
This step creates a loop through Steps 7 to 14 that is repeated for each roadway segment or intersection within the facility.

Step 15—Apply the project level EB Method (if the site-specific EB Method is not applicable).
This step is only applicable to existing conditions when observed crash data are available, but cannot be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in Part C, Appendix A.2.5.

Step 16—Sum all sites and years in the study to estimate total crash frequency.
The total estimated number of crashes within the network or facility limits during a study period of *n* years is calculated using Equation 12-10:

$$N_{total} = \left(\sum_{\substack{all \\ roadway \\ segments}} N_{rs} \right) + \left(\sum_{\substack{all \\ intersections}} N_{\text{int}} \right) \tag{12-10}$$

Where:

N_{total} = total expected number of crashes within the limits of an urban or suburban arterial for the period of interest. Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits during the study period;

N_{rs} = expected average crash frequency during the study period for a roadway segment using the predictive method; and

N_{int} = expected average crash frequency during the study period for an intersection using the predictive method.

Equation 12-10 represents the total number of crashes estimated to occur during the study period. Equation 12-11 is used to estimate the total expected average crash frequency within the network or facility limits for an average year during the study period.

$$N_{\text{total average}} = \frac{N_{\text{total}}}{n} \tag{12-11}$$

Where:

$N_{\text{total average}}$ = total expected average crash frequency estimated to occur within the defined network or facility limits for an average year during the study period; and

n = number of years in the study period.

Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.
Steps 3 through 16 of the predictive method are repeated as appropriate for the same roadway limits but for alternative conditions, treatments, periods of interest, or forecast AADTs.

Step 18—Evaluate and compare results.
The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time, for given geometric design and traffic control features, and known or estimated AADT. In addition to estimating total crashes, the estimate can be made for different crash severity types and different manners of collision. For roadway segments and intersections of arterials with five or fewer lanes, default distributions of crash severity are provided with each SPF in Section 12.6. For roadway segments and intersections of arterials with six or more lanes and one-way arterials, default distributions of crash severity can be

predicted using Severity Distribution Functions (SDFs) in Section 12.8. Default distributions for manners of collisions for all site roadway segment and intersection types are provided with each SPF in Section 12.6. These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

12.5 ROADWAY SEGMENTS AND INTERSECTIONS

Section 12.4 provides an explanation of the predictive method. Sections 12.5 through 12.9 provide the specific detail necessary to apply the predictive method steps. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

In Step 5 of the predictive method, the roadway within the defined limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as “sites.” A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA *Interactive Highway Safety Design Model* (IHSDM) (4).

Roadway segments begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Figure 12-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 12 provides predictive models for stop-controlled (three- and four-leg) and signalized (three- and four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 12-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 12-2) within 250 feet of the center of the intersection.

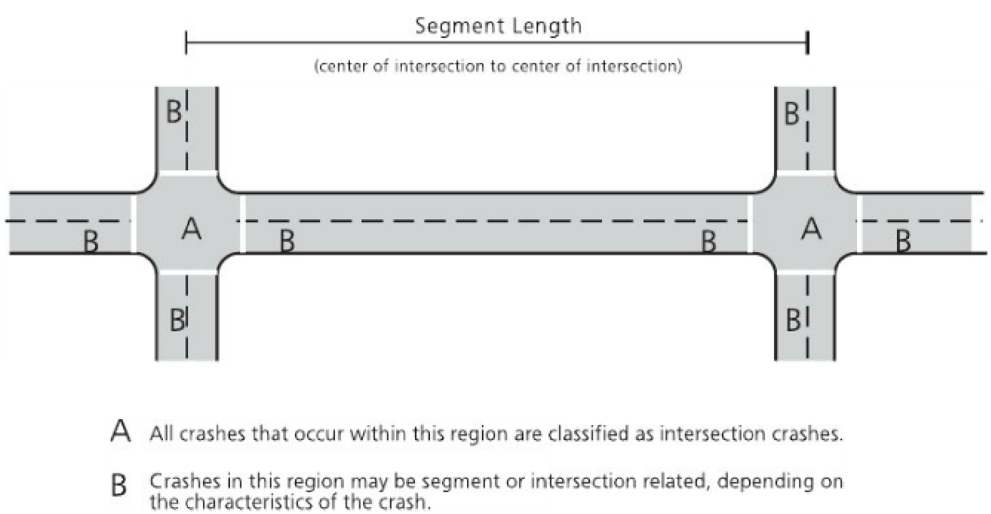

Figure 12-2. Definition of Roadway Segments and Intersections

The segmentation process produces a set of roadway segments of varying length, each of which is homogenous with respect to characteristics such as traffic volumes and key roadway design characteristics and traffic control features. Figure 12-2 shows the segment length, L, for a single homogenous roadway segment occurring between two intersections. However, several homogenous roadway segments can occur between two intersections. A new (unique) homogenous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

For Arterials with Five or Fewer Lanes

- AADT (vehicles/day)
- Number of through lanes
- Presence of a center TWLTL
- Presence/type of median
- Median width (feet). Measure the median width at successive points along the roadway. Round the measured median width at each point to the nearest 10 ft. If the rounded value exceeds 100 ft, then set it to 100 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 30 to 20 ft).
- Presence/type of on-street parking
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Presence of lighting
- Presence of automated speed enforcement
- Speed category (based on actual traffic speed or posted speed limit)

For Arterials with Six or More Lanes

- AADT (vehicles/day)
- Number of through lanes
- Presence of a center TWLTL
- Presence/type of median
- Median width (feet). Measure the median width at successive points along the roadway. Round the measured median width at each point to the nearest 10 ft. If the rounded value exceeds 90 ft, then set it to 90 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 30 to 20 ft).
- Lane width (feet). Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 11.5 to 12.0 ft).
- Outside shoulder width (feet). Measure the outside shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 7 ft).
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)

- Presence of automated speed enforcement
- Speed category (based on actual traffic speed or posted speed limit)

For One-way Arterials

- AADT (vehicles/day)
- Number of through lanes
- Lane width (feet). Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 11.5 to 12.0 ft).
- Right shoulder width (feet). Measure the right shoulder width at successive points along the roadway. Compute an average shoulder width for each point and round this average to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 6 to 7 ft).
- Presence/type of on-street parking
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Presence of automated speed enforcement
- Speed category (based on actual traffic speed or posted speed limit)

In addition, each individual intersection is treated as a separate site for which the intersection-related crashes are estimated using the predictive method.

There is no minimum roadway segment length, L, for application of predictive models for roadway segments. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation effort and not affect results.

Applying the Empirical Bayes Method

In order to apply the site-specific EB Method, observed crashes are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway-segment related. The methodology for assigning crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3. The EB Method uses a parameter associated with each SPF, known as the overdispersion parameter, k. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. In applying the EB Method for urban and suburban arterials with five or fewer lanes, whenever the predicted average crash frequency for a specific roadway segment during the multiyear study period is less than 1/k (the inverse of the overdispersion parameter for the relevant SPF), consideration should be given to combining adjacent roadway segments and applying the project-level EB Method. This guideline for the minimum crash frequency for a roadway segment applies only to the SPFs for urban and suburban arterials with five or fewer lanes which were developed using fixed-value overdispersion parameters. It is not needed in Chapters 10 or 11, or in Chapter 12 for other roadway segment types because the relevant SPFs were developed using length-dependent overdispersion parameters.

12.6 SAFETY PERFORMANCE FUNCTIONS

In Step 9 of the predictive method, the appropriate SPFs are used to predict crash frequencies for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for the HSM, the dependent variable estimated is the predicted average crash frequency for a roadway segment or intersection under base conditions, and the independent variables are the AADTs of the roadway segment or intersections legs (and, for roadway segments, the length of the roadway segment).

The predicted crash frequencies for base conditions obtained with the SPFs are used in the predictive models in Equation 12-3 through 12-9. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3.The SPFs in Chapter 12 are summarized in Table 12-2.

Table 12-2. Safety Performance Functions included in Chapter 12

Chapter 12 SPFs for Urban and Suburban Arterials	SPF Components by Collision Type	SPF Equations, Tables, and Figures
Two-way roadway segments with five or fewer lanes	multiple-vehicle nondriveway collisions	Equations 12-12, 12-13, 12-14; Tables 12-3, 12-4; Figure 12-3
	multiple-vehicle driveway-related collisions	Equations 12-15, 12-16, 12-17; Table 12-5; Figures 12-4, 12-5, 12-6, 12-7, 12-8
	single-vehicle crashes	Equations 12-18, 12-19, 12-20; Tables 12-6, 12-7; Figure 12-9
Two-way roadway segments with six or more lanes	total multiple-vehicle collisions (driveway-related and nondriveway)	Equation 12-21; Tables 12-8, 12-9; Figure 12-10
	single-vehicle crashes	Equation 12-23; Tables 12-10, 12-11; Figure 12-11
One-way roadway segments	total multiple-vehicle collisions (driveway-related and nondriveway)	Equation 12-21; Tables 12-12, 12-13; Figure 12-12
	single-vehicle crashes	Equation 12-23; Tables 12-14, 12-15; Figure 12-13
All segments	vehicle-pedestrian collisions	Equation 12-24; Table 12-16
	vehicle-bicycle collisions	Equation 12-25; Table 12-17
Intersections of two-way arterials with five or fewer lanes	multiple-vehicle collisions	Equations 12-26, 12-27, 12-28; Tables 12-20, 12-21; Figures 12-14, 12-15, 12-16, 12-17
	single-vehicle crashes	Equations 12-29, 12-30, 12-31, 12-32; Tables 12-22, 12-23; Figures 12-18, 12-19, 12-20, 12-21
Intersections of two-way arterials with at least one intersecting street having six or more lanes; intersections of one-way arterials	total multiple-vehicle collisions and single-vehicle crashes	Equation 12-33; Tables 12-24, 12-25, 12-26; Figures 12-22, 12-23, 12-24, 12-25, 12-26, 12-27, 12-28, 12-29
All intersections	vehicle-pedestrian collisions	Equations 12-35, 12-36, 12-37; Tables 12-27, 12-28, 12-29
	vehicle-bicycle collisions	Equation 12-38; Table 12-30

Some highway agencies may have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience. These models may be substituted for models presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Part C, Appendix A.

12.6.1. Safety Performance Functions for Urban and Suburban Arterial Roadway Segments

The predictive model for estimating average crash frequency on a particular urban or suburban arterial roadway segment was presented in Equations 12-3 through 12-6. The effect of AADT on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPFs for urban and suburban arterial roadway segments are presented in this section. Urban and suburban arterial roadway segments are defined in Section 12.3.

SPFs and adjustment factors are provided for the 12 types of roadway segments defined in Section 12.3.1. Guidance on the estimation of traffic volumes for roadway segments for use in SPFs is presented in Step 3 of the predictive method describe in Section 12.4. The SPFs for roadway segments on urban and suburban arterials are applicable to the following AADT ranges:

- 2U: 0 to 32,600 vehicles per day
- 3T: 0 to 32,900 vehicles per day
- 4U: 0 to 40,100 vehicles per day
- 4D: 0 to 66,000 vehicles per day
- 5T: 0 to 53,800 vehicles per day
- 6U: 0 to 78,000 vehicles per day
- 6D: 0 to 118,000 vehicles per day
- 7T: 0 to 94,000 vehicles per day
- 8D: 0 to 152,000 vehicles per day
- 2O: 0 to 34,000 vehicles per day
- 3O: 0 to 29,000 vehicles per day
- 4O: 0 to 29,000 vehicles per day

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Other types of roadway segments may be found on urban and suburban arterials but are not addressed by the predictive models in Chapter 12.

For collision types other than vehicle-pedestrian and vehicle-bicycle, the SPFs for arterial roadway segments with five or fewer lanes differ from the SPFs for arterial roadway segments with six or more lanes and one-way arterial roadway segments. The SPFs for these two categories of roadway segments are presented separately in Section 12.6.1.1 and 12.6.1.2. Section 12.6.1.3 and 12.6.1.4 provide the SPFs for predicting vehicle-pedestrian and vehicle-bicycle collisions for all arterial roadway segments types.

12.6.1.1. SPFs for Collisions (Other than Vehicle-Pedestrian or Vehicle-Bicycle) on Arterial Roadway Segments with Five or Fewer Lanes

For arterial roadway segments with five or fewer lanes, SPFs are provided for three types of collisions (other than vehicle-pedestrian or vehicle-bicycle): multiple-vehicle nondriveway collisions, multi-vehicle driveway-related collision, and single-vehicle crashes.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions on roadway segments is applied using Equation 12-12.

$$N_{spf\ rs\,nondwy} = \exp(a + b \times \ln(AADT) + \ln(L)) \qquad (12\text{-}12)$$

Where:

AADT = average annual daily traffic volume (vehicles/day) on roadway segment;

L = length of roadway segment (mi); and

a, b = regression coefficients.

Table 12-3 presents the values of the coefficients a and b used in Equation 12-12 for each roadway type. The overdispersion parameter, k, is also presented in Table 12-3. Figure 12-3 presents the graphical form of the SPF for multiple-vehicle nondriveway collisions on different roadway segment types.

Table 12-3. SPF Coefficients for Multiple-Vehicle Nondriveway Collisions on Roadway Segments with Five or Fewer Lanes

	Coefficients Used in Equation 12-12		
Roadway Type	**Intercept (a)**	**AADT (b)**	**Overdispersion Parameter (k)**
Total Crashes			
2U	-15.22	1.68	0.84
3T	-12.40	1.41	0.66
4U	-11.63	1.33	1.01
4D	-12.34	1.36	1.32
5T	-9.70	1.17	0.81
FI Crashes			
2U	-16.22	1.66	0.65
3T	-16.45	1.69	0.59
4U	-12.08	1.25	0.99
4D	-12.76	1.28	1.31
5T	-10.47	1.12	0.62
PDO Crashes			
2U	-15.62	1.69	0.87
3T	-11.95	1.33	0.59
4U	-12.53	1.38	1.08
4D	-12.81	1.38	1.34
5T	-9.97	1.17	0.88

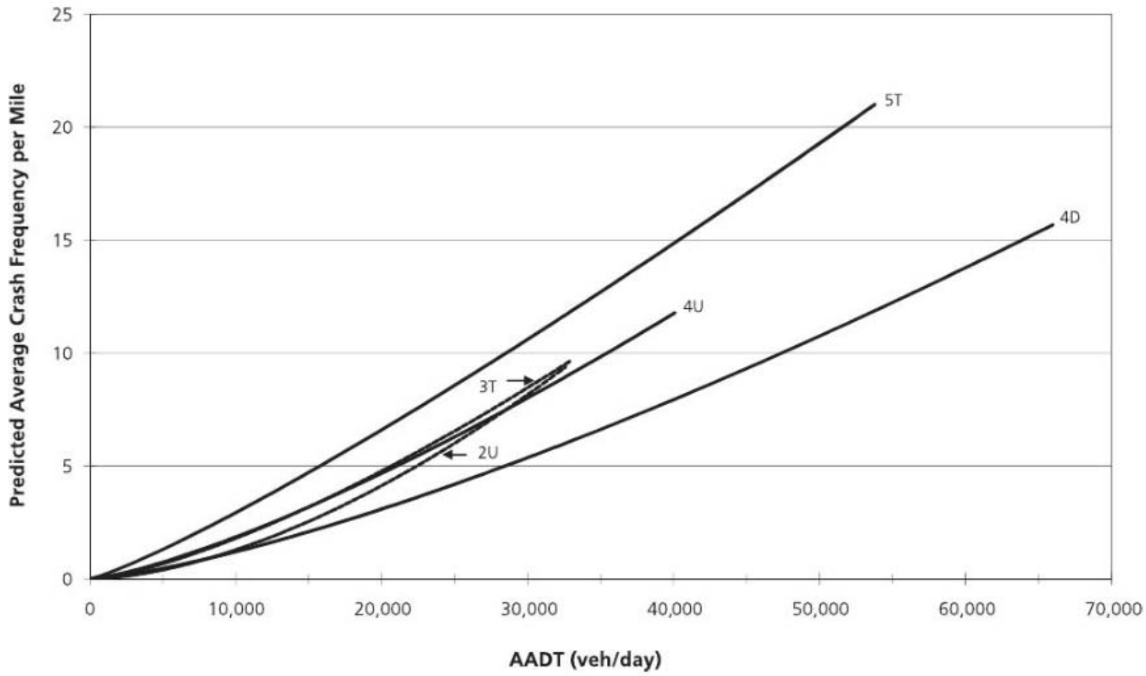

Figure 12-3. Graphical Form of the SPF for Multiple-Vehicle Nondriveway Collisions on Roadway Segments with Five or Fewer Lanes (from Equation 12-12 and Table 12-3)

Equation 12-12 is first applied to determine $N_{spf\ rs\ nondwy}$ using the coefficients for total crashes in Table 12-3. $N_{spf\ rs\ nondwy}$ is then divided into components by severity level, $N_{spf\ rs\ nondwy(FI)}$ for FI crashes and $N_{spf\ rs\ nondwy(PDO)}$ for PDO crashes. These preliminary values of $N_{spf\ rs\ nondwy(FI)}$ and $N_{spf\ rs\ nondwy(PDO)}$, designated as $N'_{spf\ rs\ nondwy(FI)}$ and $N'_{spf\ rs\ nondwy(PDO)}$ in Equation 12-13, are determined with Equation 12-12 using the coefficients for FI and PDO crashes, respectively, in Table 12-3. The adjustments in Equations 12-13 and 12-14 are then made to assure that $N_{spf\ rs\ nondwy(FI)}$ and $N_{spf\ rs\ nondwy(PDO)}$ sum to $N_{spf\ rs\ nondwy}$.

$$N_{spf\ rs\,nondwy(FI)} = N_{spf\ rs\,nondwy(total)}\left(\frac{N'_{spf\ rs\,nondwy(FI)}}{N'_{spf\ rs\,nondwy(FI)}+N'_{spf\ rs\,nondwy(PDO)}}\right) \quad (12\text{-}13)$$

$$N_{spf\ rs\,nondwy(PDO)} = N_{spf\ rs\,nondwy(total)} - N_{spf\ rs\,nondwy(FI)} \quad (12\text{-}14)$$

The proportions in Table 12-4 are used to separate $N_{spf\ rs\ nondwy(FI)}$ and $N_{spf\ rs\ nondwy(PDO)}$ into components by manner of collision.

Table 12-4. Distribution of Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Roadway Segments with Five or Fewer Lanes

	Proportion of Crashes by Severity Level for Specific Roadway Types									
	2U		3T		4U		4D		5T	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.730	0.778	0.845	0.842	0.511	0.506	0.832	0.662	0.846	0.651
Head-on collision	0.068	0.004	0.034	0.020	0.077	0.004	0.020	0.007	0.021	0.004
Angle collision	0.085	0.079	0.069	0.020	0.181	0.130	0.040	0.036	0.050	0.059
Sideswipe, same direction	0.015	0.031	0.001	0.078	0.093	0.249	0.050	0.223	0.061	0.248
Sideswipe, opposite direction	0.073	0.055	0.017	0.020	0.082	0.031	0.010	0.001	0.004	0.009
Other multiple-vehicle collisions	0.029	0.053	0.034	0.020	0.056	0.080	0.048	0.071	0.018	0.029

Source: HSIS data for Washington (2002-2006)

Multiple-Vehicle Driveway-Related Collisions

The model presented above for multiple-vehicle collisions addressed only collisions that are not related to driveways. Driveway-related collisions also generally involve multiple vehicles, but are addressed separately because the frequency of driveway-related collisions on a roadway segment depends on the number and type of driveways. Only unsignalized driveways are considered; signalized driveways are analyzed as signalized intersections.

The total number of multiple-vehicle driveway-related collisions within a roadway segment is determined using Equation 12-15.

$$N_{spf\ rs dwy(\text{total})} = \sum_{\substack{\text{all} \\ \text{driveway} \\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000} \right)^{(t)} \tag{12-15}$$

Where:

N_j = number of driveway-related collisions per driveway per year for driveway type *j* from Table 12-5;

n_j = number of driveways within roadway segment of driveway type *j* including all driveways on both sides of the road; and

t = coefficient for traffic volume adjustment from Table 12-5.

The number of driveways of a specific type, n_j, is the sum of the number of driveways of that type for both sides of the road combined. The number of driveways is determined separately for each side of the road and then added together.

Seven specific driveway types have been considered in modeling. These are:

- Major commercial
- Minor commercial
- Major industrial/institutional
- Minor industrial/institutional
- Major residential
- Minor residential
- Other driveways

Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with less than 50 parking spaces. It is not intended that an exact count of the number of parking spaces be made for each site. Driveways can be readily classified as major or minor from a quick review of aerial photographs that show parking areas or through user judgment based on the character of the establishment served by the driveway. Commercial driveways provide access to establishments that serve retail customers. Residential driveways serve single- and multiple-family dwellings. Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Commercial sites with no restriction on access along an entire property frontage are generally counted as two driveways.

Figure 12-4 through Figure 12-8 present the graphical form of the SPF for driveway-related collisions on roadway types 2U, 3T, 4U, 4D, and 5T, respectively.

Table 12-5. SPF Coefficients for Multiple-Vehicle Driveway Related Collisions on Roadway Segments with Five or Fewer Lanes

	Coefficients for Specific Roadway Types				
Driveway Type (j)	**2U**	**3T**	**4U**	**4D**	**5T**
Number of Driveway-Related Collisions per Driveway per Year (N_j)					
Major commercial	0.158	0.102	0.182	0.033	0.165
Minor commercial	0.050	0.032	0.058	0.011	0.053
Major industrial/institutional	0.172	0.110	0.198	0.036	0.181
Minor industrial/institutional	0.023	0.015	0.026	0.005	0.024
Major residential	0.083	0.053	0.096	0.018	0.087
Minor residential	0.016	0.010	0.018	0.003	0.016
Other	0.025	0.016	0.029	0.005	0.027
Regression Coefficient for AADT (t)					
All driveways	1.000	1.000	1.172	1.106	1.172
Overdispersion Parameter (k)					
All driveways	0.81	1.10	0.81	1.39	0.10
Proportion of FI Crashes (f_{dwy})					
All driveways	0.323	0.243	0.342	0.284	0.269
Proportion of PDO Crashes					
All driveways	0.677	0.757	0.658	0.716	0.731

Note: Includes only unsignalized driveways; signalized driveways are analyzed as signalized intersections. Major driveways serve 50 or more parking spaces; minor driveways serve less than 50 parking spaces.

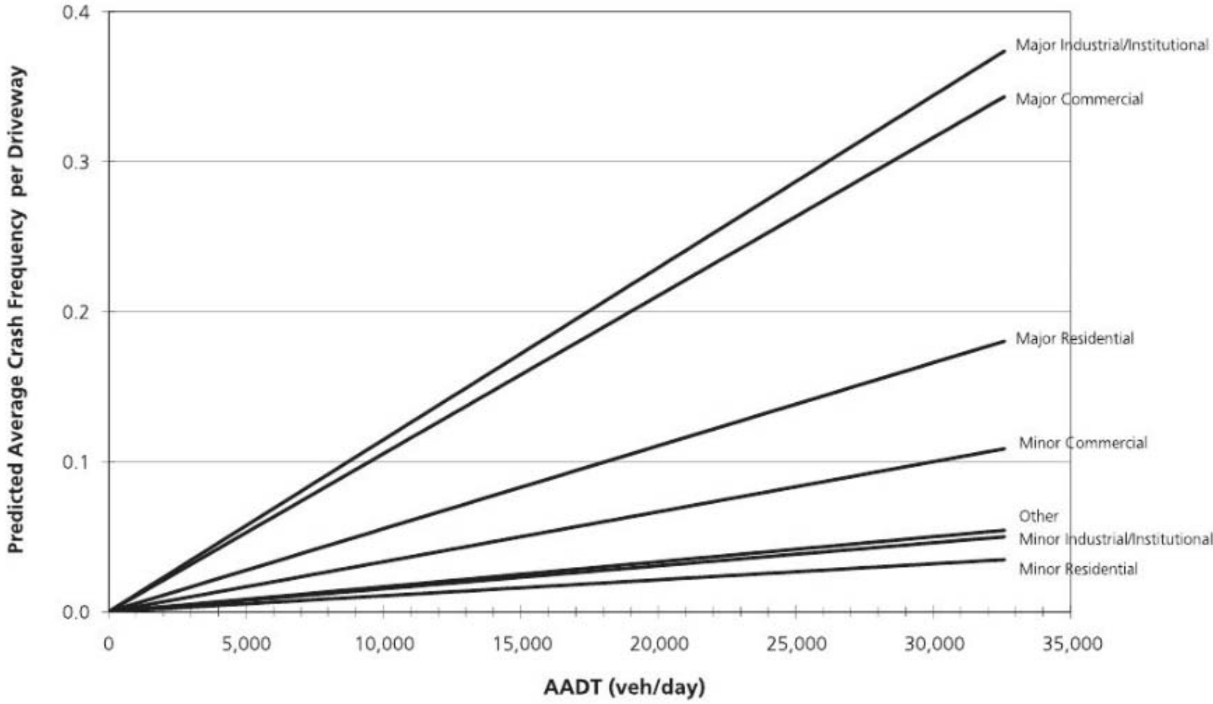

Figure 12-4. Graphical Form of the SPF for Multiple-Vehicle Driveway-Related Collisions on Two-Lane Undivided Arterials Roadway Segments (2U) (from Equation 12-15 and Table 12-5)

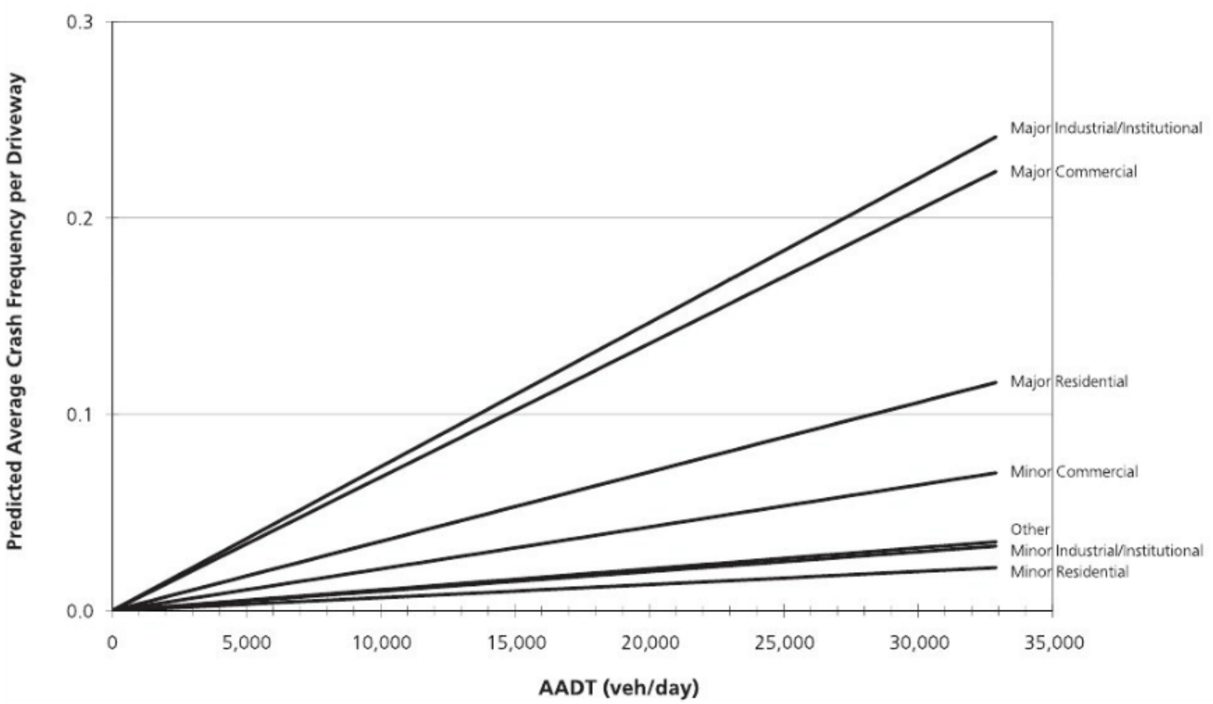

Figure 12-5. Graphical Form of the SPF for Multiple-Vehicle Driveway-Related Collisions on Three-Lane Arterial Roadway Segments Including a Center TWLTL (3T) (from Equation 12-15 and Table 12-5)

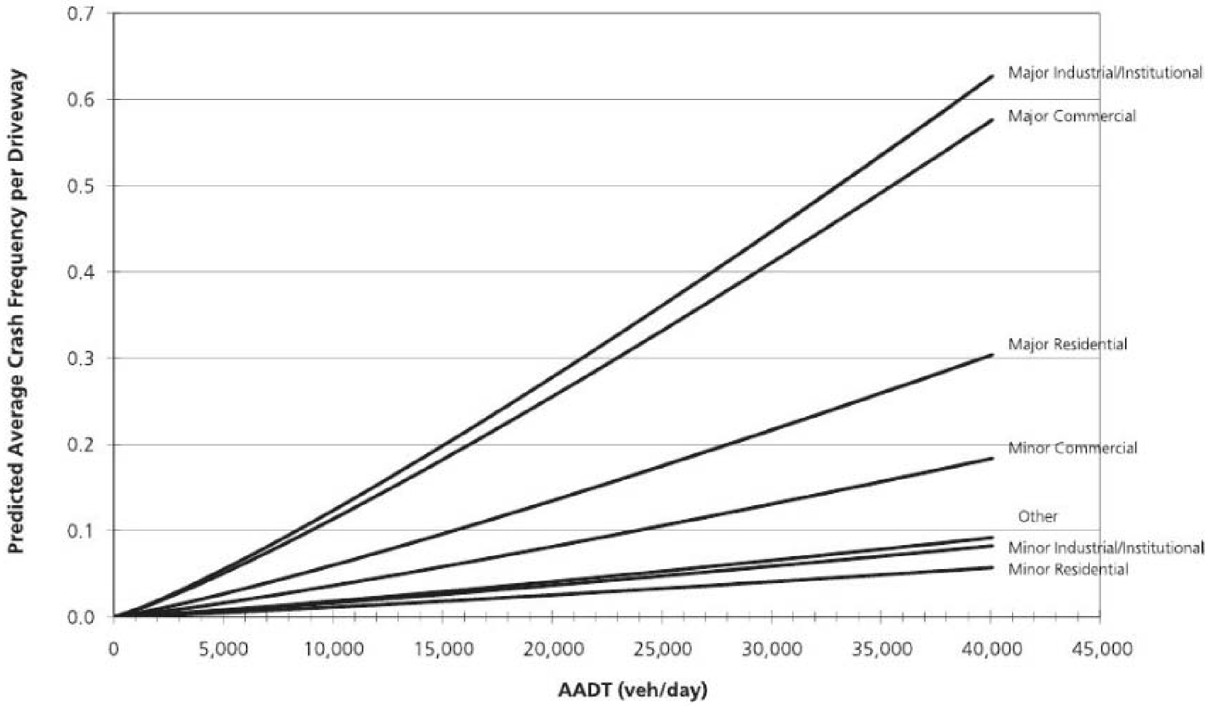

Figure 12-6. Graphical Form of the SPF for Multiple-Vehicle Driveway-Related Collisions on Four-Lane Undivided Arterial Roadway Segments (4U) (from Equation 12-15 and Table 12-5)

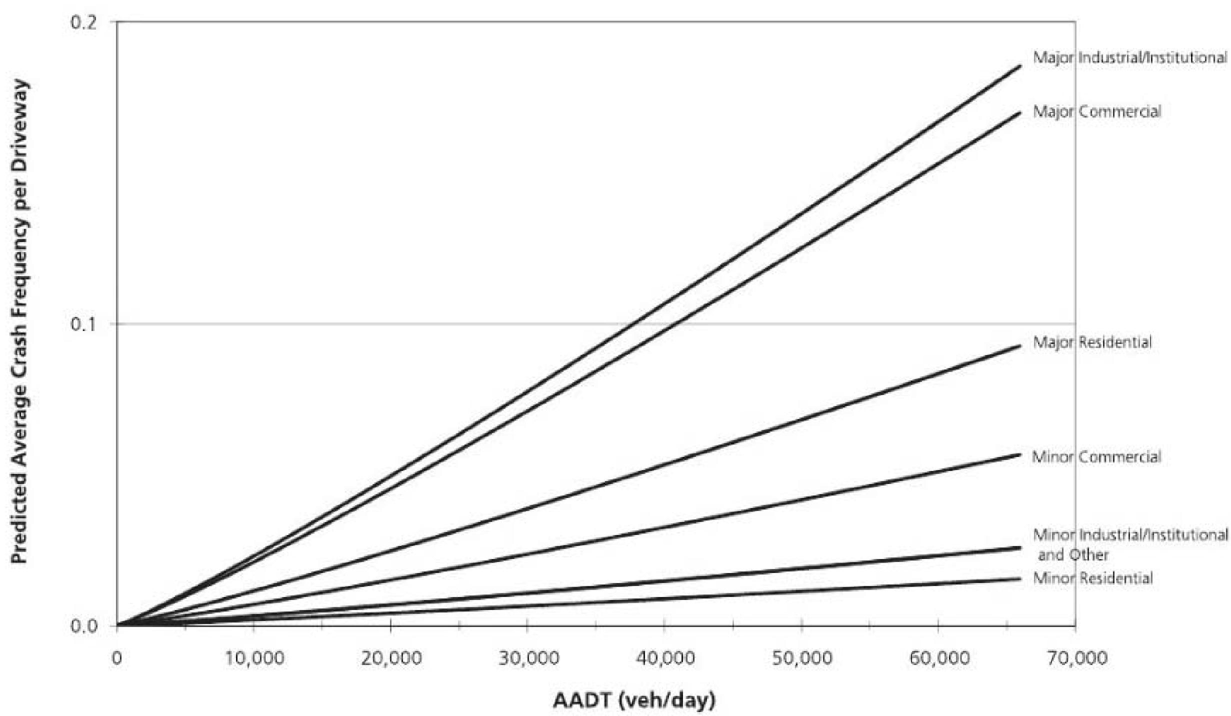

Figure 12-7. Graphical Form of the SPF for Multiple-Vehicle Driveway-Related Collisions on Four-Lane divided Arterial Roadway Segments (4D) (from Equation 12-15 and Table 12-5)

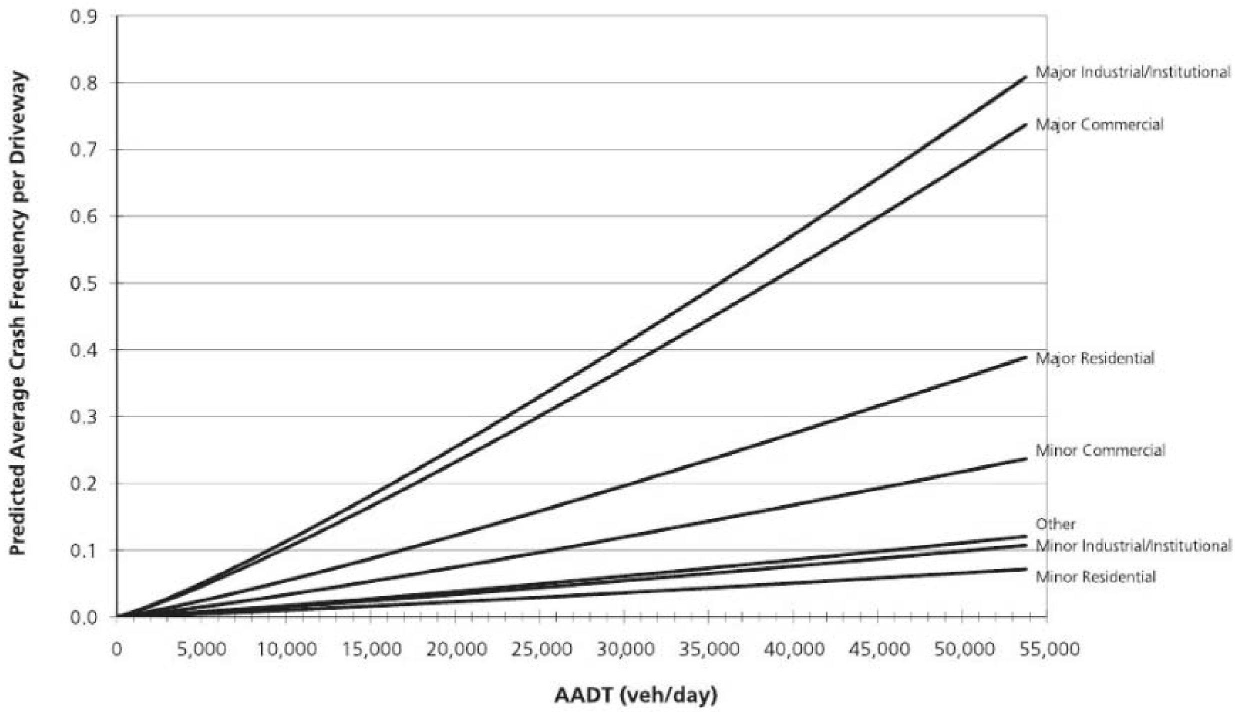

Figure 12-8. Graphical Form of the SPF for Multiple-Vehicle Driveway-Related Collisions on Five-Lane Arterial Roadway Segments Including a Center TWLTLane (5T) (from Equation 12-15 and Table 12-5)

Driveway-related collisions can be separated into components by severity level using Equations 12-16 and 12-17.

$$N_{spf\ rs\ dwy(FI)} = N_{spf\ rs\ dwy(\text{total})} \times f_{dwy} \quad (12\text{-}16)$$

$$N_{spf\ rs\ dwy(PDO)} = N_{spf\ rs\ dwy(\text{total})} - N_{spf\ rs\ dwy(FI)} \quad (12\text{-}17)$$

Where:

f_{dwy} = proportion of driveway-related collisions that involve fatalities or injuries.

The values of f_{dwy} are shown in Table 12-5.

Single-Vehicle Crashes

The SPF for single-vehicle crashes on roadway segments is applied using Equation 12-18.

$$N_{spf\ rs\ sv} = \exp(a + b \times \ln(AADT) + \ln(L)) \quad (12\text{-}18)$$

Table 12-6 presents the values of the coefficients a and b used in Equation 12-18 for each roadway type. The overdispersion parameter, k, is also presented in Table 12-6. Figure 12-9 presents the graphical form of the SPF for single-vehicle crashes on different roadway segment types.

Table 12-6. SPF Coefficients for Single-Vehicle Crashes on Roadway Segments with Five or Fewer Lanes

	Coefficients Used in Equation 12-18		
Road Type	**Intercept (a)**	**AADT (b)**	**Overdispersion Parameter (k)**
Total Crashes			
2U	-5.47	0.56	0.81
3T	-5.74	0.54	1.37
4U	-7.99	0.81	0.91
4D	-5.05	0.47	0.86
5T	-4.82	0.54	0.52
FI Crashes			
2U	-3.96	0.23	0.5
3T	-6.37	0.47	1.06
4U	-7.37	0.61	0.54
4D	-8.71	0.66	0.28
5T	-4.43	0.35	0.36
PDO Crashes			
2U	-6.51	0.64	0.87
3T	-6.29	0.56	1.93
4U	-8.5	0.84	0.97
4D	-5.04	0.45	1.06
5T	-5.83	0.61	0.55

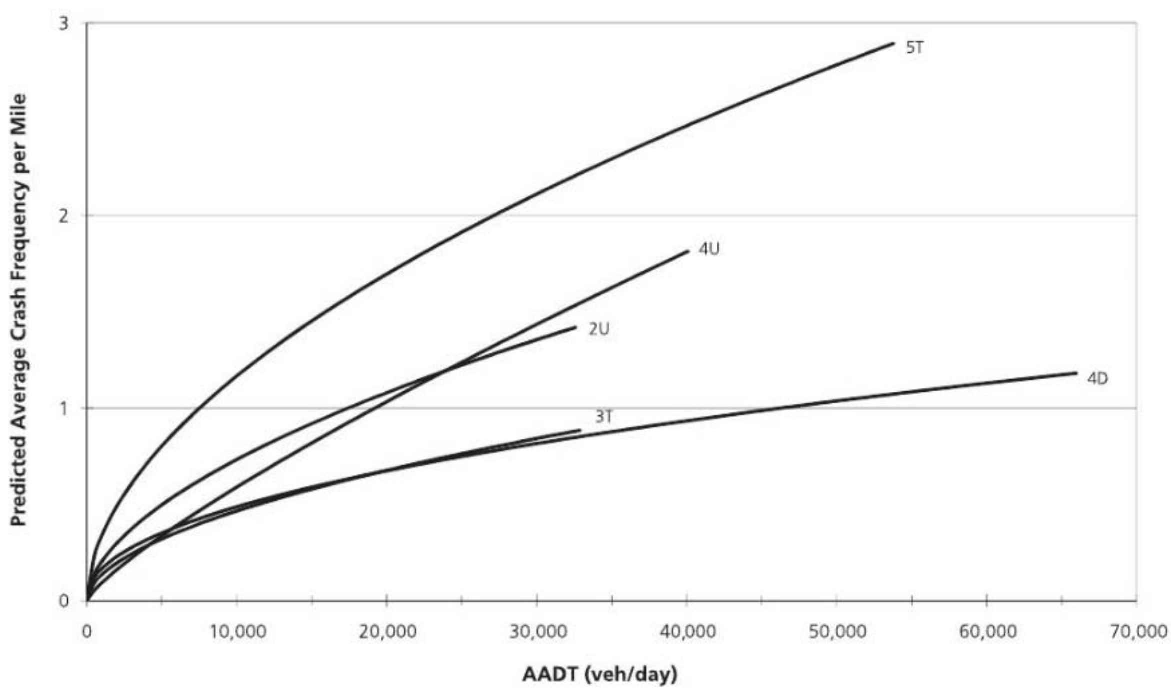

Figure 12-9. Graphical Form of the SPF for Single-Vehicle Crashes on Roadway Segments with Five or Fewer Lanes (from Equation 12-18 and Table 12-6)

Equation 12-18 is first applied to determine $N_{spf\,rs\,sv}$ using the coefficients for total crashes in Table 12-6. $N_{spf\,rs\,sv}$ is then divided into components by severity level; $N_{spf\ rs\ sv(FI)}$ for FI crashes and $N_{spf\ rs\ sv(PDO)}$ for PDO crashes. These preliminary values of $N_{spf\ rs\ sv(FI)}$ and $N_{spf\ rs\ sv(PDO)}$, designated as $N'_{spf\ rs\ sv(FI)}$ and $N'_{spf\ rs\ sv(PDO)}$ in Equation 12-19, are determined with Equation 12-18 using the coefficients for FI and PDO crashes, respectively, in Table 12-6. The adjustments in Equations 12-19 and 12-20 are then made to assure that $N_{spf\ rs\ sv(FI)}$ and $N_{spf\ rs\ sv(PDO)}$ sum to $N_{spf\ rs\ sv}$.

$$N_{spf\ rs\ sv(FI)} = N_{spf\ rs\ sv(total)} \left(\frac{N'_{spf\ rs\ sv(FI)}}{N'_{spf\ rs\ sv(FI)} + N'_{spf\ rs\ sv(PDO)}} \right) \tag{12-19}$$

$$N_{spf\ rs\ sv(PDO)} = N_{spf\ rs\ sv(total)} - N_{spf\ rs\ sv(FI)} \tag{12-20}$$

The proportions in Table 12-7 are used to separate $N_{spf\ rs\ sv(FI)}$ and $N_{spf\ rs\ sv(PDO)}$ into components by manner of collision.

Table 12-7. Distribution of Single-Vehicle Crashes by Manner of Collision for Roadway Segments with Five or Fewer Lanes

	Proportion of Crashes by Severity Level for Specific Roadway Types									
	2U		3T		4U		4D		5T	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with animal	0.026	0.066	0.001	0.001	0.001	0.001	0.001	0.063	0.016	0.049
Collision with fixed object	0.723	0.759	0.688	0.963	0.612	0.809	0.500	0.813	0.398	0.768
Collision with other object	0.010	0.013	0.001	0.001	0.020	0.029	0.028	0.016	0.005	0.061
Other single-vehicle crashes	0.241	0.162	0.310	0.035	0.367	0.161	0.471	0.108	0.581	0.122

Source: HSIS data for Washington (2002-2006)

12.6.1.2. SPFs for Collisions (Other than Vehicle-Pedestrian or Vehicle-Bicycle) on Arterial Roadway Segments with Six or More Lanes

For arterial roadway segments with six or more lanes, SPFs are provided for two types of collisions (other than vehicle-pedestrian or vehicle-bicycle): multiple-vehicle collisions, and single-vehicle crashes. In the predictive models for arterial roadway segments with six or more lanes, multiple-vehicle collisions include both nondriveway and driveway-related collisions and the safety impacts of driveways are captured through driveway-related CMFs, as described in Section 12.7.1.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle collisions on roadway segments is applied using Equation 12-21.

$$N_{spf\ rs\ mv} = \exp(a + b \times \ln(AADT) + \ln(L)) \tag{12-21}$$

Table 12-8 presents the values of the coefficients a and b used in Equation 12-21 for each roadway type. The value of the overdispersion parameter associated with the SPF is determined as a function of the segment length. This value is computed using Equation 12-22.

$$k = \frac{1}{e^{(c+\ln(L))}} \tag{12-22}$$

Where:

c = regression coefficient from Table 12-8.

Table 12-8. SPF Coefficients for Multiple-Vehicle Collisions on Roadway Segments with Six or More Lanes (for use in Equations 12-21 and 12-22)

Roadway Type	a	b	c
FI Crashes			
6U	-15.42	1.63	2.87
6D	-11.56	1.24	2.05
7T	-11.44	1.24	1.30
8D	-11.38	1.24	2.49
PDO Crashes			
6U	-15.68	1.70	3.00
6D	-9.21	1.06	1.91
7T	-9.20	1.06	1.08
8D	-8.84	1.06	1.67

Figure 12-10 presents the graphical form of the SPF for multiple-vehicle collisions on different roadway segment types with six or more lanes.

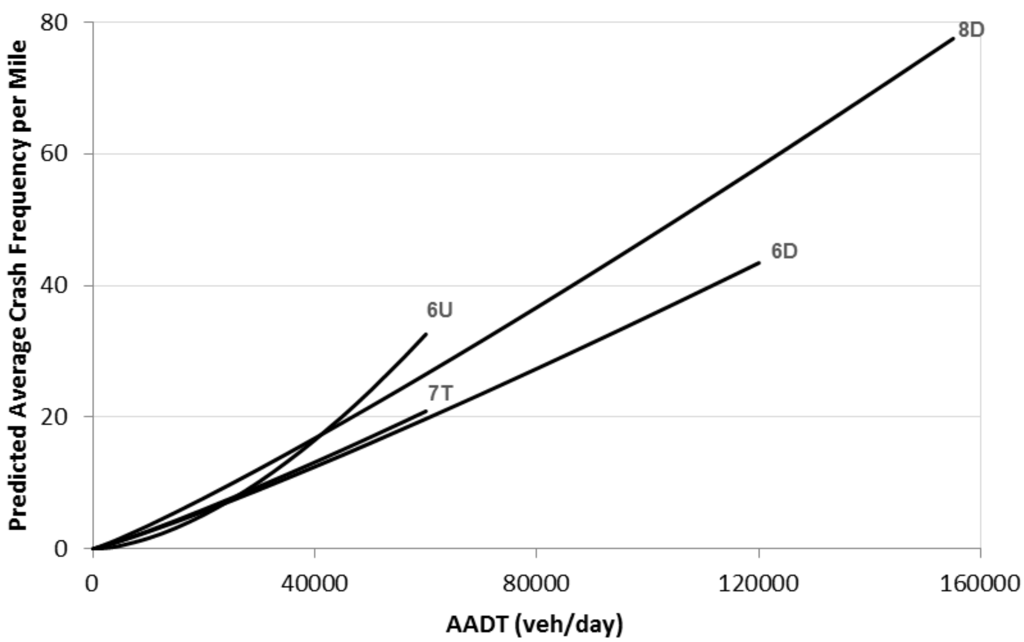

Figure 12-10. Graphical Form of the SPF for Multiple-Vehicle Collisions on Roadway Segments with Six or More Lanes (from Equation 12-21 and Table 12-8)

The proportions in Table 12-9 are used to separate $N_{spf\ rs\ mv(FI)}$ and $N_{spf\ rs\ mv(PDO)}$ into components by manner of collision for roadway segments with six or more lanes.

Table 12-9. Distribution of Multiple-Vehicle Collisions by Manner of Collision for Roadway Segments with Six or More Lanes

	Proportion of Crashes by Severity Level for Specific Roadway Types							
	6U		6D		7T		8D	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.752	0.586	0.769	0.591	0.694	0.588	0.746	0.647
Head-on collision	0.037	0.008	0.012	0.012	0.034	0.012	0.006	0.000
Angle collision	0.064	0.052	0.091	0.081	0.148	0.092	0.147	0.093
Sideswipe, same direction	0.083	0.302	0.087	0.262	0.072	0.255	0.073	0.236
Sideswipe, opposite direction	0.028	0.005	0.011	0.020	0.020	0.024	0.011	0.012
Other multiple-vehicle collisions	0.037	0.046	0.030	0.033	0.031	0.029	0.017	0.012

Source: HSIS data for California (2006-2010)

Single-Vehicle Crashes

The SPF for single-vehicle crashes on roadway segments with six or more lanes are applied using Equation 12-23.

$$N_{spf\ rs\,sv} = \exp(a + b \times \ln(AADT) + \ln(L)) \qquad (12\text{-}23)$$

Table 12-10 presents the values of the coefficients a and b used in Equation 12-23 for each roadway type. The value of the overdispersion parameter associated with the SPF is determined as a function of the segment length using Equation 12-22 and coefficient c determined from Table 12-10.

Table 12-10. SPF Coefficients for Single-Vehicle Crashes on Roadway Segments with Six or More Lanes and One-Way Roadway Segments (for use in Equations 12-23 and 12-22)

Roadway Type	a	b	c
FI Crashes			
6U	-4.54	0.37	3.08
6D	-5.26	0.46	1.50
7T	-4.54	0.37	3.08
8D	-5.36	0.46	2.01
PDO Crashes			
6U	-3.98	0.34	1.97
6D	-4.71	0.43	2.00
7T	-3.98	0.34	1.97
8D	-4.34	0.43	1.84

Figure 12-11 presents the graphical form of the SPF for single-vehicle crashes on different roadway segment types with six or more lanes.

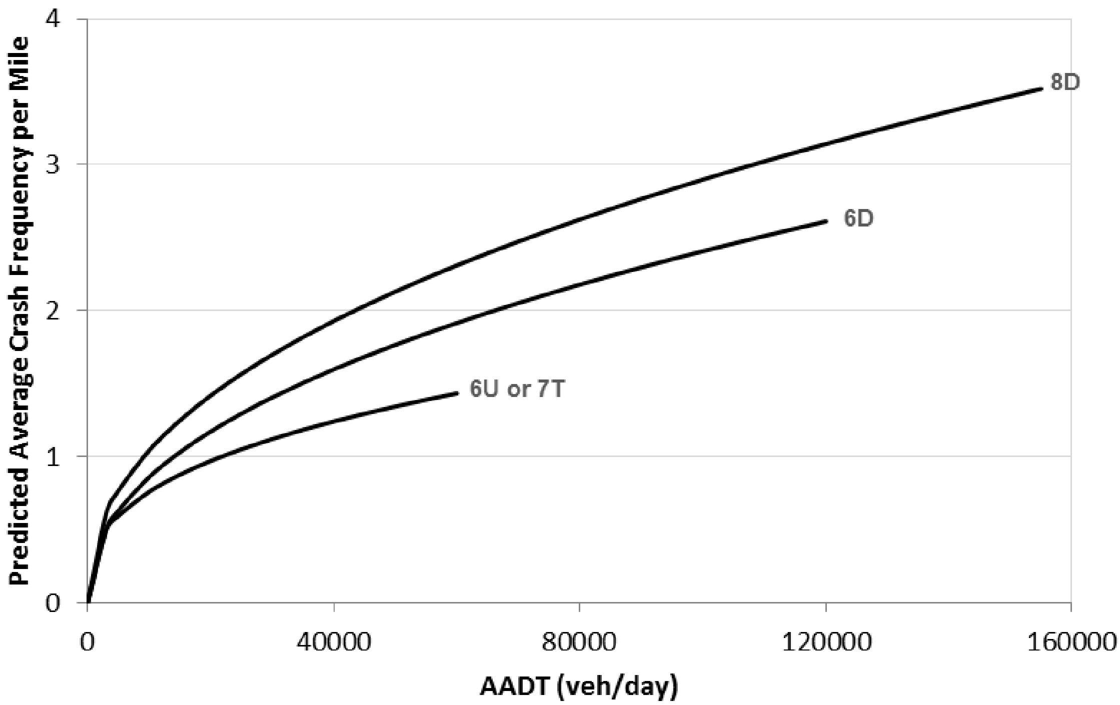

Figure 12-11. Graphical Form of the SPF for Single-Vehicle Crashes on Roadway Segments with Six or More Lanes (from Equation 12-23 and Table 12-10)

The proportions in Table 12-11 are used to separate $N_{spf\,rs\,sv(FI)}$ and $N_{spf\,rs\,sv(PDO)}$ into components by manner of collision for roadway segments with six or more lanes.

Table 12-11. Distribution of Single-Vehicle Crashes by Manner of Collision for Roadway Segments with Six or More Lanes

	Proportion of Crashes by Severity Level for Specific Roadway Types							
	6U		6D		7T		8D	
Manner of Collision	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with fixed object – left [a]	0.100	0.174	0.296	0.353	0.158	0.248	0.167	0.273
Collision with fixed object – right [b]	0.350	0.413	0.332	0.397	0.495	0.481	0.611	0.591
Collision with other object	0.050	0.130	0.032	0.073	0.011	0.037	0.000	0.045
Other single-vehicle crashes	0.500	0.283	0.339	0.177	0.337	0.234	0.222	0.091

[a] Where the vehicle collides with a fixed object to the left of its travel direction
[b] Where the vehicle collides with a fixed object to the right of its travel direction
Source: HSIS data for California (2006-2010)

12.6.1.3. SPFs for Collisions (Other than Vehicle-Pedestrian or Vehicle-Bicycle) on One-Way Arterial Roadway Segments

For one-way arterial roadway segments, SPFs are provided for two types of collisions (other than vehicle-pedestrian or vehicle-bicycle): multiple-vehicle collisions, and single-vehicle crashes. In the predictive models one-way arterial roadway segments, multiple-vehicle collisions include both nondriveway and driveway-related collisions and the safety impacts of driveways are captured through driveway-related CMFs, as described in Section 12.7.1.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle collisions on roadway segments is applied using Equation 12-21. Table 12-12 presents the values of the coefficients a and b used in Equation 12-21 for each roadway type. The value of the overdispersion parameter associated with the SPF is determined as a function of the segment length. This value is computed using Equation 12-22.

Where:

c = regression coefficient from Table 12-8.

Table 12-12. SPF Coefficients for Multiple-Vehicle Collisions on Roadway Segments with One-Way Roadway Segments (for use in Equations 12-21 and 12-22)

Roadway Type	a	b	c
FI Crashes			
2O	-11.48	1.26	2.12
3O	-11.49	1.26	2.57
4O	-11.74	1.26	2.46
PDO Crashes			
2O	-8.26	1.02	2.46
3O	-8.27	1.02	2.45
4O	-8.68	1.02	2.52

Figure 12-12 presents the graphical form of the SPF for different one-way roadway segment types.

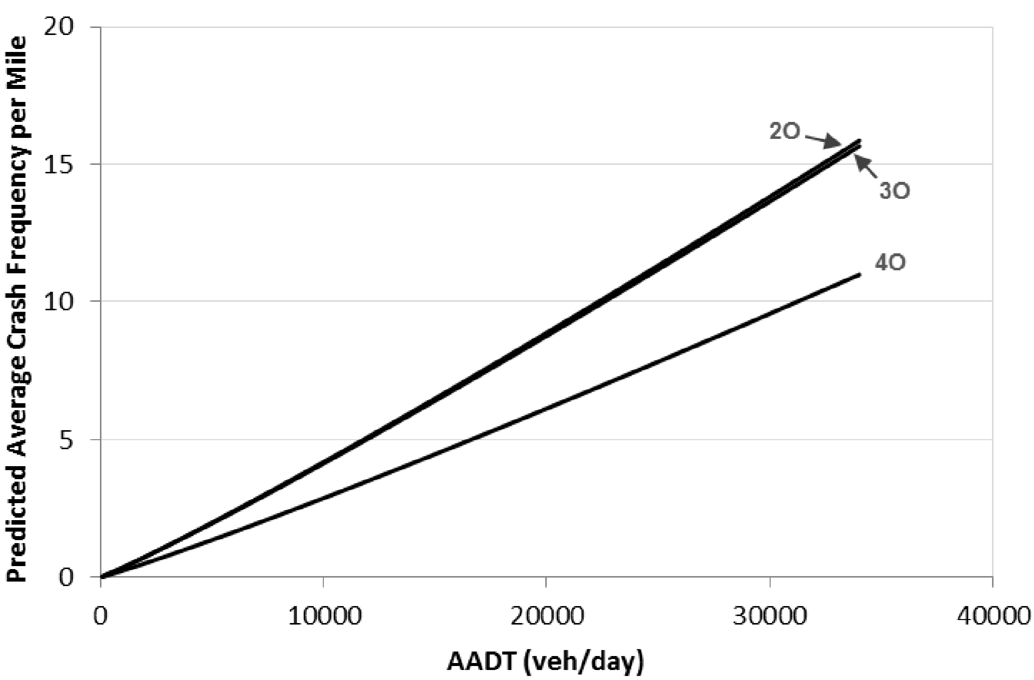

Figure 12-12. Graphical Form of the SPF for Multiple-Vehicle Collisions on One-Way Roadway Segments (from Equation 12-21 and Table 12-12)

The proportions in Table 12-13 are used to separate $N_{spf\ rs\ mv(FI)}$ and $N_{spf\ rs\ mv(PDO)}$ into components by manner of collision for one-way roadway segments.

Table 12-13. Distribution of Multiple-Vehicle Collisions by Manner of Collision for One-Way Roadway Segments

	Proportion of Crashes by Severity Level for Specific Roadway Types					
	2O		3O		4O	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.617	0.445	0.671	0.435	0.714	0.400
Head-on collision	0.021	0.017	0.013	0.013	0.000	0.067
Angle collision	0.128	0.076	0.133	0.115	0.000	0.000
Sideswipe, same direction	0.170	0.336	0.133	0.384	0.143	0.467
Sideswipe, opposite direction	0.043	0.042	0.013	0.017	0.000	0.000
Other multiple-vehicle collisions	0.021	0.084	0.038	0.036	0.143	0.067

Source: HSIS data for California (2006-2010)

Single-Vehicle Crashes

The SPF for single-vehicle crashes on roadway segments with six or more lanes and one-way roadway segments are applied using Equation 12-23. Table 12-14 presents the values of the coefficients a and b used in Equation 12-23 for each roadway type. The value of the overdispersion parameter associated with the SPF is determined as a function of the segment length using Equation 12-22 and coefficient c determined from Table 12-10.

Table 12-14. SPF Coefficients for Single-Vehicle Crashes on Roadway Segments with One-Way Roadway Segments (for use in Equations 12-23 and 12-22)

Roadway Type	a	b	c
FI Crashes			
2O	-5.32	0.42	1.19
3O	-4.93	0.42	1.94
4O	-4.93	0.42	1.94
PDO Crashes			
2O	-4.71	0.43	2.12
3O	-4.72	0.43	1.98
4O	-4.72	0.43	1.98

Figure 12-13 presents the graphical form of the SPF for single-vehicle crashes on different one-way roadway segment types.

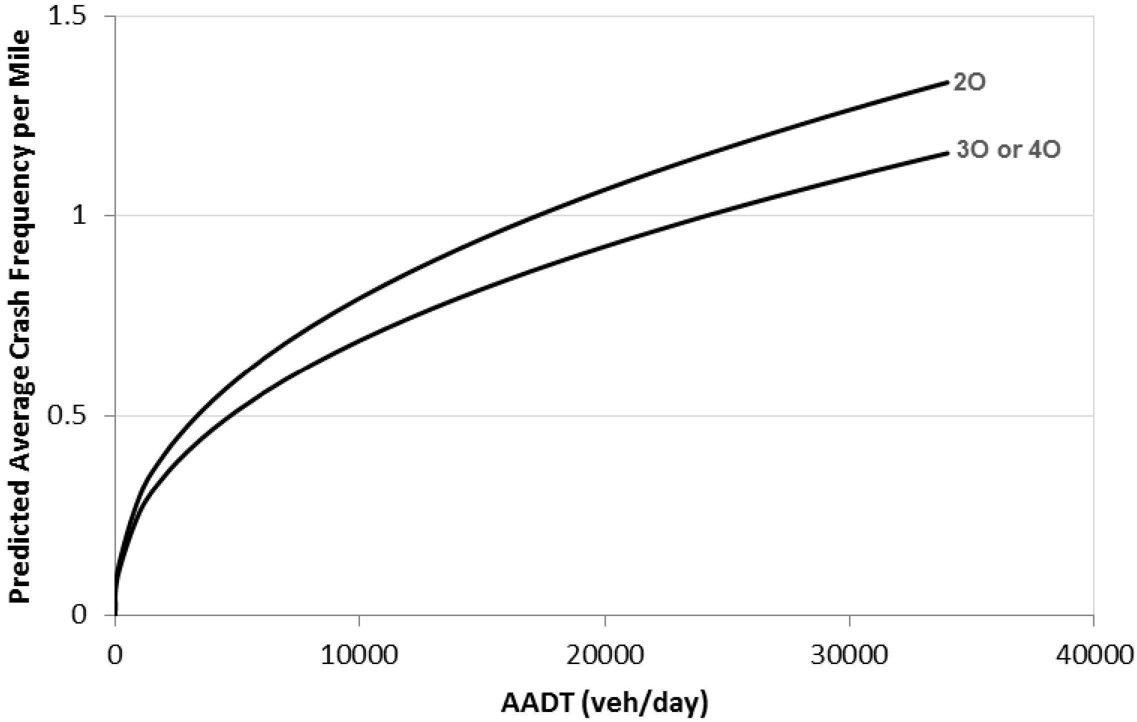

Figure 12-13. Graphical Form of the SPF for Single-Vehicle Crashes on One-Way Roadway Segments (from Equation 12-23 and Table 12-10)

The proportions in Table 12-13 are used to separate $N_{spf\ rs\ sv(FI)}$ and $N_{spf\ rs\ sv(PDO)}$ into components by manner of collision for one-way roadway segments.

Table 12-15. Distribution of Single-Vehicle Crashes by Manner of Collision for One-Way Roadway Segments

	Proportion of Crashes by Severity Level for Specific Roadway Types					
	2O		3O		4O	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with animal	0.400	0.261	0.182	0.489	0.286	0.167
Collision with fixed object	0.100	0.435	0.182	0.289	0.429	0.667
Collision with other object	0.000	0.130	0.091	0.044	0.000	0.000
Other single-vehicle crashes	0.500	0.174	0.545	0.178	0.286	0.167

Source: HSIS data for California (2006-2010)

12.6.1.4. SPFs for Vehicle-Pedestrian Collisions on Arterial Roadway Segments

The number of vehicle-pedestrian collisions per year for a roadway segment is estimated using Equation 12-24.

$$N_{pedr} = N_{br} \times f_{pedr} \qquad (12\text{-}24)$$

Where:

f_{pedr} = pedestrian crash adjustment factor.

The value of N_{br} in Equation 12-24 is determined using Equation 12-4.

Table 12-16 presents the values of f_{pedr} for use in Equation 12-24. All vehicle-pedestrian collisions are considered to be FI crashes. The values of f_{pedr} are likely to depend on the climate and the walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-16 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-16. Pedestrian Crash Adjustment Factor for Roadway Segments

	Pedestrian Crash Adjustment Factor (f_{pedr})	
Road Type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.036	0.005
3T	0.041	0.013
4U	0.022	0.009
4D	0.067	0.019
5T	0.030	0.023
6U	0.018	0.013
6D	0.029	0.015
7T	0.034	0.014
8D	--	0.023
2O	0.017	0.018
3O	0.024	0.017
4O	0.021	0.030

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as FI crashes and none as PDO crashes.
Source: HSIS data from Washington (2002–2006) for roadway segments with five or fewer lanes; HSIS data from California and Illinois (2006–2010) and state data from Texas (2008-2012) for roadway segments with six or more lanes; HSIS data from California and Illinois (2006–2010) and state data from Texas (2008-2012) and Oregon (2006–2010) for one-way roadway segments.
-- : not available

12.6.1.5. SPFs for Vehicle-Bicycle Collisions on Arterial Roadway Segments

The number of vehicle-bicycle collisions per year for a roadway segment is estimated using Equation 12-25.

$$N_{biker} = N_{br} \times f_{biker} \qquad (12\text{-}25)$$

Where:

f_{biker} = bicycle crash adjustment factor.

The value of N_{br} in Equation 12-25 is determined using Equation 12-4.

Table 12-17 presents the values of f_{biker} for use in Equation 12-25. All vehicle-bicycle collisions are considered to be FI crashes. The values of f_{biker} are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-17 with suitable values for their own state or community through the calibration process (see Appendix A to Part C).

Table 12-17. Bicycle Crash Adjustment Factors for Roadway Segments

	Bicycle Crash Adjustment Factor (f_{biker})	
Road Type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.018	0.004
3T	0.027	0.007
4U	0.011	0.002
4D	0.013	0.005
5T	0.050	0.012
6U	0.013	0.007
6D	0.007	0.008
7T	0.025	0.001
8D	--	0.014
2O	0.011	0.016
3O	0.011	0.012
4O	0.021	0.007

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as FI crashes and none as PDO crashes.
Source: HSIS data from Washington (2002–2006) for roadway segments with five or fewer lanes; HSIS data from California and Illinois (2006–2010) and state data from Texas (2008-2012) for roadway segments with six or more lanes; HSIS data from California and Illinois (2006–2010) and state data from Texas (2008-2012) and Oregon (2006–2010) for one-way roadway segments.
-- : not available

12.6.2 Safety Performance Functions for Urban and Suburban Arterial Intersections

The predictive model for estimating average crash frequency at a particular arterial intersection was presented in Equation 12-7 through 12-9. The structure of the predictive models for intersections is similar to the predictive models for roadway segments. The SPFs for urban and suburban arterial intersections are presented in this section. Urban and suburban arterial intersections are defined in Section 12.3.

The effect of traffic volume on predicted crash frequency for intersections is incorporated through SPFs, while the effects of geometric and traffic control features are incorporated through CMFs. Each of the SPFs for intersections incorporates separate effect for the AADTs on the major- and minor-road legs, respectively.

Intersections are divided into four categories based on the two-way or one-way traffic flow and the number of lanes on the intersecting roads. These are:

- *2×2 with five or fewer lanes*—intersections of two arterials with two-way traffic and five or fewer through lanes at the intersection.
- *2×2 with six or more lanes*—intersections of two arterials with two-way traffic where at least one intersecting road has six or more through lanes at the intersection.
- *1×2*—intersections of an arterial with one-way traffic and an arterial with two-way traffic
- *1×1*—intersections of two arterials with two-way traffic

In each category of intersections listed above, SPFs and adjustment factors have been developed for four types of intersections. These are:

- Three-leg intersections with stop control on minor-road approach (3ST)
- Three-leg signalized intersections (3SG)

- Four-leg intersections with stop control on minor-road approaches (4ST)
- Four-leg signalized intersections (4SG)

Other types of intersection may be found on urban and suburban arterials but are not addressed by the Chapter 12 SPFs.

The SPFs for each of the intersection types identified above predict average crash frequency per year for all crashes that occur within the limits of the intersection and intersection-related crashes that occur on the intersection legs.

Guidance on the estimation of traffic volumes for the major and minor road legs for use in the SPFs is presented in Step 3. For 2×2 and 1×1 intersections, the major and minor roads are defined as the road with the higher and lower AADT, respectively. For 1×2 intersections, however, the one-way road is designated as major road and the two-way road as minor road regardless of the AADTs. The AADT(s) used in the SPF are the AADT(s) for the selected year of evaluation period. The SPFs for intersections are applicable to the range of AADTs specified in Table 12-18.

Table 12-18. Range of AADT for Application of SPFs for Intersections

Intersection Type	Range of $AADT_{maj}$ (vehicles per day)	Range of $AADT_{min}$ (vehicles per day)
2×2 with five or fewer lanes		
3ST	0 – 45,700	0 – 9,300
4ST	0 – 46,800	0 – 5,900
3SG	0 – 58,100	0 – 16,400
4SG	0 – 67,700	0 – 33,400
2×2 with six or more lanes		
3ST	0 – 66,800	0 – 8,600
4ST	0 – 54,600	0 – 4,600
3SG	0 – 94,000	0 – 31,000
4SG	0 – 137,600	0 – 68,400
1×2		
3ST	0 – 42,700	0 – 13,400
4ST	0 – 23,400	0 – 19,200
3SG	0 – 43,800	0 – 58,800
4SG	0 – 77,000	0 – 98,900
1×1		
3ST	0 – 16,900	0 – 11,100
4ST	0 – 11,000	0 – 6,800
3SG	0 – 20,100	0 – 7,500
4SG	0 – 24,300	0 – 16,900

The SPF for vehicle-pedestrian collisions at signalized intersections is applicable to the range of AADTs and pedestrian volumes specified in Table 12-19.

Table 12-19. Range of AADT and Pedestrian Volume for Application of SPFs for Vehicle-Pedestrian Collisions at Signalized Intersections

Intersection Type	Range of $AADT_{maj}$ (Vehicles per Day)	Range of $AADT_{min}$ (Vehicles per Day)	Range of PedVol [a] (Pedestrian per Day)
3SG	0 – 74,300	0 – 51,500	0 – 34,200
4SG	0 – 80,200	0 – 49,100	0 – 12,600

[a] PedVol = daily pedestrian volume crossing all intersection legs

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

For collision types other than vehicle-pedestrian and vehicle-bicycle, the SPFs for 2×2 intersections with five or fewer lanes differ from the SPFs for 2×2 intersections with six or more lanes and one-way arterial intersections (1×2 or 1×1). The SPFs for these two categories of intersections are presented separately in Section 12.6.2.1 and 12.6.2.2. Section 12.6.2.3 and 12.6.2.4 provide the SPFs for predicting vehicle-pedestrian and vehicle-bicycle collisions for all intersection types.

12.6.2.1. SPFs for Collisions (Other than Vehicle-Pedestrian or Vehicle-Bicycle) on Intersections of Two-Way Arterials with Five or Fewer Lanes

For intersections of two-way arterials with five or fewer lanes, SPFs are provided for two types of collisions (other than vehicle-pedestrian or vehicle-bicycle): multiple-vehicle collisions, and single-vehicle crashes.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle intersection-related collisions is applied using Equation 12-26.

$$N_{spf\ int\ mv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{\min})) \tag{12-26}$$

Where:

$AADT_{maj}$ = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined); and

a, b, c = regression coefficients.

Table 12-20 presents the values of the coefficients a, b, and c used in Equation 12-26 for each intersection type. The overdispersion parameter, k, is also presented in Table 12-20.

Figure 12-14 through Figure 12-17 present the graphical form of the SPF for intersection-related multiple-vehicle collisions at 3ST, SG, 4ST, and 4SG intersections of two-way arterials with five or fewer lanes, respectively.

Table 12-20. SPF Coefficients for Multiple-Vehicle Collisions at 2×2 Intersections with Five or Fewer Lanes

	Coefficients Used in Equation 12-26			
Intersection Type	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	Overdispersion Parameter (k)
Total Crashes				
3ST	-13.36	1.11	0.41	0.80
3SG	-12.13	1.11	0.26	0.33
4ST	-8.90	0.82	0.25	0.40
4SG	-10.99	1.07	0.23	0.39
FI Crashes				
3ST	-14.01	1.16	0.30	0.69
3SG	-11.58	1.02	0.17	0.30
4ST	-11.13	0.93	0.28	0.48
4SG	-13.14	1.18	0.22	0.33
PDO Crashes				
3ST	-15.38	1.2	0.51	0.77
3SG	-13.24	1.14	0.30	0.36
4ST	-8.74	0.77	0.23	0.40
4SG	-11.02	1.02	0.24	0.44

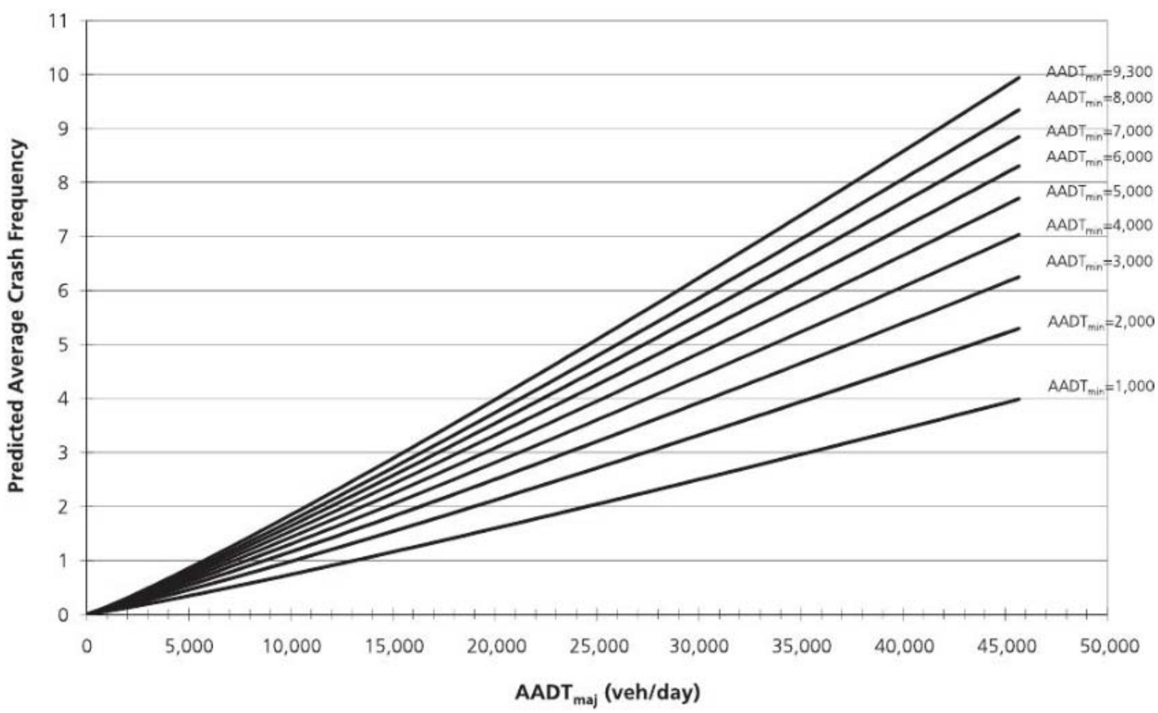

Figure 12-14. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle Collisions at 3ST Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-26 and Table 12-20)

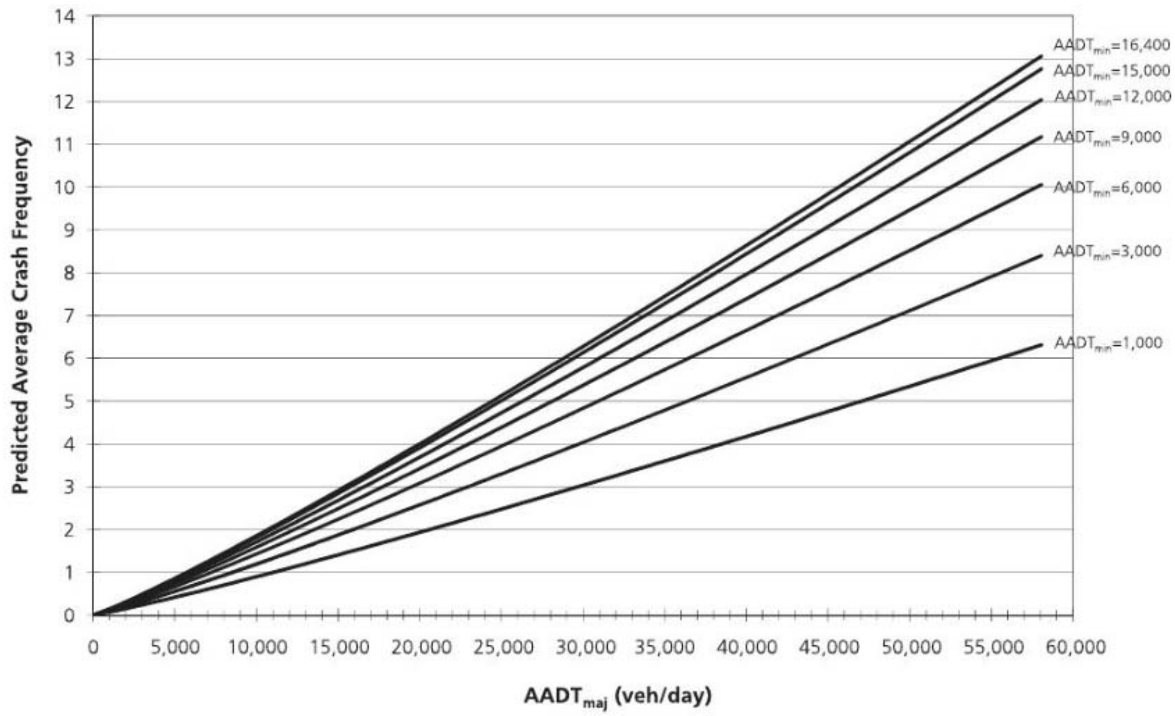

Figure 12-15. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle Collisions at 3SG Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-26 and Table 12-20)

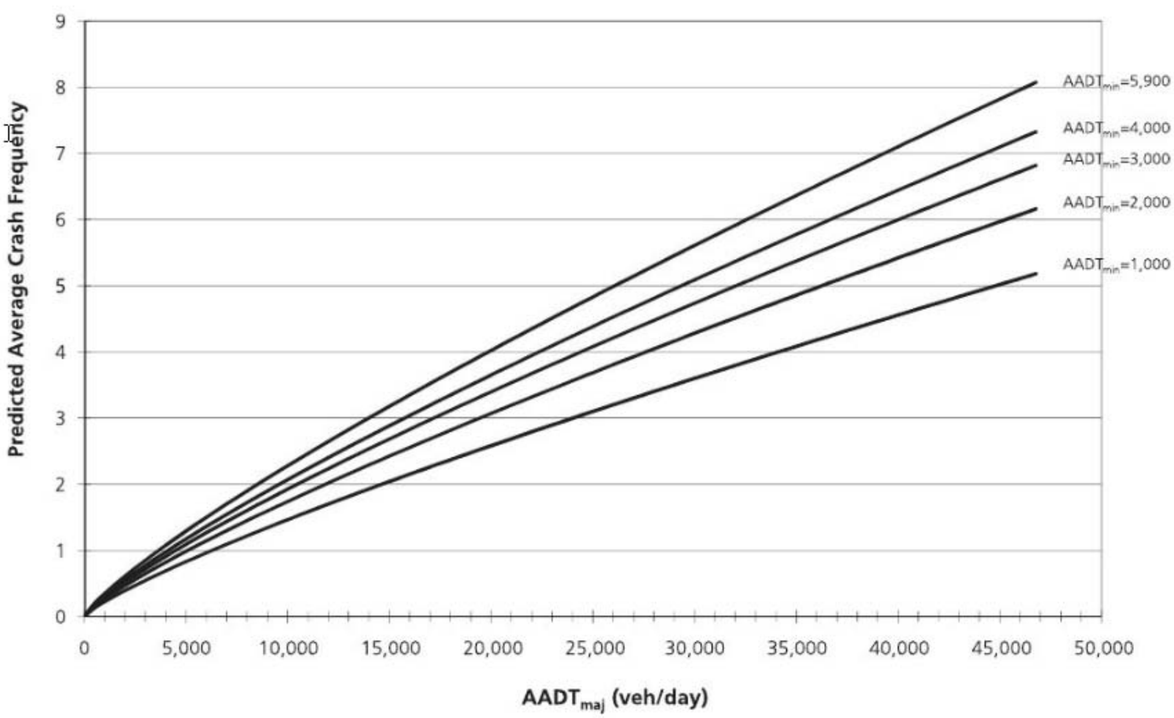

Figure 12-16. Graphical Form of the SPF for Multiple-Vehicle Collisions at 4ST Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-26 and Table 12-20)

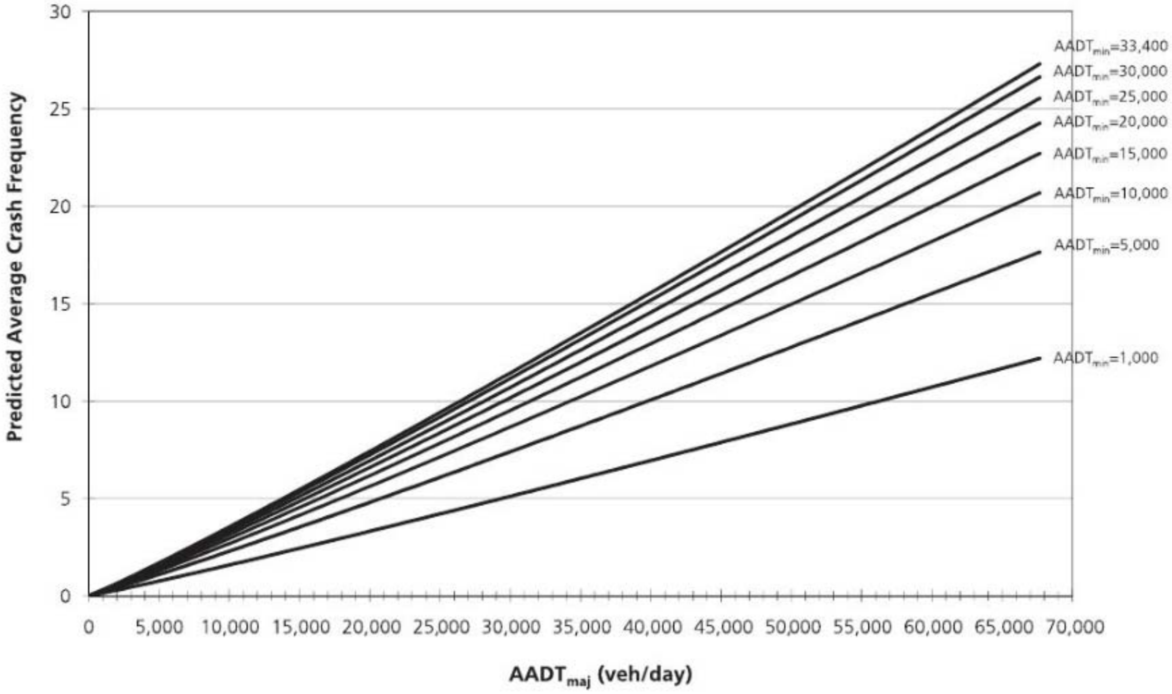

Figure 12-17. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle Collisions at 4SG Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-26 and Table 12-20)

Equation 12-26 is first applied to determine $N_{spf\ int\ mv}$ using the coefficients for total crashes in Table 12-20. $N_{spf\ int\ mv}$ is then divided into components by crash severity level, $N_{spf\ int\ mv(FI)}$for FI crashes and $N_{spf\ int\ mv(PDO)}$ for PDO crashes. These preliminary values of $N_{spf\ int\ mv(FI)}$ and $N_{spf\ int\ mv(PDO)}$, designated as $N'_{spf\ int\ mv(FI)}$ and $N'_{spf\ int\ mv(PDO)}$ in Equation 12-27, are determined with Equation 12-26 using the coefficients for FI and PDO crashes, respectively, in Table 12-20. The adjustments in Equations 12-27 and 12-28 are then made to assure that $N_{spf\ int\ mv(FI)}$ and $N_{spf\ int\ mv(PDO)}$ sum to $N_{spf\ int\ mv}$.

$$N_{spf\ int\,mv(FI)} = N_{spf\ int\,mv(total)}\left(\frac{N'_{spf\ int\,mv(FI)}}{N'_{spf\ int\,mv(FI)}+N'_{spf\ int\,mv(PDO)}}\right) \quad (12\text{-}27)$$

$$N_{spf\ int\,mv(PDO)} = N_{spf\ int\,mv(total)} - N_{spf\ int\,mv(FI)} \quad (12\text{-}28)$$

The proportions in Table 12-21 are used to separate $N_{spf\ int\ mv(FI)}$ and $N_{spf\ int\ mv(PDO)}$ into components by manner of collision.

Table 12-21. Distribution of Multiple-Vehicle Collisions by Manner of Collision for 2×2 Intersections with Five or Fewer Lanes

	Proportion of Crashes by Severity Level for Specific Roadway Types							
	3ST		3SG		4ST		4SG	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.421	0.440	0.549	0.546	0.338	0.374	0.450	0.483
Head-on collision	0.045	0.023	0.038	0.020	0.041	0.030	0.049	0.030
Angle collision	0.343	0.262	0.280	0.204	0.440	0.335	0.347	0.244
Sideswipe collision	0.126	0.040	0.076	0.032	0.121	0.044	0.099	0.032
Other multiple-vehicle collisions	0.065	0.235	0.057	0.198	0.060	0.217	0.055	0.211

Source: HSIS data for California (2002-2006)

Single-Vehicle Crashes

The SPF for single-vehicle intersection-related crashes is applied using Equation 12-29.

$$N_{spf\ int\ sv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})) \quad (12\text{-}29)$$

Table 12-22 presents the values of the coefficients a, b, and c used in Equation 12-29 for each intersection type. The overdispersion parameter, k, is also presented in Table 12-22.

Figure 12-18 through Figure 12-21 present the graphical form of the SPF for intersection-related single-vehicle collisions at 3ST, SG, 4ST, and 4SG intersections of two-way arterials with five or fewer lanes, respectively.

Table 12-22. SPF Coefficients for Single-Vehicle Crashes at 2×2 Intersections with Five or Fewer Lanes

	Coefficients Used in Equation 12-29			
Intersection Type	Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	Overdispersion Parameter (k)
Total Crashes				
3ST	-6.81	0.16	0.51	1.14
3SG	-9.02	0.42	0.40	0.36
4ST	-5.33	0.33	0.12	0.65
4SG	-10.21	0.68	0.27	0.36
FI Crashes				
3ST				
3SG	-9.75	0.27	0.51	0.24
4ST				
4SG	-9.25	0.43	0.29	0.09
PDO Crashes				
3ST	-8.36	0.25	0.55	0.29
3SG	-9.08	0.45	0.33	0.53
4ST	-7.04	0.36	0.25	0.54
4SG	-11.34	0.78	0.25	0.44

Note: Where no models are available, Equation 12-32 is used.

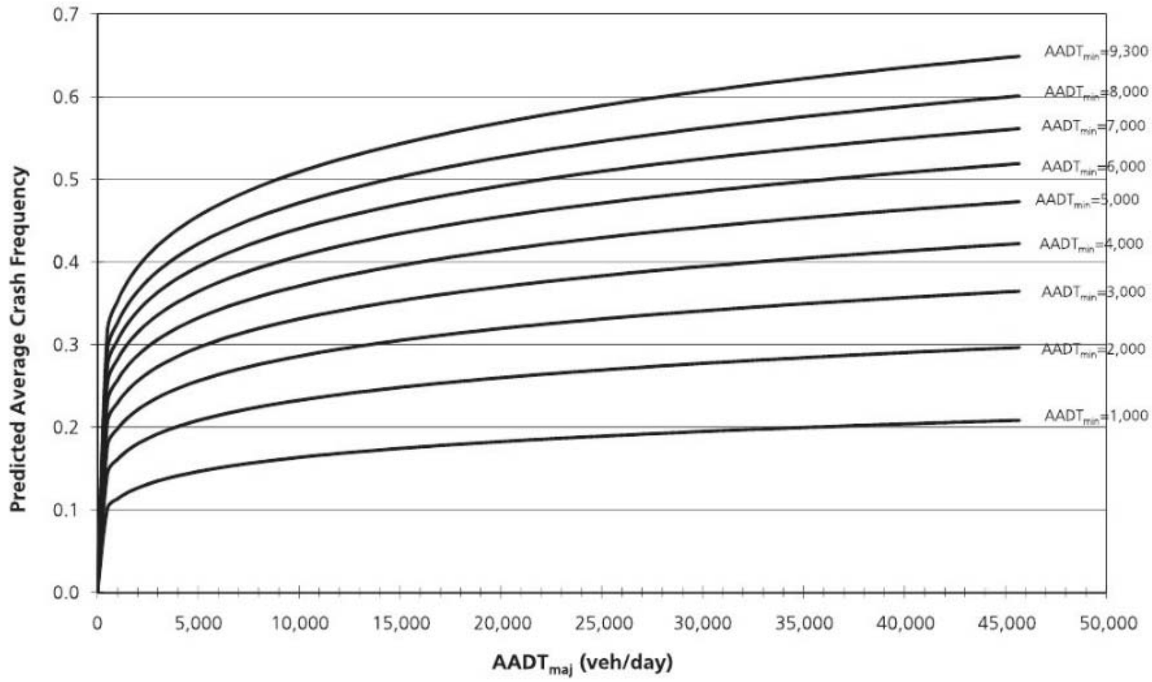

Figure 12-18. Graphical Form of the SPF for Intersection-Related Single-Vehicle Crashes at 3ST Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-29 and Table 12-22)

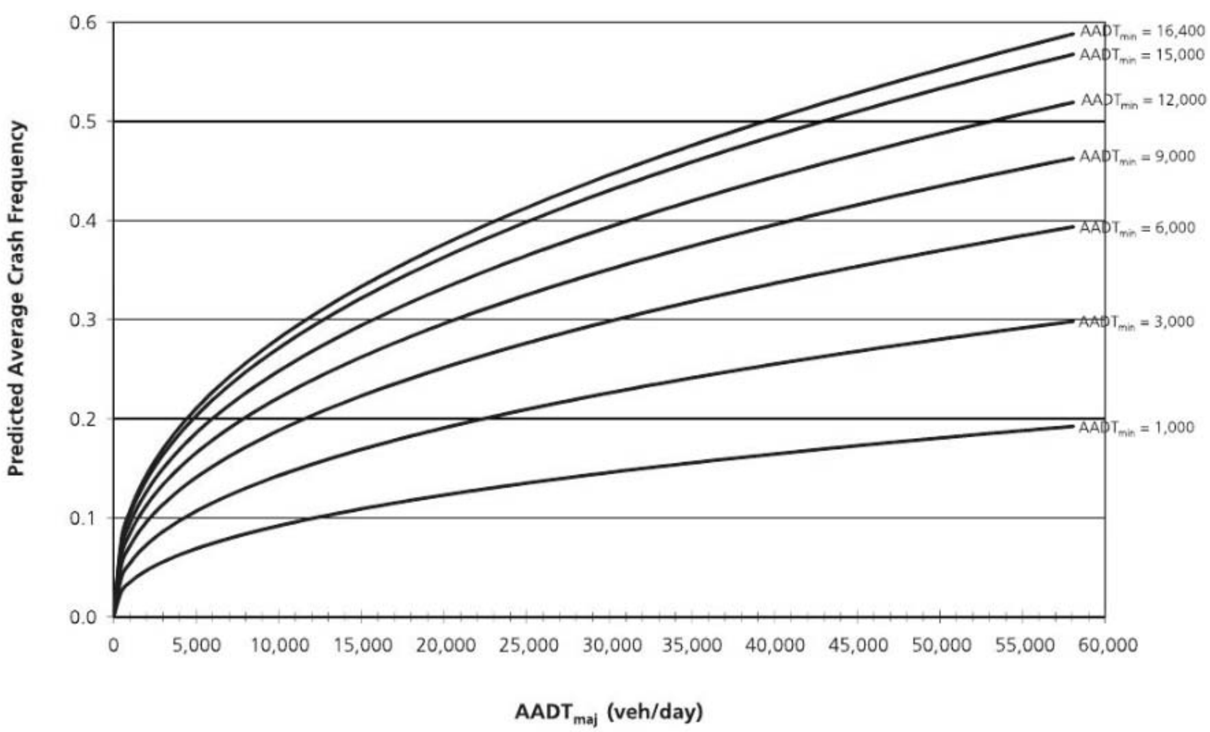

Figure 12-19. Graphical Form of the SPF for Intersection-Related Single-Vehicle Crashes at 3SG Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-29 and Table 12-22)

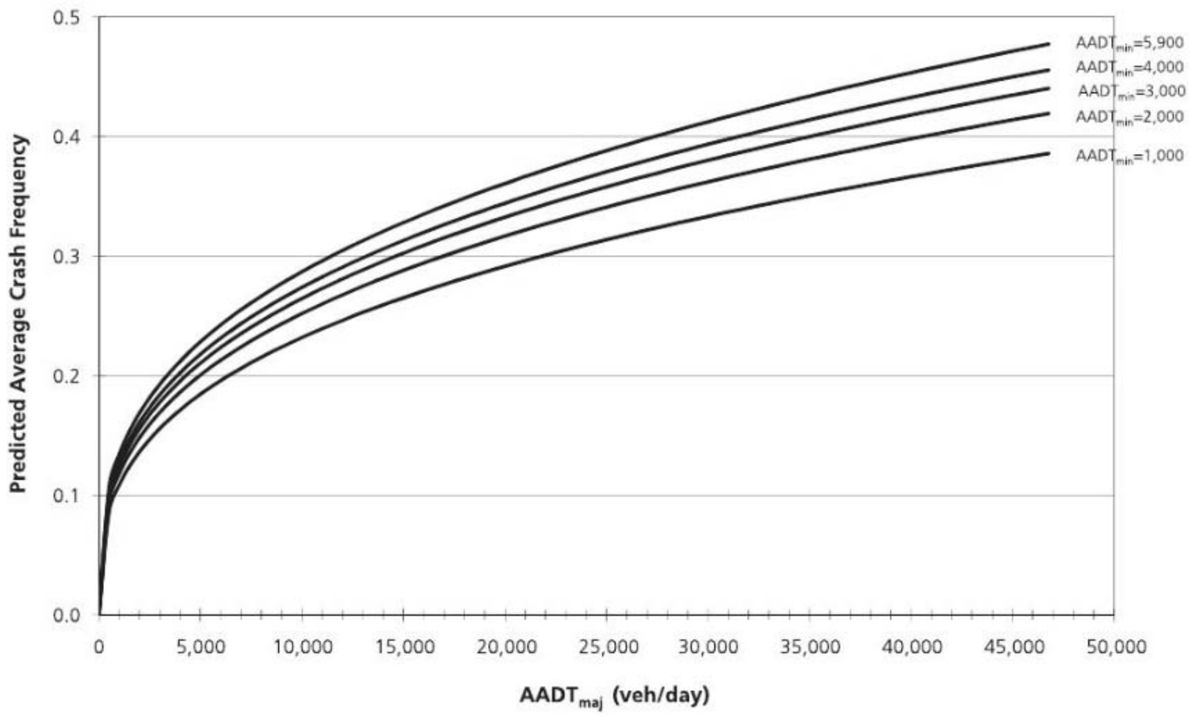

Figure 12-20. Graphical Form of the SPF for Intersection-Related Single-Vehicle Crashes at 4ST Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-29 and Table 12-22)

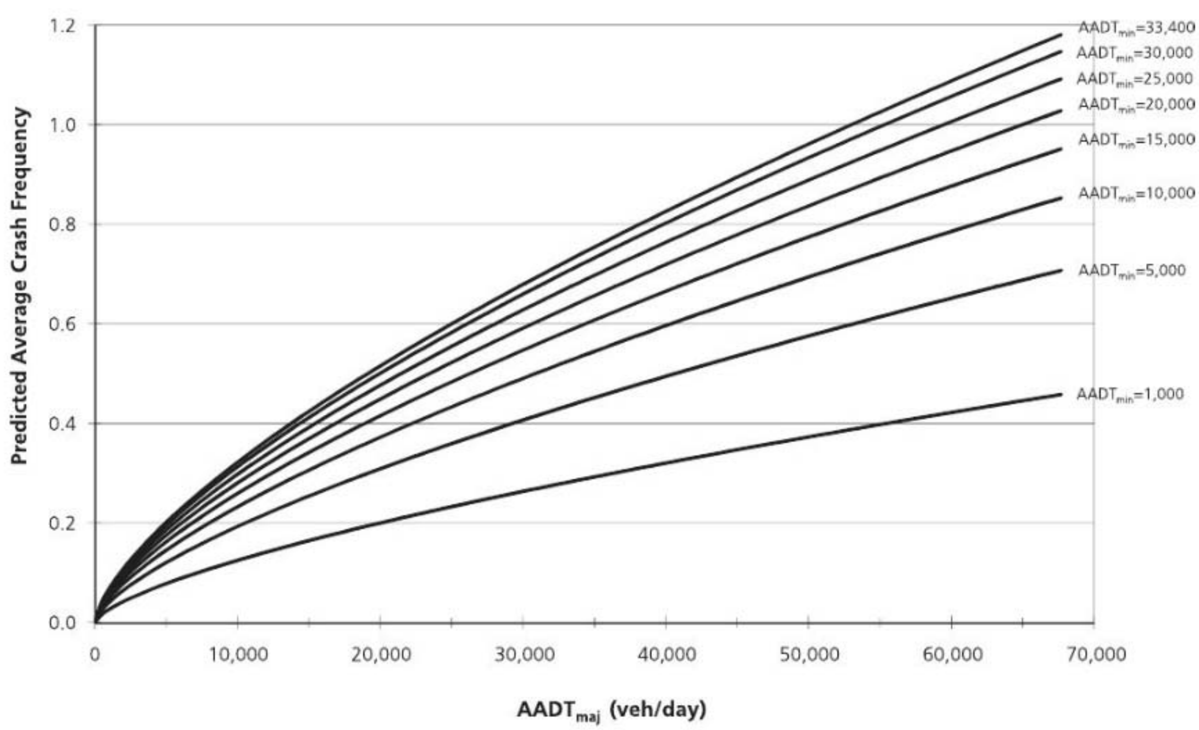

Figure 12-21. Graphical Form of the SPF for Intersection-Related Single-Vehicle Crashes at 4SG Intersections of Two-Way Arterials with Five or Fewer Lanes (from Equation 12-29 and Table 12-22)

Equation 12-29 is first applied to determine $N_{spf\ int\ sv}$ using the coefficients for total crashes in Table 12-22. $N_{spf\ int\ sv}$ is then divided into components by crash severity level, $N_{spf\ int\ sv(FI)}$for FI crashes and $N_{spf\ int\ sv(PDO)}$ for PDO crashes. These preliminary values of $N_{spf\ int\ sv(FI)}$ and $N_{spf\ int\ sv(PDO)}$, designated as $N'_{spf\ int\ sv(FI)}$ and $N'_{spf\ int\ sv(PDO)}$ in Equation 12-30, are determined with Equation 12-29 using the coefficients for FI and PDO crashes, respectively, in Table 12-22. The adjustments in Equations 12-30 and 12-31 are then made to assure that $N_{spf\ int\ sv(FI)}$ and $N_{spf\ int\ sv(PDO)}$ sum to $N_{spf\ int\ sv}$.

$$N_{spf int\,sv(FI)} = N_{spf\ int\,sv(total)}\left(\frac{N'_{spf\ int\,sv(FI)}}{N'_{spf\ int\,sv(FI)}+N'_{spf\ int\,sv(PDO)}}\right) \quad (12\text{-}30)$$

$$N_{spf\ int\,sv(PDO)} = N_{spf\ int\,sv(total)} - N_{spf\ int\,sv(FI)} \quad (12\text{-}31)$$

The proportions in Table 12-23 are used to separate $N_{spf\ int\ sv(FI)}$ and $N_{spf\ int\ sv(PDO)}$ into components by crash type.

Table 12-23. Distribution of Single-Vehicle Crashes by Manner of Collision for 2×2 Intersections with Five or Fewer Lanes

	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3ST		3SG		4ST		4SG	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with parked vehicle	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001
Collision with animal	0.003	0.018	0.001	0.003	0.001	0.026	0.002	0.002
Collision with fixed object	0.762	0.834	0.653	0.895	0.679	0.847	0.744	0.870
Collision with other object	0.090	0.092	0.091	0.069	0.089	0.070	0.072	0.070
Other single-vehicle collisions	0.039	0.023	0.045	0.018	0.051	0.007	0.040	0.023
Noncollision crashes	0.105	0.030	0.209	0.014	0.179	0.049	0.141	0.034

Source: HSIS data for California (2002-2006)

Since there are no models for FI crashes at 3ST and 4ST intersections in Table 12-22, Equation 12-30 is replaced with Equation 12-32 in these cases.

$$N_{spf\ int\ sv(FI)} = N_{spf\ int\ sv(\mathrm{total})} \times f_{bisv} \quad (12\text{-}32)$$

Where:

f_{bisv} = proportion of FI crashes for combined sites.

The default values of f_{bisv} in Equation 12-32 is 0.31 for 3ST and 0.28 for 4ST intersections. It is recommended that these default values be updated based on locally available data.

12.6.2.2. SPFs for Collisions (Other than Vehicle-Pedestrian or Vehicle-Bicycle) on Intersections of Two-Way Arterials with Six or More Lanes and Intersections of One-Way Arterials

For intersections of two-way arterials with six or more lanes and intersections of one-way arterials, a single SPF is used to predict multiple-vehicle collisions and single-vehicle crashes (i.e., all crashes other than vehicle-pedestrian and vehicle-bicycle).

The SPF for multiple-vehicle and single-vehicle intersection-related collisions is applied using Equation 12-33.

$$N_{spf\ int\ mv+sv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{\min})) \quad (12\text{-}33)$$

Table 12-24 presents the values of the coefficients a, b, and c used in Equation 12-33 for each intersection type. The overdispersion parameter, k, is also presented in Table 12-24. The value of the overdispersion parameter associated with the SPF is determined using Equation 12-34. For special cases where only one leg of a 4-leg intersection is characterized as one-way, it is suggested to apply the models for 1×2 and 2×2 (six or more lanes) and compute the average.

$$k = \frac{1}{d} \tag{12-34}$$

Where:

d = regression coefficient from Table 12-24.

Figure 12-22 through Figure 12-25 present the graphical form of the SPF for intersection-related multiple-vehicle and single-vehicle collisions at 3ST, SG, 4ST, and 4SG intersections of two-way arterials with six or more lanes, respectively.

Table 12-24. SPF Coefficients for Multiple-Vehicle and Single-Vehicle Collisions at 2×2 Intersections with Six or More Lanes, 1×2, and 1×1 intersections

		Coefficients Used in Equation 12-33 and 12-34			
Intersection Type	**Intersection Category**	**a**	**b**	**c**	**d**
FI Crashes					
3ST	1×1	-9.22	0.65	0.11	0.50
	1×2	-9.12	0.65	0.11	0.50
	2×2 with 6 or more lanes	-15.03	1.09	0.53	1.54
3SG	1×1	-11.31	0.59	0.56	1.05
	1×2	-11.21	0.59	0.56	1.05
	2×2 with 6 or more lanes	-7.11	0.65	0.16	1.93
4ST	1×1	-10.93	0.67	0.41	1.88
	1×2	-10.83	0.67	0.41	1.88
	2×2 with 6 or more lanes	-10.08	0.58	0.60	1.67
4SG	1×1	-5.57	0.18	0.37	0.75
	1×2	-5.47	0.18	0.37	0.75
	2×2 with 6 or more lanes	-4.63	0.36	0.27	1.77
PDO Crashes					
3ST	1×1	-17.99	1.53	0.31	0.97
	1×2	-17.60	1.53	0.31	0.97
	2×2 with 6 or more lanes	-14.97	1.35	0.15	1.34
3SG	1×1	-7.46	0.49	0.35	1.11
	1×2	-7.07	0.49	0.35	1.11
	2×2 with 6 or more lanes	-5.07	0.47	0.14	1.00
4ST	1×1	-12.46	0.86	0.51	1.04
	1×2	-12.06	0.86	0.51	1.04
	2×2 with 6 or more lanes	-12.01	0.67	0.75	0.88
4SG	1×1	-6.31	0.38	0.36	0.50
	1×2	-5.92	0.38	0.36	0.50
	2×2 with 6 or more lanes	-3.77	0.27	0.27	1.01

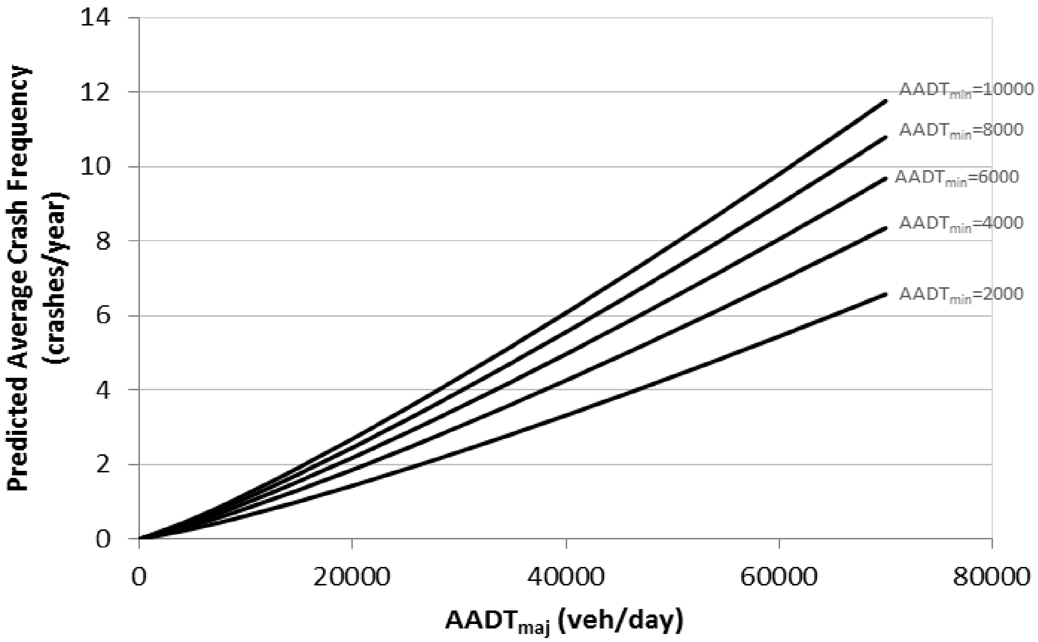

Figure 12-22. Graphical form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 3ST Intersections of Two-Way Arterials with Six or More Lanes (from Equation 12-33 and Table 12-24)

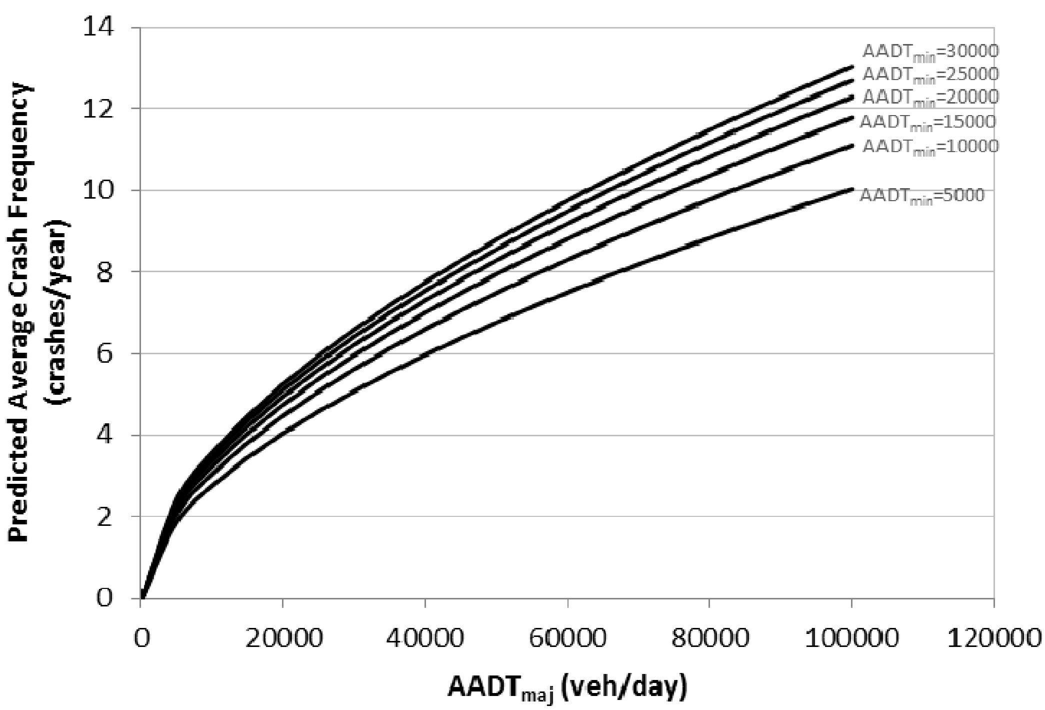

Figure 12-23. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 3SG Intersections of Two-Way Arterials with Six or More Lanes (from Equation 12-33 and Table 12-24)

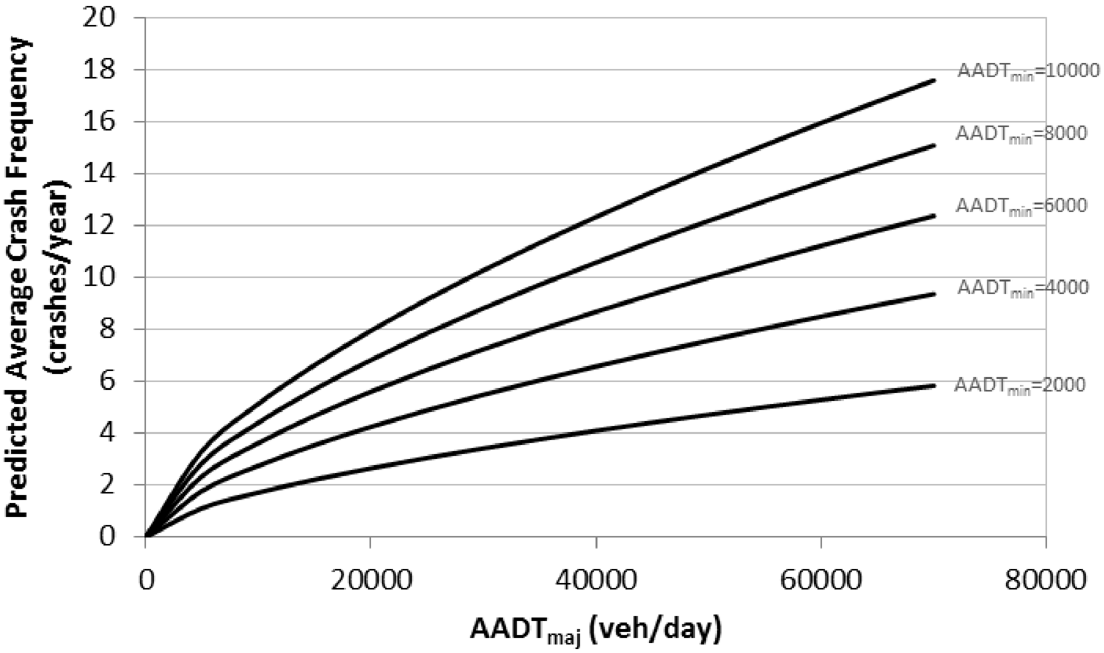

Figure 12-24. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 4ST Intersections of Two-Way Arterials with Six or More Lanes (from Equation 12-33 and Table 12-24)

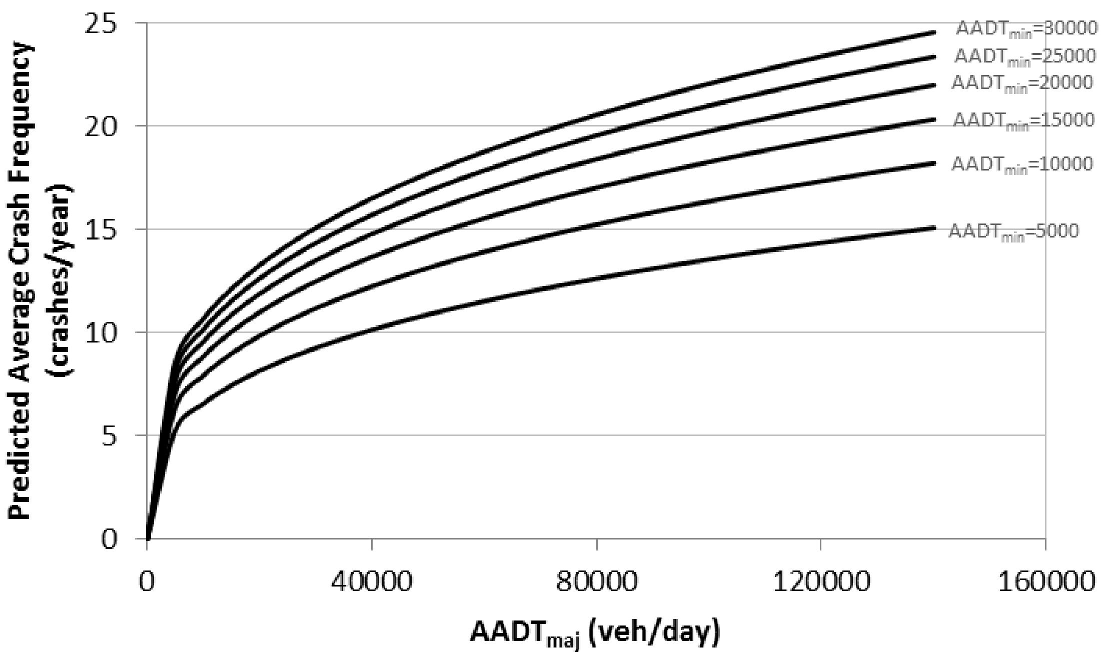

Figure 12-25. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 4SG Intersections of Two-Way Arterials with Six or More Lanes (from Equation 12-33 and Table 12-24)

The proportions in Table 12-25 are used to separate $N_{bi(FI)}$ and $N_{bi(PDO)}$ into components by manner of collision for 2×2 intersections with six or more lanes.

Table 12-25. Distribution of Multiple-Vehicle and Single-Vehicle Crashes by Manner of Collision for 2×2 Intersections with Six or More Lanes

	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3ST		3SG		4ST		4SG	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Head-on collision	0.043	0.023	0.056	0.034	0.030	0.012	0.093	0.046
Angle collision	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552
Sideswipe	0.052	0.120	0.063	0.149	0.055	0.122	0.038	0.171
Other multiple-vehicle	0.021	0.012	0.028	0.000	0.024	0.024	0.029	0.022
Single-vehicle crashes	0.026	0.062	0.056	0.074	0.006	0.037	0.012	0.061

Source: HSIS data for California (2006-2010)

Figure 12-26 through Figure 12-29 present the graphical form of the SPF for intersection-related multiple-vehicle and single-vehicle collisions at 1×2 Intersections of 3ST, SG, 4ST, and 4SG type, respectively.

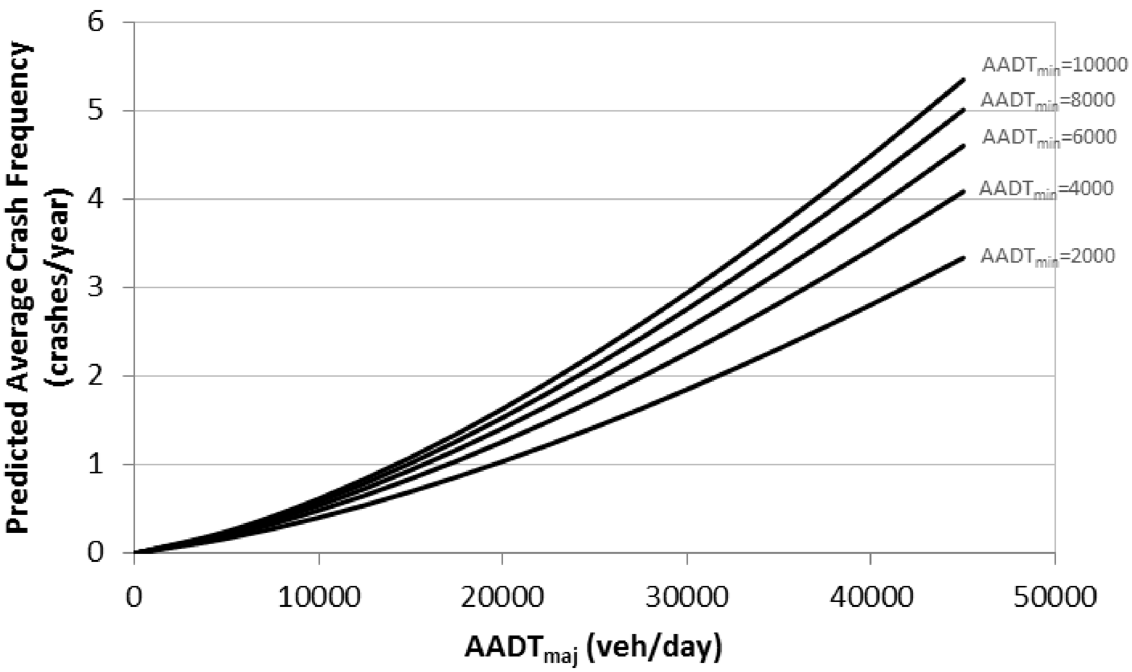

Figure 12-26. Graphical form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 1×2 3ST Intersections (from Equation 12-33 and Table 12-24)

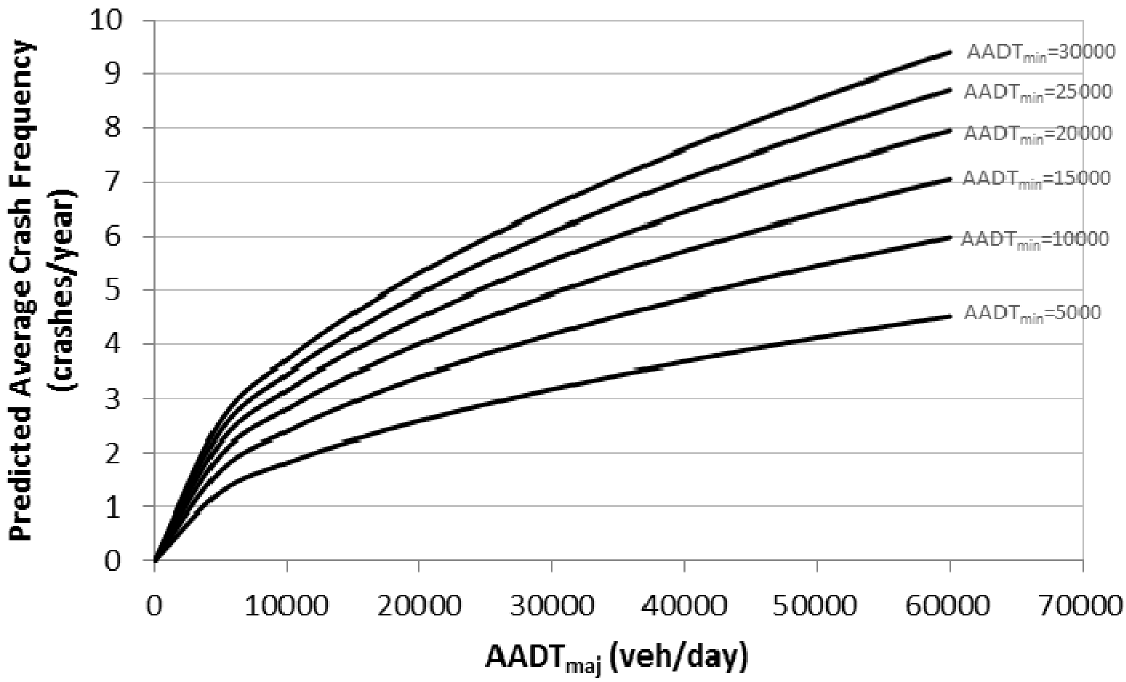

Figure 12-27. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 1×2 3SG Intersections (from Equation 12-33 and Table 12-24)

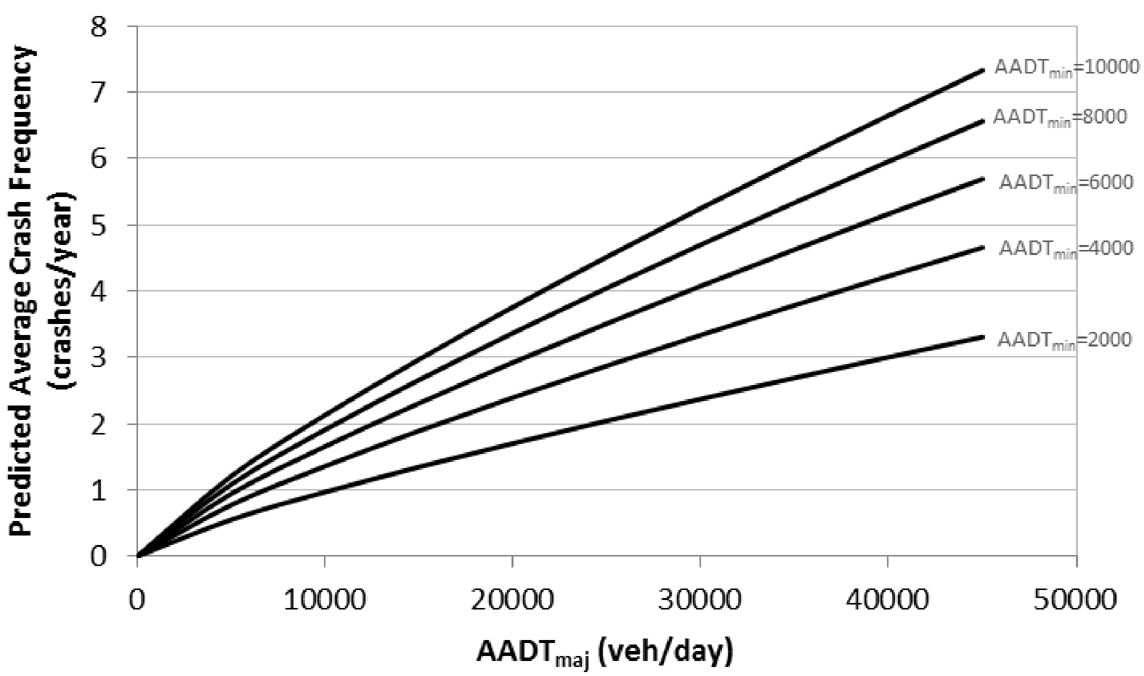

Figure 12-28. Graphical form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 1×2 4ST Intersections (from Equation 12-33 and Table 12-24)

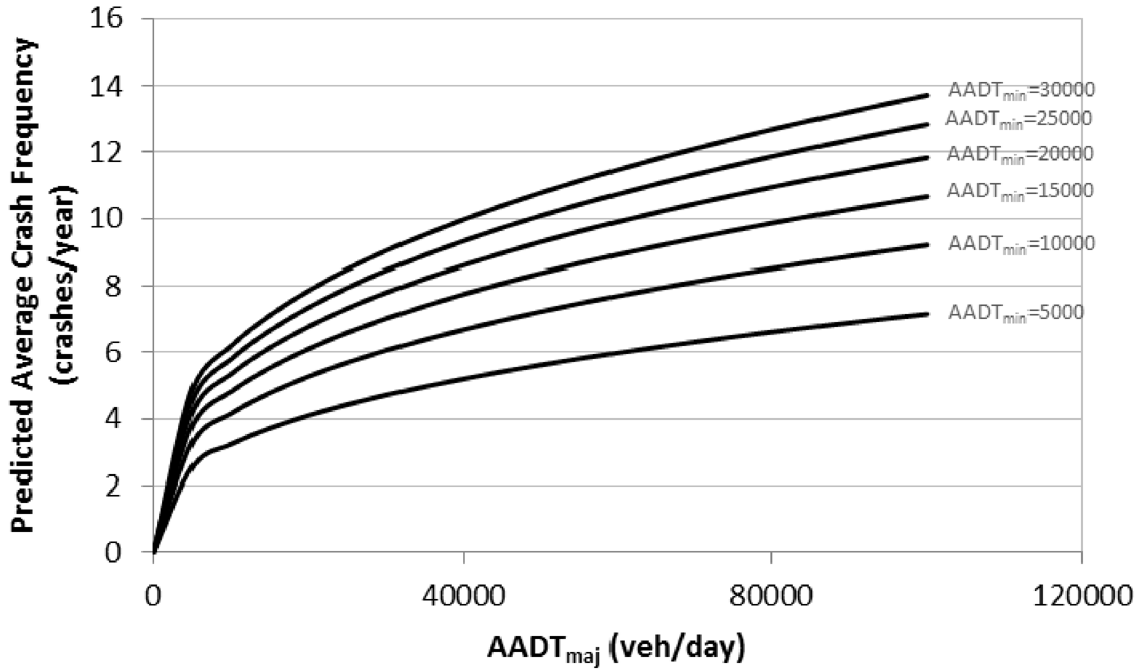

Figure 12-29. Graphical Form of the SPF for Intersection-Related Multiple-Vehicle and Single-Vehicle Crashes at 1×2 4SG Intersections (from Equation 12-33 and Table 12-24)

The proportions in Table 12-26 are used to separate $N_{bi(FI)}$ and $N_{bi(PDO)}$ into components by manner of collision for 1×2 and 1×1 intersections.

Table 12-26. Distribution of Multiple-Vehicle and Single-Vehicle Crashes by Manner of Collision for 1×2 or 1×1 Intersections

	Proportion of Crashes by Severity Level for Specific Intersection Types							
	3ST		3SG		4ST		4SG	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Head-on collision	0.000	0.000	0.000	0.000	0.028	0.020	0.039	0.030
Angle collision	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733
Sideswipe	0.400	0.350	0.000	0.214	0.075	0.157	0.059	0.145
Other multiple-vehicle	0.100	0.050	0.000	0.071	0.009	0.013	0.030	0.012
Single-vehicle crashes	0.100	0.250	0.000	0.000	0.019	0.039	0.006	0.021

Source: HSIS data for California (2006-2010)

12.6.2.3. SPFs for Vehicle-Pedestrian Collisions on Arterial Intersections

Separate SPFs are provided for estimation of the number of vehicle-pedestrian collisions at signalized and unsignalized intersections.

SPFs for Signalized Intersections

The number of vehicle-pedestrian collisions per year at a signalized intersection is estimated with a SPF and a set of CMFs that apply specifically to vehicle-pedestrian collisions. The model for estimating vehicle-pedestrian collisions at signalized intersections is presented by Equation 12-35.

$$N_{pedi} = N_{pedbase} \times (CMF_{1p} \times CMF_{2p} \times CMF_{3p}) \tag{12-35}$$

Where:

$N_{pedbase}$ = predicted average crash frequency of vehicle-pedestrian collisions per year at an individual signalized intersection for base conditions; and

$CMF_{1p} \ldots CMF_{3p}$ = crash modification factors for vehicle-pedestrian collisions at signalized intersections.

The SPF for vehicle-pedestrian collisions at signalized intersections is presented in Equation 12-36.

$$N_{pedbase} = \exp\left(a + b \times \ln(AADT_{\text{total}}) + c \times \ln\left(\frac{AADT_{low}}{AADT_{high}}\right) + d \times \ln(PedVol) + e \times n_{lanesx} \right) \tag{12-36}$$

Where:

$AADT_{high}$ = average daily traffic volumes (vehicles per day) of the intersecting road with the greater AADT

$AADT_{low}$ = sum of the average daily traffic volumes (vehicles per day) of the intersecting road with the lower AADT

$AADT_{total}$ = sum of the average daily traffic volumes (vehicles per day) for the two intersecting roads (=$AADT_{high}$ + $AADT_{low}$);

$PedVol$ = sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs;

n_{lanesx} = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands; and

a, b, c, d, e = regression coefficients.

For 2×2 and 1×1 intersections, $AADT_{high}$ and $AADT_{low}$ always correspond to $AADT_{maj}$ and $AADT_{min}$, respectively. For 1×2 intersections, however, if the major (i.e., one-way) road has lower AADT than the minor (two-way) road, $AADT_{high}$ will correspond to $AADT_{min}$ and $AADT_{low}$ to $AADT_{maj}$. Only pedestrian crossing maneuvers immediately adjacent to the intersection (e.g., at a marked crosswalk or along the extended path of any sidewalk present) are considered in determining the pedestrian volumes.

Table 12-27 presents the values of the coefficients a, b, c, d, and e used in Equation 12-36.Theese coefficients are intended for estimating total vehicle-pedestrian collisions. All vehicle-pedestrian collisions are considered to be FI crashes.

The application of Equation 12-36 requires data on the total daily pedestrian volumes crossing the intersection legs. Reliable estimates will be obtained when the value of PedVol in Equation 12-36 is based on actual pedestrian volume counts. Where pedestrian volume counts are not available, they may be estimated using Table 12-28. Replacing the values in Table 12-28 with locally derived values is encouraged.

The value of n_{lanesx} in Equation 12-36 represents the maximum number of traffic lanes that a pedestrian must cross in any crossing maneuver at the intersection. Both through and turning lanes that are crossed by a pedestrian along the crossing path are considered. If the crossing path is broken by an island that provides a suitable refuge for the pedestrian so that the crossing may be accomplished in two (or more) stages, then the number of lanes crossed in each stage is considered separately. To be considered as a suitable refuge, an island must be raised or depressed; a flush or painted island is not treated as a refuge for purposes of determining the values of n_{lanesx}.

Table 12-27. SPF Coefficients for Vehicle-Pedestrian Collisions at Signalized Intersections

	Coefficients Used in Equation 12-36					Overdispersion Parameter
	Intercept	$AADT_{total}$	$AADT_{low}/AADT_{high}$	PedVol	n_{lanesx}	
Intersection Type	**(a)**	**(b)**	**(c)**	**(d)**	**(e)**	**(k)**
Total crashes						
3SG	-6.60	0.05	0.24	0.41	0.09	0.52
4SG	-9.53	0.40	0.26	0.45	0.04	0.24

Table 12-28. Estimates of Daily Pedestrian Volume Crossing All Intersection Legs Based on General Level of Pedestrian Activity

	Estimate of PedVol (pedestrians/day) for Use in Equation 12-36	
General Level of Pedestrian Activity	**3SG Intersections**	**4SG Intersections**
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

SPFs for Stop-Controlled Intersections

The number of vehicle-pedestrian collisions per year for a stop-controlled intersection is estimated using Equation 12-37.

$$N_{pedi} = N_{bi} \times f_{pedi} \qquad (12\text{-}37)$$

Where:

f_{pedi} = pedestrian crash adjustment factor.

The value of N_{bi} in Equation 12-37 is determined using Equation 12-8.

Table 12-29 presents the values of f_{pedi} for use in Equation 12-37. All vehicle-pedestrian collisions are considered to be FI crashes. The values of f_{pedi} are likely to depend on the climate and walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-29 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-29. Pedestrian Crash Adjustment Factors for Stop-Controlled Intersections

Intersection Category	Intersection Type	Pedestrian Crash Adjustment Factor (f_{pedi})
2×2 with five or fewer lanes	3ST	0.021
	4ST	0.022
2×2 with six or more lanes	3ST	0.051
	4ST	0.049
1×2 or 1×1	3ST	0.015
	4ST	0.020

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as FI crashes and none as PDO crashes.
Source: HSIS data from California (2002-2006) for 2×2 intersections with five or fewer lanes; HSIS data from California and Illinois (2006-2010) and state data from Texas (2008-2012) and Michigan (2008-2012) for other intersection categories.

12.6.2.4. SPFs for Vehicle-Bicycle Collisions on Arterial Intersections

The number of vehicle-bicycle collisions per year for an intersection is estimated using Equation 12-38.

$$N_{bikei} = N_{bi} \times f_{bikei} \qquad (12\text{-}38)$$

Where:

f_{bikei} = bicycle crash adjustment factor.

The value of N_{bi} in Equation 12-38 is determined using Equation 12-8.

Table 12-30 presents the values for f_{bikei} for use in Equation 12-38. All vehicle-bicycle collisions are considered to be FI crashes. The values of f_{bikei} are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encourages to replaces the values in Table 12-30 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-30. Bicycle Crash Adjustment Factors for Intersections

Intersection Category	Intersection Type	Bicycle Crash Adjustment Factor (f_{bikei})
2×2 with five or fewer lanes	3ST	0.016
	3SG	0.011
	4ST	0.018
	4SG	0.015
2×2 with six or more lanes	3ST	0.048
	3SG	0.029
	4ST	0.039
	4SG	0.019
1×2 or 1×1	3ST	0.018
	3SG	0.016
	4ST	0.022
	4SG	0.012

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as FI crashes and none as PDO crashes.
Source: HSIS data from California (2002-2006) for 2×2 intersections with five or fewer lanes; HSIS data from California and Illinois (2006-2010) and state data from Texas (2008-2012) and Michigan (2008-2012) for other intersection categories.

12.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method outlined in Section 12.4, crash modification factors are applied to the SPFs selected in Step 9. The SPFs provided in Chapter 12 were presented in Section 12.6. A general overview of CMFs is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the SPFs presented in Section 12.6.

CMFs are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 12 shown in Equations 12-1 and 12-2. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has a CMF with a value greater than 1.00; any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 12 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions of the SPFs. The CMFs presented in Chapter 12 and the specific SPFs which they apply to are summarized in Table 12-31. As Table 12-31 indicates, each CMF may be applicable to certain categories of roadway segments or intersections.

Table 12-31. Summary of CMFs in Chapter 12 and the Corresponding SPFs

Applicable SPF	CMF	CMF Description	Applicable site type(s)	CMF Equations and Tables
Roadway Segments	CMF_{1r}	On-Street Parking	Two-way segments with 5- lanes[a] & One-way segments	Equation 12-39, Table 12-32
	CMF_{2r}	Roadside Fixed Objects	All roadway segments	Equations 12-40, 12-41, Table 12-33, Table 12-34
	CMF_{3r}	Median Width	All two-way segments	Table 12-35
	CMF_{4r}	Lighting	Two-way segments with 5- lanes	Equation 12-42, Table 12-36
	CMF_{5r}	Automated Speed Enforcement	All roadway segments	See text
	CMF_{6r}	Lane Width	Two-way segments with 6+ lanes[b]	Equation 12-43
	CMF_{7r}	Outside Shoulder Width	Two-way segments with 6+ lanes	Equation 12-44
	CMF_{8r}	Highway-Rail Grade Crossings	Two-way segments with 6+ lanes	Equation 12-45
	CMF_{9r}	Median Barriers	Two-way segments with 6+ lanes	Equation 12-46, Table 12-37
	CMF_{10r}	Major Industrial Driveways	Two-way segments with 6+ lanes	Equation 12-47
	CMF_{11r}	Major Commercial Driveways	Two-way segments with 6+ lanes & One-way segments	Equation 12-48, Table 12-38
	CMF_{12r}	Minor Driveways	Two-way segments with 6+ lanes & One-way segments	Equation 12-49, Table 12-39
	CMF_{13r}	Right Shoulder Width	One-way segments	Equation 12-50
Multiple-Vehicle Collisions and Single-Vehicle Crashes at Intersections	CMF_{1i}	Intersection Left-Turn Lanes	2×2 intersections with 5- lanes[c]	Table 12-40
	CMF_{2i}	Intersection Left-Turn Signal Phasing	All 2×2 intersections	Table 12-41
	CMF_{3i}	Intersection Right-Turn Lanes	2×2 intersections with 5- lanes	Table 12-42
	CMF_{4i}	Right-Turn-on-Red	All intersections	Equation 12-51
	CMF_{5i}	Lighting	All intersections	Equation 12-52, Table 12-43
	CMF_{6i}	Red-Light Cameras	All intersections	Equations 12-53, 12-54, 12-55, 12-56, 12-57
	CMF_{7i}	Number of Lanes	2×2 intersections with 6+ lanes & 1×2 and 1×1 intersections	Equations 12-58, 12-59, 12-60, Table 12-44
	CMF_{8i}	Intersection Right-Turn Channelization	2×2 intersections with 6+ lanes[d]	Equation 12-61
	CMF_{9i}	U-Turn Prohibition	2×2 intersections with 6+ lanes	Equation 12-62
Vehicle-Pedestrian Collisions at Signalized Intersections	CMF_{1p}	Bus Stops	All intersections	Table 12-45
	CMF_{2p}	Schools	All intersections	Table 12-46
	CMF_{3p}	Alcohol Sales Establishments	All intersections	Table 12-47

[a] five or fewer lanes
[b] six or more lanes
[c] intersections of two-way arterials where both intersecting arterials have five or less through lanes
[d] intersections of two-way arterials where at least one of the intersecting arterials has six or more lanes

12.7.1. Crash Modification Factors for Roadway Segments

The effects of individual geometric design and traffic control features of urban and suburban arterial roadway segments are represented in the predictive models by CMFs. These CMFs are determined in Step 10 of the predictive method and used in Equation 12-4 to adjust the SPF for urban and suburban arterial roadway segments to account for differences between the base condition and the local site conditions.

CMF_{1r}—On-Street Parking

For roadway segments with five or fewer lanes, the CMF for on-street parking, where present, is based on research by Bonneson (1). For one-way roadway segments, the CMF is based on research by Lord et al. (11). This CMF does not apply to arterials with six or more lanes. The base condition for this CMF is the absence of on-street parking on the roadway segment. The CMF for on-street parking is determined using Equation 12-39.

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0) \qquad (12\text{-}39)$$

Where:

CMF_{1r} = crash modification factor for the effect of on-street parking;

f_{pk} = factor from Table 12-32;

p_{pk} = proportion of curb length with on-street parking = ($0.5\ L_{pk}/L$);

L_{pk} = sum of curb length with on-street parking for both sides of the road combined (miles); and

L = length of roadway segment (miles).

The CMF for on-street parking applies to all collision types other than vehicle-pedestrian and vehicle-bicycle.

The sum of curb length with on-street parking (L_{pk}) can be determined from field measurements or video log review to verify parking regulations. Estimates can be made by deducting from twice the roadway segment length allowances for intersection widths, crosswalks, and driveway widths.

Table 12-32. Values of f_{pk} Used in Determining the CMF for On-Street Parking

	Type of Parking and Land Use			
	Parallel Parking		Angle Parking	
Roadway Segment Type	Residential/Other	Commercial or Industrial/Institution	Residential/Other	Commercial or Industrial/Institutiona
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999
2O	1.112		4.364	
3O	1.359		4.364	
4O	1.359		4.364	

CMF_{2r}—Roadside Fixed Objects

The CMF for roadside fixed objects is applicable to all roadway segment types. However, when applied to roadway segments with six or more lanes and one-way roadway segments, this CMF has a different form and application than when applied to roadway segments with five or fewer lanes, as described below. For all roadway segment types, the base condition for this CMF is the absence of roadside fixed objects on the roadway segment.

For roadway segments with five or fewer lanes, the CMF for roadside fixed objects has been adapted from the work of Zeeger and Cynecki (16) on predicting utility pole crashes and is determined using Equation 12-40.

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo}) \qquad (12\text{-}40)$$

Where:

CMF_{2r} = crash modification factor for the effect of roadside fixed objects;

f_{offset} = fixed-object offset factor from Table 12-33;

D_{fo} = fixed-object density (fixed objects/mi) for both sides of the road combined; and

p_{fo} = fixed-object collisions as a proportion of total crashes from Table 12-34.

For roadway segments with five or fewer lanes, the CMF for roadside fixed objects applies to all collision types other than vehicle-pedestrian and vehicle-bicycle.

For roadway segments with six or more lanes and one-way roadway segments, the CMF is based on research by Lord et al. (11) and determined using Equation 12-41.

$$CMF_{2r} = f_{offset} \times D_{fo} \times 0.01 + 1.0 \quad (12\text{-}41)$$

The value of f_{offset} is determined from Table 12-33. For roadway segments with six or more lanes, the CMF for roadside fixed objects applies only to single-vehicle crashes.

For all roadway segment types, if the computed value of CMF_{2r} is less than 1.00, it is set equal to 1.00. This can only occur for very low fixed object densities. In estimating the density of fixed objects (D_{fo}), only point objects that are 4 inches or more in diameter and do not have breakaway design are considered. Point objects that are within 70 ft of one another longitudinally along the road are counted as a single object. Continuous objects that are not behind point objects are counted as one point object for each 70 ft of length. The offset distance (O_{fo}) shown in Table 12-33 is an estimate of the average distance from the edge of the traveled way to roadside objects over an extended roadway segment. If the average offset to fixed objects exceeds 30 ft, use the value of offset for 30 ft. Only fixed objects on the roadside on the right side of the roadway in each direction of travel are considered; fixed objects in the roadway median on divided arterials are not considered.

Table 12-33. Fixed-Object Offset Factor

	Fixed-Object Offset Factor (f_{offset})		
	Two-Way Roadway Segments		One-Way Roadway Segments
Offset to Fixed Objects (O_{fo}) (ft)	Five or Fewer Lanes	Six or More Lanes	
2	0.232	0.770	0.829
5	0.133	0.519	0.626
10	0.087	0.270	0.391
15	0.068	0.140	0.245
20	0.057	0.073	0.153
25	0.049	0.038	0.096
30	0.044	0.020	0.060

Table 12-34. Proportion of Fixed-Object Collisions for Roadway Segments with Five or Fewer Lanes

Roadway Segment Type	Proportion of Fixed-Object Collisions (p_{fo})
2U	0.059
3T	0.034
4U	0.037
4D	0.036
5T	0.016

Note: replacement of the proportions in this table with locally derived values is encouraged.

CMF_{3r}—Median Width

The CMF for median width on divided roadway segments of urban and suburban arterials is presented in Table 12-35. For 4D roadway segments, the CMF is based on the work of Harkey et al. (6). For 6D and 8D roadway segments, the CMF is based on the work of Lord et al. (11). The base condition for this CMF is a median width of 15ft. The CMF applies to all collision types other than vehicle-pedestrian and vehicle-bicycle, and represents the effect of median width in reducing cross-median collisions. The CMF for 4D roadway segments in Table 12-35 has been adapted from the CMF in Table 13-12 based on the estimate by Harkey et al. (6) that cross-median collisions represent 12.0 percent of crashes on divided arterials and the assumption that nonintersection collision types other than cross-median collisions are not affected by median width.

This CMF applies only to traversable medians without traffic barriers; it is not applicable to medians serving as TWLTLs (a CMF for TWLTLs is provided in Chapter 16). The effect of traffic barriers on safety would be expected to be a function of barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified for roadway segments with five or fewer lanes. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers for arterials with five or fewer lanes. For arterials with six or more lanes, CMF_{9r} accounts for the effect of median barrier on multiple-vehicle collisions and single-vehicle crashes.

The value of the CMF for median width is 1.00 for undivided facilities.

Table 12-35. CMFs for Median Widths on Divided Roadway Segments without a Median Barrier (CMF_{3r})

	CMF_{3r}	
Median Width (ft)	**4D**	**6D or 8D**
10	1.01	1.03
15	1.00	1.00
20	0.99	0.97
30	0.98	0.92
40	0.97	0.87
50	0.96	0.82
60	0.95	0.77
70	0.94	0.73
80	0.93	0.69
90	0.93	0.65
100	0.92	0.62

CMF_{4r}—Lighting

The CMF for lighting is applicable only to roadway segments with five or fewer lanes. The base condition for lighting is the absence of roadway segment lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (3), using Equation 12-42.

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})) \quad (12\text{-}42)$$

Where:

CMF_{4r} = crash modification factor for the effect of roadway segment lighting;

p_{inr} = proportion of total nighttime crashes for unlighted roadway segments that involve a fatality or injury;

p_{pnr} = proportion of total nighttime crashes for unlighted roadway segments that involve property damage only; and

p_{nr} = proportion of total crashes for unlighted roadway segments that occur at night.

This CMF applies to all collision types other than vehicle-pedestrian and vehicle-bicycle. Table 12-36 presents default values for the nighttime crash proportions p_{nr}, p_{inr}, and p_{pnr}. Replacement of the estimates in Table 12-36 with locally derived values is encouraged. If lighting installation increases the density of roadside fixed objects, the value of CMF_{2r} is adjusted accordingly.

Table 12-36. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Segment Type	**FI p_{inr}**	**PDO p_{pnr}**	**p_{nr}**
2U	0.424	0.576	0.316
3T	0.429	0.571	0.304
4U	0.517	0.483	0.365
4D	0.364	0.636	0.410
5T	0.432	0.568	0.274

CMF_{5r}—Automated Speed Enforcement

The CMF for automated speed enforcement applies to all roadway segment types and all collision types (other than vehicle-pedestrian and vehicle-bicycle). Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The base condition for automated speed enforcement is that it is absent. Chapter 17 presents a CMF of 0.83 for the reduction of all types of FI crashes from implementation of automated speed enforcement. This CMF is assumed to apply to roadway segments between intersections with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of the CMF for automated speed enforcement would be 0.95.

CMF_{6r}—Lane Width

The CMF for lane width is applicable only to two-way arterials with six or more lanes. The CMF is based on research by Lord et al. (11) and applies to all collision types (other than vehicle-pedestrian and vehicle-bicycle). The base condition for lane width is 12 ft. Where the lane width varies between the two directions of travel on a roadway segment, the average lane width is computed and used to determine the CMF. The CMF for lane width is determined using Equation 12-43.

$$CMF_{6r} = e^{-0.0219(W_l - 12)} \quad (12\text{-}43)$$

Where:

CMF_{6r} = crash modification factor for the effect of lane width; and

W_l = lane width (ft).

CMF_{7r}—Outside Shoulder Width

The CMF for outside shoulder width is applicable only to two-way arterials with six or more lanes. Outside shoulder width refers to the width of the right shoulders in each direction of travel on a two-way arterial. The CMF is based on research by Lord et al. (11) and applies to all collision types (other than vehicle-pedestrian and vehicle-bicycle). The base condition for outside shoulder width is 1.5 ft. Where the right shoulder width varies between the two directions of travel on a roadway segment, the average shoulder width is computed and used to determine the CMF. The CMF for outside shoulder width is determined using Equation 12-44.

$$CMF_{7r} = e^{-0.0285(W_{os} - 1.5)} \quad (12\text{-}44)$$

Where:

CMF_{7r} = crash modification factor for the effect of outside shoulder width; and

W_{os} = outside shoulder width (ft).

CMF_{8r}—Highway-Rail Grade Crossings

The CMF for highway-rail grade crossings is applicable only to roadway segment with six or more lanes. The CMF captures the safety impact of highway-rail grade crossings within a roadway segment. This CMF is based on research by Lord et al. (11) and applies to all collision types (other than vehicle-pedestrian and vehicle-bicycle). The base condition is no highway-rail grade crossings within a roadway segment. The CMF for highway-rail grade crossings is determined using Equation 12-45.

$$CMF_{8r} = e^{\left(0.0388 \times \frac{n_{hrx}}{L}\right)} \qquad (12\text{-}45)$$

Where:

CMF_{8r} = crash modification factor for the effect of highway-rail grade crossings; and

n_{hrx} = number of highway-rail grade crossings within the roadway segment.

CMF_{9r}—Median Barriers

The CMF for median barriers is based on research by Lord et al. (11) and is applicable only to cable barriers, concrete barriers, and guardrails on roadway segments with six or more lanes. The base condition is a median with no barrier. The CMF for median barriers is determined using Equation 12-46.

$$CMF_{9r} = e^{(a \times I_{bar})} \qquad (12\text{-}46)$$

Where:

CMF_{9r} = crash modification factor for the effect of median barriers; and

I_{bar} = indicator variable representing the presence of median barrier (=1 if barrier is present; 0 otherwise).

The regression coefficient for Equation 12-46 is provided in Table 12-37. The CMF for median barrier applies to both multiple-vehicle and single-vehicle crashes but, unlike other CMFs in Chapter 12, it takes different values when applied to multiple-vehicle and single-vehicle crashes. As the coefficient values in Table 12-37 suggest, presence of median barriers is expected to reduce the average crash frequency of multiple-vehicle collisions while increasing the average crash frequency of single-vehicle crashes.

Table 12-37. Coefficient for Median Barrier CMF

Collision Type	Regression Coefficient (a)
Multiple-vehicle	-0.5106
Single-vehicle	0.6766

CMF_{10r}—Major Industrial Driveways

The CMF for major industrial driveways is applicable only to roadway segments with six or more lanes. This CMF is based on research by Lord et al. (11) and only applies to multiple-vehicle collisions. The base condition is one major industrial driveway per mile. The CMF for major industrial driveways is determined using Equation 12-47.

$$CMF_{10r} = e^{0.0107\left(\frac{n_{id}}{L} - 1\right)} \qquad (12\text{-}47)$$

Where:

CMF_{10r} = crash modification factor for the effect of major industrial driveways; and

n_{id} = number of major industrial driveways within the roadway segment.

CMF_{11r}—Major Commercial Driveways

The CMF for major commercial driveways is applicable only to roadway segments with six or more lanes and one-way roadway segments. This CMF is based on research by Lord et al. (11) and only applies to multiple-vehicle collisions. The base condition is two major commercial driveways per mile. The CMF for major industrial driveways is determined using Equation 12-48.

$$CMF_{11r} = e^{a\left(\frac{n_{cd}}{L}-2\right)} \quad (12\text{-}48)$$

Where:

CMF_{11r} = crash modification factor for the effect of major commercial driveways; and

n_{cd} = number of major commercial driveways within the roadway segment.

The regression coefficient for Equation 12-48 is provided in Table 12-38.

Table 12-38. Coefficient for Major Commercial Driveway CMF

Roadway Segment Type	Regression Coefficient (*a*)
Two-way with six or more lanes	0.0350
One-way	0.0177

CMF_{12r}—Minor Driveways

The CMF for minor driveways is applicable only to roadway segments with six or more lanes and one-way roadway segments. This CMF is based on research by Lord et al. (11) and only applies to multiple-vehicle collisions. The base condition is 10 minor driveways per mile. The CMF for major industrial driveways is determined using Equation 12-49.

$$CMF_{12r} = e^{a\left(\frac{n_{mnd}}{L}-10\right)} \quad (12\text{-}49)$$

Where:

CMF_{12r} = crash modification factor for the effect of minor driveways; and

n_{mnd} = number of minor driveways within the roadway segment.

The regression coefficient for Equation 12-49 is provided in Table 12-39.

Table 12-39. Coefficient for Minor Driveways CMF

Roadway Segment Type	Regression Coefficient (*a*)
Two-way with six or more lanes	0.0054
One-way	0.0046

CMF_{13r}—Right Shoulder Width

The CMF for right shoulder width is applicable only to one-way roadway segments. The base condition for right shoulder width is 4 ft. The CMF is based on research by Lord et al. (11) and applies to all collision types (other than vehicle-pedestrian and vehicle-bicycle). The CMF for right shoulder width is determined using Equation 12-50.

$$CMF_{13r} = e^{-0.0201(W_{rs}-4)} \tag{12-50}$$

Where:

CMF_{13r} = crash modification factor for the effect of right shoulder width; and

W_{rs} = right shoulder width (ft).

12.7.2. Crash Modification Factors for Intersections

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by CMFs. CMF_{1i} through CMF_{9i} are applied to multiple-vehicle collisions and single-vehicle crashes at intersections, but not to vehicle-pedestrian and vehicle-bicycle collisions.

CMF_{1i}—Intersection Left-Turn Lanes

The CMF for intersection left-turn lanes is applicable only to 2×2 intersections with five or fewer lanes. The base condition for this CMF is the absence of left-turn lanes on the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 12-40. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation for left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes. There is no indication of any change in crash frequency for providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considering applying Table 12-40. The CMFs in the table apply to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle). The CMFs for installation of left-turn lanes are based on research by Harwood et al. (7). A CMF of 1.00 is always used when no left-turn lanes are present.

Table 12-40. Crash Modification Factor (CMF_{1i}) for Installation of Left-Turn Lanes on Intersection Approaches

Intersection Type	Intersection Traffic Control	Number of Approaches with Left-turn Lanes[a]			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg	Minor-road stop control[b]	0.67	0.45	—	—
	Traffic signal	0.93	0.86	0.80	—
Four-leg intersection	Minor-road stop control[b]	0.73	0.53	—	—
	Traffic signal	0.90	0.81	0.73	0.66

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes.
[b] Stop signs present on minor-road approaches only.

CMF_{2i}—Intersection Left-Turn Signal Phasing

For 2×2 intersections with five or fewer lanes, the CMF for intersection left-turn signal phasing is based on the results of work by Hauer (10), as modified in a study by Lyon et al. (12). For 2×2 intersections with six or more lanes, the CMF is based on the work by Lord et al. (11). The CMF for left-turn signal phasing is not applicable to intersections of one-way arterials (1×2 or 1×1). Types of left-turn signal phasing considered include permissive, protected, protected/permissive, and permissive/protected. Protected/permissive operation is also referred to as a leading left-turn signal phase; permissive/protected operation is also referred to as a lagging left-turn signal phase. The CMF values are presented in Table 12-41. The base condition for this CMF is permissive left-turn signal phasing. This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) and is applicable only to signalized intersections. A CMF value of 1.00 is always used for unsignalized intersections.

If several approaches to a signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.

Table 12-41. Crash Modification Factor (CMF_{2i}) for Type of Left-Turn Signal Phasing

Type of Left-Turn Signal Phasing	CMF_{2i}	
	2×2 (Five or Fewer Lanes)	2×2 (Six or More Lanes)
Permissive	1.00	1.00
Protected/permissive or permissive/protected	0.99	1.00
Protected	0.94	0.86

Note: Use CMF_{2i} = 1.00 for all unsignalized intersections. If several approaches to a signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.

CMF_{3i}—Intersection Right-Turn Lanes

The CMF for intersection right-turn lanes is applicable only to 2×2 intersections with five or fewer lanes. The base condition for this CMF is the absence of right-turn lanes on the intersection approaches. The CMFs for presence of right-turn lanes based on research by Harwood et al. (7) are presented in Table 12-42. These CMFs apply to installation of right-turn lanes on any approaches to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes. There is no indication of any change in crash frequency for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considering in applying Table 12-42.

The CMFs in Table 12-42 apply to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle). A CMF value of 1.00 is always used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

Table 12-42. Crash Modification Factor (CMF_{3i}) for Installation of Right-Turn Lanes on Intersection Approaches

Intersection Type	Type of Traffic Control	Number of Approaches with Right-Turn Lanes[a]			
		One Approach	Two Approaches	Three Approaches	Four Approaches
Three-leg intersection	Minor-road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	—	—
Four-leg intersection	Minor-road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

[a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes.
[b] Stop signs present on minor-road approaches only.

CMF_{4i}—Right-Turn-on-Red

The CMF for prohibiting right-turn-on-red on one or more approaches to a signalized intersection has been derived from a study by Clark (2) and from the CMFs for right-turn-on-red operation shown in Chapter 14. The base condition for this CMF is permitting a right-turn-on-red from all approaches to a signalized intersection. The CMF for right-turn-on-red is determined using Equation 12-51.

$$CMF_{4i} = 0.98^{(n_{prohib})} \tag{12-51}$$

Where:

CMF_{4i} = crash modification factor for the effect of prohibiting right turns on red; and

n_{prohib} = number of signalized intersection approaches for which right-turn-on-red is prohibited.

This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) and is applicable only to signalized intersections (of any category). A CMF value of 1.00 is used for unsignalized intersections.

CMF_{5i}—Intersection Lighting

The CMF for intersection lighting is applicable to all intersection types. The base condition for this CMF is the absence of intersection lighting. The CMF for lighted intersections adapted from the work of Elvik and Vaa (3) is determined using Equation 12-52.

$$CMF_{5i} = 1 - 0.38 \times p_{ni} \qquad (12\text{-}52)$$

Where:

CMF_{5i} = crash modification factor for the effect of intersection lighting; and

p_{ni} = proportion of total crashes for unlighted intersections that occur at night.

This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle). Table 12-43 presents default values for the nighttime crash proportion, p_{ni}. HSM users are encouraged to replace the estimates in Table 12-43 with locally derived values.

Table 12-43. Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night p_{ni}
3ST	0.238
4ST	0.229
3SG and 4SG	0.235

CMF_{6i}—Red Light Cameras

The CMF for red light cameras is applicable only to signalized intersections (of any category). The base condition for red light cameras is their absence. The CMF for installation of a red light camera for enforcement of red signal violations at a signalized intersection is based on an evaluation by Persaud et al. (13). As shown in Chapter 14, this study indicates a CMF for red light camera installation of 0.74 for right-angle collisions and a CMF of 1.18 for rear-end collisions. In other words, red light cameras would typically be expected to reduce right-angle collisions and increase rear-end collisions. There is no evidence that red light installation affects other collision types. Therefore, a CMF for the effect of red light camera installation on all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) can be computed using Equation 12-53.

$$CMF_{6i} = 1 - p_{ra} \times (1 - 0.74) - p_{re} \times (1 - 1.18) \qquad (12\text{-}53)$$

Where:

CMF_{6i} = crash modification factor for the effect of red light cameras at signalized intersections;

p_{ra} = proportion of crashes that are multiple-vehicle, right-angle collisions;

p_{re} = proportion of crashes that are multiple-vehicle, rear-end collisions;

For intersections of two-way arterials with five or fewer lanes, p_{ra} and p_{re} are determined using Equations 12-54 and 12-55.

$$P_{ra} = \frac{P_{ramv(FI)} \times N_{bimv(FI)} + P_{ramv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \qquad (12\text{-}54)$$

$$P_{re} = \frac{P_{remv(FI)} \times N_{bimv(FI)} + P_{remv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \quad (12\text{-}55)$$

Where:

$p_{ramv(FI)}$ = proportion of multiple-vehicle FI crashes represented by right-angle collisions;

$p_{ramv(PDO)}$ = proportion of multiple-vehicle PDO crashes represented by right-angle collisions;

$p_{remv(FI)}$ = proportion of multiple-vehicle FI crashes represented by rear-end collisions; and

$p_{remv(PDO)}$ = proportion of multiple-vehicle PDO crashes represented by rear-end collisions.

The value of $N_{bimv(FI)}$ is available from Equation 12-27, the value of $N_{bimv(PDO)}$ is available from Equation 12-28, and the value of N_{bisv} is available from Equation 12-29. The values of $p_{ramv(FI)}$, $p_{ramv(PDO)}$, $p_{remv(FI)}$, and $p_{remv(PDO)}$ can be determined from data for the applicable intersection type in Table 12-21. These values may be updated with data for a particular jurisdiction as part of the calibration process presented in Part C, Appendix A.

For intersections of two-way arterials with six or more lanes, p_{ra} and p_{re} are determined using Equations 12-56 and 12-57.

$$P_{ra} = \frac{P_{ra(FI)} \times N_{bi(FI)} + P_{ra(PDO)} \times N_{bi(PDO)}}{(N_{bi(FI)} + N_{bi(PDO)})} \quad (12\text{-}56)$$

$$P_{re} = \frac{P_{re(FI)} \times N_{bi(FI)} + P_{re(PDO)} \times N_{bi(PDO)}}{(N_{bi(FI)} + N_{bi(PDO)})} \quad (12\text{-}57)$$

Where:

$p_{ra(FI)}$ = proportion of multiple-vehicle and single-vehicle FI crashes represented by right-angle collisions;

$p_{ra(PDO)}$ = proportion of multiple-vehicle and single-vehicle PDO crashes represented by right-angle collisions;

$p_{re(FI)}$ = proportion of multiple-vehicle and single-vehicle FI crashes represented by rear-end collisions; and

$p_{re(PDO)}$ = proportion of multiple-vehicle and single-vehicle PDO crashes represented by rear-end collisions.

The values of $N_{bi(FI)}$ and $N_{bimv(PDO)}$ are available from Equation 12-33. The values of $p_{ra(FI)}$, $p_{ra(PDO)}$, $p_{re(FI)}$, and $p_{re(PDO)}$ can be determined from data for the applicable intersection type in Table 12-25 and Table 12-26. These values may be updated with data for a particular jurisdiction as part of the calibration process presented in Part C, Appendix A.

The data in Table 12-21, Table 12-25, and Table 12-26, by definition, represent average values for a broad range of signalized intersections. Because jurisdictions are likely to implement red-light cameras at intersections with higher than average proportions of right-angle collisions, it is acceptable to replace the values in with estimate based on data for a specific intersection when determining the value of the red light camera CMF.

CMF_{7i}—Number of Lanes

The CMF for the number of lanes on the intersecting arterials at an intersection is applicable only to 2×2 signalized intersections with six or more lanes and signalized intersections of one-way arterials (1×2 or 1×1). For 2×2 intersections with six or more lanes, the base condition for this CMF is six lanes on the major road and two lanes on the minor road. For 1×2 or 1×1 intersections, the base condition is two lanes on the major road and two lanes on the minor road. This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle). The CMF is based on the work of Lord et al. (11) and computed using Equations 12-58 to 12-60.

$$CMF_{7i} = (e^{a(N_{maj}-N_{maj(base)})}P_{maj} + (1-P_{maj})) \times (e^{a(N_{min}-2)}P_{min} + (1-P_{min})) \quad (12\text{-}58)$$

$$P_{maj} = \frac{AADT_{maj}}{AADT_{maj} + AADT_{min}} \quad (12\text{-}59)$$

$$P_{min} = \frac{AADT_{min}}{AADT_{maj} + AADT_{min}} \quad (12\text{-}60)$$

where,

N_{maj} = number of lanes on the major road (excluding the left-turn and right-turn lanes added at the intersection);

$N_{maj(base)}$ = number of lanes on the major road under base conditions: six for 2×2 intersections with six or more lanes, and two for 1×2 or 1×1 intersections (excluding the left-turn and right-turn lanes added at the intersection);

N_{min} = number of lanes on the minor road;

P_{maj} = proportion of AADT on the major road; and

P_{min} = proportion of AADT on the minor road.

The regression coefficient of Equation 12-58 is provided in Table 12-44.

Table 12-44. Coefficient for Number of Lanes CMF

Intersection Category	Regression Coefficient (*a*)
2×2 with six or more lanes	0.194
1×2 or 1×1	0.242

This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections.

CMF$_{8i}$—Intersection Right-Turn Channelization
The CMF for intersection right-turn channelization is applicable only to 2×2 intersections with six or more lanes. The base condition for this CMF is the absence of right-turn channelization at both approaches of the major road. The CMF for intersection right turn channelization is based on research by Lord et al. (11) and determined using Equation 12-61.

$$CMF_{8i} = e^{(0.2175 \times n_{ch})} \quad (12\text{-}61)$$

Where:

n_{ch} = number of major road approaches with channelized right turn lanes.

This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections.

CMF$_{9i}$—U-Turn Prohibition
The CMF for prohibiting U-turns on one or more approaches to a signalized intersection is applicable only to 2×2 intersections with six or more lanes. The base condition for this CMF is permitting U-turns at all approaches of a signalized intersection. The CMF for U-turn prohibition is based on research by Lord et al. (11) and determined using Equation 12-62.

$$CMF_{9i} = 0.96^{(n_{u-prohib})} \quad (12\text{-}62)$$

Where:

CMF_{9i} = crash modification factor for the effect of prohibiting U-turns; and

$n_{u\text{-}prohib}$ = number of signalized intersection approaches from which U-turn is prohibited.

This CMF applies to all intersection crash types (other than vehicle-pedestrian and vehicle-bicycle) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections.

12.7.3. Crash Modification Factors for Vehicle-Pedestrian Collisions at Signalized Intersections

The effects of major sources of pedestrian activity (i.e., bus stops, schools, alcohol sales establishments) on vehicle-pedestrian collisions at signalized intersection are represented by CMFs. CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions at signalized intersections, but not to multiple-vehicle collisions and single-vehicle crashes and not to other intersection types..

CMF_{1p}—Bus Stop

The CMFs for the number of bus stops within 1,000 ft of the center of the intersection are presented in Table 12-45. The base condition for bus stops is the absence of bus stops near the intersection. This CMF applies only to vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

Table 12-45. Crash Modification Factor (CMF_{1p}) for the Number of Bus Stops near the Intersection

Number of Bus Stops within 1,000 ft of the Intersection	CMF_{1p}
0	1.00
1 or 2	2.78
3 or more	4.15

In applying Table 12-45, multiple bus stops at the same intersection (i.e., bus stops in different intersection quadrants or located some distance apart along the same intersection leg) are counted separately. Bus stops located at adjacent intersections would also be counted as long as any portion of the bus stop is located within 1,000 ft of the intersection being evaluated.

CMF_{2p}—Schools

The base condition for school is the absence of a school near the intersection. The CMF for schools within 1,000 ft of the center of the intersection is presented in Table 12-46. A school may be counted if any portion of the school grounds is within 1,000 ft of the intersection. Where one or more schools are located near the intersection, the value of the CMF is independent of the number of schools present. This CMF applies only to vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with a school nearby is likely to experience more vehicle-pedestrian collisions than an intersection without schools even if the traffic and pedestrian volumes at the two intersections are identical. Such increased crash frequencies indicate that school children are at higher risk than other pedestrians.

Table 12-46. Crash Modification Factor (CMF_{2p}) for the Presence of Schools near the Intersection

Number of Schools within 1,000 ft of the Intersection	CMF_{2p}
No school present	1.00
School present	1.35

CMF_{3p}—Alcohol Sales Establishments

The base condition for alcohol sales establishments is the absence of alcohol sales establishments near the intersection. The CMF for the number of alcohol sales establishments within 1,000 ft of the center of an intersection is presented in Table 12-47. Any alcohol sales establishment wholly or partly within 1,000 ft of the intersection may be counted. This CMF applies only to vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with alcohol sales establishments nearby is likely to experience more vehicle-pedestrian collisions than an intersection without alcohol sales establishments even if the traffic and pedestrian volumes at the two intersections are identical. This indicated the likelihood of higher risk behavior on the part of either pedestrians or drivers near alcohol sales establishments. The CMF included any alcohol sales establishment which may include liquor stores, bars, restaurants, convenience stores, or grocery stores. Alcohol sales establishments are counted if they are on any intersection leg or even another street, as long as they are within 1,000 ft of the intersection being evaluated.

Table 12-47. Crash Modification Factor (CMF_{3p}) for the Number of Alcohol Sales Establishments near the Intersection

Number of Alcohol Sales Establishments within 1,000 ft of the Intersection	CMF_{3p}
0	1.00
1-8	1.12
9 or more	1.56

12.8. SEVERITY DISTRIBUTION FUNCTIONS

The SDFs are regression models for estimating the predicted average crash frequency for the following severity levels: fatal (*K*), incapacitating injury (*A*), non-incapacitating injury (*B*), and possible injury (*C*). Each SDF was developed with observed crash data for a set of similar sites. The SDFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SDFs developed for Chapter 12, the dependent variable is the predicted average crash frequency of each severity level for a roadway segment or an intersection, and the independent variables include various geometric features, traffic control features, and area type (i.e., urban or suburban). In this section, separate SDFs are provided for roadway segments and intersections of arterials with six or more lanes and one-way arterials.

The predictive models used in Chapter 12 to predict average severity distribution are of the general form shown in Equation 12-63.

$$N_j = N_{br,FI} \times P_j \tag{12-63}$$

Where:

N_j = predicted average crash frequency for severity level *j* (*j* = *K*, *A*, *B*, or *C*);

$N_{br,FI}$ = predicted average crash frequency for FI crashes on an individual roadway segment; and

P_j = probability of occurrence for severity level *j* (*j* = *K*, *A*, *B*, or *C*).

There is an SDF associated with each severity level *j* in the predictive model. Each SDF also contains a calibration factor which is used to calibrate it to local conditions.

12.8.1. SDFs for Urban and Suburban Arterial Roadway Segments with Six or More Lanes

The SDFs for roadway segments with six or more lanes are described by Equations 12-64 to 12-68.

$$P_K = \frac{\exp(V_K)}{\frac{1.0}{C_{SDF,6+}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \tag{12-64}$$

$$P_A = \frac{\exp(V_A)}{\frac{1.0}{C_{SDF,6+}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \tag{12-65}$$

$$P_B = \frac{\exp(V_B)}{\frac{1.0}{C_{SDF,6+}} + \exp(V_K) + \exp(V_A) + \exp(V_B)} \quad (12\text{-}66)$$

$$P_C = 1.0 - (P_K + P_A + P_B) \quad (12\text{-}67)$$

$$V_j = a + (b \times I_{urban}) + (c \times PSL) + (d \times I_{6D}) + (e \times I_{8D}) \quad (12\text{-}68)$$

Where:

V_j = systematic component of crash severity likelihood for severity level j;

$C_{SDF,\,6+}$ = calibration factor to adjust SDF to local conditions for roadway segments with six or more lanes;

I_{urban} = area type indicator variable (= 1 if urban, 0 if suburban);

PSL = posted speed limit (mph);

I_{6D} = indicator variable for six-lane divided highway (= 1 if six-lane divided, 0 otherwise);

I_{8D} = indicator variable for eight-lane divided highway (= 1 if 8-lane divided, 0 otherwise); and

a, b, c, d, e = regression coefficients.

The regression coefficients for Equation 12-68 are provided in Table 12-48.

Table 12-48. SDF Coefficients for Roadway Segments with Six or More Lanes

		Regression Coefficients				
Severity Level (*j*)	**Variable**	***a***	***b***	***c***	***d***	***e***
Fatal (*K*)	V_K	-5.114	-0.471	0.044	-0.333	-0.230
Incapacitating injury (*A*)	V_A	-1.735	-0.251	0.000	-0.292	-0.523
Non-incapacitating injury (*B*)	V_B	-0.575	-0.251	0.000	-0.094	-0.237

The SDF is applicable to roadway segments with a posted speed limit in the range of 25 to 60 mph.

The sign of a regression coefficient in Table 12-48 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with the area type indicates that the chance of a crash resulting in a fatality is lower in an urban area than a crash in suburban area. A similar trend exists for the relationship between area type and probability of incapacitating injury and non-incapacitating injury crashes. By inference, the chance of a crash resulting in a possible injury increases in the urban area.

12.8.2. SDFs for One-Way Urban and Suburban Arterial Roadway Segments

The SDFs for one-way roadway segments are described by Equations 12-69 to 12-73.

$$P_K = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{SDF,ow}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A} \quad (12\text{-}69)$$

$$P_A = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{SDF,ow}} + \exp(V_{K+A}) + \exp(V_B)} \times (1.0 - P_{K|K+A}) \quad (12\text{-}70)$$

$$P_B = \frac{\exp(V_B)}{\frac{1.0}{C_{SDF,ow}} + \exp(V_{K+A}) + \exp(V_B)} \qquad (12\text{-}71)$$

$$P_C = 1.0 - (P_K + P_A + P_B) \qquad (12\text{-}72)$$

$$V_j = a + (b \times W_l) + (c \times W_{rs}) + (d \times I_{urban}) + (e \times I_{bike}) \qquad (12\text{-}73)$$

Where:

V_j = systematic component of crash severity likelihood for severity level *j*;

$P_{K|K+A}$ = probability of a fatal crash given that the crash has a severity of either fatal or incapacitating injury on a one-way roadway segment;

$C_{SDF,\,ow}$ = calibration factor to adjust SDF to local conditions for one-way roadway segments;

W_l = lane width (ft);

W_{rs} = right shoulder width (ft);

I_{bike} = bike lane presence indicator variable (= 1 if present, 0.0 otherwise); and

a, b, c, d, e = regression coefficients.

The first term in Equation 12-69 estimates the probability of a fatal or incapacitating injury crash. The second term (i.e., $P_{K|K+A}$) is used to convert the estimate into the probability of a fatal crash. A value of 0.099 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes on one-way roadway segments.

The regression coefficients for Equation 12-73 are provided in Table 12-49.

Table 12-49. SDF Coefficients for One-way Roadway Segments

		Regression Coefficients				
Severity Level (*j*)	**Variable**	***a***	***b***	***c***	***d***	***e***
Fatal or incapacitating injury (*K+A*)	V_{K+A}	0.293	-0.123	-0.126	-0.399	0.997
Non-incapacitating injury (*B*)	V_B	-0.381	0.000	-0.058	0.000	0.504

The SDF is applicable to one-way roadway segments with two, three or four lanes.

The sign of a regression coefficient in Table 12-49 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with right shoulder width indicates that the proportion of fatal and incapacitating injury crashes decreases with an increase in the right shoulder width. A similar trend exists for non-incapacitating injury crashes. By inference, the proportion of possible injury crashes increases with an increase in the right shoulder width.

12.8.3. SDFs for 2×2 Signalized Intersections with Six or More Lanes

The SDFs for 2×2 signalized intersections with six or more lanes are similarly described by Equations 12-69 to 12-72.

A value of 0.094 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at 2×2 signalized intersections with six or more lanes.

A model for estimating the systematic component of crash severity (V_j) for 2×2 signalized intersections with six or more lanes is described by Equation 12-74.

$$V_j = a + (b \times I_{urban}) + (c \times I_{rtor}) + (d \times I_{uturn}) + (e \times n_{lt}) + (f \times I_{light}) \quad (12\text{-}74)$$

Where:

I_{rtor} = right-turn-on-red prohibition indicator variable (= 1 if prohibited, 0 if allowed);

I_{uturn} = U-turn prohibition indicator variable (= 1 if prohibited, 0.0 if allowed);

n_{lt} = number of major street approaches with left-turn lanes;

I_{light} = lighting presence indicator variable (= 1 if present, 0 otherwise); and

a, b, c, d, e, f = regression coefficients.

The regression coefficients for Equation 12-74 are provided in Table 12-50.

Table 12-50. SDF Coefficients for 2×2 Signalized Intersections with Six or More Lanes

		Regression Coefficients					
Severity Level (*j*)	**Variable**	***a***	***b***	***c***	***d***	***e***	***f***
Fatal or incapacitating injury (*K*+*A*)	V_{K+A}	-1.767	-0.116	-1.166	-0.142	-0.178	-0.331
Non-incapacitating injury (*B*)	V_B	-0.725	-0.116	-1.074	-0.069	-0.108	0.000

The sign of a regression coefficient in Table 12-50 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with right-turn-on-red prohibition indicates that the proportion of fatal and incapacitating injury crashes decreases when right-turn movements are prohibited on red. A similar trend exists for non-incapacitating injury crashes. By inference, the proportion of possible injury crashes increases when right-turn movements are prohibited on red.

12.8.4. SDFs for 1×2 and 1×1 Signalized Intersections

The SDFs for 1×2 and 1×1 signalized intersections are similarly described by Equations 12-69 to 12-72.

A value of 0.046 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at 1×2 and 1x1 signalized intersections.

A model for estimating the systematic component of crash severity (V_j) for 1×2 and 1×1 signalized intersections is described by Equation 12-75.

$$V_j = a + (b \times I_{urban}) + (c \times I_{Maj\_lt}) + (d \times I_{Maj\_ch}) + (e \times I_{Min\_ch}) \quad (12\text{-}75)$$

Where:

I_{Maj_lt} = presence of left-turn lane on the major road indicator variable (= 1.0 if present, 0.0 if absent);

I_{Maj_ch} = presence of right-turn channelization on the major road indicator variable (= 1.0 if present, 0.0 if absent);

I_{Min_ch} = presence of right-turn channelization on the minor road indicator variable (= 1.0 if it is present, 0.0 if it is absent); and

a, b, c, d, e = regression coefficients.

The regression coefficients for Equation 12-75 are provided in Table 12-51.

Table 12-51. SDF Coefficients for 1×2 and 1×1 Signalized Intersections

		Regression Coefficients				
Severity Level (*j*)	**Variable**	***a***	***b***	***c***	***d***	***e***
Fatal or incapacitating injury (*A*+ *K*)	V_{K+A}	-2.042	-0.407	-0.296	0.000	-0.306
Non-incapacitating injury (*B*)	V_B	-0.741	-0.099	-0.255	0.557	-0.504

The sign of a regression coefficient in Table 12-51 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with presence of left-turn lane on the major road indicates that the proportion of fatal and incapacitating injury crashes decreases when the left-turn lane is present on the major road. A similar trend exists for non-incapacitating injury crashes. By inference, the proportion of possible injury *C* crashes increases with the presence of left-turn lane on the major road.

12.8.5. SDFs for 2×2 (with Six or More Lanes), 1×2, and 1×1 Stop-Controlled Intersections

The SDFs for 2×2 (with six or more lanes), 1×2, and 1×1 stop-controlled intersections are similarly described by Equations 12-69 to 12-72.

A value of 0.043 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at 2×2 (with six or more lanes), 1×2, and 1×1 stop-controlled intersections.

A model for estimating the systematic component of crash severity (V_j) for 2×2 (with six or more lanes), 1×2, and 1×1 stop-controlled intersections is described by Equation 12-76.

$$V_j = a + (b \times I_{urban}) + (c \times I_{light}) + (d \times I_{Min\_lt}) \qquad (12\text{-}76)$$

Where:

I_{light} = presence of intersection lighting indicator variable (= 1.0 if present, 0.0 if absent);

I_{Min_lt} = presence of left-turn lane on the minor road indicator variable (= 1.0 if present, 0.0 if absent); and

a, b, c, d = regression coefficients.

The regression coefficients for Equation 12-76 are provided in Table 12-52.

Table 12-52. SDF Coefficients for 2×2 (with Six or More Lanes), 1×2, and 1×1 Stop-Controlled Intersections

		Regression Coefficients			
Severity Level (*j*)	**Variable**	***a***	***b***	***c***	***d***
Fatal or incapacitating injury (*A*+ *K*)	V_{K+A}	-1.106	-0.382	-0.918	0.000
Non-incapacitating injury (*B*)	V_B	-0.361	-0.278	-0.397	-0.434

The SDF is applicable only to intersections with stop control on the minor road approaches.

The sign of a regression coefficient in Table 12-52 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with presence of intersection lighting indicates that the proportion of fatal and incapacitating injury crashes decreases when lighting is present. A similar trend exists for non-incapacitating injury crashes. By inference, the proportion of possible injury crashes increases with the presence of lighting at the intersection.

12.9. CALIBRATION OF THE SPFS AND SDFS TO LOCAL CONDITIONS

In Step 11 of the predictive method, presented in Section 12.4, the predictive model is calibrated to local state or geographic conditions. Crash frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes on urban and suburban arterial highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments and intersections (defined as C_r and C_i, respectively) will have values greater than 1.0 for roadway segments or intersections that, on average, experience more crashes than those used in the development of the SPFs. The calibration factors for roadway segments or intersections that experience fewer crashes on average than those used in the development of the SPFs will have values less than 1.0. The calibration procedures are presented in Part C, Appendix A.

The SDF calibration factors for roadway segments and intersection will have values greater than 1.0 for roadway segments or intersections that, on average, experience more severe crashes than those used in the development of the SDFs. The SDF calibration factors for roadway segments or intersections that experience less severe crashes on average than those used in the development of the SPFs will have values less than one. The calibration procedures for SDFs are presented in Section B.1.4 of Appendix B to Part C, which is available in the supplement volume of the HSM as Chapters 18 and 19.

Calibration factors provide one method of incorporating local data to improve estimated crash frequencies for individual agencies or locations. Several other default values used in the methodology, such as manner of collisions distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in Part C, Appendix A.

12.10. INTERIM PREDICTIVE METHOD FOR ROUNDABOUTS

Sufficient research has not yet been conducted to form the basis for development of a predictive method for roundabouts. Since many jurisdictions are planning projects to convert existing intersections into modern roundabouts, an interim predictive method is presented here. This interim procedure is applicable to a location at which a modern roundabout has been constructed or is being planned to replace an existing signalized intersection. The interim procedure is:

1. Apply the predictive method from Chapter 12 to estimate the crash frequency, N_{int}, for the existing intersection.

2. Multiply N_{int} by the appropriate CMF from Chapter 14 for conversion on an existing intersection to a modern roundabout. The applicable CMFs are:

- 0.56 for conversion of a two-way stop-controlled intersection to a modern roundabout.
- 0.52 for conversion of a signalized intersection to a modern roundabout.

These CMFs are applicable to all crash severities and collision types for both one- and two-lane roundabouts in all settings.

At present, there are no available SPFs to determine predicted average crash frequency of an existing or newly constructed roundabout where no intersection currently exists.

12.11. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 12

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.8. This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 12.

Where urban and suburban arterials intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the arterial facility within the interchange area, cannot be addressed with the predictive method for urban and suburban arterials.

12.12. APPLICATION OF CHAPTER 12 PREDICTIVE METHOD

The predictive method presented in Chapter 12 applies to urban and suburban arterials. The predictive method is applied by following the 18 steps presented in Section 12.4. Appendix 12A provides a series of worksheets for applying the predictive method and the predictive models detailed in this chapter. All computations within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed for consistency in computations. In the last stage of computation, rounding the final estimate of the expected average crash frequency to one decimal place is recommended. Spreadsheet programs are also available to assist with application of the Chapter 12 predictive methods. These spreadsheets can be obtained upon request from NCHRP. They are populated with the equations and coefficients documented in Chapter 12. The spreadsheets are configured so the analyst can enter data to describe a site's characteristics and obtain the predicted or expected average crash frequency for the site.

12.13. SUMMARY

The predictive method is used to estimate the expected average crash frequency for a series of contiguous sites (entire urban or suburban arterial facility), or a single individual site. An urban or suburban facility is defined in Section 12.3.

The predictive method for urban and suburban arterial highways is applied by following the 18 steps of the predictive method presented in Section 12.4. Predictive models, developed for urban and suburban arterial facilities, are applied in Steps 9, 10, and 11 of the method. These models have been developed to estimate the predicted average crash frequency of an individual intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Where observed data are available, the EB Method may be applied in Step 13 or 15 of the predicative method to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project-specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Each predictive model in Chapter 12 consists of a set of SPFs and CMFs, a calibration factor, and pedestrian and bicycle crash adjustment factors. The SPFs are selected in Step 9 and are used to estimate the predicted average crash frequency of each collision type for a site with base conditions. This estimate can be for either total crashes or organized by crash-severity or manner of collision distribution. In order to account for differences between the base conditions of the SPF and the actual conditions of the local site, CMFs are applied in Step 10 which adjust the predicted number of crashes according to the geometric and traffic control conditions of the site.

In order to account for the differences in state or regional crash frequencies, the SPF is calibrated to the specific state and/or geographic region to which they apply. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 12.14 presents 10 sample problems which detail the application of the predictive method. A series of template worksheets have been developed to assist with applying the predictive method in Chapter 12. These worksheets are utilized to solve the sample problems in Section 12.14, and Appendix 12A contains blank version of the worksheets.

12.14. SAMPLE PROBLEMS

In this section, 10 sample problems are presented using the predictive method steps for urban and suburban arterials. Sample Problems 1 through 4 illustrate how to calculate the predicted average crash frequency for urban and suburban arterial roadway segments. Sample Problems 5 through 8 illustrate how to calculate the predicted average crash frequency for urban and suburban arterial intersections. Sample Problem 9 illustrates how to combine the results from Sample Problems 1, 2, 5, and 6 in a case where site-specific observed crash data are available (i.e., using the site-specific EB Method). Sample Problem 10 illustrates how to combine the results from Sample Problems 1, 2, 5, and 6 in a case where site-specific observed crash data are not available (i.e., using the project-level EB Method).

Problem No.	Page No.	Description
1	12-82	Predicted average crash frequency for a three-lane TWLTL arterial roadway segment
2	12-97	Predicted average crash frequency for a four-lane divided arterial roadway segment

3	12-101	Predicted average crash frequency for a seven-lane TWLTL arterial roadway segment
4	12-115	Predicted average crash frequency for a three-lane one-way arterial roadway segment
5	12-132	Predicted average crash frequency for a three-leg stop-controlled intersection with five or fewer lanes
6	12-135	Predicted average crash frequency for a four-leg signalized intersection with five or fewer lanes
7	12-153	Predicted average crash frequency for a four-leg stop-controlled intersection with six or more lanes
8	12-161	Predicted average crash frequency for a three-leg signalized intersection of a one-way arterial
9	12-171	Expected average crash frequency for a facility when site-specific observed crash data are available
10	12-176	Expected average crash frequency for a facility when site-specific observed crash data are not available

12.14.1. Sample Problem 1

The Site/Facility
A three-lane urban arterial roadway segment with a center TWLTL.

The Question
What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 1.5-mi length
- 11,000 veh/day
- 1.0 mi of parallel on-street commercial parking on each side of street
- 30 driveways (10 minor commercial, 2 major residential, 15 minor residential, 3 minor industrial/institutional)
- 10 roadside fixed objects per mile
- 6-ft offset to roadside fixed objects
- Lighting present
- No automated speed enforcement
- 35-mph posted speed

Assumptions
Collision type distributions used are the default values presented in Table 12-4 and Table 12-7 and Equations 12-24 and 12-25.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 7.0 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 1, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For roadway segments with five or fewer lanes, SPF values are determined for multiple-vehicle nondriveway, multiple-vehicle driveway-related, single- vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-12 and Table 12-3 as follows:

$$N_{spf\ rs\ nondwy} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ nondwy(total)} = \exp(-12.40 + 1.41 \times \ln(11{,}000) + \ln(1.5))$$

$$= 3.805 \text{ crashes/year}$$

$$N_{spf\ rs\ nondwy(FI)} = \exp(-16.45 + 1.69 \times \ln(11{,}000) + \ln(1.5))$$

$$= 0.728 \text{ crashes/year}$$

$$N_{spf\ rs\ nondwy(PDO)} = \exp(-11.95 + 1.33 \times \ln(11{,}000) + \ln(1.5))$$

$$= 2.298 \text{ crashes/year}$$

These initial values for FI and PDO crashes are then adjusted using Equations 12-13 and 12-14 to assure that they sum to the value for total crashes as follows:

$$N_{spf\ rs\ nondwy(FI)} = N_{spf\ rs\ nondwy(total)} \left(\frac{N'_{spf\ rs\ nondwy(FI)}}{N'_{spf\ rs\ nondwy(FI)} + N'_{spf\ rs\ nondwy(PDO)}} \right)$$

$$= 3.085 \left(\frac{0.728}{0.728 + 2.298} \right)$$

$$= 0.742 \text{ crashes/year}$$

$$N_{spf\ rs\ nondwy(PDO)} = N_{spf\ rs\ nondwy(total)} - N_{spf\ rs\ nondwy(FI)}$$

$$= 3.085 - 0.742$$

$$= 2.343 \text{ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-15 as follows:

$$N_{spf\ rs\ dwy(\text{total})} = \sum_{\substack{\text{all} \\ \text{driveway} \\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000} \right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 1 is 10 minor commercial, two major residential, 15 minor residential, and three minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a three-lane arterial are provided in Table 12-5.

$$N_{spf\ rs\ dwy(\text{total})} = 10 \times 0.032 \times \left(\frac{11{,}000}{15{,}000} \right)^{(1.0)} + 2 \times 0.053 \times \left(\frac{11{,}000}{15{,}000} \right)^{(1.0)}$$

$$+ 15 \times 0.010 \times \left(\frac{11{,}000}{15{,}000} \right)^{(1.0)} + 3 \times 0.015 \times \left(\frac{11{,}000}{15{,}000} \right)^{(1.0)}$$

$$= 0.455 \text{ crashes/year}$$

Driveway-related collisions can be separated into components by severity level using Equations 12-16 and 12-17 as follows:

From Table 12-5, for a three-lane arterial the proportion of driveway-related collisions that involve fatalities and injuries, $f_{dwy} = 0.243$.

$$N_{spf\ rs\ dwy(FI)} = N_{spf\ rs\ dwy(\text{total})} \times f_{dwy}$$
$$= 0.455 \times 0.243$$
$$= 0.111 \text{ crashes/year}$$

$$N_{spf\ rs\ dwy(PDO)} = N_{spf\ rs\ dwy(\text{total})} - N_{spf\ rs\ dwy(FI)}$$
$$= 0.455 - 0.111$$
$$= 0.344 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for the roadway segment is calculated from Equation 12-18 and Table 12-6 as follows:

$$N_{spf\ rs\ sv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ sv(total)} = \exp(-5.74 + 0.54 \times \ln(11{,}000) + \ln(1.5))$$
$$= 0.734 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(FI)} = \exp(-6.37 + 0.47 \times \ln(11{,}000) + \ln(1.5))$$
$$= 0.204 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(PDO)} = \exp(-6.29 + 0.56 \times \ln(11{,}000) + \ln(1.5))$$
$$= 0.510 \text{ crashes/year}$$

These initial values for FI and PDO crashes are then adjusted using Equations 12-19 and 12-20 to assure that they sum to the value for total crashes as follows:

$$N_{spf\ rs\ sv(FI)} = N_{spf\ rs\ sv(total)} \left(\frac{N'_{spf\ rs\ sv(FI)}}{N'_{spf\ rs\ sv(FI)} + N'_{spf\ rs\ sv(PDO)}} \right)$$
$$= 0.734 \left(\frac{0.204}{0.204 + 0.510} \right)$$
$$= 0.210 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(PDO)} = N_{spf\ rs\ sv(total)} - N_{spf\ rs\ sv(FI)}$$
$$= 0.734 - 0.210$$
$$= 0.524 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

On-Street Parking (CMF_{1r})
CMF_{1r} is calculated from Equation 12-39 as follows:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0)$$

The proportion of curb length with on-street parking, p_{pk}, is determined as follows:

$$p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Since 1.0 mile of on-street parking on each side of the road is provided, the sum of curb length with on-street parking for both sides of the road combined, $L_{pk} = 2$.

$$p_{pk} = 0.5 \times \frac{2}{1.5} = 0.66$$

From Table 12-32, $f_{pk} = 2.074$.

$$\begin{aligned} CMF_{1r} &= 1 + 0.66 \times (2.074 - 1.0) \\ &= 1.71 \end{aligned}$$

Roadside Fixed Objects (CMF_{2r})
For roadway segments with five or fewer lanes, CMF_{2r} is calculated from Equation 12-40 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-33, for a roadside fixed objects with an average 6-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.124.

From Table 12-34, for a three-lane arterial, the proportion of total crashes, $p_{fo} = 0.034$.

$$\begin{aligned} CMF_{2r} &= 0.124 \times 10 \times 0.034 + (1.0 - 0.034) \\ &= 1.01 \end{aligned}$$

Median Width (CMF_{3r})
The value of CMF_{3r} is 1.00 for undivided facilities (see Section 12.7.1). It is assumed that a roadway with TWLTL is undivided.

Lighting (CMF_{4r})
CMF_{4r} is calculated from Equation 12-42 as follows:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}))$$

For a three-lane arterial, $p_{inr} = 0.429$, $p_{pnr} = 0.571$, and $p_{nr} = 0.304$ (see Table 12-36).

$$\begin{aligned} CMF_{4r} &= 1.0 - (0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571)) \\ &= 0.93 \end{aligned}$$

Automated Speed Enforcement (CMF_{5r})
Since there is no automated speed enforcement in Sample Problem 1, CMF_{5r} = 1.00 (i.e., the base condition for CMF_{5r} is the absence of automated speed enforcement).

The combined CMF value for Sample Problem 1 is calculated below.

$$CMF_{comb} = 1.71 \times 1.01 \times 0.93$$
$$= 1.61$$

For roadway segments with five or fewer lanes, CMF_{comb} applies to multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes. The predicted average crash frequency of each collision type is determined using Equation 12-6, as follows:

$$N_{brnondwy} = N_{spf\ rs\ nondwy} \times CMF_{comb}$$
$$= 3.085 \times 1.61$$
$$= 4.967 \text{ crashes/year}$$

$$N_{brdwy} = N_{spf\ rs\ dwy} \times CMF_{comb}$$
$$= 0.455 \times 1.61$$
$$= 0.734 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\,sv} \times CMF_{comb}$$
$$= 0.734 \times 1.61$$
$$= 1.182 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-4 and 12-5 as follows:

$$N_{br} = N_{brnondwy} + N_{brdwy} + N_{brsv}$$
$$= 4.967 + 0.734 + 1.182$$
$$= 6.883 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-24 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-16, for a posted speed greater than 30 mph on a three-lane arterial, the pedestrian crash adjustment factor, $f_{pedr} = 0.013$.

$$N_{pedr} = 6.883 \times 0.013$$
$$= 0.089 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-25 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-17, for a posted speed greater than 30 mph on a three-lane arterial, the bicycle crash adjustment factor, $f_{biker} = 0.007$.

$$N_{biker} = 6.883 \times 0.007$$

$$= 0.048 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$

$$= 1.00 \times (6.883 + 0.089 + 0.048)$$

$$= 7.020 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet A-1A)*—General Information and Input Data for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1B (Corresponds to Worksheet A-1B)*— Crash Modification Factors for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1C (Corresponds to Worksheet A-1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1D (Corresponds to Worksheet A-1D)*— Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1E (Corresponds to Worksheet A-1E)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1F (Corresponds to Worksheet A-1F)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1G (Corresponds to Worksheet A-1G)*—Single-Vehicle Crashes by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1H (Corresponds to Worksheet A-1H)*— Single-Vehicle Crashes by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1I (Corresponds to Worksheet A-1I)*— Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1J (Corresponds to Worksheet A-1J)*— Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes

- *Worksheet SP1K (Corresponds to Worksheet A-1K)*— Crash Severity*Type Distribution for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP1L (Corresponds to Worksheet A-1L)*— Summary Results for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP1A—General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 1.

Worksheet SP1A. General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	3T
Length of segment, *L* (mi)	—	1.5
AADT (veh/day)	—	11,000
Type of on-street parking (none/parallel/angle)	none	parallel-commercial
Proportion of curb length with on-street parking	—	0.66
Median width (ft)	15	not present
Lighting (present / not present)	not present	present
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveways (number)	—	0
Minor commercial driveways (number)	—	10
Major industrial/institutional driveways (number)	—	0
Minor industrial/institutional driveways (number)	—	3
Major residential driveways (number)	—	2
Minor residential driveways (number)	—	15
Other driveways (number)	—	0
Speed category	—	intermediate or high speed (>30 mph)
Roadside fixed object density (fixed objects/mi)	not present	10
Offset to roadside fixed objects (ft)	not present	6
Calibration factor, C_r	1.0	1.0

Worksheet SP1B—Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 6 of Worksheet SP1B which indicates the combined CMF value.

Worksheet SP1B. Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	**CMF for On-Street Parking**	CMF_{1r}	**from Equation 12-39**	1.71
(2)	**CMF for Roadside Fixed Objects**	CMF_{2r}	**from Equation 12-40**	1.01
(3)	**CMF for Median Width**	CMF_{3r}	**from Table 12-35**	1.00
(4)	**CMF for Lighting**	CMF_{4r}	**from Equation 12-42**	0.93
(5)	**CMF for Automated Speed Enforcement**	CMF_{5r}	**from Section 12.7.1**	1.00
(6)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)**	1.61

Worksheet SP1C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 1 is calculated using Equation 12-12 and entered into Column 4 of Worksheet SP1C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**		**Overdispersion Parameter, k**	**Initial $N_{spf\ rs\ nondwy}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ rs\ nondwy}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted $N_{brnondwy}$**
	from Table 12-3		**from Table 12-3**	**from Equation 12-12**		**$(4)_{total}$*(5)**	**(6) from Worksheet SP1B**		**(6)*(7)*(8)**
	a	**b**							
Total	-12.40	1.41	0.66	3.085	1.000	3.085	1.61	1.00	4.967
FI	-16.45	1.69	0.59	0.728	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.241	0.743	1.61	1.00	1.196
PDO	-11.95	1.33	0.59	2.298	$(5)_{total} - (5)_{FI}$ 0.759	2.342	1.61	1.00	3.771

Worksheet SP1D—Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1D presents the default proportions for manner of collision (from Table 12-4) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).
These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP1C) into components by crash severity and manner of collision.

Worksheet SP1D. Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brnondwy(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brnondwy(PDO)}$ (crashes/year)**	**Predicted $N_{brnondwy(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-4**	**$(9)_{FI}$ from Worksheet SP1C**	**from Table 12-4**	**$(9)_{PDO}$ from Worksheet SP1C**	**$(9)_{total}$ from Worksheet SP1C**
Total	1.000	1.196	1.000	3.771	4.967
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision	0.845	1.011	0.842	3.175	4.186
Head-on collision	0.034	0.041	0.020	0.075	0.116
Angle collision	0.069	0.083	0.020	0.075	0.158
Sideswipe, same direction	0.001	0.001	0.078	0.294	0.295
Sideswipe, opposite direction	0.017	0.020	0.020	0.075	0.095
Other multiple-vehicle collision	0.34	0.041	0.020	0.075	0.116

Worksheet SP1E—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1E determines and presents the number of driveway-related multiple-vehicle collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-5 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-5. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-15 and entered into Column 5. The overdispersion parameter from Table 12-5 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized).

Worksheet SP1E. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	Coefficient for Traffic Adjustment, t	Initial $N_{spf\ rs\ dwy}$	Overdispersion Parameter, k
Manner of Collision	Number of Driveways, n_j	from Table 12-5	from Table 12-5	Equation 12-15 n_j*N_j*(AADT/15,000)$^{(t)}$	from Table 12-5
Major commercial	0	0.102	1.000	0.000	—
Minor commercial	10	0.032	1.000	0.235	
Major industrial/institutional	0	0.110	1.000	0.000	
Minor industrial/institutional	3	0.015	1.000	0.033	
Major residential	2	0.053	1.000	0.078	
Minor residential	15	0.010	1.000	0.110	
Other	0	0.016	1.000	0.000	
Total	—	—	—	0.456	1.10

Worksheet SP1F—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP1E is entered in Column 2. This value is multiplied by the proportion of crashes by severity level (Column 3) found in Table 12-5 and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Row 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP1F. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban
Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial $N_{spf\ rs\ dwy}$	Proportion of Total Crashes (f_{dwy})	Adjusted $N_{spf\ rs\ dwy}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP1E	from Table 12-5	$(2)_{total}$*(3)	(6) from Worksheet SP1B		(4)*(5)*(6)
Total	0.456	1.000	0.456	1.61	1.00	0.734
FI	—	0.243	0.111	1.61	1.00	0.179
PDO	—	0.757	0.345	1.61	1.00	0.555

Worksheet SP1G—Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 1 is calculated using Equation 12-18 and entered into Column 4 of Worksheet SP1G. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1G. Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, k	Initial $N_{spf\ rs\ sv}$	Proportion of Total Crashes	Adjusted $N_{spf\ rs\ sv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brsv}
	from Table 12-6		from Table 12-6	from Equation 12-18		$(4)_{total}$*(5)	(6) from Worksheet SP1B		(6)*(7)*(8)
	a	b							
Total	-5.74	0.54	1.37	0.734	1.000	0.734	1.61	1.00	1.182
FI	-6.37	0.47	1.06	0.204	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.286	0.210	1.61	1.00	0.338
PDO	-6.29	0.56	1.93	0.510	$(5)_{total} - (5)_{FI}$ 0.714	0.524	1.61	1.00	0.844

Worksheet SP1H—Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1H presents the default proportions for manner of collision (from Table 12-7) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP1G) into components by crash severity and manner of collision.

Worksheet SP1H. Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-7**	**$(9)_{FI}$ from Worksheet SP1G**	**from Table 12-7**	**$(9)_{PDO}$ from Worksheet SP1G**	**$(9)_{total}$ from Worksheet SP1G**
Total	1.000	0.338	1.000	0.844	1.182
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Collision with animal	0.001	0.000	0.001	0.001	0.001
Collision with fixed object	0.688	0.233	0.963	0.813	1.046
Collision with other object	0.001	0.000	0.001	0.001	0.001
Other single-vehicle crash	0.310	0.105	0.035	0.030	0.135

Worksheet SP1I—Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes from Worksheets SP1C, SP1F, and SP1G are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-16). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1I. Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(9) from Worksheet SP1C	**(7) from Worksheet SP1F**	**(9) from Worksheet SP1G**	(2)+(3)+(4)	**from Table 12-16**		(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.013	1.00	0.089
FI	—	—	—	—	—	1.00	0.089

Worksheet SP1J—Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes from Worksheets SP1C, SP1F, and SP1G are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-17). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1J. Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**F_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(9) from Worksheet SP1C	**(7) from Worksheet SP1F**	**(9) from Worksheet SP1G**	**(2)+(3)+(4)**	**from Table 12-17**		**(5)*(6)*(7)**
Total	4.967	1.182	0.734	6.883	0.007	1.00	0.048
FI	—	—	—	—	—	1.00	0.048

Worksheet SP1K—Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1K provides a summary of all manners of collision by severity level. Values from Worksheets SP1D, SP1F, SP1H, SP1I, and SP1J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP1K. Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP1D and SP1H; (7) from Worksheet SP1F; and (8) from Worksheet SP1I and SP1J**	**(5) from Worksheet SP1D and SP1H; and (7) from Worksheet SP1F**	**(6) from Worksheets SP1D and SP1H; (7) from Worksheet SP1F; and (8) from Worksheets SP1I and SP1J**
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet SP1D)	1.011	3.175	4.186
Head-on collisions (from Worksheet SP1D)	0.041	0.075	0.116
Angle collisions (from Worksheet SP1D)	0.083	0.075	0.158
Sideswipe, same direction (from Worksheet SP1D)	0.001	0.294	0.295
Sideswipe, opposite direction (from Worksheet SP1D)	0.020	0.075	0.095
Driveway-related collisions (from Worksheet SP1F)	0.179	0.555	0.734
Other multiple-vehicle collisions (from Worksheet SP1D)	0.041	0.075	0.116
Subtotal	1.376	4.324	5.700
SINGLE_VEHICLE			
Collision with animal (from Worksheet SP1H)	0.000	0.001	0.001
Collision with fixed object (from Worksheet SP1H)	0.233	0.813	1.046
Collision with other object (from Worksheet SP1H)	0.000	0.001	0.001
Other single-vehicle crash (from Worksheet SP1H)	0.105	0.030	0.135
Collision with pedestrian (from Worksheet SP1I)	0.089	0.000	0.089
Collision with bicycle (from Worksheet SP1J)	0.048	0.000	0.048
Subtotal	0.475	0.845	1.320
Total	1.851	5.169	7.020

Worksheet SP1L—Summary Results for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP1L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP1L. Summary Results for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(total) from Worksheet SP1K**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total	7.020	1.5	4.7
FI	1.851	1.5	1.2
PDO	5.169	1.5	3.4

12.14.2. Sample Problem 2

The Site/Facility
A four-lane divided urban arterial roadway segment.

The Question
What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 0.75-mi length
- 23,000 veh/day
- On-street parking not permitted
- 8 driveways (1 major commercial, 4 minor commercial, 1 major residential, 1 minor residential, 1 minor industrial/institutional)
- 20 roadside fixed objects per mile
- 12-ft offset to roadside fixed objects
- 40-ft median
- Lighting present
- No automated speed enforcement
- 30-mph posted speed

Assumptions
Collision type distributions used are the default values presented in Table 12-4 and Table 12-7 and Equations 12-24 and 12-25.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 3.4 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For segments with five or fewer lanes, SPF values are determined for multiple-vehicle nondriveway, multiple-vehicle driveway-related, single- vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for total multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related collisions are presented below. Detailed

steps for calculating SPFs for FI and PDO crashes are presented in Sample Problem 1. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Nondriveway Collisions
The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-12 and Table 12-3 as follows:

$$N_{spf\ rs\,nondwy} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\,nondwy(total)} = \exp(-12.34 + 1.36 \times \ln(23{,}000) + \ln(0.75))$$

$$= 2.804 \text{ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions
The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-15 as follows:

$$N_{spf\ rs\,dwy(total)} = \sum_{\substack{\text{all}\\ \text{driveway}\\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15,000}\right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 2 is one major commercial, four minor commercial, one major residential, one minor residential, and one minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a four-lane divided arterial, are provided in Table 12-5.

$$N_{spf\ rs\,dwy(total)} = 1 \times 0.033 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 4 \times 0.011 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.018 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)}$$

$$+ 1 \times 0.003 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.005 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)}$$

$$= 0.165 \text{ crashes/year}$$

Single-Vehicle Crashes
The SPF for single-vehicle crashes for the roadway segment is calculated from Equation 12-18 and Table 12-6 as follows:

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{brsv(total)} = \exp(-5.05 + 0.47 \times \ln(23{,}000) + \ln(0.75))$$

$$= 0.539 \text{ crashes/year}$$

The FI and PDO SPF values for multiple-vehicle nondriveway collisions, multiple-vehicle driveway-related collisions and single-vehicle crashes can be determined by using the same procedure presented in Sample Problem 1.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

On-Street Parking (CMF_{1r})
Since on-street parking is not permitted, CMF_{1r} = 1.00 (i.e., the base condition for CMF_{1r} is the absence of on-street parking).

***Roadside Fixed Objects* (*CMF_{2r}*)**
For roadway segments with five or fewer lanes, CMF_{2r} is calculated from Equation 12-40 as follows:

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-33, for roadside fixed objects with an average 12-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.079.

From Table 12-34, for a four-lane divided arterial, the proportion of total crashes, $p_{fo} = 0.036$.

$$CMF_{2r} = 0.079 \times 20 \times 0.036 + (1.0 - 0.036)$$

$$= 1.02$$

***Median Width* (*CMF_{3r}*)**
From Table 12-35, for a four-lane divided arterial with a 40-ft median, $CMF_{3r} = 0.97$.

***Lighting* (*CMF_{4r}*)**
CMF_{4r} can be calculated from Equation 12-42 as follows:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}))$$

For a four-lane divided arterial, $p_{inr} = 0.364$, $p_{pnr} = 0.636$, and $p_{nr} = 0.410$ (see Table 12-36).

$$CMF_{4r} = 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636))$$

$$= 0.91$$

***Automated Speed Enforcement* (*CMF_{5r}*)**
Since there is no automated speed enforcement in Sample Problem 2, $CMF_{5r} = 1.00$ (i.e., the base condition for CMF_{5r} is the absence of automated speed enforcement).

The combined CMF value for Sample Problem 2 is calculated below.

$$CMF_{5r} = 1.02 \times 0.97 \times 0.91$$

$$= 0.90$$

For roadway segments with five or fewer lanes, CMF_{comb} applies to multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes. The predicted average crash frequency of each collision type is determined using Equation 12-6, as follows:

$$N_{brnondwy} = N_{spf\ rs\ nondwy} \times CMF_{comb}$$

$$= 2.804 \times 0.90$$

$$= 2.524 \text{ crashes/year}$$

$$N_{brdwy} = N_{spf\ rs\ dwy} \times CMF_{comb}$$

$$= 0.165 \times 0.90$$

$$= 0.149 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\ sv} \times CMF_{comb}$$

$$= 0.539 \times 0.90$$

$$= 0.485 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-4 and 12-5 as follows:

$$N_{br} = N_{brnondwy} + N_{brdwy} + N_{brsv}$$

$$= 4.967 + 0.734 + 1.182$$

$$= 3.158 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-24 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-16, for a posted speed of 30 mph on a four-lane divided arterial, the pedestrian crash adjustment factor, $f_{pedr} = 0.067$.

$$N_{pedr} = 3.158 \times 0.067$$

$$= 0.212 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-25 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-17, for a posted of 30 mph on a four-lane divided arterial, the bicycle crash adjustment factor, $f_{biker} = 0.013$.

$$N_{biker} = 3.158 \times 0.013$$

$$= 0.041 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$

$$= 1.00 \times (3.158 + 0.212 + 0.041)$$

$$= 3.411 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet A-1A)*—General Information and Input Data for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2B (Corresponds to Worksheet A-1B)*— Crash Modification Factors for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2C (Corresponds to Worksheet A-1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2D (Corresponds to Worksheet A-1D)*— Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2E (Corresponds to Worksheet A-1E)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2F (Corresponds to Worksheet A-1F)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2G (Corresponds to Worksheet A-1G)*—Single-Vehicle Crashes by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2H (Corresponds to Worksheet A-1H)*— Single-Vehicle Crashes by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2I (Corresponds to Worksheet A-1I)*— Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2J (Corresponds to Worksheet A-1J)*— Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2K (Corresponds to Worksheet A-1K)*— Crash Severity*Type Distribution for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes
- *Worksheet SP2L (Corresponds to Worksheet A-1L)*— Summary Results for Two-Way Urban and Suburban Arterial Roadway Segments with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP2A—General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 2.

Worksheet SP2A. General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	45
Length of segment, *L* (mi)	—	0.75
AADT (veh/day)	—	23,000
Type of on-street parking (none/parallel/angle)	none	None
Proportion of curb length with on-street parking	—	N/A
Median width (ft)	15	40
Lighting (present / not present)	not present	present
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveways (number)	—	1
Minor commercial driveways (number)	—	4
Major industrial/institutional driveways (number)	—	0
Minor industrial/institutional driveways (number)	—	1
Major residential driveways (number)	—	1
Minor residential driveways (number)	—	1
Other driveways (number)	—	0
Speed category	—	Low (<30mph)
Roadside fixed object density (fixed objects/mi)	not present	20
Offset to roadside fixed objects (ft)	not present	12
Calibration factor, C_r	1.0	1.0

Worksheet SP2B—Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 6 of Worksheet SP2B which indicates the combined CMF value.

Worksheet SP2B. Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	**CMF for On-Street Parking**	CMF_{1r}	**from Equation 12-39**	1.00
(2)	**CMF for Roadside Fixed Objects**	CMF_{2r}	**from Equation 12-40**	1.02
(3)	**CMF for Median Width**	CMF_{3r}	**from Table 12-35**	0.97
(4)	**CMF for Lighting**	CMF_{4r}	**from Equation 12-42**	0.91
(5)	**CMF for Automated Speed Enforcement**	CMF_{5r}	**from Section 12.7.1**	1.00
(6)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)**	0.90

Worksheet SP2C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 2 is calculated using Equation 12-12 and entered into Column 4 of Worksheet SP2C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**		**Overdispersion Parameter, k**	**Initial $N_{spf\ rs\ nondwy}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ rs\ nondwy}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted $N_{brnondwy}$**
	from Table 12-3		**from Table 12-3**	**from Equation 12-12**		**$(4)_{total}$*(5)**	**(6) from Worksheet SP2B**		**(6)*(7)*(8)**
	a	**b**							
Total	-12.34	1.36	1.32	2.804	1.000	2.804	0.90	1.00	2.524
FI	-12.76	1.28	1.31	0.825	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.278	0.780	0.90	1.00	0.702
PDO	-12.81	1.38	1.34	2.143	$(5)_{total} - (5)_{FI}$ 0.722	2.024	0.90	1.00	1.822

Worksheet SP2D—Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2D presents the default proportions for manner of collision (from Table 12-4) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).
These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP2C) into components by crash severity and manner of collision.

Worksheet SP2D. Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brnondwy(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brnondwy(PDO)}$ (crashes/year)**	**Predicted $N_{brnondwy(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-4**	**(9)$_{FI}$ from Worksheet SP2C**	**from Table 12-4**	**(9)$_{PDO}$ from Worksheet SP2C**	**(9)$_{total}$ from Worksheet SP2C**
Total	1.000	0.702	1.000	1.822	2.524
		(2)*(3)$_{FI}$		(4)*(5)$_{PDO}$	(3)+(5)
Rear-end collision	0.832	0.584	0.662	1.206	1.790
Head-on collision	0.020	0.014	0.007	0.013	0.027
Angle collision	0.040	0.028	0.036	0.066	0.094
Sideswipe, same direction	0.050	0.035	0.223	0.406	0.441
Sideswipe, opposite direction	0.010	0.007	0.001	0.002	0.009
Other multiple-vehicle collision	0.048	0.034	0.071	0.129	0.163

Worksheet SP2E—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2E determines and presents the number of driveway-related multiple-vehicle collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-5 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-5. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-15 and entered into Column 5. The overdispersion parameter from Table 12-5 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized).

Worksheet SP2E. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	**Coefficient for Traffic Adjustment, t**	**Initial $N_{spf\ rs\ dwy}$**	**Overdispersion Parameter, k**
Manner of Collision	**Number of Driveways, n_j**	**from Table 12-5**	**from Table 12-5**	**Equation 12-15 n_j*N_j*(AADT/15,000)$^{(t)}$**	**from Table 12-5**
Major commercial	1	0.033	1.106	0.053	—
Minor commercial	4	0.011	1.106	0.071	
Major industrial/institutional	0	0.036	1.106	0.000	
Minor industrial/institutional	1	0.005	1.106	0.008	
Major residential	1	0.018	1.106	0.029	
Minor residential	1	0.003	1.106	0.005	
Other	0	0.005	1.106	0.000	
Total	—	—	—	0.166	1.39

Worksheet SP2F—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP2E is entered in Column 2. This value is multiplied by the proportion of crashes by severity level (Column 3) found in Table 12-5 and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Row 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP2F. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban
Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial $N_{spf\ rs\ dwy}$	Proportion of Total Crashes (f_{dwy})	Adjusted $N_{spf\ rs\ dwy}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP2E	from Table 12-5	$(2)_{total}$*(3)	(6) from Worksheet SP2B		(4)*(5)*(6)
Total	0.166	1.000	0.166	0.90	1.00	0.149
FI	—	0.284	0.047	0.90	1.00	0.042
PDO	—	0.716	0.119	0.90	1.00	0.107

Worksheet SP2G—Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 2 is calculated using Equation 12-18 and entered into Column 4 of Worksheet SP2G. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2G. Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, k	Initial $N_{spf\ rs\ sv}$	Proportion of Total Crashes	Adjusted $N_{spf\ rs\ sv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brsv}
	from Table 12-6		from Table 12-6	from Equation 12-18		$(4)_{total}$*(5)	(6) from Worksheet SP2B		(6)*(7)*(8)
	a	b							
Total	-5.05	0.47	0.86	0.539	1.000	0.539	0.90	1.00	0.485
FI	-8.71	0.66	0.28	0.094	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.174	0.094	0.90	1.00	0.085
PDO	-5.04	0.45	1.06	0.446	$(5)_{total} - (5)_{FI}$ 0.826	0.445	0.90	1.00	0.401

Worksheet SP2H—Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2H presents the default proportions for manner of collision (from Table 12-7) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP2G) into components by crash severity and manner of collision.

Worksheet SP2H. Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-7**	**(9)$_{FI}$ from Worksheet SP2G**	**from Table 12-7**	**(9)$_{PDO}$ from Worksheet SP2G**	**(9)$_{total}$ from Worksheet SP2G**
Total	1.000	0.085	1.000	0.401	0.485
		(2)*(3)$_{FI}$		(4)*(5)$_{PDO}$	(3)+(5)
Collision with animal	0.001	0.000	0.063	0.025	0.025
Collision with fixed object	0.500	0.043	0.813	0.326	0.369
Collision with other object	0.208	0.002	0.016	0.006	0.008
Other single-vehicle crash	0.471	0.040	0.108	0.043	0.083

Worksheet SP2I—Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes from Worksheets SP2C, SP2F, and SP2G are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-16). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2I. Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(9) from Worksheet SP2C	**(7) from Worksheet SP2F**	**(9) from Worksheet SP2G**	(2)+(3)+(4)	**from Table 12-16**		(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.067	1.000	0.212
FI	—	—	—	—	—	1.000	0.212

Worksheet SP2J—Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle nondriveway, multiple-vehicle driveway-related, and single-vehicle crashes from Worksheets SP2C, SP2F, and SP2G are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-17). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2J. Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**F_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(9) from Worksheet SP2C	**(7) from Worksheet SP2F**	**(9) from Worksheet SP2G**	**(2)+(3)+(4)**	**from Table 12-17**		**(5)*(6)*(7)**
Total	2.524	0.485	0.149	3.158	0.013	1.000	0.041
FI	—	—	—	—	—	1.000	0.041

Worksheet SP2K—Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2K provides a summary of all manners of collision by severity level. Values from Worksheets SP2D, SP2F, SP2H, SP2I, and SP2J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP2K. Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP2D and SP2H; (7) from Worksheet SP2F; and (8) from Worksheet SP2I and SP2J**	**(5) from Worksheet SP1D and SP2H; and (7) from Worksheet SP2F**	**(6) from Worksheets SP2D and SP2H; (7) from Worksheet SP2F; and (8) from Worksheets SP2I and SP2J**
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet SP2D)	0.584	1.206	1.790
Head-on collisions (from Worksheet SP2D)	0.014	0.013	0.027
Angle collisions (from Worksheet SP2D)	0.028	0.066	0.094
Sideswipe, same direction (from Worksheet SP2D)	0.035	0.406	0.441
Sideswipe, opposite direction (from Worksheet SP2D)	0.007	0.002	0.009
Driveway-related collisions (from Worksheet SP2F)	0.042	0.107	0.149
Other multiple-vehicle collisions (from Worksheet SP2D)	0.034	0.129	0.163
Subtotal	0.744	1.929	2.673
SINGLE_VEHICLE			
Collision with animal (from Worksheet SP2H)	0.000	0.025	0.025
Collision with fixed object (from Worksheet SP2H)	0.043	0.326	0.369
Collision with other object (from Worksheet SP2H)	0.002	0.006	0.008
Other single-vehicle crash (from Worksheet SP2H)	0.040	0.043	0.083
Collision with pedestrian (from Worksheet SP2I)	0.212	0.000	0.212
Collision with bicycle (from Worksheet SP2J)	0.041	0.000	0.041
Subtotal	0.338	0.400	0.738
Total	1.082	2.329	3.411

Worksheet SP2L—Summary Results for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

Worksheet SP2L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP2L. Summary Results for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(total) from Worksheet SP1K	Roadway Segment Length, L (mi)	(2)/(3)
Total	3.411	0.75	4.5
FI	1.082	0.75	1.4
PDO	2.329	0.75	3.1

12.14.3. Sample Problem 3

The Site/Facility
A seven-lane suburban arterial roadway segment with a center TWLTL.

The Question
What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 0.8-mi length
- 26,000 veh/day
- 11-ft lanes
- 3-ft right shoulders on both travel directions
- 9 driveways (2 major commercial, 2 major industrial, 5 minor residential)
- 10 roadside fixed objects per mile
- 8-ft offset to roadside fixed objects
- No highway-rail grade crossing present
- No automated speed enforcement
- 45-mph posted speed

Assumptions
Collision type distributions used are the default values presented in Table 12-9 and Table 12-11 and Equations 12-24 and 12-25.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 3 is determined to be 7.3 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For roadway segments with six or more lanes, SPF values are determined for multiple-vehicle, single- vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Collisions
The SPF for multiple-vehicle collisions for the roadway segment is calculated from Equation 12-21 and Table 12-8 as follows:

$$N_{spf\ rs\ mv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ mv(FI)} = \exp(-11.44 + 1.24 \times \ln(26{,}000) + \ln(0.8))$$

$$= 2.566 \text{ crashes/year}$$

$$N_{spf\ rs\ mv(PDO)} = \exp(-9.20 + 1.06 \times \ln(26{,}000) + \ln(0.8))$$

$$= 3.868 \text{ crashes/year}$$

$$N_{spf\ rs\ mv(total)} = 2.566 + 3.868$$

$$= 6.434 \text{ crashes/year}$$

Single-Vehicle Crashes
The SPF for single-vehicle crashes for the roadway segment is calculated from Equation 12-23 and Table 12-10 as follows:

$$N_{spf\ rs\ sv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ sv(FI)} = \exp(-4.54 + 0.37 \times \ln(26{,}000) + \ln(0.8))$$

$$= 0.367 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(PDO)} = \exp(-3.98 + 0.34 \times \ln(26{,}000) + \ln(0.8))$$

$$= 0.474 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(total)} = 0.367 + 0.474$$

$$= 0.841 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

Roadside Fixed Objects (CMF_{2r})
For roadway segments with six or more lanes, CMF_{2r} is calculated from Equation 12-41 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times 0.01 + 1.0$$

From Table 12-33, for roadside fixed objects with an average 8-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.367.

$$CMF_{2r} = 0.367 \times 10 \times 0.01 + 1.0$$

$$= 1.037$$

Median Width (CMF_{3r})
The value of CMF_{3r} is 1.00 for undivided facilities (see Section 12.7.1). It is assumed that a roadway with TWLTL is undivided.

Automated Speed Enforcement (CMF_{5r})
Since there is no automated speed enforcement in Sample Problem 3, CMF_{5r} = 1.00 (i.e., the base condition for CMF_{5r} is the absence of automated speed enforcement).

Lane Width (CMF6r)
CMF_{6r} is calculated from Equation 12-43 as follows:

$$CMF_{6r} = e^{-0.0219(W_l - 12)}$$
$$= e^{-0.0219(11-12)}$$
$$= 1.022$$

Outside Shoulder Width (CMF7r)
CMF_{7r} is calculated from Equation 12-44 as follows:

$$CMF_{7r} = e^{-0.0285(W_{os} - 1.5)}$$
$$= e^{-0.0285(3-1.5)}$$
$$= 0.958$$

Highway-Rail Grade Crossing (CMF8r)
The value of CMF_{8r} is 1.00 in the absence of highway-rail grade crossings.

Median Barriers (CMF9r)
The value of CMF_{9r} is 1.00 in the absence of median barriers. It is assumed that a roadway with TWLTL does not have a median barrier.

Major Industrial Driveways (CMF10r)
CMF_{10r} is calculated from Equation 12-47 as follows:

$$CMF_{10r} = e^{0.0107(\frac{n_{id}}{L} - 1)}$$
$$= e^{0.0107(\frac{2}{0.8} - 1)}$$
$$= 1.016$$

Major Commercial Driveways (CMF11r)
CMF_{11r} is calculated from Equation 12-48 as follows:

$$CMF_{11r} = e^{a(\frac{n_{cd}}{L} - 2)}$$

From Table 12-38, for two-way roadway segments with six or more lanes, the coefficient *a* is 0.0350.

$$CMF_{11r} = e^{0.0350(\frac{2}{0.8} - 2)}$$
$$= 1.018$$

Minor Driveways (CMF12r)
CMF_{12r} is calculated from Equation 12-49 as follows:

$$CMF_{12r} = e^{a(\frac{n_{mnd}}{L} - 10)}$$

From Table 12-39, for two-way roadway segments with six or more lanes, the coefficient *a* is 0.0054.

$$CMF_{12r} = e^{0.0054(\frac{5}{0.8} - 10)}$$
$$= 0.980$$

For two-way roadway segments with six or more lanes, separate combined CMF values are calculated for multiple-vehicle collisions and single-vehicle crashes.

$$CMF_{comb(mv)} = 1.022 \times 0.958 \times 1.016 \times 1.018 \times 0.980$$

$$= 0.992$$

$$CMF_{comb(sv)} = 1.037 \times 1.022 \times 0.958$$

$$= 1.015$$

The predicted average crash frequency of each collision type is determined using Equation 12-6, as follows:

$$N_{brmv} = N_{spf\ rs\ mv} \times CMF_{comb(mv)}$$

$$= 6.434 \times 0.992$$

$$= 6.383 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\,sv} \times CMF_{comb(sv)}$$

$$= 0.841 \times 1.015$$

$$= 0.854 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-4 as follows:

$$N_{br} = N_{brmv} + N_{brsv}$$

$$= 6.383 + 0.854$$

$$= 7.237 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-24 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-16, for a posted speed greater than 30 mph on a seven-lane arterial, the pedestrian crash adjustment factor, $f_{pedr} = 0.014$.

$$N_{pedr} = 7.237 \times 0.014$$

$$= 0.101 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-25 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-17, for a posted speed limit greater than 30 mph on a seven-lane arterial, the bicycle crash adjustment factor, $f_{biker} = 0.001$.

N_{biker} = 7.237 × 0.001

= 0.007 crashes/year

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$

$$= 1.00 \times (7.237 + 0.101 + 0.007)$$

$$= 7.345 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 10 worksheets are provided for determining the predicted average crash frequency. The 10 worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet B-1A)*—General Information and Input Data for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3B (Corresponds to Worksheet B-1B)*—Crash Modification Factors for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3C (Corresponds to Worksheet B-1C)*—Multiple-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3D (Corresponds to Worksheet B-1D)*—Multiple-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3E (Corresponds to Worksheet B-1E)*—Single-Vehicle Crashes by Severity Level for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3F (Corresponds to Worksheet B-1F)*—Single-Vehicle Crashes by Manner of Collision for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3G(Corresponds to Worksheet B-1G)*—Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3H(Corresponds to Worksheet B-1H)*—Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3I (Corresponds to Worksheet B-1I)*—Crash Severity*Type Distribution for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes
- *Worksheet SP3J (Corresponds to Worksheet B-1J)*—Summary Results for Two-Way Urban and Suburban Arterial Roadway Segments with Six or More Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12B (for two-way urban and suburban arterials with six or more lanes).

Worksheet SP3A—General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP3A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 3.

Worksheet SP3A. General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (6U, 6D, 7T, 8D)	—	7T
Area type (urban/suburban)	—	suburban
Length of segment, *L* (mi)	—	0.8
AADT (veh/day)	—	26,000
Lane width (ft)	12	11
Outside shoulder width (ft)	1.5	3
Median width (ft)	15	not present
Median barriers (present / not present)	not present	not present
Highway-rail grade crossing density (crossing/mi)	0	0
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveway density (driveways/mi)	2	2/0.8
Major industrial/institutional driveway density (driveways/mi)	1	2/0.8
Minor driveway density (driveways/mi)	10	5/0.8
Posted speed limit (mph)	—	45
Roadside fixed object density (fixed objects/mi)	not present	10
Offset to roadside fixed objects (ft)	not present	8
Calibration factor, C_r	1.0	1.0

Worksheet SP3B—Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 11 of Worksheet SP3B which indicates the combined CMF value.

Worksheet SP3B. Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

				Collision Type	
				Multiple-Vehicle (*mv*)	**Single-Vehicle (*sv*)**
(1)	**CMF for Roadside Fixed Objects**	CMF_{2r}	**from Equation 12-41**	—	1.037
(2)	**CMF for Median Width**	CMF_{3r}	**from Table 12-35**	1.000	1.000
(3)	**CMF for Automated Speed Enforcement**	CMF_{5r}	**from Section 12.7.1**	1.000	1.000
(4)	**CMF for Lane Width**	CMF_{6r}	**from Equation 12-43**	1.022	1.022
(5)	**CMF for Outside Shoulder Width**	CMF_{7r}	**from Equation 12-44**	0.958	0.958
(6)	**CMF for Highway-Rail Grade Crossings**	CMF_{8r}	**from Equation 12-45**	1.000	1.000
(7)	**CMF for Median Barriers**	CMF_{9r}	**from Equation 12-46**	1.000	1.000
(8)	**CMF for Major Industrial Driveways**	CMF_{10r}	**from Equation 12-47**	1.016	—
(9)	**CMF for Major Commercial Driveways**	CMF_{11r}	**from Equation 12-48**	1.018	—
(10)	**CMF for Minor Driveways**	CMF_{12r}	**from Equation 12-49**	0.980	—
(11)	**Combined CMF**	CMF_{comb}	**(1)*(2)*… *(10)**	0.992	1.015

Worksheet SP3C—Multiple-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

The SPF for multiple-vehicle collisions along the roadway segment in Sample Problem 3 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP3C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 represents the combined CMF for multiple-vehicle crashes (from Row 11 in Worksheet SP3B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP3C. Multiple-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	$N_{spf\ rs\ mv}$	**Combined CMF**	**Calibration Factor, C_r**	**Predicted N_{brmv}**
	from Table 12-8			**from Equation 12-22**	**from Equation 12-21**	**$(11)_{mv}$ from Worksheet SP3B**		**(4)*(5)*(6)**
	a	**b**	**c**					
FI	-11.44	1.24	1.30	0.341	2.566	0.992	1.00	2.546
PDO	-9.20	1.06	1.08	0.424	3.868	0.992	1.00	3.837
Total	—	—	—	—	—	—	1.00	6.383

Worksheet SP3D—Multiple-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP3D presents the default proportions for manner of collision (from Table 12-9) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 7, Worksheet SP3C) into components by crash severity and manner of collision.

Worksheet SP3D. Multiple-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brmv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brmv(PDO)}$ (crashes/year)**	**Predicted $N_{brmv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-9**	**$(7)_{FI}$ from Worksheet SP3C**	**from Table 12-9**	**$(7)_{PDO}$ from Worksheet SP3C**	**$(7)_{total}$ from Worksheet SP3C**
Total	1.000	2.546	1.000	3.837	6.383
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision	0.694	1.767	0.588	2.256	4.023
Head-on collision	0.034	0.087	0.012	0.046	0.133
Angle collision	0.148	0.377	0.092	0.353	0.730
Sideswipe, same direction	0.072	0.183	0.255	0.978	1.161
Sideswipe, opposite direction	0.020	0.051	0.024	0.092	0.143
Other multiple-vehicle collision	0.031	0.079	0.029	0.111	0.190

Worksheet SP3E—Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 3 is calculated using Equation 12-23 and entered into Column 4 of Worksheet SP3E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 represents the combined CMF for single-vehicle crashes (from Row 11 in Worksheet SP3B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP3E. Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**$N_{spf\ rs\ sv}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted N_{brsv}**
	from Table 12-10			**from Equation 12-22**	**from Equation 12-23**	**$(11)_{sv}$ from Worksheet SP3B**		**(4)*(5)*(6)**
	a	**b**	**c**					
FI	-4.54	0.37	3.08	0.057	0.367	1.015	1.00	0.373
PDO	-3.98	0.34	1.97	0.174	0.474	1.015	1.00	0.481
Total	—	—	—	—	—	—	1.00	0.854

Worksheet SP3F—Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP3F presents the default proportions for manner of collision (from Table 12-11) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 7, Worksheet SP3E) into components by crash severity and manner of collision.

Worksheet SP3F. Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-11**	**$(7)_{FI}$ from Worksheet SP3E**	**from Table 12-11**	**$(7)_{PDO}$ from Worksheet SP3E**	**$(7)_{total}$ from Worksheet SP3E**
Total	1.000	0.373	1.000	0.481	0.854
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Collision with fixed object – left	0.158	0.059	0.248	0.119	0.178
Collision with fixed object – right	0.495	0.185	0.481	0.231	0.416
Collision with other object	0.011	0.004	0.037	0.018	0.022
Other single-vehicle crash	0.337	0.126	0.234	0.113	0.239

Worksheet SP3G—Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3, respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3G. Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(7) from Worksheet SP3C	**(7) from Worksheet SP3E**	**(2)+(3)**	**From Table 12-16**		**(4)*(5)*(6)**
Total	6.383	0.854	7.237	0.014	1.00	0.101
FI	—	—	—	—	1.00	0.101

Worksheet SP3H—Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3, respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3H. Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(7) from Worksheet SP3C	**(7) from Worksheet SP3E**	**(2)+(3)**	**From Table 12-17**		**(4)*(5)*(6)**
Total	6.383	0.854	7.237	0.001	1.00	0.007
FI	—	—	—	—	1.00	0.007

Worksheet SP3I—Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP3I provides a summary of all manners of collision by severity level. Values from Worksheets SP3D, SP3F, SP3G, and SP3H are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP3I. Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)
	FI	PDO	Total
Collision Type	(3) from Worksheets SP3D and SP3F; and (7) from Worksheet SP3G and SP3H	(5) from Worksheet SP3D and SP3F	(6) from Worksheets SP3D and SP3F; and (7) from Worksheets SP3G and SP3H
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet SP3D)	1.767	2.256	4.023
Head-on collision (from Worksheet SP3D)	0.087	0.046	0.133
Angle collision (from Worksheet SP3D)	0.377	0.353	0.730
Sideswipe, same direction (from Worksheet SP3D)	0.183	0.978	1.161
Sideswipe, opposite direction (from Worksheet SP3D)	0.051	0.092	0.143
Other multiple-vehicle collision (from Worksheet SP3D)	0.079	0.111	0.190
Subtotal	2.546	3.837	6.383
SINGLE_VEHICLE			
Collision with fixed object – left (from Worksheet SP3F)	0.059	0.119	0.178
Collision with fixed object – right (from Worksheet SP3F)	0.185	0.231	0.416
Collision with other object (from Worksheet SP3F)	0.004	0.018	0.022
Other single-vehicle crash (from Worksheet SP3F)	0.126	0.113	0.239
Collision with pedestrian (from Worksheet SP3G)	0.101	0.000	0.101
Collision with bicycle (from Worksheet SP3H)	0.007	0.000	0.007
Subtotal	0.481	0.481	0.962
Total	3.027	4.318	7.345

Worksheet SP3J—Summary Results for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP3J presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP3J. Summary Results for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(total) from Worksheet SP3I	Roadway Segment Length, L (mi)	(2)/(3)
Total	7.345	0.8	9.18
FI	4.318	0.8	5.40
PDO	3.027	0.8	3.78

12.14.4. Sample Problem 4

The Site/Facility
A three-lane one-way urban arterial roadway segment.

The Question
What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 0.4-mi length
- 15,000 veh/day
- 11-ft lanes
- 1.5-ft right shoulder
- 0.2 mile of parallel street parking on one side of the street and 0.1 mile on the other side
- 6 driveways (1 major commercial, 5 minor driveways)
- 10 roadside fixed objects per mile
- 6-ft offset to roadside fixed objects
- No automated speed enforcement
- 30-mph posted speed
- No bike lane

Assumptions
Collision type distributions used are the default values presented in and and Equations 12-24 and 12-25.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 4 is determined to be 3.8 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 4, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For one-way roadway segments, SPF values are determined for multiple-vehicle, single- vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Collisions
The SPF for multiple-vehicle collisions for the roadway segment is calculated from Equation 12-21 and Table 12-8 as follows:

$$N_{spf\ rs\ mv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ mv(FI)} = \exp(-11.49 + 1.26 \times \ln(15,000) + \ln(0.4))$$

$$= 0.748 \text{ crashes/year}$$

$$N_{spf\ rs\ mv(PDO)} = \exp(-8.27 + 1.02 \times \ln(15,000) + \ln(0.4))$$

$$= 1.862 \text{ crashes/year}$$

$$N_{spf\ rs\ mv(total)} = 0.748 + 1.862$$

$$= 2.610 \text{ crashes/year}$$

Single-Vehicle Crashes
The SPF for single-vehicle crashes for the roadway segment is calculated from Equation 12-23 and Table 12-10 as follows:

$$N_{spf\ rs\ sv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$N_{spf\ rs\ sv(FI)} = \exp(-4.93 + 0.42 \times \ln(15,000) + \ln(0.4))$$

$$= 0.164 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(PDO)} = \exp(-4.72 + 0.43 \times \ln(15,000) + \ln(0.4))$$

$$= 0.223 \text{ crashes/year}$$

$$N_{spf\ rs\ sv(total)} = 0.164 + 0.223$$

$$= 0.387 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

On-Street Parking (*CMF_{1r}*)
CMF_{1r} is calculated from Equation 12-39 as follows:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0)$$

The proportion of curb length with on-street parallel parking, p_{pk}, is determined as follows:

$$p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Since 0.2 and 0.1 mile of on-street parking is provided on each side of the road, the sum of curb length with on-street parking for both sides of the road combined, $L_{pk} = 0.3$.

$$p_{pk} = 0.5 \times \frac{0.3}{0.4} = 0.375$$

From Table 12-32, $f_{pk} = 1.359$.

$$CMF_{1r} = 1 + 0.375 \times (1.359 - 1.0)$$
$$= 1.135$$

***Roadside Fixed Objects* (*CMF*$_{2r}$)**

For one-way roadway segments, CMF_{2r} is calculated from Equation 12-41 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times 0.01 + 1.0$$

From Table 12-33, for roadside fixed objects with an average 6-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.579.

$$CMF_{2r} = 0.579 \times 10 \times 0.01 + 1.0$$
$$= 1.058$$

***Automated Speed Enforcement* (*CMF*$_{5r}$)**

Since there is no automated speed enforcement in Sample Problem 4, CMF_{5r} = 1.00 (i.e., the base condition for CMF_{5r} is the absence of automated speed enforcement).

***Major Commercial Driveways* (*CMF*$_{11r}$)**

CMF_{11r} is calculated from Equation 12-48 as follows:

$$CMF_{11r} = e^{a\left(\frac{n_{cd}}{L} - 2\right)}$$

From Table 12-38, for one-way roadway segments, the coefficient *a* is 0.0177.

$$CMF_{11r} = e^{0.0177\left(\frac{1}{0.4} - 2\right)}$$
$$= 1.009$$

***Minor Driveways* (*CMF*$_{12r}$)**

CMF_{12r} is calculated from Equation 12-49 as follows:

$$CMF_{12r} = e^{a\left(\frac{n_{mnd}}{L} - 10\right)}$$

From Table 12-39, for one-way roadway segments, the coefficient *a* is 0.0046.

$$CMF_{12r} = e^{0.0046\left(\frac{5}{0.4} - 10\right)}$$
$$= 1.012$$

***Right Shoulder Width* (*CMF*$_{13r}$)**

CMF_{13r} is calculated from Equation 12-50 as follows:

$$CMF_{13r} = e^{-0.0201(W_{rs} - 4)}$$
$$= e^{-0.0201(1.5 - 4)}$$
$$= 1.052$$

For one-way roadway segments, separate combined CMF values are calculated for multiple-vehicle collisions and single-vehicle crashes.

$$CMF_{comb(mv)} = 1.135 \times 1.009 \times 1.012 \times 1.052$$

$$= 1.219$$

$$CMF_{comb(sv)} = 1.135 \times 1.058 \times 1.052$$

$$= 1.263$$

The predicted average crash frequency of each collision type is determined using Equation 12-6, as follows:

$$N_{brmv} = N_{spf\ rs\ mv} \times CMF_{comb(mv)}$$

$$= 2.610 \times 1.219$$

$$= 3.182 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\ sv} \times CMF_{comb(sv)}$$

$$= 0.387 \times 1.263$$

$$= 0.489 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-4 as follows:

$$N_{br} = N_{brmv} + N_{brsv}$$

$$= 3.182 + 0.489$$

$$= 3.671 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-24 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-16, for a posted speed of 30 mph on a three-lane one-way arterial, the pedestrian crash adjustment factor, $f_{pedr} = 0.024$.

$$N_{pedr} = 3.671 \times 0.024$$

$$= 0.088 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-25 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-17, for a posted speed of 30 mph on a three-lane one-way arterial, the bicycle crash adjustment factor, $f_{biker} = 0.011$.

$$N_{biker} = 3.671 \times 0.011$$

$$= 0.040 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-3 based on the results obtained in Steps 9 through 11 as follows:

The predicted average crash frequency is calculated using Equation 12-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$

$$= 1.00 \times (3.671 + 0.088 + 0.040)$$

$$= 3.799 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 10 worksheets are provided for determining the predicted average crash frequency. The 10 worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet C-1A)*—General Information and Input Data for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4B (Corresponds to Worksheet C-1B)*—Crash Modification Factors for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4C (Corresponds to Worksheet C-1C)*—Multiple-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4D (Corresponds to Worksheet C-1D)*—Multiple-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4E (Corresponds to Worksheet C-1E)*—Single-Vehicle Crashes by Severity Level for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4F (Corresponds to Worksheet C-1F)*—Single-Vehicle Crashes by Manner of Collision for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4G(Corresponds to Worksheet C-1G)*—Vehicle-Pedestrian Collisions for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4H(Corresponds to Worksheet C-1H)*—Vehicle-Bicycle Collisions for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4I (Corresponds to Worksheet C-1I)*—Crash Severity*Type Distribution for One-Way Urban and Suburban Arterial Roadway Segments
- *Worksheet SP4J (Corresponds to Worksheet C-1J)*—Summary Results for One-Way Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12C (for one-way urban and suburban arterials).

Worksheet SP4A—General Information and Input Data for One-Way Urban and Suburban Roadway Segments

Worksheet SP4A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 4.

Worksheet SP4A. General Information and Input Data for One-Way Urban and Suburban Roadway Segments

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2O, 3O, 4O)	—	3O
Area type (urban/suburban)	—	urban
Length of segment, *L* (mi)	—	0.4
AADT (veh/day)	—	15,000
Type of on-street parking (none/parallel/angle)	none	parallel
Proportion of curb length with on-street parking	—	0.375
Lane width (ft)	—	11
Right shoulder width (ft)	4	1.5
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveway density (driveways/mi)	2	1
Minor driveway density (driveways/mi)	10	5
Speed category	—	Low (<30mph)
Bike lane (present/not present)	—	not present
Roadside fixed object density (fixed objects/mi)	not present	10
Offset to roadside fixed objects (ft)	not present	6
Calibration factor, C_r	1.0	1.0

Worksheet SP4B—Crash Modification Factors for One-Way Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 5 of Worksheet SP4B which indicates the combined CMF value.

Worksheet SP4B. Crash Modification Factors for One-Way Urban and Suburban Roadway Segments

				Collision Type	
				Multiple-Vehicle (*mv*)	Single-Vehicle (*sv*)
(1)	CMF for On-Street Parking	CMF_{1r}	from Equation 12-39	1.135	1.135
(2)	CMF for Roadside Fixed Objects	CMF_{2r}	from Equation 12-41	—	1.058
(3)	CMF for Automated Speed Enforcement	CMF_{5r}	from Section 12.7.1	1.000	1.000
(4)	CMF for Major Commercial Driveways	CMF_{11r}	from Equation 12-48	1.009	—
(5)	CMF for Minor Driveways	CMF_{12r}	from Equation 12-49	1.012	—
(6)	CMF for Right Shoulder Width	CMF_{13r}	from Equation 12-50	1.052	1.052
(7)	Combined CMF	CMF_{comb}	(1)*(2)*(3)*(4)*(5)*(6)	1.219	1.263

Worksheet SP4C—Multiple-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

The SPF for multiple-vehicle collisions along the roadway segment in Sample Problem 4 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP4C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 represents the combined CMF for multiple-vehicle crashes (from Row 5 in Worksheet SP4B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP4C. Multiple-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, k	$N_{spf\ rs\ mv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brmv}
	from Table 12-8			from Equation 12-22	from Equation 12-21	$(7)_{mv}$ from Worksheet SP4B		(4)*(5)*(6)
	a	b	c					
FI	-11.49	1.26	2.57	0.191	0.748	1.219	1.00	0.912
PDO	-8.27	1.02	2.45	0.216	1.862	1.219	1.00	2.270
Total	—	—	—	—	—	—	1.00	3.182

Worksheet SP4D—Multiple-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Roadway Segments

Worksheet SP4D presents the default proportions for manner of collision (from) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).
These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 7, Worksheet SP4C) into components by crash severity and manner of collision.

Worksheet SP4D. Multiple-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brmv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brmv(PDO)}$ (crashes/year)**	**Predicted $N_{brmv(total)}$ (crashes/year)**
Manner of Collision	**from**	**(7)$_{FI}$ from Worksheet SP4C**	**from**	**(7)$_{PDO}$ from Worksheet SP4C**	**(7)$_{total}$ from Worksheet SP4C**
Total	1.000	0.912 (2)*(3)$_{FI}$	1.000	2.270 (4)*(5)$_{PDO}$	3.182 (3)+(5)
Rear-end collision	0.671	0.612	0.435	0.987	1.599
Head-on collision	0.013	0.012	0.013	0.030	0.042
Angle collision	0.133	0.121	0.115	0.261	0.382
Sideswipe, same direction	0.133	0.121	0.384	0.872	0.993
Sideswipe, opposite direction	0.013	0.012	0.017	0.039	0.051
Other multiple-vehicle collision	0.038	0.035	0.036	0.082	0.117

Worksheet SP4E—Single-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 4 is calculated using Equation 12-23 and entered into Column 4 of Worksheet SP4E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 represents the combined CMF for single-vehicle crashes (from Row 5 in Worksheet SP4B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP4E. Single-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**$N_{spf\ rs\ sv}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted N_{brsv}**
	from Table 12-10			**from Equation 12-22**	**from Equation 12-23**	**(7)$_{sv}$ from Worksheet SP4B**		**(4)*(5)*(6)**
	a	**b**	**c**					
FI	-4.93	0.42	1.94	0.359	0.164	1.263	1.00	0.207
PDO	-4.72	0.43	1.98	0.345	0.223	1.263	1.00	0.282
Total	—	—	—	—	—	—	1.00	0.489

Worksheet SP4F—Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

Worksheet SP4F presents the default proportions for manner of collision (from) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 7, Worksheet SP4E) into components by crash severity and manner of collision.

Worksheet SP4F. Single-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
Manner of Collision	**from**	**$(7)_{FI}$ from Worksheet SP4E**	**from**	**$(7)_{PDO}$ from Worksheet SP4E**	**$(7)_{total}$ from Worksheet SP4E**
Total	1.000	0.207 $(2)*(3)_{FI}$	1.000	0.282 $(4)*(5)_{PDO}$	0.489 (3)+(5)
Collision with animal	0.182	0.038	0.489	0.138	0.176
Collision with fixed object	0.182	0.038	0.289	0.081	0.119
Collision with other object	0.091	0.019	0.044	0.012	0.031
Other single-vehicle crash	0.545	0.113	0.178	0.050	0.163

Worksheet SP4G—Vehicle-Pedestrian Collisions for One-Way Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP4C and SP4E are entered into Columns 2 and 3, respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4G. Vehicle-Pedestrian Collisions for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(7) from Worksheet SP4C	**(7) from Worksheet SP4E**	(2)+(3)	**From Table 12-16**		**(4)*(5)*(6)**
Total	3.182	0.489	3.671	0.024	1.00	0.088
FI	—	—	—	—	1.00	0.088

Worksheet SP3H—Vehicle-Bicycle Collisions for One-Way Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP4C and SP4E are entered into Columns 2 and 3, respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4H. Vehicle-Bicycle Collisions for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(7) from Worksheet SP4C	**(7) from Worksheet SP4E**	**(2)+(3)**	**From Table 12-17**		**(4)*(5)*(6)**
Total	3.182	0.489	3.671	0.011	1.00	0.040
FI	—	—	—	—	1.00	0.040

Worksheet SP4I—Crash Severity*Type Distribution for One-Way Urban and Suburban Roadway Segments

Worksheet SP4I provides a summary of all manners of collision by severity level. Values from Worksheets SP4D, SP4F, SP4G, and SP4H are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP4I. Crash Severity*Type Distribution for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP4D and SP4F; and (7) from Worksheet SP4G and SP4H**	**(5) from Worksheet SP4D and SP4F**	**(6) from Worksheets SP4D and SP4F; and (7) from Worksheets SP4G and SP4H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet SP4D)	0.612	0.987	1.599
Head-on collision (from Worksheet SP4D)	0.012	0.030	0.042
Angle collision (from Worksheet SP4D)	0.121	0.261	0.382
Sideswipe, same direction (from Worksheet SP4D)	0.121	0.872	0.993
Sideswipe, opposite direction (from Worksheet SP4D)	0.012	0.039	0.051
Other multiple-vehicle collision (from Worksheet SP4D)	0.035	0.082	0.117
Subtotal	0.912	2.270	3.182
SINGLE_VEHICLE			
Collision with animal (from Worksheet SP4F)	0.038	0.138	0.176
Collision with fixed object (from Worksheet SP4F)	0.038	0.081	0.119
Collision with other object (from Worksheet SP4F)	0.019	0.012	0.031
Other single-vehicle crash (from Worksheet SP4F)	0.113	0.050	0.163
Collision with pedestrian (from Worksheet SP4G)	0.088	0.000	0.088
Collision with bicycle (from Worksheet SP4H)	0.040	0.000	0.040
Subtotal	0.335	0.282	0.617
Total	1.247	2.552	3.799

Worksheet SP4J—Summary Results for One-Way Urban and Suburban Roadway Segments

Worksheet SP4J presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP4J. Summary Results for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(total) from Worksheet SP4I**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total	3.799	0.4	9.50
FI	1.247	0.4	3.12
PDO	2.552	0.4	6.38

12.14.5. Sample Problem 5

The Site/Facility
A three-leg stop-controlled intersection located on an urban arterial.

The Question
What is the predicted average crash frequency of the unsignalized intersection for a particular year?

The Facts

- 4-lane undivided major road
- 2-lane undivided minor road
- 1 left-turn lane on one major road approach
- No right-turn lanes on any approach
- AADT of major road is 14,000 veh/day
- AADT of minor road is 4,000 veh/day

Assumptions
Collision type distributions used are the default values from Table 12-21 and Table 12-23 and Equations 12-37 and 12-38.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem 5 is determined to be 1.6 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the intersection in Sample Problem 5, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For intersections of two-way arterials with five or fewer lanes, SPF values are determined for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Collisions
The SPF for multiple-vehicle collisions for a single three-leg stop-controlled intersection is calculated from Equation 12-26 and Table 12-20 as follows:

$$N_{spf\ int\ mv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int\ mv(\text{total})} = \exp(-13.63 + 1.11 \times \ln(14{,}000) + 0.41 \times \ln(4{,}000))$$

$$= 1.892 \text{ crashes/year}$$

$$N_{spf\ int\ mv(FI)} = \exp(-14.01 + 1.16 \times \ln(14{,}000) + 0.30 \times \ln(4{,}000))$$

$$= 0.639 \text{ crashes/year}$$

$$N_{spf\ int\ mv(PDO)} = \exp(-15.38 + 1.20 \times \ln(14{,}000) + 0.51 \times \ln(4{,}000))$$

$$= 1.358 \text{ crashes/year}$$

The initial values for FI and PDO crashes are then adjusted using Equations 12-27 and 12-28 to assure that they sum to the value for total crashes as follows:

$$N_{spf\ int\ mv(FI)} = N_{spf\ int\ mv(\text{total})} \left(\frac{N'_{spf\ int\ mv(FI)}}{N'_{spf\ int\ mv(FI)} + N'_{spf\ int\ mv(PDO)}} \right)$$

$$= 1.892 \times \left(\frac{0.639}{0.639 + 1.358} \right)$$

$$= 0.605 \text{ crashes/year}$$

$$N_{spf\ int\ mv(PDO)} = N_{spf\ int\ mv(\text{total})} - N_{spf\ int\ mv(FI)}$$

$$= 1.892 - 0.605$$

$$= 1.287 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single three-leg stop-controlled intersection is calculated from Equation 12-29 and Table 12-22 as follows:

$$N_{spf\ int\ sv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int\ sv(\text{total})} = \exp(-6.81 + 0.16 \times \ln(14{,}000) + 0.51 \times \ln(4{,}000))$$

$$= 0.349 \text{ crashes/year}$$

$$N_{spf\ int\ sv(PDO)} = \exp(-8.36 + 0.25 \times \ln(14{,}000) + 0.55 \times \ln(4{,}000))$$

$$= 0.244 \text{ crashes/year}$$

Since there are no models for FI crashes at a three-leg stop-controlled intersection, $N_{spf\ int\ sv(FI)}$ is calculated using Equation 12-32 (in place of Equation 12-30), and the initial value for $N_{spf\ int\ sv(PDO)}$ calculated above is then adjusted using Equation 12-31 to assure that FI and PDO crashes sum to the value for total crashes as follows:

$$N_{spf\ int\ sv(FI)} = N_{spf\ int\ sv(\text{total})} \times f_{bisv}$$

For a three-leg stop-controlled intersection, the default proportion of FI crashes, f_{bisv} = 0.31 (see Section 12.6.2.1, Single-Vehicle Crashes)

$$N_{spf\ int\ sv(FI)} = 0.349 \times 0.31$$

$$= 0.108 \text{ crashes/year}$$

$$N_{spf\ int\ sv(PDO)} = N_{spf\ int\ sv(\text{total})} - N_{spf\ int\ sv(FI)}$$

$$= 0.349 - 0.108$$

$$= 0.241 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

***Intersection Left-Turn Lanes* (*CMF_{1i}*)**
From Table 12-40, for a three-leg stop-controlled intersection with one left-turn lane on the major road, CMF_{1i} = 0.67.

***Intersection Left-Turn Signal Phasing* (*CMF_{2i}*)**
For unsignalized intersections, CMF_{2i} = 1.00.

***Intersection Right-Turn Lanes* (*CMF_{3i}*)**
Since no right-turn lanes are present, CMF_{3i} is 1.00 (i.e., the base condition for CMF_{3i} is the absence of right-turn lanes on the intersection approaches).

***Right-Turn-on-Red* (*CMF_{4i}*)**
For unsignalized intersections, CMF_{4i} = 1.00.

***Lighting* (*CMF_{5i}*)**
Since there is no lighting at this intersection, CMF_{5i} is 1.00 (i.e., the base condition for CMF_{5i} is the absence of intersection lighting).

***Red-Light Cameras* (*CMF_{6i}*)**
For unsignalized intersections, CMF_{6i} is always 1.00.

The combined CMF value for Sample Problem 5 is 0.67.

The predicted average crash frequency of multiple-vehicle collisions and single-vehicle crashes are determined using Equation 12-9, as follows:

$$N_{brmv} = N_{spf\ rs\ mv} \times CMF_{comb}$$

$$= 1.892 \times 0.67$$

$$= 1.268 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\ sv} \times CMF_{comb}$$

$$= 0.349 \times 0.67$$

$$= 0.234 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-8 as follows:

$$N_{bi} = N_{bimv} + N_{bisv}$$

$$= 1.268 + 0.234$$

$$= 1.502 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions is calculated from Equation 12-37 as follows:

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

From Table 12-29, for a three-leg stop-controlled intersection of a two-way arterial with five or fewer lanes, the pedestrian crash adjustment factor, $f_{pedi} = 0.021$.

N_{pedi} = 1.502 × 0.021

= 0.032 crashes/year

The SPF for vehicle-bicycle collisions is calculated from Equation 12-38 as follows:

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

From Table 12-30, for a three-leg stop-controlled intersection of a two-way arterial with five or fewer lanes, the bicycle crash adjustment factor, $f_{bikei} = 0.016$.

N_{bikei} = 1.502 × 0.016

= 0.024 crashes/year

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-7 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$

$$= 1.00 \times (1.502 + 0.032 + 0.024)$$

$$= 1.558 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 10 worksheets are provided for determining the predicted average crash frequency. The 10 worksheets include:

- *Worksheet SP5A (Corresponds to Worksheet A-2A)*—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5B (Corresponds to Worksheet A-2B)*— Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5C (Corresponds to Worksheet A-2C)*—Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5D (Corresponds to Worksheet A-2D)*— Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5E (Corresponds to Worksheet A-2E)*—Single-Vehicle Crashes by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5F (Corresponds to Worksheet A-2F)*— Single-Vehicle Crashes by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP2G (Corresponds to Worksheet A-2G)*— Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

- *Worksheet SP5J (Corresponds to Worksheet A-2J)*— Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5K (Corresponds to Worksheet A-2K)*— Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP5L (Corresponds to Worksheet A-2L)*— Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP5A—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP5A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 5.

Worksheet SP5A. General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	3ST
$AADT_{maj}$ (veh/day)	—	14,000
$AADT_{min}$ (veh/day)	—	4,000
Intersection lighting (present/not present)	not present	not present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:		
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	1
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	0
Data for signalized intersections only:		
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red-light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 1000 ft of the intersection	0	N/A
Schools within 1000 ft of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 1000 ft of the intersection	0	N/A

Worksheet SP5B—Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 7 of Worksheet SP5B which indicates the combined CMF value.

Worksheet SP5B. Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	**CMF for Left-Turn Lanes**	CMF_{1i}	**from Table 12-40**	0.67
(2)	**CMF for Left-Turn Signal Phasing**	CMF_{2i}	**from Table 12-41**	1.00
(3)	**CMF for Right-Turn Lanes**	CMF_{3i}	**from Table 12-42**	1.00
(4)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	1.00
(5)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	1.00
(6)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	1.00
(7)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)**	0.67

Worksheet SP5C—Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 5 is calculated using Equation 12-26 and entered into Column 4 of Worksheet SP5C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 5 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 7 in Worksheet SP5B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP5C. Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**Initial $N_{spf\ int\ mv}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ int\ mv}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bimv}**
	from Table 12-20			**from Table 12-20**	**from Equation 12-26**		**$(4)_{total}$*(5)**	**(7) from Worksheet SP5B**		**(6)*(7)*(8)**
	A	**b**	**c**							
Total	-13.36	1.11	0.41	0.80	1.892	1.000	1.892	0.67	1.00	1.268
FI	-14.01	1.16	0.30	0.69	0.639	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.320	0.605	0.67	1.00	0.405
PDO	-15.38	1.20	0.51	0.77	1.358	$(5)_{total} - (5)_{FI}$ 0.680	1.287	0.67	1.00	0.862

Worksheet SP5D—Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP5D presents the default proportions for manner of collision (from Table 12-21) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP5C) into components by crash severity and manner of collision.

Worksheet SP5D. Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bimv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bimv(PDO)}$ (crashes/year)**	**Predicted $N_{bimv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-21**	**$(9)_{FI}$ from Worksheet SP5C**	**from Table 12-21**	**$(9)_{PDO}$ from Worksheet SP5C**	**$(9)_{total}$ from Worksheet SP5C**
Total	1.000	0.405 $(2)*(3)_{FI}$	1.000	0.862 $(4)*(5)_{PDO}$	1.268 (3)+(5)
Rear-end collision	0.421	0.171	0.440	0.379	0.550
Head-on collision	0.045	0.018	0.023	0.020	0.038
Angle collision	0.343	0.139	0.262	0.226	0.365
Sideswipe	0.126	0.051	0.040	0.034	0.085
Other multiple-vehicle collision	0.065	0.026	0.235	0.203	0.229

Worksheet SP5E—Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The SPF for single-vehicle crashes at the intersection in Sample Problem 5 is calculated using Equation 12-18 and entered into Column 4 of Worksheet SP5E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 5 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 7 in Worksheet SP5B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of Single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP5E. Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**Initial $N_{spf\ int\ sv}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ int\ sv}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bisv}**
	from Table 12-22			**from Table 12-22**	**from Equation 12-29**		**$(4)_{total}$*(5)**	**(7) from Worksheet SP5B**		**(6)*(7)*(8)**
	a	**b**	**c**							
Total	-6.81	0.16	0.51	1.14	0.349	1.000	0.349	0.67	1.00	0.234
FI	N/A	N/A	N/A	N/A	0.108	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ N/A	0.108	0.67	1.00	0.072
PDO	-8.36	0.25	0.55	1.29	0.244	$(5)_{total} - (5)_{FI}$ 0.693	0.242	0.67	1.00	0.162

Worksheet SP5F—Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP5F presents the default proportions for manner of collision (from Table 12-23) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP5E) into components by crash severity and manner of collision.

Worksheet SP5F. Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision $Manner_{(FI)}$	**Predicted $N_{bisv(FI)}$ (crashes/year)**	**Proportion of Collision $Manner_{(PDO)}$**	**Predicted $N_{bisv(PDO)}$ (crashes/year)**	**Predicted $N_{bisv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-23**	**$(9)_{FI}$ from Worksheet SP5E**	**from Table 12-23**	**$(9)_{PDO}$ from Worksheet SP5E**	**$(9)_{total}$ from Worksheet SP5E**
Total	1.000	0.072 $(2)*(3)_{FI}$	1.000	0.162 $(4)*(5)_{PDO}$	0.234 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.003	0.000	0.000
Collision with animal	0.003	0.000	0.018	0.003	0.003
Collision with fixed object	0.762	0.055	0.834	0.135	0.190
Collision with other object	0.090	0.006	0.092	0.015	0.021
Other single-vehicle collision	0.039	0.003	0.023	0.004	0.007
Single-vehicle noncollision	0.105	0.008	0.030	0.005	0.013

Worksheet SP5G—Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP5C and SP5E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-29). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP5G. Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	f_{pedi}	Calibration Factor, C_i	Predicted N_{pedi}
	(9) from Worksheet SP5C	(9) from Worksheet SP5E	(2)+(3)	From Table 12-29		(4)*(5)*(6)
Total	1.268	0.234	1.502	0.021	1.00	0.032
FI	—	—	—	—	1.00	0.032

Worksheet SP5J—Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP5C and SP5E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-30). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP5J. Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	F_{bikei}	Calibration Factor, C_i	Predicted N_{bikei}
	(9) from Worksheet SP5C	(9) from Worksheet SP5E	(2)+(3)	from Table 12-30		(4)*(5)*(6)
Total	1.268	0.234	1.502	0.016	1.000	0.024
FI	—	—	—	—	1.000	0.024

Worksheet SP5K—Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP5K provides a summary of all manners of collision by severity level. Values from Worksheets SP5D, SP5F, SP5G, and SP5J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP5K. Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP5D and SP5F; (7) from Worksheets SP5G and SP5J**	**(5) from Worksheet SP5D and SP5F**	**(6) from Worksheets SP5D and SP5F; (7) from Worksheets SP5G and SP5J**
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet SP5D)	0.171	0.379	0.550
Head-on collisions (from Worksheet SP5D)	0.018	0.020	0.038
Angle collisions (from Worksheet SP5D)	0.139	0.226	0.365
Sideswipe (from Worksheet SP5D)	0.051	0.034	0.085
Other multiple-vehicle collisions (from Worksheet SP5D)	0.026	0.203	0.229
Subtotal	0.405	0.862	1.267
SINGLE_VEHICLE			
Collision with parked vehicle (from Worksheet SP5F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP5F)	0.000	0.003	0.003
Collision with fixed object (from Worksheet SP5F)	0.055	0.135	0.190
Collision with other object (from Worksheet SP5F)	0.006	0.015	0.021
Other single-vehicle collision (from Worksheet SP5F)	0.003	0.004	0.007
Single-vehicle noncollision (from Worksheet SP5F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP5G)	0.032	0.000	0.032
Collision with bicycle (from Worksheet SP5J)	0.024	0.000	0.024
Subtotal	0.128	0.162	0.290
Total	0.533	1.024	1.557

Worksheet SP5L—Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP5L presents a summary of the results.

Worksheet SP5L. Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet SP5K**
Total	1.557
FI	0.533
PDO	1.024

12.14.6. Sample Problem 6

The Site/Facility
A four-leg signalized intersection located on an urban arterial.

The Question
What is the predicted average crash frequency of the signalized intersection for a particular year?

The Facts

- 4-lane divided major road
- 2-lane undivided minor road
- 1 left-turn lane on each of the two major road approaches
- 1 right-turn lane on each of the two major road approaches
- Protected/permissive left-turn signal phasing on major road
- AADT of major road is 15,000 veh/day
- AADT of minor road is 9,000 veh/day
- Lighting is present
- No approaches with prohibited right-turn-on-red
- Four-lane divided major road
- Two-lane undivided minor road
- Pedestrian volume is 1,500 peds/day
- The number of bus stops within 1,000 ft of intersection is 2
- A school is present within 1,000 ft of intersection
- The number of alcohol establishments within 1,000 ft of intersection is 6

Assumptions
Collision type distributions used are the default values from Table 12-21 and Table 12-23 and Equations 12-35 and 12-38.

The calibration factor is assumed to be 1.00.

The maximum number of lanes crossed by a pedestrian is assumed to be four (crossing two through lanes, one left-turn lane, and one right-turn lane across one side of the divided major road).

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem 6 is determined to be 3.4 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the intersection in Sample Problem 6, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For intersections of two-way arterials with five or fewer lanes, SPF values are determined for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for total multiple- and single-vehicle collisions are presented below. Detailed steps for calculating SPFs for FI and PDO crashes are presented in Sample Problem 5 (for FI base crashes at a four-leg signalized intersection, Equation 12-30 in place of Equation 12-32 is used). The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Collisions
The SPF for multiple-vehicle collisions for a single four-leg signalized intersection is calculated from Equation 12-26 and Table 12-20 as follows:

$$N_{spf\ int\ mv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int\ mv(\text{total})} = \exp(-10.99 + 1.07 \times \ln(15{,}000) + 0.23 \times \ln(9{,}000))$$

$$= 4.027 \text{ crashes/year}$$

Single-Vehicle Crashes
The SPF for single-vehicle crashes for a single four-leg signalized intersection is calculated from Equation 12-29 and Table 12-22 as follows:

$$N_{spf\ int\ sv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int\ sv(\text{total})} = \exp(-10.21 + 0.68 \times \ln(15{,}000) + 0.27 \times \ln(9{,}000))$$

$$= 0.297 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{9i} are applied to multiple-vehicle and single-vehicle collisions, while CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions.

***Intersection Left-Turn Lanes* (*CMF_{1i}*)**
From Table 12-40, for a four-leg signalized intersection with one left-turn lane on each of the two approaches, CMF_{1i} = 0.81.

***Intersection Left-Turn Signal Phasing* (*CMF_{2i}*)**
From Table 12-41, for a four-leg signalized intersection with protected/permissive left-turn signal phasing for two approaches, CMF_{2i} = 0.98 (0.99*0.99).

***Intersection Right-Turn Lanes* (*CMF_{3i}*)**
From Table 12-42, for a four-leg signalized intersection with one right-turn lane on each of the two approaches, CMF_{3i} = 0.92.

***Right-Turn-on-Red* (*CMF_{4i}*)**
Since right-turn-on-red (RTOR) is not prohibited on any of the intersection legs, CMF_{4i} = 1.00 (i.e., the base condition for CMF_{4i} is permitting a RTOR at all approaches to a signalized intersection).

Lighting (CMF_{5i})
CMF_{5i} is calculated from Equation 12-52.

$$CMF_{5i} = 1 - 0.38 \times p_{ni}$$

From Table 12-43, the proportion of crashes that occur at night, $p_{ni} = 0.235$.

$$CMF_{5i} = 1 - 0.38 \times 0.235$$
$$= 0.91$$

Red-Light Cameras (CMF_{6i})
Since no red light cameras are present at this intersection, $CMF_{6i} = 1.00$ (i.e., the base condition for CMF_{6i} is the absence of red light cameras).

The combined CMF value applied to multiple-vehicle and single-vehicle crashes in Sample Problem 6 is calculated below.

$$CMF_{comb} = 0.81 \times 0.98 \times 0.92 \times 0.91$$
$$= 0.66$$

The predicted average crash frequency of multiple-vehicle collisions and single-vehicle crashes are determined using Equation 12-9, as follows:

$$N_{brmv} = N_{spf\ rs\ mv} \times CMF_{comb}$$
$$= 4.027 \times 0.66$$
$$= 2.658 \text{ crashes/year}$$

$$N_{brsv} = N_{spf\ rs\ sv} \times CMF_{comb}$$
$$= 0.297 \times 0.66$$
$$= 0.196 \text{ crashes/year}$$

Bus Stops (CMF_{1p})
From Table 12-45, for two bus stop within 1,000 ft of the center of the intersection, $CMF_{1p} = 2.78$.

Schools (CMF_{2p})
From Table 12-46, for one school within 1,000 ft of the center of the intersection, $CMF_{2p} = 1.35$.

Alcohol Sale Establishments (CMF_{3p})
From Table 12-47, for six alcohol sales establishments within 1,000 ft of the center of the intersection, $CMF_{3p} = 1.12$.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The SPF for vehicle-pedestrian collisions for a four-leg signalized intersection is calculated from Equation 12-35 as follows:

$$N_{pedi} = N_{pedbase} \times (CMF_{1p} \times CMF_{2p} \times CMF_{3p})$$

$N_{pedbase}$ is calculated from Equation 12-36 using the coefficients from Table 12-27.

$$N_{pedbase} = \exp\left(a + b \times \ln(AADT_{\text{total}}) + c \times \ln\left(\frac{AADT_{low}}{AADT_{high}}\right) + d \times \ln(PedVol) + e \times n_{lanesx}\right)$$

$$= \exp\left(-9.53 + 0.40 \times \ln(24{,}000) + 0.26 \times \ln\left(\frac{9{,}000}{15{,}000}\right) + 0.45 \times \ln(1{,}500) + 0.04 \times 4\right)$$

$$= 0.113 \text{ crashes/year}$$

The CMF values for vehicle-pedestrian collisions calculated above are CMF_{1p} = 2.78, CMF_{2p} = 1.35, and CMF_{3p} = 1.12.

$$N_{pedi} = 0.113 \times 2.78 \times 1.35 \times 1.12$$

$$= 0.475 \text{ crashes/year}$$

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions), N_{bi}, must be calculated in order to determine vehicle-bicycle crashes. N_{bi} is determined from Equation 12-8 as follows:

$$N_{bi} = N_{bimv} + N_{bisv}$$

$$= 2.658 + 0.196$$

$$= 2.854 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-38 as follows:

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

From Table 12-30, for a four-leg signalized intersection of a two-way arterial with five or fewer lanes, the bicycle crash adjustment factor, $f_{bikei} = 0.015$.

$$N_{bikei} = 2.854 \times 0.015$$

$$= 0.043 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem 6 that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-7 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$

$$= 1.00 \times (2.854 + 0.475 + 0.043)$$

$$= 3.372 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 11 worksheets are provided for determining the predicted average crash frequency. The 11 worksheets include:

- *Worksheet SP6A (Corresponds to Worksheet A-2A)*—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

- *Worksheet SP6B (Corresponds to Worksheet A-2B)*— Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6C (Corresponds to Worksheet A-2C)*—Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6D (Corresponds to Worksheet A-2D)*— Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6E (Corresponds to Worksheet A-2E)*—Single-Vehicle Crashes by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6F (Corresponds to Worksheet A-2F)*— Single-Vehicle Crashes by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6H (Corresponds to Worksheet A-2H)*— Crash Modification Factors for Vehicle-Pedestrian Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6I (Corresponds to Worksheet A-2I)*— Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6J (Corresponds to Worksheet A-2J)*— Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6K (Corresponds to Worksheet A-2K)*— Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP6L (Corresponds to Worksheet A-2L)*— Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP6A—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP6A is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 6.

Worksheet SP6A. General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	4SG
$AADT_{maj}$ (veh/day)	—	15,000
$AADT_{min}$ (veh/day)	—	9,000
Intersection lighting (present/not present)	not present	present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:		
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Data for signalized intersections only:		
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with left-turn signal phasing	—	2
Number of approaches with right-turn-on-red prohibited	0	0
Type of left-turn signal phasing	permissive	protected/permissive
Intersection red-light cameras (present/not present)	not present	not present
Sum of all pedestrian crossing volumes (PedVol)	—	1,500
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	4
Number of bus stops within 1000 ft of the intersection	0	2
Schools within 1000 ft of the intersection (present/not present)	not present	present
Number of alcohol sales establishments within 1000 ft of the intersection	0	6

Worksheet SP6B—Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 7 of Worksheet SP6B which indicates the combined CMF value.

Worksheet SP6B. Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	**CMF for Left-Turn Lanes**	CMF_{1i}	**from Table 12-40**	0.81
(2)	**CMF for Left-Turn Signal Phasing**	CMF_{2i}	**from Table 12-41**	0.98
(3)	**CMF for Right-Turn Lanes**	CMF_{3i}	**from Table 12-42**	0.92
(4)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	1.00
(5)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	0.91
(6)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	1.00
(7)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)**	0.66

Worksheet SP6C—Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 6 is calculated using Equation 12-26 and entered into Column 4 of Worksheet SP6C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 6 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 7 in Worksheet SP6B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP6C. Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients from Table 12-20			Overdispersion Parameter, k from Table 12-20	Initial $N_{spf\ int\ mv}$ from Equation 12-26	Proportion of Total Crashes	Adjusted $N_{spf\ int\ mv}$ $(4)_{total}$*(5)	Combined CMF (7) from Worksheet SP6B	Calibration Factor, C_i	Predicted N_{bimv} (6)*(7)*(8)
	A	b	c							
Total	-10.99	1.07	0.23	0.39	4.027	1.000	4.027	0.66	1.000	2.658
FI	-13.14	1.18	0.22	0.33	1.233	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.318	1.281	0.66	1.000	0.845
PDO	-11.02	1.02	0.24	0.44	2.647	$(5)_{total} - (5)_{FI}$ 0.682	2.746	0.66	1.000	1.812

Worksheet SP6D—Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP6D presents the default proportions for manner of collision (from Table 12-21) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP6C) into components by crash severity and manner of collision.

Worksheet SP6D. Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	Predicted $N_{bimv(FI)}$ (crashes/year)	Proportion of Collision Manner$_{(PDO)}$	Predicted $N_{bimv(PDO)}$ (crashes/year)	Predicted $N_{bimv(total)}$ (crashes/year)
Manner of Collision	from Table 12-21	$(9)_{FI}$ from Worksheet SP6C	from Table 12-21	$(9)_{PDO}$ from Worksheet SP6C	$(9)_{total}$ from Worksheet SP6C
Total	1.000	0.845 $(2)*(3)_{FI}$	1.000	1.812 $(4)*(5)_{PDO}$	2.658 (3)+(5)
Rear-end collision	0.450	0.380	0.483	0.875	1.255
Head-on collision	0.049	0.041	0.030	0.054	0.095
Angle collision	0.347	0.293	0.244	0.442	0.735
Sideswipe	0.099	0.084	0.032	0.058	0.142
Other multiple-vehicle collision	0.055	0.046	0.211	0.382	0.428

Worksheet SP6E—Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The SPF for single-vehicle crashes at the intersection in Sample Problem 6 is calculated using Equation 12-18 and entered into Column 4 of Worksheet SP6E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 6 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that FI and PDO crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Row 7 in Worksheet SP6B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of Single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP6E. Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, k	Initial $N_{spf\ int\ sv}$	Proportion of Total Crashes	Adjusted $N_{spf\ int\ sv}$	Combined CMF	Calibration Factor, C_i	Predicted N_{bisv}
	from Table 12-22			from Table 12-22	from Equation 12-29		$(4)_{total}*(5)$	(7) from Worksheet SP6B		(6)*(7)*(8)
	a	b	c							
Total	-10.21	0.68	0.27	0.36	0.297	1.000	0.297	0.66	1.000	0.196
FI	-9.25	0.43	0.29	0.09	0.084	$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$ 0.287	0.085	0.66	1.000	0.056
PDO	-11.34	0.78	0.25	0.44	0.209	$(5)_{total} - (5)_{FI}$ 0.713	0.212	0.66	1.000	0.140

Worksheet SP6F—Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP6F presents the default proportions for manner of collision (from Table 12-23) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP6E) into components by crash severity and manner of collision.

Worksheet SP6F. Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bisv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bisv(PDO)}$ (crashes/year)**	**Predicted $N_{bisv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-23**	**$(9)_{FI}$ from Worksheet SP6E**	**from Table 12-23**	**$(9)_{PDO}$ from Worksheet SP6E**	**$(9)_{total}$ from Worksheet SP6E**
Total	1.000	0.056 $(2)*(3)_{FI}$	1.000	0.140 $(4)*(5)_{PDO}$	0.196 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.001	0.000	0.000
Collision with animal	0.002	0.000	0.002	0.000	0.000
Collision with fixed object	0.744	0.042	0.870	0.122	0.164
Collision with other object	0.072	0.004	0.070	0.010	0.014
Other single-vehicle collision	0.040	0.002	0.023	0.003	0.005
Single-vehicle noncollision	0.141	0.008	0.034	0.005	0.013

Worksheet SP6H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values for vehicle-pedestrian collisions. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 4 of Worksheet SP6H which indicates the combined CMF value for vehicle-pedestrian collisions.

Worksheet SP6H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	**CMF for Bus Stops**	CMF_{1p}	**from Table 12-45**	2.78
(2)	**CMF for Schools**	CMF_{2p}	**from Table 12-46**	1.35
(3)	**CMF for Alcohol Sales Establishments**	CMF_{3p}	**from Table 12-47**	1.12
(4)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)**	4.20

Worksheet SP6I—Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted number of vehicle-pedestrian collisions per year for base conditions at a signalized intersection, $N_{pedbase}$, is calculated using Equation 12-35 and entered into Column 4 of Worksheet SP6I. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 6 (as the EB Method is not utilized). Column 5 represents the combined CMF for vehicle-pedestrian collisions (from Row 4 in Worksheet SP6H), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of vehicle-pedestrian collisions using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP6I. Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients					Overdispersion Parameter, k	$N_{pedbase}$	Combined CMF	Calibration Factor, C_i	Predicted N_{pedi}
	from Table 12-27					from Table 12-27	from Equation 12-35	(4) from Worksheet SP6H		(4)*(5)*(6)
	a	b	c	d	e					
Total	-9.53	0.40	0.26	0.45	0.04	0.24	0.113	4.20	1.000	0.475
FI	—	—	—	—	—	—	—	—	1.000	0.475

Worksheet SP6J—Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheets SP6C and SP6E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-30). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP6J. Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	F_{bikei}	Calibration Factor, C_i	Predicted N_{bikei}
	(9) from Worksheet SP6C	(9) from Worksheet SP6E	(2)+(3)	from Table 12-30		(4)*(5)*(6)
Total	2.658	0.196	2.854	0.015	1.000	0.043
FI	—	—	—	—	1.000	0.043

Worksheet SP6K—Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP6K provides a summary of all manners of collision by severity level. Values from Worksheets SP6D, SP6F, SP6G, and SP6J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP6K. Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	FI	PDO	Total
Collision Type	(3) from Worksheets SP6D and SP6F; (7) from Worksheets SP6I and SP6J	(5) from Worksheet SP6D and SP6F	(6) from Worksheets SP6D and SP6F; (7) from Worksheets SP6I and SP6J
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet SP6D)	0.380	0.875	1.255
Head-on collisions (from Worksheet SP6D)	0.041	0.054	0.095
Angle collisions (from Worksheet SP6D)	0.293	0.442	0.735
Sideswipe (from Worksheet SP6D)	0.084	0.058	0.142
Other multiple-vehicle collisions (from Worksheet SP6D)	0.046	0.382	0.428
Subtotal	0.844	1.811	2.655
SINGLE_VEHICLE			
Collision with parked vehicle (from Worksheet SP6F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP6F)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SP6F)	0.042	0.122	0.164
Collision with other object (from Worksheet SP6F)	0.004	0.010	0.014
Other single-vehicle collision (from Worksheet SP6F)	0.002	0.003	0.005
Single-vehicle noncollision (from Worksheet SP6F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP6I)	0.475	0.000	0.475
Collision with bicycle (from Worksheet SP6J)	0.043	0.000	0.043
Subtotal	0.574	0.140	0.714
Total	1.418	1.951	3.369

Worksheet SP6L—Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP6L presents a summary of the results.

Worksheet SP6L. Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(total) from Worksheet SP6K
Total	3.369
FI	1.418
PDO	1.951

12.14.7. Sample Problem 7

The Site/Facility
A four-leg stop-controlled intersection located on a suburban two-way arterial with six lanes.

The Question
What is the predicted average crash frequency of the stop-controlled intersection for a particular year?

The Facts

- Six-lane divided major road
- Two-lane undivided minor road
- No left-turn lane on minor road approaches
- AADT of major road is 25,000 veh/day
- AADT of minor road is 2,000 veh/day
- Intersection is lighted

Assumptions
Collision type distributions used are the default values presented in Table 12-25 and Equations 12-37 and 12-38.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the stop-controlled intersection in Sample Problem 7 is determined to be 3.0 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the intersection in Sample Problem 7, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For intersections of two-way arterials with six or more lanes, SPF values are determined for multiple-vehicle and single-vehicle collisions, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle and Single-Vehicle Collisions
The SPF for multiple-vehicle and single-vehicle collisions for a single four-leg stop-controlled intersection is calculated from Equation 12-33 and Table 12-24 as follows:

$$N_{spf\ int} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int(FI)} = \exp(-10.08 + 0.58 \times \ln(25{,}000) + 0.60 \times \ln(2{,}000))$$

$$= 1.425 \text{ crashes/year}$$

$$N_{spf\ int(PDO)} = \exp(-12.01 + 0.67 \times \ln(25,000) + 0.75 \times \ln(2,000))$$
$$= 1.609 \text{ crashes/year}$$

$$N_{spf\ int(total)} = 1.425 + 1.609$$
$$= 3.034 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

***Intersection Left-Turn Signal Phasing* (*CMF*$_{2i}$)**
For unsignalized intersections, $CMF_{2i} = 1.00$.

***Right-Turn-on-Red* (*CMF*$_{4i}$)**
For unsignalized intersections, $CMF_{4i} = 1.00$.

***Lighting* (*CMF*$_{5i}$)**
CMF_{5i} is calculated from Equation 12-52.

$$CMF_{5i} = 1 - 0.38 \times p_{ni}$$

From Table 12-43, the proportion of crashes that occur at night, $p_{ni} = 0.229$.

$$CMF_{5i} = 1 - 0.38 \times 0.229$$
$$= 0.913$$

***Red-Light Cameras* (*CMF*$_{6i}$)**
For unsignalized intersections, $CMF_{6i} = 1.00$.

***Number of Lanes* (*CMF*$_{7i}$)**
For unsignalized intersections, $CMF_{7i} = 1.00$.

***Intersection Right-Turn Channelization* (*CMF*$_{8i}$)**
For unsignalized intersections, $CMF_{8i} = 1.00$.

***U-Turn Prohibition* (*CMF*$_{9i}$)**
For unsignalized intersections, $CMF_{8i} = 1.00$.

The combined CMF value for Sample Problem 7 is 0.913.

The predicted average crash frequency of multiple-vehicle and single-vehicle collisions is determined using Equation 12-9, as follows:

$$N_{bi} = N_{spf\ int} \times CMF_{comb}$$
$$= 3.034 \times 0.913$$
$$= 2.770 \text{ crashes/year}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The SPF for vehicle-pedestrian collisions for the intersection is calculated from Equation 12-37 as follows:

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

From Table 12-29, for a four-leg stop-controlled intersection of a two-way arterial with six or more lanes, the pedestrian crash adjustment factor, $f_{pedi} = 0.049$.

$$N_{pedi} = 2.770 \times 0.049$$
$$= 0.136 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions for the intersection is calculated from Equation 12-38 as follows:

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

From Table 12-30, for a four-leg stop-controlled intersection of a two-way arterial with six or more lanes, the bicycle crash adjustment factor, $f_{bikei} = 0.039$.

$$N_{bikei} = 2.770 \times 0.039$$
$$= 0.108 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-7 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$
$$= 1.00 \times (2.770 + 0.136 + 0.108)$$
$$= 3.014 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 9 worksheets are provided for determining the predicted average crash frequency. The 9 worksheets include:

- *Worksheet SP7A (Corresponds to Worksheet B-2A)*—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7B (Corresponds to Worksheet B-2B)*—Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7C (Corresponds to Worksheet B-2C)*—Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7D (Corresponds to Worksheet B-2D)*—Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7E (Corresponds to Worksheet B-2E)*— Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7H (Corresponds to Worksheet B-2H)*—Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes
- *Worksheet SP7I (Corresponds to Worksheet B-2I)*—Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

- *Worksheet SP7J (Corresponds to Worksheet B-2J)*—Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12B (for two-way urban and suburban arterials with six or more lanes).

Worksheet SP7A—General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

Worksheet SP7A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 7.

Worksheet SP7A. General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	4ST
Area type (urban/suburban)	—	suburban
$AADT_{maj}$ (veh/day)	—	25,000
$AADT_{min}$ (veh/day)	—	2,000
Intersection lighting (present/not present)	not present	present
Calibration factor, C_i	1.00	1.00
Data for stop-controlled intersections only:		
Left-turn lane on a minor-road approach (present/not present)	—	not present
Data for signalized intersections only:		
Total number of lanes on major road	6	N/A
Total number of lanes on minor road	2	N/A
Number of major-road approaches with left-turn lanes (0, 1, 2)	—	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Number of approaches with U-turn prohibited	0	N/A
Number of major road approaches with channelized right-turn lane	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red-light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 1000 ft of the intersection	0	N/A
Schools within 1000 ft of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 1000 ft of the intersection	0	N/A

Worksheet SP7B—Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 8 of Worksheet SP7B which indicates the combined CMF value.

Worksheet SP7B. Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	**CMF for Left-Turn Signal Phasing**	CMF_{2i}	**from Table 12-41**	1.000
(2)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	1.000
(3)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	0.913
(4)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	1.000
(5)	**CMF for Number of Lanes**	CMF_{7i}	**from Equation 12-58**	1.000
(6)	**CMF for Right-Turn Channelization**	CMF_{8i}	**from Equation 12-61**	1.000
(7)	**CMF for U-Turn Prohibition**	CMF_{9i}	**from Equation 12-62**	1.000
(8)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)*(7)**	0.913

Worksheet SP7C—Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

The SPF for multiple-vehicle and single-vehicle collisions at the intersection in Sample Problem 7 is calculated using Equation 12-33 and entered into Column 4 of Worksheet SP7C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 7 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Row 8 in Worksheet SP7B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle and single-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP7C. Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)				(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients from Table 12-24**				**Overdispersion Parameter, k**	$N_{spf\ int}$	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bi}**
	a	**b**	**c**	**d**	**from Equation 12-34**	**from Equation 12-33**	**(8) from Worksheet SP7B**		**(4)*(5)*(6)**
FI	-10.08	0.58	0.60	1.67	0.599	1.425	0.913	1.00	1.301
PDO	-12.01	0.67	0.75	0.88	1.136	1.609	0.913	1.00	1.469
Total	—	—	—	—	—	—	—	1.00	2.770

Worksheet SP7D—Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

Worksheet SP7D presents the default proportions for manner of collision (from Table 12-25) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle and single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle and single-vehicle crashes (from Column 7, Worksheet SP7C) into components by crash severity and manner of collision.

Worksheet SP7D. Multiple-Vehicle and Single-Vehicle Collisions by Collision Type for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bi(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bi(PDO)}$ (crashes/year)**	**Predicted $N_{bi(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-25**	**$(7)_{FI}$ from Worksheet SP7C**	**from Table 12-25**	**$(7)_{PDO}$ from Worksheet SP7C**	**$(7)_{total}$ from Worksheet SP7C**
Total	1.000	1.301	1.000	1.469	2.770
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision	0.079	0.103	0.098	0.144	0.247
Head-on collision	0.030	0.039	0.012	0.018	0.057
Angle collision	0.806	1.049	0.707	1.039	2.088
Sideswipe	0.055	0.072	0.122	0.179	0.251
Other multiple-vehicle collision	0.024	0.031	0.024	0.035	0.066
Single-Vehicle Crash	0.006	0.008	0.037	0.054	0.062

Worksheet SP7E—Vehicle-Pedestrian Collisions for Intersections of One-Way Urban and Suburban Arterials

The predicted average crash frequency of multiple-vehicle and single-vehicle collisions from Worksheet SP7C is entered into Columns 2. Column 3 contains the pedestrian crash adjustment factor (see Table 12-29). Column 4 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 5) is the product of Columns 2, 3, and 4. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP7E. Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	**Predicted N_{bi}**	**f_{pedi}**	**Calibration Factor, C_i**	**Predicted N_{pedi}**
	(7) from Worksheet SP7C	**from Table 12-29**		**(2)*(3)*(4)**
Total	2.770	0.049	1.00	0.136
FI	—	—	1.00	0.136

Worksheet SP7H—Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

The predicted average crash frequency of multiple-vehicle and single-vehicle collisions from Worksheet SP7C is entered into Columns 2. Column 3 contains the bicycle crash adjustment factor (see Table 12-30). Column 4 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 5) is the product of Columns 2, 3, and 4. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP7H. Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	**Predicted N_{bi}**	**F_{bikei}**	**Calibration Factor, C_i**	**Predicted N_{pedi}**
	(7) from Worksheet SP7C	**from Table 12-30**		**(2)*(3)*(4)**
Total	2.770	0.039	1.00	0.108
FI	—	—	1.00	0.108

Worksheet SP7I—Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

Worksheet SP7I provides a summary of all manners of collision by severity level. Values from Worksheets SP7D, SP7G, and SP7H are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP7I. Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP7D; (5) from Worksheets SP7E; (5) from Worksheet SP7H**	**(5) from Worksheet SP7D**	**(6) from Worksheets SP7D; (5) from Worksheets SP7E; (5) from Worksheet SP7H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet SP7D)	0.103	0.144	0.247
Head-on collision (from Worksheet SP7D)	0.039	0.018	0.057
Angle collision (from Worksheet SP7D)	1.049	1.039	2.088
Sideswipe (from Worksheet SP7D)	0.072	0.179	0.251
Other multiple-vehicle collision (from Worksheet SP7D)	0.031	0.035	0.066
Subtotal	1.294	1.415	2.709
SINGLE_VEHICLE			
Collision with pedestrian (from Worksheet SP7E)	0.136	0.000	0.136
Collision with bicycle (from Worksheet SP7H)	0.108	0.000	0.108
Other single-vehicle crash (from Worksheet SP7D)	0.008	0.054	0.062
Subtotal	0.252	0.054	0.306
Total	1.546	1.469	3.014

Worksheet SP7J—Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

Worksheet SP7J presents a summary of the results.

Worksheet SP7J. Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet SP7I**
Total	3.014
FI	1.546
PDO	1.469

12.14.8. Sample Problem 8

The Site/Facility
A three-leg signalized intersection of an urban one-way arterial with a two-way arterial.

The Question
What is the predicted average crash frequency of the signalized intersection for a particular year?

The Facts

- Top side of the "T" intersection: one-way road with three lanes
- Stem of the "T" intersection: two-way divided road with four lanes (both directions)
- AADT of the one-way road is 18,000 veh/day
- AADT of the two-way road is 22,000 veh/day
- Right-turn-on-red prohibited from the stem of the "T" intersection
- No channelized right turn lane
- No red light camera
- Intersection is not lighted
- Pedestrian volume is 800 peds/day
- A bus stop within 1,000 ft of intersection
- No school within 1,000 ft of intersection
- The number of alcohol sales establishments with 1,000 ft of intersection is 5

Assumptions
Collision type distributions used are the default values presented in Table 12-26 and Equations 12-35 and 12-38.

The calibration factor is assumed to be 1.00.

The maximum number of lanes crossed by a pedestrian is assumed to be three (crossing three through lanes on the one-way road).

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem 8 is determined to be 7.1 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the intersection in Sample Problem 8, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

For intersections of one-way arterials (1×2 or 1×1), SPF values are determined for multiple-vehicle and single-vehicle collisions, vehicle-pedestrian, and vehicle-bicycle collisions. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle and Single-Vehicle Collisions

For a 1×2 intersection, the one-way road is designated as major road and the two-way road as minor road regardless of the AADTs. The SPF for multiple-vehicle or single-vehicle collisions for a single three-leg signalized intersection is calculated from Equation 12-33 and Table 12-24 as follows:

$$N_{spf\ int} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$$

$$N_{spf\ int(FI)} = \exp(-11.21 + 0.59 \times \ln(18{,}000) + 0.56 \times \ln(22{,}000))$$

$$= 1.186 \text{ crashes/year}$$

$$N_{spf\ int(PDO)} = \exp(-7.07 + 0.49 \times \ln(18{,}000) + 0.35 \times \ln(22{,}000))$$

$$= 3.423 \text{ crashes/year}$$

$$N_{spf\ int(total)} = 1.186 + 3.423$$

$$= 4.609 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{7i} are applied to multiple-vehicle and single-vehicle collisions, while CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions.

Right-Turn-on-Red (CMF_4i)

CMF_{4i} is calculated from Equation 12-51.

$$CMF_{4i} = 0.98^{(n_{prohib})}$$

Right-turn-on-red (RTOR) is prohibited from one intersection approach. Therefore $CMF_{4i} = 0.98$.

Lighting (CMF_5i)

Since there is no lighting at this intersection, CMF_{5i} is 1.00 (i.e., the base condition for CMF_{5i} is the absence of intersection lighting).

Red-Light Cameras (CMF_6i)

Since no red light cameras are present at this intersection, $CMF_{6i} = 1.00$ (i.e., the base condition for CMF_{6i} is the absence of red light cameras).

Number of Lanes (CMF_7i)

For 1×2 intersections, CMF_{7i} is calculated from Equation 12-58.

$$CMF_{7i} = (e^{0.242(N_{maj}-2)}P_{maj} + (1-P_{maj})) \times (e^{0.242(N_{min}-2)}P_{min} + (1-P_{min}))$$

P_{maj} and P_{min} are determined using Equations 12-59 and 12-60.

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

$$= \frac{18000}{18000 + 22000}$$

$$= 0.45$$

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

$$= \frac{22000}{18000 + 22000}$$

$$= 0.55$$

The major road has three lanes whereas the minor road has four lanes. CMF_{7i} is calculated below:

$$CMF_{7i} = (e^{0.242(3-2)}0.45 + (1-0.45)) \times (e^{0.242(4-2)}0.55 + (1-0.55))$$

$$= 1.508$$

The combined CMF value applied to multiple-vehicle and single-vehicle crashes in Sample Problem 8 is calculated below.

$$CMF_{comb} = 0.98 \times 1.508$$

$$= 1.478$$

The predicted average crash frequency of multiple-vehicle and single-vehicle collisions is determined using Equation 12-9, as follows:

$$N_{bi} = N_{spf\ int} \times CMF_{comb}$$

$$= 4.609 \times 1.478$$

$$= 6.811 \text{ crashes/year}$$

Bus Stops (CMF_{1p})

From Table 12-45, for one bus stop within 1,000 ft of the center of the intersection, $CMF_{1p} = 2.78$.

Schools (CMF_{2p})

From Table 12-46, for no school present within 1,000 ft of the center of the intersection, $CMF_{2p} = 1.00$.

Alcohol Sale Establishments (CMF_{3p})

From Table 12-47, for five alcohol sales establishments within 1,000 ft of the center of the intersection, $CMF_{3p} = 1.12$.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The SPF for vehicle-pedestrian collisions for a three-leg signalized intersection is calculated from Equation 12-35 as follows:

$$N_{pedi} = N_{pedbase} \times (CMF_{1p} \times CMF_{2p} \times CMF_{3p})$$

$N_{pedbase}$ is calculated from Equation 12-36 using the coefficients from Table 12-27.

$$N_{pedbase} = \exp\left(a + b \times \ln(AADT_{\text{total}}) + c \times \ln\left(\frac{AADT_{low}}{AADT_{high}}\right) + d \times \ln(PedVol) + e \times n_{lanesx}\right)$$

$$= \exp\left(-6.60 + 0.05 \times \ln(40,000) + 0.24 \times \ln\left(\frac{18,000}{22,000}\right) + 0.41 \times \ln(800) + 0.09 \times 3\right)$$

$$= 0.045 \text{ crashes/year}$$

The CMF values for vehicle-pedestrian collisions calculated above are CMF_{1p} = 2.78, CMF_{2p} = 1.00, and CMF_{3p} = 1.12.

$$N_{pedi} = 0.045 \times 2.78 \times 1.00 \times 1.12$$

$$= 0.139 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions for the intersection is calculated from Equation 12-38 as follows:

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

From Table 12-30, for a 1×2 three-leg signalized intersection, the bicycle crash adjustment factor, $f_{bikei} = 0.016$.

$$N_{bikei} = 6.811 \times 0.016$$

$$= 0.109 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-7 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$

$$= 1.00 \times (6.811 + 0.139 + 0.109)$$

$$= 7.059 \text{ crashes/year}$$

WORKSHEETS
The step-by-step instructions above were provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 8 worksheets are provided for determining the predicted average crash frequency. The 8 worksheets include:

- *Worksheet SP8A (Corresponds to Worksheet C-2A)*—General Information and Input Data for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8B (Corresponds to Worksheet C-2B)*— Crash Modification Factors for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8C (Corresponds to Worksheet C-2C)*—Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8D (Corresponds to Worksheet C-2D)*— Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of One-Way Urban and Suburban Arterials

- *Worksheet SP8F (Corresponds to Worksheet C-2F)*—Crash Modification Factors for Vehicle-Pedestrian Collisions for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8G (Corresponds to Worksheet C-2G)*—Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8H (Corresponds to Worksheet C-2H)*— Vehicle-Bicycle Collisions for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8I (Corresponds to Worksheet C-2I)*— Crash Severity*Type Distribution for Intersections of One-Way Urban and Suburban Arterials
- *Worksheet SP8J (Corresponds to Worksheet C-2J)*— Summary Results for Intersections of One-Way Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12C (for one-way urban and suburban arterials).

Worksheet SP8A—General Information and Input Data for Intersections of One-Way Urban and Suburban Arterials

Worksheet SP8A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 8.

Worksheet SP8A. General Information and Input Data for Intersections of One-Way Urban and Suburban Arterials

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection Category (1×2, 1×1)	—	1×2
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	3SG
Area type (urban/suburban)	—	urban
$AADT_{maj}$ (veh/day)	—	18,000
$AADT_{min}$ (veh/day)	—	22,000
Intersection lighting (present/not present)	not present	not present
Calibration factor, C_i	1.00	1.00
Data for stop-controlled intersections only:		
Left-turn lane on a minor-road approach (present/not present)	—	N/A
Data for signalized intersections only:		
Total number of lanes on major road	2	3
Total number of lanes on minor road	2	4
Number of approaches with right-turn-on-red prohibited	0	1
Left-turn lane on a major-road approach (present/not present)	—	not present
Channelized right-turn lane on a major-road approach (present/not present)	—	not present
Channelized right-turn lane on a minor-road approach (present/not present)	—	not present
Intersection red-light cameras (present/not present)	not present	not present
Sum of all pedestrian crossing volumes (PedVol)	—	800
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	3
Number of bus stops within 1000 ft of the intersection	0	1
Schools within 1000 ft of the intersection (present/not present)	not present	not present
Number of alcohol sales establishments within 1000 ft of the intersection	0	5

Worksheet SP8B—Crash Modification Factors for Intersections of One-Way Urban and Suburban Arterials

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 5 of Worksheet SP8B which indicates the combined CMF value.

Worksheet SP8B. Crash Modification Factors for Intersections of One-Way Urban and Suburban Arterials

(1)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	0.980
(2)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	1.000
(3)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	1.000
(4)	**CMF for Number of Lanes**	CMF_{7i}	**from Equation 12-58**	1.508
(5)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)**	1.478

Worksheet SP8C—Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of One-Way Urban and Suburban Arterials

The SPF for multiple-vehicle and single-vehicle collisions at the intersection in Sample Problem 8 is calculated using Equation 12-33 and entered into Column 4 of Worksheet SP8C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 8 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Row 5 in Worksheet SP8B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle and single-vehicle crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP8C. Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)				(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients				Overdispersion Parameter, k	$N_{spf\ int}$	Combined CMF	Calibration Factor, C_i	Predicted N_{bi}
	from Table 12-24				from Equation 12-34	from Equation 12-33	(5) from Worksheet SP8B		(4)*(5)*(6)
	a	b	c	d					
FI	-11.21	0.59	0.56	1.05	0.952	1.186	1.478	1.00	1.752
PDO	-7.07	0.49	0.35	1.11	0.901	3.423	1.478	1.00	5.059
Total	—	—	—	—	—	—	—	1.00	6.811

Worksheet SP8D—Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of One-Way Urban and Suburban Arterials

Worksheet SP8D presents the default proportions for manner of collision (from Table 12-25) by crash severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 4)

Using the default proportions, the predicted average crash frequency for multiple-vehicle and single-vehicle crashes by manner of collision is presented in Columns 3 (FI), 5 (PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle and single-vehicle crashes (from Column 7, Worksheet SP8C) into components by crash severity and manner of collision.

Worksheet SP8D. Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bi(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bi(PDO)}$ (crashes/year)**	**Predicted $N_{bi(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-26**	**(7)$_{FI}$ from Worksheet SP8C**	**from Table 12-26**	**(7)$_{PDO}$ from Worksheet SP8C**	**(7)$_{total}$ from Worksheet SP8C**
Total	1.000	1.752 (2)*(3)$_{FI}$	1.000	5.059 (4)*(5)$_{PDO}$	6.811 (3)+(5)
Rear-end collision	0.111	0.194	0.143	0.723	0.918
Head-on collision	0.000	0.000	0.000	0.000	0.000
Angle collision	0.889	1.558	0.571	2.889	4.446
Sideswipe	0.000	0.000	0.214	1.083	1.083
Other multiple-vehicle collision	0.000	0.000	0.071	0.359	0.359
Single-Vehicle Crash	0.000	0.000	0.000	0.000	0.000

Worksheet SP8F. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values for vehicle-pedestrian collisions. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Row 4 of Worksheet SP8F which indicates the combined CMF value for vehicle-pedestrian collisions.

Worksheet SP8F. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials

(1)	**CMF for Bus Stops**	CMF_{1p}	**from Table 12-45**	2.78
(2)	**CMF for Schools**	CMF_{2p}	**from Table 12-46**	1.00
(3)	**CMF for Alcohol Sales Establishments**	CMF_{3p}	**from Table 12-47**	1.12
(4)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)**	3.11

Worksheet SP8G—Vehicle-Pedestrian Collisions for Signalized Intersections One-Way Urban and Suburban Arterials

The predicted number of vehicle-pedestrian collisions per year for base conditions at a signalized intersection, $N_{pedbase}$, is calculated using Equation 12-35 and entered into Column 4 of Worksheet SP8G. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 8 (as the EB Method is not utilized). Column 5 represents the combined CMF for vehicle-pedestrian collisions (from Row 4 in Worksheet SP8F), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of vehicle-pedestrian collisions using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP8G. Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients					Overdispersion Parameter, k	$N_{pedbase}$	Combined CMF	Calibration Factor, C_i	Predicted N_{pedi}
	from Table 12-27					from Table 12-27	from Equation 12-35	(4) from Worksheet SP8F		(4)*(5)*(6)
	a	b	c	d	e					
Total	-6.60	0.05	0.24	0.41	0.09	0.52	0.045	3.11	1.00	0.139
FI	—	—	—	—	—	—	—	—	1.00	0.139

Worksheet SP8H—Vehicle-Bicycle Collisions for Intersections of One-Way Urban and Suburban Arterials

The predicted average crash frequency of multiple-vehicle and single-vehicle crashes from Worksheet SP8C is entered into Columns 2. Column 3 contains the bicycle crash adjustment factor (see Table 12-30). Column 4 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 5) is the product of Columns 2, 3, and 4. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP8H. Vehicle-Bicycle Collisions for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Predicted N_{bi}	F_{bikei}	Calibration Factor, C_i	Predicted N_{pedi}
	(7) from Worksheet SP8C	from Table 12-30		(2)*(3)*(4)
Total	6.812	0.016	1.00	0.109
FI	—	—	1.00	0.109

Worksheet SP8I—Crash Severity*Type Distribution for Intersections of One-Way Urban and Suburban Arterials

Worksheet SP8I provides a summary of all manners of collision by severity level. Values from Worksheets SP8D, SP8E, and SP8H are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP8I. Crash Severity*Type Distribution for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets SP8D; (7) from Worksheets SP8G; (5) from Worksheet SP8H**	**(5) from Worksheet SP8D**	**(6) from Worksheets SP8D; (7) from Worksheets SP8G; (5) from Worksheet SP8H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet SP8D)	0.194	0.723	0.918
Head-on collision (from Worksheet SP8D)	0.000	0.000	0.000
Angle collision (from Worksheet SP8D)	1.558	2.889	4.446
Sideswipe (from Worksheet SP8D)	0.000	1.083	1.083
Other multiple-vehicle collision (from Worksheet SP8D)	0.000	0.359	0.359
Subtotal	1.752	5.054	6.811
SINGLE_VEHICLE			
Collision with pedestrian (from Worksheet SP8G)	0.139	0.000	0.139
Collision with bicycle (from Worksheet SP8H)	0.109	0.000	0.109
Other single-vehicle crash (from Worksheet SP8D)	0.000	0.000	0.000
Subtotal	0.248	0.000	0.248
Total	2.000	5.059	7.059

Worksheet SP8J—Summary Results for Intersections of One-Way Urban and Suburban Arterials

Worksheet SP8J presents a summary of the results.

Worksheet SP8J. Summary Results for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet SP8I**
Total	7.059
FI	2.000
PDO	5.059

12.14.9. Sample Problem 9

The Project

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments from Sample Problem 1 and 2 and intersections from Sample Problems 5 and 6.)

The Question

What is the expected crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2, 4, and 5 and the observed crash frequencies using the site-specific EB Method?

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersections (3ST intersection, 4SG intersection)
- 34 observed crashes (3T segment: 7 multiple-vehicle nondriveway, 2 multiple-vehicle driveway-related, 4 single-vehicle; 4D segment: 6 multiple-vehicle nondriveway, 1 multiple-vehicle driveway-related, 3 single-vehicle; 3SG intersection: 2 multiple-vehicle, 3 single-vehicle; 4SG intersection: 6 multiple-vehicle, 0 single-vehicle)

Outline of Solution

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted crash frequencies for the project using the site-specific EB Method (i.e., observed crashes are assigned to specific intersections or roadway segments) presented in Part C, Appendix A.2.4.

Results

The expected average crash frequency for the project is 25.4 crashes per year (rounded to one decimal place).

WORKSHEETS

To apply the site-specific EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP9A (Corresponds to Worksheet A-3A)*— Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP9B (Corresponds to Worksheet A-3B)*— Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP9C (Corresponds to Worksheet A-3C)*— Site-Specific EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP9A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted average crash frequencies by severity level and collision type determined in Sample Problems 1, 2, 5, and 6 are entered into Columns 2 through 4 of Worksheet SP9A. Column 5 presents the observed crash frequencies by site and collision type, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from Part C, Appendix A is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8. Detailed calculation of Columns 7 and 8 are provided below.

Worksheet SP9A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**Weighted Adjustment, w**	**Expected Average Crash Frequency, $N_{expected\ (vehicle)}$ (crashes/year)**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-5**	**Equation A-4**
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1	4.967	1.196	3.771	7	0.66	0.234	6.524
Segment 2	2.524	0.702	1.822	6	1.32	0.231	5.197
Multiple-Vehicle Driveway-Related							
Segment 1	0.734	0.179	0.555	2	1.10	0.553	1.300
Segment 2	0.149	0.042	0.107	1	1.39	0.828	0.295
Single-Vehicle							
Segment 1	1.182	0.338	0.844	4	1.37	0.382	2.924
Segment 2	0.485	0.085	0.401	3	0.86	0.706	1.224
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1	1.268	0.405	0.862	2	0.80	0.496	1.637
Intersection 2	2.658	0.845	1.812	6	0.39	0.491	4.359
Single-Vehicle							
Intersection 1	0.234	0.072	0.162	3	1.14	0.789	0.818
Intersection 2	0.196	0.056	0.140	0	0.36	0.934	0.183
Combined (Sum of Column)	14.397	3.920	10.476	34	—	—	24.461

Column 7 — Weighted Adjustments

The weighted adjustment, w, to be placed on the predictive model estimate is calculated using Equation A-5 as follows:

$$w = \frac{1}{1 + k \times \left(\sum_{\substack{\text{all study} \\ \text{years}}} N_{\text{predicted}} \right)}$$

Multiple-Vehicle Nondriveway Collisions

Segment 1

$$w = \frac{1}{1 + 0.66 \times (4.967)} = 0.234$$

Segment 2

$$w = \frac{1}{1 + 1.32 \times (2.524)} = 0.231$$

Multiple-Vehicle Driveway-Related Collisions

Segment 1

$$w = \frac{1}{1 + 1.10 \times (0.734)} = 0.553$$

Segment 2

$$w = \frac{1}{1 + 1.39 \times (0.149)} = 0.828$$

Single-Vehicle Crashes

Segment 1

$$w = \frac{1}{1 + 1.37 \times (1.182)} = 0.382$$

Segment 2

$$w = \frac{1}{1 + 0.86 \times (0.485)} = 0.706$$

Multiple-Vehicle Crashes

Intersection 1

$$w = \frac{1}{1 + 0.80 \times (1.268)} = 0.496$$

Intersection 2

$$w = \frac{1}{1 + 0.39 \times (2.658)} = 0.491$$

Single-Vehicle Crashes

Intersection 1

$$w = \frac{1}{1 + 1.149 \times (0.234)} = 0.789$$

Intersection 2

$$w = \frac{1}{1 + 0.36 \times (0.196)} = 0.934$$

Column 8 — Expected Average Crash Frequency

The estimate of expected average crash frequency, $N_{expected}$, is calculated using Equation A-4 as follows:

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

Multiple-Vehicle Nondriveway Collisions

Segment 1 $N_{expected} = 0.234 \times 4.967 + (1 - 0.234) \times 7 = 6.524$

Segment 2 $N_{expected} = 0.231 \times 2.524 + (1 - 0.231) \times 6 = 5.197$

Multiple-Vehicle Driveway-Related Collisions

Segment 1 $N_{expected} = 0.553 \times 0.734 + (1 - 0.553) \times 2 = 1.300$

Segment 2 $N_{expected} = 0.828 \times 0.149 + (1 - 0.828) \times 1 = 0.295$

Single-Vehicle Crashes

Segment 1 $N_{expected} = 0.382 \times 1.182 + (1 - 0.382) \times 4 = 2.924$

Segment 2 $N_{expected} = 0.706 \times 0.485 + (1 - 0.706) \times 3 = 1.224$

Multiple-Vehicle Crashes

Intersection 1 $N_{expected} = 0.496 \times 1.268 + (1 - 0.496) \times 2 = 1.637$

Intersection 2 $N_{expected} = 0.491 \times 2.658 + (1 - 0.491) \times 6 = 4.359$

Single-Vehicle Crashes

Intersection 1 $N_{expected} = 0.789 \times 0.234 + (1 - 0.789) \times 3 = 0.818$

Intersection 2 $N_{expected} = 0.934 \times 0.196 + (1 - 0.934) \times 0 = 0.183$

Worksheet SP9B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP9B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1, 2, 5, and 6.

Worksheet SP9B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheet SP9C. Site-Specific EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP9C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the site-specific EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP9C. Site-Specific EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet SP9A**	**$(2)_{comb}$ from Worksheet SP9B**	**$(3)_{comb}$ from Worksheet SP9B**	**$(8)_{comb}$ from Worksheet SP9A**	**(3)+(4)+(5)**
	14.397	0.808	0.156	24.461	25.4
FI	**$(3)_{comb}$ from Worksheet SP9A**	**$(2)_{comb}$ from Worksheet SP9B**	**$(3)_{comb}$ from Worksheet SP9B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
	3.920	0.808	0.156	6.660	7.6
PDO	**$(4)_{comb}$ from Worksheet SP9A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
	10.476	0.000	0.000	17.800	17.8

12.14.10. Sample Problem 10

The Project

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments from Sample Problem 1 and 2 and intersections from Sample Problems 5 and 6.)

The Question

What is the expected crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2, 4, and 5 and the observed crash frequencies using the project-level EB Method?

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersections (3ST intersection, 4SG intersection)
- 34 observed crashes (but no information is available to attribute specific crashes to specific sites)

Outline of Solution

Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e., observed crash data for individual roadway segments and intersections are not available, but observed crashes are assigned to a facility as a whole) presented in Part C, Appendix A.2.5.

Results

The expected average crash frequency for the project is 26.0 crashes per year (rounded to one decimal place).

WORKSHEETS

To apply the project-level EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP10A (Corresponds to Worksheet A-4A)*— Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP10B (Corresponds to Worksheet A-4B)*— Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes
- *Worksheet SP10C (Corresponds to Worksheet A-4C)*— Project-Level EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A (for two-way urban and suburban arterials with five or fewer lanes).

Worksheet SP10A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

The predicted average crash frequencies by severity level and collision type, excluding vehicle-pedestrian and vehicle-bicycle collisions, determined in Sample Problems 1, 2, 4, and 5 are entered in Columns 2 through 4 of Worksheet SP10A. Column 5 presents the total observed crash frequencies combined for all sites, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates N_{w0}, and Column 8 calculates N_{w1}. Equations A-10 through A-14 from Part C, Appendix A are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

Worksheet SP10A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**$N_{predicted\ w0}$**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-8 $(6)*(2)^2$**
ROADWAY SEGMENTS						
Multiple-Vehicle Nondriveway						
Segment 1	4.967	1.196	3.771	—	0.66	16.283
Segment 2	2.524	0.702	1.822	—	1.32	8.409
Multiple-Vehicle Driveway-Related						
Segment 1	0.734	0.179	0.555	—	1.10	0.593
Segment 2	0.149	0.042	0.107	—	1.39	0.031
Single-Vehicle						
Segment 1	1.182	0.338	0.844	—	1.37	1.914
Segment 2	0.485	0.085	0.401	—	0.86	2.202
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1	1.268	0.405	0.862	—	0.80	1.286
Intersection 2	2.658	0.845	1.812	—	0.39	2.755
Single-Vehicle						
Intersection 1	0.234	0.072	0.162	—	1.14	0.062
Intersection 2	0.196	0.056	0.140	—	0.36	0.014
Combined (Sum of Column)	14.397	3.920	10.476	34	—	31.549

Worksheet SP10A. continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
Collision Type/ Site Type	**$N_{predicted\ w1}$**	**w_0**	**N_0**	**w_1**	**N_1**	**$N_{predicted/comb\ (vehicle)}$**
	Equation A-9 ***sqrt*((6)*(2))**	**Equation A-10**	**Equation A-11**	**Equation A-12**	**Equation A-13**	**Equation A-14**
ROADWAY SEGMENTS						
Multiple-Vehicle Nondriveway						
Segment 1	1.811	—	—	—	—	—
Segment 2	1.825	—	—	—	—	—
Multiple-Vehicle Driveway-Related						
Segment 1	0.899	—	—	—	—	—
Segment 2	0.455	—	—	—	—	—
Single-Vehicle						
Segment 1	1.273	—	—	—	—	—
Segment 2	0.646	—	—	—	—	—
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1	1.007	—	—	—	—	—
Intersection 2	1.018	—	—	—	—	—
Single-Vehicle						
Intersection 1	0.516	—	—	—	—	—
Intersection 2	0.266	—	—	—	—	—
Combined (Sum of Column)	9.716	0.313	27.864	0.597	22.297	25.080

$N_{predicted\ w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

$$N_{\text{predicted}\,w0} = \sum_{j=1}^{5} k_{rmj} N_{rmj}^2 + \sum_{j=1}^{5} k_{rsj} N_{rsj}^2 + \sum_{j=1}^{5} k_{rdj} N_{rdj}^2 + \sum_{j=1}^{4} k_{imj} N_{imj}^2 + \sum_{j=1}^{4} k_{isj} N_{isj}^2 \tag{A-8}$$

$N_{predicted\ w1}$ = Predicted number of total crashes assuming that crash frequencies are perfectly correlated

$$N_{\text{predicted}\,w1} = \sum_{j=1}^{5} \sqrt{k_{rmj} N_{rmj}} + \sum_{j=1}^{5} \sqrt{k_{rsj} N_{rsj}} + \sum_{j=1}^{5} \sqrt{k_{rdj} N_{rdj}} + \sum_{j=1}^{4} \sqrt{k_{imj} N_{imj}} + \sum_{j=1}^{4} \sqrt{k_{isj} N_{isj}} \tag{A-9}$$

Column 9— w_0

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent, w0, is calculated using Equation A-10 as follows:

$$w_0 = \frac{1}{1+\frac{N_{\text{predicted } w0}}{N_{\text{predicted }(total)}}}$$

$$= \frac{1}{1+\frac{31.549}{14.397}}$$

$$= 0.313$$

Column 10—N_0

The expected crash frequency based on the assumption that different roadway elements are statistically independent, N_0, is calculated using Equation A-11 as follows:

$$N_0 = w_0 \times N_{\text{predicted(total)}} + (1 - w_0) \times N_{\text{observed(total)}}$$

$$= 0.313 \times 14.397 + (1 - 0.313) \times 34$$

$$= 27.864$$

Column 11—w_1

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated, w_1, is calculated using Equation A-12 as follows:

$$w_1 = \frac{1}{1+\frac{N_{\text{predicted } w1}}{N_{\text{predicted }(total)}}}$$

$$= \frac{1}{1+\frac{9.716}{14.397}}$$

$$= 0.597$$

Column 12—N_1

The expected crash frequency based on the assumption that different roadway elements are perfectly correlated, N_1, is calculated using Equation A-13 as follows:

$$N_1 = w_1 \times N_{\text{predicted(total)}} + (1 - w_1) \times N_{\text{observed(total)}}$$

$$= 0.597 \times 14.397 + (1 - 0.597) \times 34$$

$$= 22.297$$

Column 13—$N_{expected/comb}$

The expected average crash frequency based of combined sites, $N_{expected/comb}$, is calculated using Equation A-14 as follows:

$$N_1 = \frac{N_0 + N_1}{2}$$

$$= \frac{27.864 + 22.297}{2}$$

$$= 25.080$$

Worksheet SP10B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP10B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1, 2, 4, and 5.

Worksheet SP10B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)
Site Type	**N_{ped}**	**N_{bike}**
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheet SP10C. Project-Level EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

Worksheet SP10C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the project-level EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP10C. Project-Level EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet SP10A**	**$(2)_{comb}$ from Worksheet SP10B**	**$(3)_{comb}$ from Worksheet SP10B**	**$(13)_{comb}$ from Worksheet SP10A**	**(3)+(4)+(5)**
	14.397	0.808	0.156	25.080	26.0
FI	**$(3)_{comb}$ from Worksheet SP10A**	**$(2)_{comb}$ from Worksheet SP10B**	**$(3)_{comb}$ from Worksheet SP10B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
	3.920	0.808	0.156	6.829	7.8
PDO	**$(4)_{comb}$ from Worksheet SP10A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
	10.476	0.000	0.000	18.250	18.30

12.15. REFERENCES

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APPENDIX 12A—WORKSHEETS FOR PREDICTIVE METHOD FOR TWO-WAY URBAN AND SUBURBAN ARTERIALS WITH FIVE OR FEWER LANES

Worksheet A—1A. General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	
Length of segment, *L* (mi)	—	
AADT (veh/day)	—	
Type of on-street parking (none/parallel/angle)	none	
Proportion of curb length with on-street parking	—	
Median width (ft)	15	
Lighting (present / not present)	not present	
Auto speed enforcement (present/not present)	not present	
Major commercial driveways (number)	—	
Minor commercial driveways (number)	—	
Major industrial/institutional driveways (number)	—	
Minor industrial/institutional driveways (number)	—	
Major residential driveways (number)	—	
Minor residential driveways (number)	—	
Other driveways (number)	—	
Speed category	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration factor, C_r	1.0	

Worksheet A—1B. Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	**CMF for On-Street Parking**	CMF_{1r}	**from Equation 12-39**	
(2)	**CMF for Roadside Fixed Objects**	CMF_{2r}	**from Equation 12-40**	
(3)	**CMF for Median Width**	CMF_{3r}	**from Table 12-35**	
(4)	**CMF for Lighting**	CMF_{4r}	**from Equation 12-42**	
(5)	**CMF for Automated Speed Enforcement**	CMF_{5r}	**from Section 12.7.1**	
(6)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)**	

Worksheet A—1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**		**Overdispersion Parameter, k**	**Initial $N_{spf\ rs\ nondwy}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ rs\ nondwy}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted $N_{brnondwy}$**
	from Table 12-3		**from Table 12-3**	**from Equation 12-12**		**$(4)_{total}$*(5)**	**(6) from Worksheet A-1B**		**(6)*(7)*(8)**
	a	**b**							
Total									
FI					$(4)_{FI}$ / $((4)_{FI}$+$(4)_{PDO})$				
PDO					$(5)_{total}$ – $(5)_{FI}$				

Worksheet A—1D. Multiple-Vehicle Nondriveway Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brnondwy(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brnondwy(PDO)}$ (crashes/year)**	**Predicted $N_{brnondwy(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-4**	**$(9)_{FI}$ from Worksheet A-1C**	**from Table 12-4**	**$(9)_{PDO}$ from Worksheet A-1C**	**$(9)_{total}$ from Worksheet A-1C**
Total	1.000	(2)*$(3)_{FI}$	1.000	(4)*$(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

Worksheet A—1E. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	Coefficient for Traffic Adjustment, t	Initial $N_{spf\ rs\ dwy}$	Overdispersion Parameter, k
Manner of Collision	Number of Driveways, n_j	from Table 12-5	from Table 12-5	Equation 12-15 $n_j*N_j*(AADT/15,000)^{(t)}$	from Table 12-5
Major commercial					—
Minor commercial					
Major industrial/institutional					
Minor industrial/institutional					
Major residential					
Minor residential					
Other					
Total	—	—	—		

Worksheet A—1F. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Two-Way Urban and Suburban
Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial $N_{spf\ rs\ dwy}$	Proportion of Total Crashes (f_{dwy})	Adjusted $N_{spf\ rs\ dwy}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP1E	from Table 12-5	$(2)_{total}$*(3)	(6) from Worksheet SP1B		(4)*(5)*(6)
Total						
FI	—					
PDO	—					

Worksheet A—1G. Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	SPF Coefficients		Overdispersion Parameter, k	Initial $N_{spf\ rs\ sv}$	Proportion of Total Crashes	Adjusted $N_{spf\ rs\ sv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brsv}
	from Table 12-6		from Table 12-6	from Equation 12-18		$(4)_{total}$*(5)	(6) from Worksheet A-1B		(6)*(7)*(8)
	a	b							
Total									
FI					$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$				
PDO					$(5)_{total} - (5)_{FI}$				

Worksheet A—1H. Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-7**	**(9)$_{FI}$ from Worksheet A-1G**	**from Table 12-7**	**(9)$_{PDO}$ from Worksheet A-1G**	**(9)$_{total}$ from Worksheet A-1G**
Total	1.000	(2)*(3)$_{FI}$	1.000	(4)*(5)$_{PDO}$	(3)+(5)
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle crash					

Worksheet A—1I. Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(9) from Worksheet A-1C	**(7) from Worksheet A-1F**	**(9) from Worksheet A-1G**	**(2)+(3)+(4)**	**from Table 12-16**		**(5)*(6)*(7)**
Total							
FI	—	—	—	—	—		

Worksheet A—1J. Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**Predicted $N_{brnondwy}$**	**Predicted N_{brdwy}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**F_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(9) from Worksheet A-1C	**(7) from Worksheet A-1F**	**(9) from Worksheet A-1G**	**(2)+(3)+(4)**	**from Table 12-17**		**(5)*(6)*(7)**
Total							
FI	—	—	—	—	—		

Worksheet A—1K. Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets A-1D and A-1H; (7) from Worksheet A-1F; and (8) from Worksheet A-1I and A-1J**	**(5) from Worksheet A-1D and A-1H; and (7) from Worksheet A-1F**	**(6) from Worksheets A-1D and A-1H; (7) from Worksheet A-1F; and (8) from Worksheets A-1I and A-1J**
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet A-1D)			
Head-on collisions (from Worksheet A-1D)			
Angle collisions (from Worksheet A-1D)			
Sideswipe, same direction (from Worksheet A-1D)			
Sideswipe, opposite direction (from Worksheet A-1D)			
Driveway-related collisions (from Worksheet A-1F)			
Other multiple-vehicle collisions (from Worksheet A-1D)			
Subtotal			
SINGLE_VEHICLE			
Collision with animal (from Worksheet A-1H)			
Collision with fixed object (from Worksheet A-1H)			
Collision with other object (from Worksheet A-1H)			
Other single-vehicle crash (from Worksheet A-1H)			
Collision with pedestrian (from Worksheet A-1I)			
Collision with bicycle (from Worksheet A-1J)			
Subtotal			
Total			

Worksheet A—1L. Summary Results for Two-Way Urban and Suburban Roadway Segments with Five or Fewer Lanes

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(total) from Worksheet A-1K**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total			
FI			
PDO			

Worksheet A—2A. General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	
$AADT_{maj}$ (veh/day)	—	
$AADT_{min}$ (veh/day)	—	
Intersection lighting (present/not present)	not present	
Calibration factor, C_i	1.00	
Data for unsignalized intersections only:		
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	
Data for signalized intersections only:		
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with left-turn signal phasing	—	
Number of approaches with right-turn-on-red prohibited	0	
Type of left-turn signal phasing	permissive	
Intersection red-light cameras (present/not present)	not present	
Sum of all pedestrian crossing volumes (PedVol)	—	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	
Number of bus stops within 1000 ft of the intersection	0	
Schools within 1000 ft of the intersection (present/not present)	not present	
Number of alcohol sales establishments within 1000 ft of the intersection	0	

Worksheet A—2B. Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	**CMF for Left-Turn Lanes**	CMF_{1i}	**from Table 12-40**	
(2)	**CMF for Left-Turn Signal Phasing**	CMF_{2i}	**from Table 12-41**	
(3)	**CMF for Right-Turn Lanes**	CMF_{3i}	**from Table 12-42**	
(4)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	
(5)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	
(6)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	
(7)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)**	

Worksheet A—2C. Multiple-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**Initial $N_{spf\ int\ mv}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ int\ mv}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bimv}**
	from Table 12-20			**from Table 12-20**	**from Equation 12-26**		**$(4)_{total}$*(5)**	**(7) from Worksheet A-2B**		**(6)*(7)*(8)**
	a	**b**	**c**							
Total										
FI						$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$				
PDO						$(5)_{total} - (5)_{FI}$				

Worksheet A—2D. Multiple-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision $Manner_{(FI)}$	**Predicted $N_{bimv(FI)}$ (crashes/year)**	**Proportion of Collision $Manner_{(PDO)}$**	**Predicted $N_{bimv(PDO)}$ (crashes/year)**	**Predicted $N_{bimv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-21**	**$(9)_{FI}$ from Worksheet A-2C**	**from Table 12-21**	**$(9)_{PDO}$ from Worksheet A-2C**	**$(9)_{total}$ from Worksheet A-2C**
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					

Worksheet A—2E. Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**Initial $N_{spf\ int\ sv}$**	**Proportion of Total Crashes**	**Adjusted $N_{spf\ int\ sv}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bisv}**
	from Table 12-22			**from Table 12-22**	**from Equation 12-29**		**$(4)_{total}$*(5)**	**(7) from Worksheet A-2B**		**(6)*(7)*(8)**
	a	**b**	**c**							
Total										
FI						$(4)_{FI}$ / $((4)_{FI}+(4)_{PDO})$				
PDO						$(5)_{total} - (5)_{FI}$				

Worksheet A—2F. Single-Vehicle Collisions by Manner of Collision for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bisv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bisv(PDO)}$ (crashes/year)**	**Predicted $N_{bisv(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-23**	**$(9)_{FI}$ from Worksheet A-2E**	**from Table 12-23**	**$(9)_{PDO}$ from Worksheet A-2E**	**$(9)_{total}$ from Worksheet A-2E**
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Collision with parked vehicle					
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					
Single-vehicle noncollision					

Worksheet A—2G. Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{bimv}**	**Predicted N_{bisv}**	**Predicted N_{bi}**	**f_{pedi}**	**Calibration Factor, C_i**	**Predicted N_{pedi}**
	(9) from Worksheet A-2C	**(9) from Worksheet A-2E**	(2)+(3)	**From Table 12-29**		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet A—2H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	**CMF for Bus Stops**	CMF_{1p}	**from Table 12-45**	
(2)	**CMF for Schools**	CMF_{2p}	**from Table 12-46**	
(3)	**CMF for Alcohol Sales Establishments**	CMF_{3p}	**from Table 12-47**	
(4)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)**	

Worksheet A—2I. Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**					**Overdispersion Parameter, k**	**$N_{pedbase}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{pedi}**
	from Table 12-27					**from Table 12-27**	**from Equation 12-35**	**(4) from Worksheet A-2H**		**(4)*(5)*(6)**
	a	**b**	**c**	**d**	**e**					
Total										
FI	—	—	—	—	—	—	—	—		

Worksheet A—2J. Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{bimv}**	**Predicted N_{bisv}**	**Predicted N_{bi}**	**F_{bikei}**	**Calibration Factor, C_i**	**Predicted N_{bikei}**
	(9) from Worksheet A-2C	**(9) from Worksheet A-2E**	(2)+(3)	**from Table 12-30**		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet A—2K. Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)
Collision Type	**FI**	**PDO**	**Total**
	(3) from Worksheets A-2D and A-2F; (7) from Worksheets A-2G or A-2I; and (7) from A-2J	**(5) from Worksheet A-2D and A-2F**	**(6) from Worksheets A-2D and A-2F; (7) from Worksheets A-2G or A-2I; and (7) from A-2J**
MULTIPLE_VEHICLE			
Rear-end collisions (from Worksheet A-2D)			
Head-on collisions (from Worksheet A-2D)			
Angle collisions (from Worksheet A-2D)			
Sideswipe (from Worksheet A-2D)			
Other multiple-vehicle collisions (from Worksheet A-2D)			
Subtotal			
SINGLE_VEHICLE			
Collision with parked vehicle (from Worksheet A-2F)			
Collision with animal (from Worksheet A-2F)			
Collision with fixed object (from Worksheet A-2F)			
Collision with other object (from Worksheet A-2F)			
Other single-vehicle collision (from Worksheet A-2F)			
Single-vehicle noncollision (from Worksheet A-2F)			
Collision with pedestrian (from Worksheet A-2G or A-2I)			
Collision with bicycle (from Worksheet A-2J)			
Subtotal			
Total			

Worksheet A—2L. Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet A-2K**
Total	
FI	
PDO	

Worksheet A—3A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**Weighted Adjustment, w**	**Expected Average Crash Frequency, $N_{expected\ (vehicle)}$ (crashes/year)**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-5**	**Equation A-4**
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Multiple-Vehicle Driveway-Related							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Single-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)							

Worksheet A—3B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet A—3C. Site-Specific EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet A-3A**	**$(2)_{comb}$ from Worksheet A-3B**	**$(3)_{comb}$ from Worksheet A-3B**	**$(8)_{comb}$ from Worksheet A-3A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet A-3A**	**$(2)_{comb}$ from Worksheet A-3B**	**$(3)_{comb}$ from Worksheet A-3B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet A-3A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

Worksheet A—4A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**$N_{predicted\ w0}$**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-8 (6)*(2)^2**
ROADWAY SEGMENTS						
Multiple-Vehicle Nondriveway						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Multiple-Vehicle Driveway-Related						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Single-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet A—4A. continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
Collision Type/ Site Type	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{predicted/comb\ (vehicle)}$
	Equation A-9 *sqrt*((6)*(2))	**Equation A-10**	**Equation A-11**	**Equation A-12**	**Equation A-13**	**Equation A-14**
ROADWAY SEGMENTS						
Multiple-Vehicle Nondriveway						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Multiple-Vehicle Driveway-Related						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Single-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet A—4B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet A—4C. Project-Level EB Method Summary Results for Two-Way Urban and Suburban Arterials with Five or Fewer Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet A-4A**	**$(2)_{comb}$ from Worksheet A-4B**	**$(3)_{comb}$ from Worksheet A-4B**	**$(13)_{comb}$ from Worksheet A-4A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet A-4A**	**$(2)_{comb}$ from Worksheet A-4B**	**$(3)_{comb}$ from Worksheet A-4B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet A-4A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

APPENDIX 12B—WORKSHEETS FOR PREDICTIVE METHOD FOR TWO-WAY URBAN AND SUBURBAN ARTERIALS WITH SIX OR MORE LANES

Worksheet B—1A. General Information and Input Data for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	

Input Data	Base Conditions	Site Conditions
Road type (6U, 6D, 7T, 8D)	—	
Area type (urban/suburban)	—	
Length of segment, L (mi)	—	
AADT (veh/day)	—	
Lane width (ft)	12	
Outside shoulder width (ft)	1.5	
Median width (ft)	15	
Median barriers (present / not present)	not present	
Highway-rail grade crossing density (crossing/mi)	0	
Auto speed enforcement (present/not present)	not present	
Major commercial driveway density (driveways/mi)	2	
Major industrial driveway density (driveways/mi)	1	
Minor driveway density (driveways/mi)	10	
Posted speed limit (mph)	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration factor, C_r	1.0	

Worksheet B—1B. Crash Modification Factors for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

				Collision Type	
				Multiple-Vehicle (*mv*)	**Single-Vehicle (*sv*)**
(1)	CMF for Roadside Fixed Objects	CMF_{2r}	from Equation 12-41	—	
(2)	CMF for Median Width	CMF_{3r}	from Table 12-35		
(3)	CMF for Automated Speed Enforcement	CMF_{5r}	from Section 12.7.1		
(4)	CMF for Lane Width	CMF_{6r}	from Equation 12-43		
(5)	CMF for Outside Shoulder Width	CMF_{7r}	from Equation 12-44		
(6)	CMF for Highway-Rail Grade Crossings	CMF_{8r}	from Equation 12-45		
(7)	CMF for Median Barriers	CMF_{9r}	from Equation 12-46		
(8)	CMF for Major Industrial Driveways	CMF_{10r}	from Equation 12-47		—
(9)	CMF for Major Commercial Driveways	CMF_{11r}	from Equation 12-48		—
(10)	CMF for Minor Driveways	CMF_{12r}	from Equation 12-49		—
(11)	Combined CMF	CMF_{comb}	(1)*(2)*… *(10)		

Worksheet B—1C. Multiple-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, k	$N_{spf\ rs\ mv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brmv}
	from Table 12-8			from Equation 12-22	from Equation 12-21	$(11)_{mv}$ from Worksheet B-1B		(4)*(5)*(6)
	a	b	c					
FI								
PDO								
Total	—	—	—	—	—	—		

Worksheet B—1D. Multiple-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision $Manner_{(FI)}$	Predicted $N_{brmv(FI)}$ (crashes/year)	Proportion of Collision $Manner_{(PDO)}$	Predicted $N_{brmv(PDO)}$ (crashes/year)	Predicted $N_{brmv(total)}$ (crashes/year)
Manner of Collision	from Table 12-9	$(7)_{FI}$ from Worksheet B-1C	from Table 12-9	$(7)_{PDO}$ from Worksheet B-1C	$(7)_{total}$ from Worksheet B-1C
Total	1.000	(2)*$(3)_{FI}$	1.000	(4)*$(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

Worksheet B—1E. Single-Vehicle Collisions by Severity Level for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**			**Overdispersion Parameter, k**	**$N_{spf\ rs\ sv}$**	**Combined CMF**	**Calibration Factor, C_r**	**Predicted N_{brsv}**
	from Table 12-10			**from Equation 12-22**	**from Equation 12-23**	**$(11)_{sv}$ from Worksheet B-1B**		**(4)*(5)*(6)**
	a	**b**	**c**					
FI								
PDO								
Total	—	—	—	—	—	—		

Worksheet B—1F. Single-Vehicle Collisions by Manner of Collision for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Manner of Collision	**Proportion of Collision Manner$_{(FI)}$**	**Predicted $N_{brsv(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{brsv(PDO)}$ (crashes/year)**	**Predicted $N_{brsv(total)}$ (crashes/year)**
	from Table 12-11	**$(7)_{FI}$ from Worksheet B-1E**	**from Table 12-11**	**$(7)_{PDO}$ from Worksheet B-1E**	**$(7)_{total}$ from Worksheet B-1E**
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Collision with fixed object – left					
Collision with fixed object – right					
Collision with other object					
Other single-vehicle crash					

Worksheet B—1G. Vehicle-Pedestrian Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{pedr}**	**Calibration Factor, C_r**	**Predicted N_{pedr}**
	(7) from Worksheet B-1C	**(7) from Worksheet B-1E**	(2)+(3)	**From Table 12-16**		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet B—1H. Vehicle-Bicycle Collisions for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**Predicted N_{brmv}**	**Predicted N_{brsv}**	**Predicted N_{br}**	**f_{biker}**	**Calibration Factor, C_r**	**Predicted N_{biker}**
	(7) from Worksheet B-1C	**(7) from Worksheet B-1E**	(2)+(3)	**From Table 12-17**		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet B—1I. Crash Severity*Type Distribution for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets B-1D and B-1F; and (7) from Worksheet B-1G and B-1H**	**(5) from Worksheet B-1D and B-1F**	**(6) from Worksheets B-1D and B-1F; and (7) from Worksheets B-1G and B-1H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet B-1D)			
Head-on collision (from Worksheet B-1D)			
Angle collision (from Worksheet B-1D)			
Sideswipe, same direction (from Worksheet B-1D)			
Sideswipe, opposite direction (from Worksheet B-1D)			
Other multiple-vehicle collision (from Worksheet B-1D)			
Subtotal			
SINGLE_VEHICLE			
Collision with fixed object – left (from Worksheet B-1F)			
Collision with fixed object – right (from Worksheet B-1F)			
Collision with other object (from Worksheet B-1F)			
Other single-vehicle crash (from Worksheet B-1F)			
Collision with pedestrian (from Worksheet B-1G)			
Collision with bicycle (from Worksheet B-1H)			
Subtotal			
Total			

Worksheet B—1J. Summary Results for Two-Way Urban and Suburban Roadway Segments with Six or More Lanes

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(total) from Worksheet B-1I**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total			
FI			
PDO			

Worksheet B—2A. General Information and Input Data for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	
Area type (urban/suburban)	—	
$AADT_{maj}$ (veh/day)	—	
$AADT_{min}$ (veh/day)	—	
Intersection lighting (present/not present)	not present	
Calibration factor, C_i	1.00	
Data for stop-controlled intersections only:		
Left-turn lane on a minor-road approach (present/not present)	—	
Data for signalized intersections only:		
Total number of lanes on major road	6	
Total number of lanes on minor road	2	
Number of major-road approaches with left-turn lanes (0, 1, 2)	—	
Number of approaches with left-turn signal phasing	—	
Number of approaches with right-turn-on-red prohibited	0	
Number of approaches with U-turn prohibited	0	
Number of major road approaches with channelized right-turn lane	0	
Type of left-turn signal phasing	permissive	
Intersection red-light cameras (present/not present)	not present	
Sum of all pedestrian crossing volumes (PedVol)	—	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	
Number of bus stops within 1000 ft of the intersection	0	
Schools within 1000 ft of the intersection (present/not present)	not present	
Number of alcohol sales establishments within 1000 ft of the intersection	0	

Worksheet B—2B. Crash Modification Factors for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	**CMF for Left-Turn Signal Phasing**	CMF_{2i}	**from Table 12-41**	
(2)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	
(3)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	
(4)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	
(5)	**CMF for Number of Lanes**	CMF_{7i}	**from Equation 12-58**	
(6)	**CMF for Right-Turn Channelization**	CMF_{8i}	**from Equation 12-61**	
(7)	**CMF for U-Turn Prohibition**	CMF_{9i}	**from Equation 12-62**	
(8)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)*(7)**	

Worksheet B—2C. Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)				(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**				**Overdispersion Parameter, k**	**$N_{spf\ int}$**	**Combined CMF**	**Calibration Factor, C_i**	**Predicted N_{bi}**
	from Table 12-24				**from Equation 12-34**	**from Equation 12-33**	**(8) from Worksheet B-2B**		**(4)*(5)*(6)**
	a	**b**	**c**	**d**					
FI									
PDO									
Total	—	—	—	—	—	—	—		

Worksheet B—2D. Multiple-Vehicle and Single-Vehicle Collisions by Collision Type for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	**Predicted $N_{bi(FI)}$ (crashes/year)**	**Proportion of Collision Manner$_{(PDO)}$**	**Predicted $N_{bi(PDO)}$ (crashes/year)**	**Predicted $N_{bi(total)}$ (crashes/year)**
Manner of Collision	**from Table 12-25**	**$(7)_{FI}$ from Worksheet B-2C**	**from Table 12-25**	**$(7)_{PDO}$ from Worksheet B-2C**	**$(7)_{total}$ from Worksheet B-2C**
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					
Single-Vehicle Crash					

Worksheet B—2E. Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	**Predicted N_{bi}**	**f_{pedi}**	**Calibration Factor, C_i**	**Predicted N_{pedi}**
	(7) from Worksheet B-2C	**from Table 12-29**		**(2)*(3)*(4)**
Total				
FI	—	—		

Worksheet B—2F. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	**CMF for Bus Stops**	***CMF_{1p}***	**from Table 12-45**	
(2)	**CMF for Schools**	***CMF_{2p}***	**from Table 12-46**	
(3)	**CMF for Alcohol Sales Establishments**	***CMF_{3p}***	**from Table 12-47**	
(4)	**Combined CMF**	***CMF_{comb}***	**(1)*(2)*(3)**	

Worksheet B—2G. Vehicle-Pedestrian Collisions for Signalized Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients					Overdispersion Parameter, k	$N_{pedbase}$	Combined CMF	Calibration Factor, C_i	Predicted N_{pedi}
	from Table 12-27					from Table 12-27	from Equation 12-35	(4) from Worksheet B-2F		(4)*(5)*(6)
	a	b	c	d	e					
Total										
FI	—	—	—	—	—	—	—	—		

Worksheet B—2H. Vehicle-Bicycle Collisions for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Predicted N_{bi}	F_{bikei}	Calibration Factor, C_i	Predicted N_{pedi}
	(7) from Worksheet B-2C	from Table 12-30		(2)*(3)*(4)
Total				
FI	—	—		

Worksheet B—2I. Crash Severity*Type Distribution for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)
Collision Type	FI	PDO	Total
	(3) from Worksheets B-2D; (5) from Worksheets B-2E or (7) from Worksheets B-2G; (5) from Worksheet B-2H	(5) from Worksheet B-2D	(6) from Worksheets B-2D; (5) from Worksheets B-2E or (7) from Worksheets B-2G; (5) from Worksheet B-2H
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet B-2D)			
Head-on collision (from Worksheet B-2D)			
Angle collision (from Worksheet B-2D)			
Sideswipe (from Worksheet B-2D)			
Other multiple-vehicle collision (from Worksheet B-2D)			
Subtotal			
SINGLE_VEHICLE			
Collision with pedestrian (from Worksheet B-2E or B-2G)			
Collision with bicycle (from Worksheet B-2H)			
Other single-vehicle crash (from Worksheet B-2D)			
Subtotal			
Total			

Worksheet B—2J. Summary Results for Intersections of Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet B-2I**
Total	
FI	
PDO	

Worksheet B—3A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**Weighted Adjustment, w**	**Expected Average Crash Frequency, $N_{expected\ (vehicle)}$ (crashes/year)**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-5**	**Equation A-4**
ROADWAY SEGMENTS							
Multiple-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)							

Worksheet B—3B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet B—3C. Site-Specific EB Method Summary Results for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet B-3A**	**$(2)_{comb}$ from Worksheet B-3B**	**$(3)_{comb}$ from Worksheet B-3B**	**$(8)_{comb}$ from Worksheet B-3A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet B-3A**	**$(2)_{comb}$ from Worksheet B-3B**	**$(3)_{comb}$ from Worksheet B-3B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet B-3A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

Worksheet B—4A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**$N_{predicted\ w0}$**
	$N_{predicted\ (total)}$	**$N_{predicted\ (FI)}$**	**$N_{predicted\ (PDO)}$**			**Equation A-8 (6)*(2)^2**
ROADWAY SEGMENTS						
Multiple-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet B—4A. continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
Collision Type/ Site Type	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{predicted/comb\ (vehicle)}$
	Equation A-9 *sqrt*((6)*(2))	**Equation A-10**	**Equation A-11**	**Equation A-12**	**Equation A-13**	**Equation A-14**
ROADWAY SEGMENTS						
Multiple-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet B—4B. Predicted Pedestrian and Bicycle Crashes for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet B—4C. Project-Level EB Method Summary Results for Two-Way Urban and Suburban Arterials with Six or More Lanes

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet B-4A**	**$(2)_{comb}$ from Worksheet B-4B**	**$(3)_{comb}$ from Worksheet B-4B**	**$(13)_{comb}$ from Worksheet A-4A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet B-4A**	**$(2)_{comb}$ from Worksheet B-4B**	**$(3)_{comb}$ from Worksheet B-4B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet B-4A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

APPENDIX 12C—WORKSHEETS FOR PREDICTIVE METHOD FOR ONE-WAY URBAN AND SUBURBAN ARTERIALS

Worksheet C—1A. General Information and Input Data for One-Way Urban and Suburban Roadway Segments

General Information	Location Information	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2O, 3O, 4O)	—	
Area type (urban/suburban)	—	
Length of segment, *L* (mi)	—	
AADT (veh/day)	—	
Type of on-street parking (none/parallel/angle)	none	
Proportion of curb length with on-street parking	—	
Lane width (ft)	—	
Right shoulder width (ft)	4	
Auto speed enforcement (present/not present)	not present	
Major commercial driveway density (driveways/mi)	2	
Minor driveway density (driveways/mi)	10	
Speed category	—	
Bike lane (present/not present)	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration factor, C_r	1.0	

Worksheet C—1B. Crash Modification Factors for One-Way Urban and Suburban Roadway Segments

				Collision Type	
				Multiple-Vehicle (*mv*)	**Single-Vehicle (*sv*)**
(1)	**CMF for On-Street Parking**	CMF_{1r}	**from Equation 12-39**		
(2)	**CMF for Roadside Fixed Objects**	CMF_{2r}	**from Equation 12-41**	—	
(3)	**CMF for Automated Speed Enforcement**	CMF_{5r}	**from Section 12.7.1**		
(4)	**CMF for Major Commercial Driveways**	CMF_{11r}	**from Equation 12-48**		—
(5)	**CMF for Minor Driveways**	CMF_{12r}	**from Equation 12-49**		—
(6)	**CMF for Right Shoulder Width**	CMF_{13r}	**from Equation 12-50**		
(7)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)*(5)*(6)**		

Worksheet C—1C. Multiple-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, k	$N_{spf\ rs\ mv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brmv}
	from Table 12-8			from Equation 12-22	from Equation 12-21	$(7)_{mv}$ from Worksheet C-1B		(4)*(5)*(6)
	a	b	c					
FI								
PDO								
Total	—	—	—	—	—	—		

Worksheet C—1D. Multiple-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision $\text{Manner}_{(FI)}$	Predicted $N_{brmv(FI)}$ (crashes/year)	Proportion of Collision $\text{Manner}_{(PDO)}$	Predicted $N_{brmv(PDO)}$ (crashes/year)	Predicted $N_{brmv(total)}$ (crashes/year)
Manner of Collision	from	$(7)_{FI}$ from Worksheet C-1C	from	$(7)_{PDO}$ from Worksheet C-1C	$(7)_{total}$ from Worksheet C-1C
Total	1.000		1.000		
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

Worksheet C—1E. Single-Vehicle Collisions by Severity Level for One-Way Urban and Suburban Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			Overdispersion Parameter, k	$N_{spf\ rs\ sv}$	Combined CMF	Calibration Factor, C_r	Predicted N_{brsv}
	from Table 12-10			from Equation 12-22	from Equation 12-23	$(7)_{sv}$ from Worksheet C-1B		(4)*(5)*(6)
	a	b	c					
FI								
PDO								
Total	—	—	—	—	—	—		

Worksheet C—1F. Single-Vehicle Collisions by Manner of Collision for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Manner$_{(FI)}$	Predicted $N_{brsv(FI)}$ (crashes/year)	Proportion of Collision Manner$_{(PDO)}$	Predicted $N_{brsv(PDO)}$ (crashes/year)	Predicted $N_{brsv(total)}$ (crashes/year)
Manner of Collision	from	$(7)_{FI}$ from Worksheet C-1E	from	$(7)_{PDO}$ from Worksheet C-1E	$(7)_{total}$ from Worksheet C-1E
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle crash					

Worksheet C—1G. Vehicle-Pedestrian Collisions for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{br}	f_{pedr}	Calibration Factor, C_r	Predicted N_{pedr}
	(7) from Worksheet C-1C	(7) from Worksheet C-1E	(2)+(3)	From Table 12-16		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet C—1H. Vehicle-Bicycle Collisions for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Crash Severity Level	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{br}	f_{biker}	Calibration Factor, C_r	Predicted N_{biker}
	(7) from Worksheet C-1C	(7) from Worksheet C-1E	(2)+(3)	From Table 12-17		(4)*(5)*(6)
Total						
FI	—	—	—	—		

Worksheet C—1I. Crash Severity*Type Distribution for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets C-1D and C-1F; and (7) from Worksheet C-1G and C-1H**	**(5) from Worksheet C-1D and C-1F**	**(6) from Worksheets C-1D and C-1F; and (7) from Worksheets C-1G and C-1H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet C-1D)			
Head-on collision (from Worksheet C -1D)			
Angle collision (from Worksheet C -1D)			
Sideswipe, same direction (from Worksheet C -1D)			
Sideswipe, opposite direction (from Worksheet C -1D)			
Other multiple-vehicle collision (from Worksheet C -1D)			
Subtotal			
SINGLE_VEHICLE			
Collision with animal (from Worksheet C -1F)			
Collision with fixed object (from Worksheet C -1F)			
Collision with other object (from Worksheet C -1F)			
Other single-vehicle crash (from Worksheet C -1F)			
Collision with pedestrian (from Worksheet C -1G)			
Collision with bicycle (from Worksheet C -1H)			
Subtotal			
Total			

Worksheet C—1J. Summary Results for One-Way Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(total) from Worksheet C-1I**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total			
FI			
PDO			

Worksheet C—2A. General Information and Input Data for Intersections of One-Way Urban and Suburban Arterials

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection Category (1×2, 1×1)	—	
Intersection Type (3ST, 3SG, 4ST, 4SG)	—	
Area type (urban/suburban)	—	
$AADT_{maj}$ (veh/day)	—	
$AADT_{min}$ (veh/day)	—	
Intersection lighting (present/not present)	not present	
Calibration factor, C_i	1.00	
Data for stop-controlled intersections only:		
Left-turn lane on a minor-road approach (present/not present)	—	
Data for signalized intersections only:		
Total number of lanes on major road	2	
Total number of lanes on minor road	2	
Number of approaches with right-turn-on-red prohibited	0	
Left-turn lane on a major-road approach (present/not present)	—	
Channelized right-turn lane on a major-road approach (present/not present)	—	
Channelized right-turn lane on a minor-road approach (present/not present)	—	
Intersection red-light cameras (present/not present)	not present	
Sum of all pedestrian crossing volumes (PedVol)	—	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	
Number of bus stops within 1000 ft of the intersection	0	
Schools within 1000 ft of the intersection (present/not present)	not present	
Number of alcohol sales establishments within 1000 ft of the intersection	0	

Worksheet C—2B. Crash Modification Factors for Intersections of One-Way Urban and Suburban Arterials

(1)	**CMF for Right-Turn-on-Red**	CMF_{4i}	**from Equation 12-51**	
(2)	**CMF for Lighting**	CMF_{5i}	**from Equation 12-52**	
(3)	**CMF for Red-Light Cameras**	CMF_{6i}	**from Equation 12-53**	
(4)	**CMF for Number of Lanes**	CMF_{7i}	**from Equation 12-58**	
(5)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)*(4)**	

Worksheet C—2C. Multiple-Vehicle and Single-Vehicle Collisions by Severity Level for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)				(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients				Overdispersion Parameter, k	$N_{spf\ int}$	Combined CMF	Calibration Factor, C_i	Predicted N_{bi}
	from Table 12-24				from Equation 12-34	from Equation 12-33	(5) from Worksheet C-2B		(4)*(5)*(6)
	a	b	c	d					
FI									
PDO									
Total	—	—	—	—	—	—	—		

Worksheet C —2D. Multiple-Vehicle and Single-Vehicle Collisions by Manner of Collision for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Manner of Collision	Proportion of Collision Manner$_{(FI)}$	Predicted $N_{bi(FI)}$ (crashes/year)	Proportion of Collision Manner$_{(PDO)}$	Predicted $N_{bi(PDO)}$ (crashes/year)	Predicted $N_{bi(total)}$ (crashes/year)
	from Table 12-26	$(7)_{FI}$ from Worksheet C-2C	from Table 12-26	$(7)_{PDO}$ from Worksheet C-2C	$(7)_{total}$ from Worksheet C-2C
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					
Single-Vehicle Crash					

Worksheet C —2E. Vehicle-Pedestrian Collisions for Stop-Controlled Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	Predicted N_{bi}	f_{pedi}	Calibration Factor, C_i	Predicted N_{pedi}
	(7) from Worksheet C-2C	from Table 12-29		(2)*(3)*(4)
Total				
FI	—	—		

Worksheet C —2F. Crash Modification Factors for Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials

(1)	**CMF for Bus Stops**	CMF_{1p}	**from Table 12-45**	
(2)	**CMF for Schools**	CMF_{2p}	**from Table 12-46**	
(3)	**CMF for Alcohol Sales Establishments**	CMF_{3p}	**from Table 12-47**	
(4)	**Combined CMF**	CMF_{comb}	**(1)*(2)*(3)**	

Worksheet C —2G. Vehicle-Pedestrian Collisions for Signalized Intersections of One-Way Urban and Suburban Arterials

(1)	(2)					(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**					**Overdispersion Parameter, k**	$N_{pedbase}$	**Combined CMF**	**Calibration Factor,** C_i	**Predicted** N_{pedi}
	from Table 12-27					**from Table 12-27**	**from Equation 12-35**	**(4) from Worksheet C-2F**		**(4)*(5)*(6)**
	a	**b**	**c**	**d**	**e**					
Total										
FI	—	—	—	—	—	—	—	—		

Worksheet C —2H. Vehicle-Bicycle Collisions for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)
Crash Severity Level	**Predicted** N_{bi}	F_{bikei}	**Calibration Factor,** C_i	**Predicted** N_{pedi}
	(7) from Worksheet C-2C	**from Table 12-30**		**(2)*(3)*(4)**
Total				
FI	—	—		

Worksheet C —2I. Crash Severity*Type Distribution for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)
	FI	**PDO**	**Total**
Collision Type	**(3) from Worksheets C-2D; (5) from Worksheets C-2E or (7) from Worksheets C-2G; (5) from Worksheet C-2H**	**(5) from Worksheet C-2D**	**(6) from Worksheets C-2D; (5) from Worksheets C-2E or (7) from Worksheets C-2G; (5) from Worksheet C-2H**
MULTIPLE_VEHICLE			
Rear-end collision (from Worksheet C-2D)			
Head-on collision (from Worksheet C-2D)			
Angle collision (from Worksheet C-2D)			
Sideswipe (from Worksheet C-2D)			
Other multiple-vehicle collision (from Worksheet C-2D)			
Subtotal			
SINGLE_VEHICLE			
Collision with pedestrian (from Worksheet C-2E or C-2G)			
Collision with bicycle (from Worksheet C-2H)			
Other single-vehicle crash (from Worksheet C-2D)			
Subtotal			
Total			

Worksheet C —2J. Summary Results for Intersections of One-Way Urban and Suburban Arterials

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(total) from Worksheet C-2I**
Total	
FI	
PDO	

Worksheet C—3A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**Weighted Adjustment, w**	**Expected Average Crash Frequency, $N_{expected\ (vehicle)}$ (crashes/year)**
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			**Equation A-5**	**Equation A-4**
ROADWAY SEGMENTS							
Multiple-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)							

Worksheet C—3B. Predicted Pedestrian and Bicycle Crashes for One-Way Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet C—3C. Site-Specific EB Method Summary Results for One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet C-3A**	**$(2)_{comb}$ from Worksheet C-3B**	**$(3)_{comb}$ from Worksheet C-3B**	**$(8)_{comb}$ from Worksheet C-3A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet C-3A**	**$(2)_{comb}$ from Worksheet C-3B**	**$(3)_{comb}$ from Worksheet C-3B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet C-3A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

Worksheet C—4A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type/ Site Type	**Predicted Average Crash Frequency (crashes/year)**			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	$N_{predicted\ w0}$
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			**Equation A-8 $(6)*(2)^2$**
ROADWAY SEGMENTS						
Multiple-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet C—4A. continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
Collision Type/ Site Type	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{predicted/comb\ (vehicle)}$
	Equation A-9 *sqrt*((6)*(2))	**Equation A-10**	**Equation A-11**	**Equation A-12**	**Equation A-13**	**Equation A-14**
ROADWAY SEGMENTS						
Multiple-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet C—4B. Predicted Pedestrian and Bicycle Crashes for One-Way Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet C—4C. Project-Level EB Method Summary Results for One-Way Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	**$(2)_{comb}$ from Worksheet C-4A**	**$(2)_{comb}$ from Worksheet C-4B**	**$(3)_{comb}$ from Worksheet C-4B**	**$(13)_{comb}$ from Worksheet C-4A**	**(3)+(4)+(5)**
FI	**$(3)_{comb}$ from Worksheet C-4A**	**$(2)_{comb}$ from Worksheet C-4B**	**$(3)_{comb}$ from Worksheet C-4B**	**$(5)_{total}*(2)_{FI} / (2)_{total}$**	**(3)+(4)+(5)**
PDO	**$(4)_{comb}$ from Worksheet C-4A**	—	—	**$(5)_{total}*(2)_{PDO} / (2)_{total}$**	**(3)+(4)+(5)**
		0.000	0.000		

APPENDIX B. WORKSHOP SAMPLE PROBLEMS

EXERCISE 1: TWO-WAY ARTERIAL SEGMENT

Location: Six-lane divided arterial section
Study year: 2016 **Area type:** Urban
Crash data description: No crash data

INPUT DATA

Basic Roadway Data
- Number of lanes: 6
- Segment length: 0.30 mi
- Posted speed limit: 45 mph
- Number of highway-rail grade crossings: 0
- Automated speed enforcement: no

Cross-Section Data
- Lane width: 12 ft
- Outside shoulder width: 4 ft
- Inside shoulder width: 1 ft
- Median width: 10 ft
- Median type: curb

Roadside Data
- Roadside fixed-object offset: 10 ft
- Roadside fixed-object density: 50/mile

Driveway Data
- Major commercial driveways: 1
- Major industrial driveways: 1
- Minor driveways: 5

Traffic Data
- AADT (year 2016): 56,000 veh/day

Crash Data
- Not available

OUTPUT SUMMARY

What is the total predicted number of crashes? *6.543*

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.764	3.779	6.543
Multiple-vehicle crashes	2.358	3.456	
Single-vehicle crashes	0.259	0.323	
Vehicle-pedestrian crashes	0.096		
Vehicle-bicycle crashes	0.051		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.067	1.067
Single-vehicle crashes	1.087	1.087

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.036	0.186	0.725	1.818

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		6D	.
Segment length, mi		0.3	.
Annual average daily traffic (AADT), veh/day		56000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**3 major comm. driveways per mile.**
	Major industrial	1	**3 major industrial driveways per mile.**
	Minor	5	**17 minor driveways per mile.**
Cross Section Data			
Lane width, ft		12	.
Outside shoulder width, ft		4	.
Median width, ft		10	.
Median barrier present?		No	.
Roadside Data			
Roadside fixed object count		15	**50 objects per mile.**
Average roadside fixed object offset, ft		10	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.000	1.000	1.000	1.000
Outside shoulder width	0.931	0.931	0.931	0.931
Median width	1.029	1.029	1.029	1.029
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.048		1.048	
Major industrial driveways	1.025		1.025	
Minor driveways	1.037		1.037	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.135		1.135

EXERCISE 1a: TWO-WAY ARTERIAL SEGMENT

Location: Six-lane divided arterial section
Study year: 2014 **Area type:** Urban
Crash data description: Data for each individual segment
Crash data year: 2014

INPUT DATA

Traffic Data

AADT (year 2014): 48,000 veh/day

Crash Data

Crash Type	Count	
	Fatal-and-injury	Property-damage-only
Multiple-vehicle	8	14
Single-vehicle	1	1

OUTPUT SUMMARY

What is the total expected number of crashes? ……………………............ *15.271*

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2014

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.314	3.237	5.551
Multiple-vehicle crashes	1.948	2.935	
Single-vehicle crashes	0.241	0.303	
Vehicle-pedestrian crashes	0.081		
Vehicle-bicycle crashes	0.043		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.067	1.067
Single-vehicle crashes	1.087	1.087

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.030	0.156	0.607	1.521

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		6D	.
Segment length, mi		0.3	.
Annual average daily traffic (AADT), veh/day		48000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**3 major comm. driveways per mile.**
	Major industrial	1	**3 major industrial driveways per mile.**
	Minor	5	**17 minor driveways per mile.**
Cross Section Data			
Lane width, ft		12	.
Outside shoulder width, ft		4	.
Median width, ft		10	.
Median barrier present?		No	.
Roadside Data			
Roadside fixed object count		15	**50 objects per mile.**
Average roadside fixed object offset, ft		10	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.000	1.000	1.000	1.000
Outside shoulder width	0.931	0.931	0.931	0.931
Median width	1.029	1.029	1.029	1.029
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.048		1.048	
Major industrial driveways	1.025		1.025	
Minor driveways	1.037		1.037	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.135		1.135

Crash Totals Tabulation

Empirical Bayes adjustment type:
Site-specific

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	14.928
VP+VB:	0.343
F+I:	5.404
PDO:	9.867
Total:	15.271

Total Expected Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	4.704	9.481	0.357	0.386	5.060	9.867	0.224	0.119
Intersections:					0.000	0.000	0.000	0.000
Total:	4.704	9.481	0.357	0.386	5.060	9.867	0.224	0.119

Segment Site Information				Predicted crash frequency, crashes / year						Site-specific observed crash totals			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2016	6D		1.948	2.935	0.241	0.303	0.081	0.043	8	14	1	1

Segment Site Information				Expected crash frequency, crashes / year						Combined CMF			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2016	6D		4.704	9.481	0.357	0.386	0.224	0.119	1.067	1.067	1.087	1.087

EXERCISE 2: TWO-WAY ARTERIAL SEGMENT

Location: Six-lane arterial section with a center two-way left-turn lane (TWLTL)
Study year: 2014 **Area type:** Suburban
Crash data description: Data for each individual segment
Crash data year: 2014

INPUT DATA

Basic Roadway Data
- Number of lanes: 6 (plus one TWLTL)
- Segment length: 0.50 mi
- Posted speed limit: 30 mph
- Number of highway-rail grade crossings: 1
- Automated speed enforcement: yes

Cross-Section Data
- Lane width: 11 ft
- Outside shoulder width: 2 ft

Roadside Data
- Roadside fixed-object offset: 5 ft
- Roadside fixed-object density: 80/mile

Driveway Data
- Major commercial driveways: 2
- Major industrial driveways: 1
- Minor driveways: 10

Traffic Data
- AADT (year 2014): 26,000 veh/day

Crash Data

Crash Type	Count	
	Fatal-and-injury	Property-damage-only
Multiple-vehicle	3	5
Single-vehicle	1	2

OUTPUT SUMMARY

What is the total expected number of crashes? ……………………………… *8.034*

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2014

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.272	3.469	5.741
Multiple-vehicle crashes	1.659	3.012	
Single-vehicle crashes	0.294	0.457	
Vehicle-pedestrian crashes	0.184		
Vehicle-bicycle crashes	0.136		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.034	1.246
Single-vehicle crashes	1.279	1.542

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.029	0.228	0.726	1.290

Input Data	*Value*	*Advisory Messages*
Basic Roadway Data		
Area type	Suburban	.
Segment type	7T	**6 lanes + two-way left-turn lane.**
Segment length, mi	0.5	.
Annual average daily traffic (AADT), veh/day	26000	.
Number of highway-rail grade crossings present	1	**2 crossings per mile.**
Posted speed limit, mi/h	30	.
Automated speed enforcement present?	Yes	.
Access Data		
Driveway count — Major commercial	2	**4 major comm. driveways per mile.**
Major industrial	1	**2 major industrial driveways per mile.**
Minor	10	**20 minor driveways per mile.**
Cross Section Data		
Lane width, ft	11	.
Outside shoulder width, ft	2	.
Median width, ft	10	.
Median barrier present?	No	.
Roadside Data		
Roadside fixed object count	40	**80 objects per mile.**
Average roadside fixed object offset, ft	5	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.034	0.034
Adjustment factor for bicyclists (f_{bike})	0.025	0.025
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors

	F+I		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.022	1.022	1.022	1.022
Outside shoulder width	0.986	0.986	0.986	0.986
Median width	1.000	1.000	1.000	1.000
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.081	1.081	1.081	1.081
Major commercial driveways	1.073		1.073	
Major industrial driveways	1.011		1.011	
Minor driveways	1.055		1.055	
Automated speed enforcement	0.830	0.830	1.000	1.000
Roadside fixed objects		1.416		1.416

Crash Totals Tabulation

Empirical Bayes adjustment type:
Site-specific

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	7.586
VP+VB:	0.448
F+I:	3.055
PDO:	4.978
Total:	8.034

Total Expected Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	2.296	4.347	0.312	0.631	2.608	4.978	0.258	0.190
Intersections:					0.000	0.000	0.000	0.000
Total:	2.296	4.347	0.312	0.631	2.608	4.978	0.258	0.190

Segment Site Information				Predicted crash frequency, crashes / year						Site-specific observed crash totals			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2014	7T		1.659	3.012	0.294	0.457	0.184	0.136	3	5	1	2

Segment Site Information				Expected crash frequency, crashes / year						Combined CMF			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2014	7T		2.296	4.347	0.312	0.631	0.258	0.190	1.034	1.246	1.279	1.542

EXERCISE 3: TWO-WAY ARTERIAL SEGMENT

Location: Conversion of a six-lane divided section into an eight-lane divided section
Study year: 2016 **Area type:** Urban
Crash data description: No crash data

INPUT DATA (for six-lane divided section)

Use data in Exercise 1

INPUT DATA (for eight-lane divided section)

Basic Roadway Data

Number of lanes: 8
Segment length: 0.30 mi
Posted speed limit: 45 mph
Number of highway-rail grade crossings: 0
Automated speed enforcement: no

Cross-Section Data

Lane width: 11 ft
Outside shoulder width: 1 ft
Inside shoulder width: 1 ft
Median width: 2 ft
Median type: concrete barrier

Roadside Data

Roadside fixed-object offset: 10 ft
Roadside fixed-object density: 50/mile

Driveway Data

Major commercial driveways: 1
Major industrial driveways: 1
Minor driveways: 5

Traffic Data

AADT (year 2016): 56,000 veh/day

Crash Data

Not available

OUTPUT SUMMARY

What is the total predicted number of crashes for the six-lane divided section? ….

6.543

What is the total predicted number of crashes for the eight-lane divided section? …

7.346

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.764	3.779	6.543
Multiple-vehicle crashes	2.358	3.456	
Single-vehicle crashes	0.259	0.323	
Vehicle-pedestrian crashes	0.096		
Vehicle-bicycle crashes	0.051		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.067	1.067
Single-vehicle crashes	1.087	1.087

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.036	0.186	0.725	1.818

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		6D	.
Segment length, mi		0.3	.
Annual average daily traffic (AADT), veh/day		56000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**3 major comm. driveways per mile.**
	Major industrial	1	**3 major industrial driveways per mile.**
	Minor	5	**17 minor driveways per mile.**
Cross Section Data			
Lane width, ft		12	.
Outside shoulder width, ft		4	.
Median width, ft		10	.
Median barrier present?		No	.
Roadside Data			
Roadside fixed object count		15	**50 objects per mile.**
Average roadside fixed object offset, ft		10	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I* *Multiple*	*F+I* *Single*	*PDO* *Multiple*	*PDO* *Single*
Lane width	1.000	1.000	1.000	1.000
Outside shoulder width	0.931	0.931	0.931	0.931
Median width	1.029	1.029	1.029	1.029
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.048		1.048	
Major industrial driveways	1.025		1.025	
Minor driveways	1.037		1.037	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.135		1.135

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.774	4.572	7.346
Multiple-vehicle crashes	1.975	3.499	
Single-vehicle crashes	0.537	1.073	
Vehicle-pedestrian crashes	0.163		
Vehicle-bicycle crashes	0.099		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	0.746	0.746
Single-vehicle crashes	2.493	2.493

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.042	0.156	0.661	1.915

Input Data	*Value*	*Advisory Messages*
Basic Roadway Data		
Area type	Urban	.
Segment type	8D	.
Segment length, mi	0.3	.
Annual average daily traffic (AADT), veh/day	56000	.
Number of highway-rail grade crossings present	0	.
Posted speed limit, mi/h	45	.
Automated speed enforcement present?	No	.
Access Data		
Driveway count — Major commercial	1	**3 major comm. driveways per mile.**
Major industrial	1	**3 major industrial driveways per mile.**
Minor	5	**17 minor driveways per mile.**
Cross Section Data		
Lane width, ft	11	.
Outside shoulder width, ft	1	.
Median width, ft	2	.
Median barrier present?	Yes	.
Roadside Data		
Roadside fixed object count	15	**50 objects per mile.**
Average roadside fixed object offset, ft	10	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.023	0.023
Adjustment factor for bicyclists (f_{bike})	0.014	0.014
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.022	1.022	1.022	1.022
Outside shoulder width	1.014	1.014	1.014	1.014
Median width	1.077	1.077	1.077	1.077
Median barrier	0.600	1.967	0.600	1.967
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.048		1.048	
Major industrial driveways	1.025		1.025	
Minor driveways	1.037		1.037	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.135		1.135

EXERCISE 4: ONE-WAY ARTERIAL SEGMENT

Location: Two-lane one-way arterial section
Study year: 2014 **Area type:** Urban
Crash data description: Data for each individual segment
Crash data year: 2014

INPUT DATA

Basic Roadway Data

Number of lanes: 2
Segment length: 0.50 mi
Posted speed limit: 30 mph
Bike lanes: None
Automated speed enforcement: no
Parallel parking: on the left side throughout the section
Angle parking: on the right side throughout the section

Cross-Section Data

Lane width: 11 ft
Right shoulder width: 0 ft

Roadside Data

Roadside fixed-object offset: 5 ft
Roadside fixed-object density: 16/mile

Driveway Data

Major commercial driveways: 1
Minor driveways: 10

Traffic Data

AADT (year 2014): 12,000 veh/day

Crash Data

Crash Type	Count	
	Fatal-and-injury	Property-damage-only
Multiple-vehicle	1	2
Single-vehicle	0	1

OUTPUT SUMMARY

What is the total predicted number of crashes? …………………………... *7.236*

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information		Site Information	
Analyst		Street number	
Agency		Street name	
Date		Segment number	1
Location		Analysis year	2014

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	2.987	6.881	9.868
Multiple-vehicle crashes	2.291	6.018	
Single-vehicle crashes	0.427	0.863	
Vehicle-pedestrian crashes	0.163		
Vehicle-bicycle crashes	0.106		

Combined CMF

	F+I	PDO
Multiple-vehicle crashes	3.214	3.214
Single-vehicle crashes	3.377	3.377

Severity distribution for F+I crashes

K	A	B	C
0.036	0.328	1.065	1.558

Input Data

Input Data	Value	Advisory Messages
Basic Roadway Data		
Area type	Urban	.
Segment type	2O	.
Segment length, mi	0.5	.
Bicycle lanes present?	No	.
Annual average daily traffic (AADT), veh/day	12000	.
Posted speed limit, mi/h	30	.
Automated speed enforcement present?	No	.
Access Data		
Driveway count — Major commercial	1	**2 major comm. driveways per mile.**
Driveway count — Minor	10	**20 minor driveways per mile.**
Cross Section Data		
Lane width, ft	11	.
Right shoulder width, ft	0	.
Roadside Data		
On-street parallel parking length on right side, mi	0	.
On-street angle parking length on right side, mi	0.5	.
On-street parallel parking length on left side, mi	0.5	.
On-street angle parking length on left side, mi	0	.
Roadside fixed object count	8	**16 objects per mile.**
Average roadside fixed object offset, ft	5	.

Calibration Factors

Calibration Factors	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.017	0.017
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors

Crash Modification Factors	F+I Multiple	F+I Single	PDO Multiple	PDO Single
Right shoulder width	1.084	1.084	1.084	1.084
On-street parallel parking	1.056	1.056	1.056	1.056
On-street angle parking	2.682	2.682	2.682	2.682
Major commercial driveways	1.000		1.000	
Minor driveways	1.047		1.047	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.100		1.100

Crash Totals Tabulation

Empirical Bayes adjustment type:
Site-specific

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	7.039
VP+VB:	0.197
F+I:	2.369
PDO:	4.868
Total:	7.236

Total Expected Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	1.833	3.981	0.339	0.886	2.172	4.868	0.120	0.077
Intersections:					0.000	0.000	0.000	0.000
Total:	1.833	3.981	0.339	0.886	2.172	4.868	0.120	0.077

Segment Site Information				Predicted crash frequency, crashes / year						Site-specific observed crash totals			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2014	2O		2.291	6.018	0.427	0.863	0.163	0.106	1	2	0	1

Segment Site Information				Expected crash frequency, crashes / year						Combined CMF			
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle	
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO
1	2014	2O		1.833	3.981	0.339	0.886	0.120	0.077	3.214	3.214	3.377	3.377

EXERCISE 5: ONE-WAY ARTERIAL SEGMENT

Location: Conversion of a two-lane one-way section with parking on both sides into a three-lane one-way section with no parking
Study year: 2016 **Area type:** Urban
Crash data description: No crash data

INPUT DATA (for two-lane one-way section)
Use data in Exercise 4
Traffic Data
AADT (year 2016): 16,000 veh/day

INPUT DATA (for three-lane one-way section)

Basic Roadway Data
Number of lanes: 3
Segment length: 0.50 mi
Posted speed limit: 30 mph
Bike lanes: none
Automated speed enforcement: no
Parallel parking: no
Angle parking: no
Cross-Section Data
Lane width: 11 ft
Right shoulder width: 4 ft
Roadside Data
Roadside fixed-object offset: 5 ft
Roadside fixed-object density: 16/mile
Driveway Data
Major commercial driveways: 1
Minor driveways: 10
Traffic Data
AADT (year 2016): 16,000 veh/day
Crash Data
Not available

OUTPUT SUMMARY

What is the total predicted number of crashes for the two-lane one-way section? ….

13.180

What is the total predicted number of crashes for the three-lane one-way section? …

4.359

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	4.133	9.047	13.180
Multiple-vehicle crashes	3.292	8.071	
Single-vehicle crashes	0.482	0.977	
Vehicle-pedestrian crashes	0.218		
Vehicle-bicycle crashes	0.141		

Combined CMF

	F+I	PDO
Multiple-vehicle crashes	3.214	3.214
Single-vehicle crashes	3.377	3.377

Severity distribution for F+I crashes

K	A	B	C
0.050	0.454	1.473	2.156

Input Data

Input Data		Value	Advisory Messages
Basic Roadway Data			
Area type		Urban	.
Segment type		2O	.
Segment length, mi		0.5	.
Bicycle lanes present?		No	.
Annual average daily traffic (AADT), veh/day		16000	.
Posted speed limit, mi/h		30	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**2 major comm. driveways per mile.**
	Minor	10	**20 minor driveways per mile.**
Cross Section Data			
Lane width, ft		11	.
Right shoulder width, ft		0	.
Roadside Data			
On-street parallel parking length on right side, mi		0	.
On-street angle parking length on right side, mi		0.5	.
On-street parallel parking length on left side, mi		0.5	.
On-street angle parking length on left side, mi		0	.
Roadside fixed object count		8	**16 objects per mile.**
Average roadside fixed object offset, ft		5	.

Calibration Factors

Calibration Factors	Value	Default Values
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.017	0.017
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors

Crash Modification Factors	F+I Multiple	F+I Single	PDO Multiple	PDO Single
Right shoulder width	1.084	1.084	1.084	1.084
On-street parallel parking	1.056	1.056	1.056	1.056
On-street angle parking	2.682	2.682	2.682	2.682
Major commercial driveways	1.000		1.000	
Minor driveways	1.047		1.047	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.100		1.100

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	1.441	2.918	4.359
Multiple-vehicle crashes	1.062	2.603	
Single-vehicle crashes	0.232	0.315	
Vehicle-pedestrian crashes	0.101		
Vehicle-bicycle crashes	0.046		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.047	1.047
Single-vehicle crashes	1.100	1.100

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.012	0.109	0.464	0.856

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		3O	.
Segment length, mi		0.5	.
Bicycle lanes present?		No	.
Annual average daily traffic (AADT), veh/day		16000	.
Posted speed limit, mi/h		30	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**2 major comm. driveways per mile.**
	Minor	10	**20 minor driveways per mile.**
Cross Section Data			
Lane width, ft		11	.
Right shoulder width, ft		4	.
Roadside Data			
On-street parallel parking length on right side, mi		0	.
On-street angle parking length on right side, mi		0	.
On-street parallel parking length on left side, mi		0	.
On-street angle parking length on left side, mi		0	.
Roadside fixed object count		8	**16 objects per mile.**
Average roadside fixed object offset, ft		5	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.024	0.024
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Right shoulder width	1.000	1.000	1.000	1.000
On-street parallel parking	1.000	1.000	1.000	1.000
On-street angle parking	1.000	1.000	1.000	1.000
Major commercial driveways	1.000		1.000	
Minor driveways	1.047		1.047	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.100		1.100

EXERCISE 6: TWO-WAY INTERSECTION (2×2)

Location: Three-leg signalized intersection on eight-lane divided arterial
Study period: 2015 **Area type:** Suburban
Crash data description: No crash data

INPUT DATA

Basic Intersection Data

Intersection traffic control mode: Signal
Lighting: Present
Number of Lanes
Major Street: 8 lanes
Minor Street: 4 lanes
Left-Turn Lanes
Major Street: One approach (one lane)
Right-Turn Channelization
Major Street: Yes (one approach)
Red-light camera: No

Traffic Control

Left-Turn Operational Mode
Protected-only mode on the major continuous street: Yes
Right-Turn-On-Red Prohibition
Number of approaches: 1 (from the minor street)
U-Turn Prohibition
Number of approaches: 2 (both on the major street)

Traffic Data

Major Street
AADT (year 2015): 60,000 veh/day
Minor Street
AADT (year 2015): 15,500 veh/day

Pedestrian Data

Level of pedestrian activity: Medium
Refugee islands: None
Number of schools: 1
Number of bus stops: 2
Alcohol sales establishments: 1

Crash Data

Not available

OUTPUT SUMMARY

What is the total predicted number of crashes? …………………………... *12.766*

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information		*Site Information*	
Analyst		Major street name	
Agency		Minor street name	
Date		Intersection number	1
Location		Analysis year	2015

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	7.093	5.673	12.766
Total-vehicle crashes	6.482	5.673	
Vehicle-pedestrian crashes	0.259		
Vehicle-bicycle crashes	0.352		

Combined CMF

	F+I	*PDO*
Total-vehicle crashes	1.328	1.328
Vehicle-pedestrian crashes	6.275	

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.035	0.341	1.845	4.872

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Suburban		.
Number of legs	3		**3SG intersection type**
Traffic control type	Signalized		.
Lighting present?	Yes		.
Red-light cameras present?	No		.
Daily pedestrian volume crossing all legs (peds/day)	400		.
Maximum number of lanes crossed by a pedestrian	8		.
Number of bus stops within 1,000 ft of intersection	2		.
School(s) present within 1,000 ft of intersection?	Yes		.
Alcohol sales establishments within 1,000 ft	1		.
Street Data	*Major*	*Minor*	.
Street configuration	Two-way	Two-way	**2x2 intersection configuration**
Annual average daily traffic (AADT), veh/day	60000	15500	.
Number of through lanes	8	4	.
Number of approaches with left-turn lanes	1	2	.
Number of left-turn movements with protected phasing	1	0	.
Number of right-turn movements prohibited on red	0	1	.
Number of U-turn movements prohibited	2	0	.
Number of approaches with right-turn channelization	1	0	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.051	0.051
Adjustment factor for bicyclists (f_{bike})	0.029	0.029
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.094	0.094

Manner of Collision Proportions

2x2 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	*F+I*	*PDO*
Total-vehicle crash CMFs		
Lighting	0.911	0.911
Red-light cameras	1.000	1.000
Left-turn signal phasing	0.860	0.860
Right-turn-on-red	0.980	0.980
U-turn prohibition	0.922	0.922
Right-turn channelization	1.243	1.243
Number of lanes	1.511	1.511
Vehicle-pedestrian crash CMFs		
Bus stops	4.150	
Schools	1.350	
Alcohol sales establishments	1.120	

EXERCISE 7: TWO-WAY INTERSECTION (2×2)

Location: Four-leg stop-controlled intersection on six-lane divided arterial
Study period: 2014 **Area type:** Suburban
Crash data description: Data for each individual intersection
Crash data year: 2014

INPUT DATA

Basic Intersection Data

Intersection traffic control mode: Stop control on minor street
Lighting: Present
Number of Lanes
Major Street: 6 lanes
Minor Street: 2 lanes
Left-Turn Lanes
Major Street: Present (both approaches)
Minor Street: None

Traffic Data

Major Street
AADT (year 2014): 40,000 veh/day
Minor Street
AADT (year 2014): 4,500 veh/day

Crash Data

Crash Type	Count	
	Fatal-and-injury	Property-damage-only
Total-vehicle	3	5

OUTPUT SUMMARY

What is the total predicted number of crashes? …………………………... *8.341*

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	1
Analysis year	2014

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	3.349	3.697	7.046
Total-vehicle crashes	2.779	3.697	
Vehicle-pedestrian crashes	0.317		
Vehicle-bicycle crashes	0.253		

Combined CMF

	F+I	*PDO*
Total-vehicle crashes	0.913	0.913
Vehicle-pedestrian crashes	6.275	

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.012	0.265	0.980	2.092

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Suburban		.
Number of legs	4		4ST intersection type
Traffic control type	Two-way stop		.
Lighting present?	Yes		.
Red-light cameras present?	No		.
Daily pedestrian volume crossing all legs (peds/day)	400		.
Maximum number of lanes crossed by a pedestrian	8		.
Number of bus stops within 1,000 ft of intersection	2		.
School(s) present within 1,000 ft of intersection?	Yes		.
Alcohol sales establishments within 1,000 ft	1		.
Street Data	*Major*	*Minor*	#N/A
Street configuration	Two-way	Two-way	2x2 intersection configuration
Annual average daily traffic (AADT), veh/day	40000	4500	.
Number of through lanes	6	2	.
Number of approaches with left-turn lanes	1	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	1	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	1	0	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.049	0.049
Adjustment factor for bicyclists (f_{bike})	0.039	0.039
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.043	0.043

Manner of Collision Proportions

2x2 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	*F+I*	*PDO*
Total-vehicle crash CMFs		
Lighting	0.913	0.913
Red-light cameras	1.000	1.000
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.000	1.000
Vehicle-pedestrian crash CMFs		
Bus stops	4.150	
Schools	1.350	
Alcohol sales establishments	1.120	

Crash Totals Tabulation

Empirical Bayes adjustment type:
Site-specific

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	7.667
VP+VB:	0.675
F+I:	3.592
PDO:	4.750
Total:	8.341

Total Expected Crash Frequency, crashes / year

Site type	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Intersections:					2.917	4.750	0.376	0.299
Total:	0.000	0.000	0.000	0.000	2.917	4.750	0.376	0.299

Intersection Site Information				Predicted crash frequency, crashes / year				Site-specific observed crash totals		
				Total-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Total-vehicle		Vehicle-pedestrian
Number	Year	Type	Configuration	F+I	PDO	F+I	F+I	F+I	PDO	F+I
1	2014	4ST	Two-way	2.779	3.697	0.317	0.253	3	5	

Intersection Site Information				Expected crash frequency, crashes / year				Combined CMF		
				Total-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Total-vehicle		Vehicle-pedestrian
Number	Year	Type	Configuration	F+I	PDO	F+I	F+I	F+I	PDO	F+I
1	2014	4ST	Two-way	2.917	4.750	0.376	0.299	0.913	0.913	6.275

EXERCISE 8: ONE-WAY INTERSECTION

Location: Conversion of a two-way minor street into one-way at a four-leg intersection on one-way arterial
Study period: 2015 **Area type:** Urban
Crash data description: No crash data

INPUT DATA

Basic Intersection Data

Intersection traffic control mode: Signal
Lighting: Present
Minor Street: Two-way to one-way conversion
Number of Lanes
Major Street: 4 lanes
Minor Street: 2 lanes
Left-Turn Lanes
Major Street: One approach (one lane)
Right-Turn Channelization
Major Street: No
Minor Street: No
Red-light camera: Yes
Right-Turn-On-Red Prohibition
Number of approaches: 0

Traffic Data

Major Street
AADT (year 2015): 24,000 veh/day
Minor Street
AADT (year 2015): 10,500 veh/day

Pedestrian Data

Level of pedestrian activity: High
Refugee islands: None
Number of schools: 0
Number of bus stops: 1
Alcohol sales establishments: 2

Crash Data

Not available

OUTPUT SUMMARY

What is the total predicted number of crashes when minor street is two-way?...

4.973

What is the total predicted number of crashes when minor street is one-way?...

3.726

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	1
Analysis year	2015

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	1.399	3.574	4.973
Total-vehicle crashes	0.818	3.574	
Vehicle-pedestrian crashes	0.528		
Vehicle-bicycle crashes	0.053		

Combined CMF

	F+I	*PDO*
Total-vehicle crashes	1.028	1.028
Vehicle-pedestrian crashes	3.114	

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.003	0.061	0.335	1.000

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Urban		.
Number of legs	4		**4SG intersection type**
Traffic control type	Signalized		.
Lighting present?	Yes		.
Red-light cameras present?	Yes		.
Daily pedestrian volume crossing all legs (peds/day)	3200		.
Maximum number of lanes crossed by a pedestrian	4		.
Number of bus stops within 1,000 ft of intersection	1		.
School(s) present within 1,000 ft of intersection?	No		.
Alcohol sales establishments within 1,000 ft	2		.
Street Data	*Major*	*Minor*	.
Street configuration	One-way	Two-way	**1x2 intersection configuration**
Annual average daily traffic (AADT), veh/day	24000	10500	.
Number of through lanes	4	2	.
Number of approaches with left-turn lanes	1	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	0	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	0	0	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.020	0.020
Adjustment factor for bicyclists (f_{bike})	0.012	0.012
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.046	0.046

Manner of Collision Proportions

2x2 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	*F+I*	*PDO*
Total-vehicle crash CMFs		
Lighting	0.911	0.911
Red-light cameras	0.788	0.788
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.433	1.433
Vehicle-pedestrian crash CMFs		
Bus stops	2.780	
Schools	1.000	
Alcohol sales establishments	1.120	

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information		Site Information	
Analyst		Major street name	
Agency		Minor street name	
Date		Intersection number	1
Location		Analysis year	2015

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	1.307	2.420	3.726
Total-vehicle crashes	0.740	2.420	
Vehicle-pedestrian crashes	0.528		
Vehicle-bicycle crashes	0.038		

Combined CMF

	F+I	PDO
Total-vehicle crashes	1.028	1.028
Vehicle-pedestrian crashes	3.114	

Severity distribution for F+I crashes

K	A	B	C
0.003	0.057	0.312	0.934

Input Data

Input Data	Value		Advisory Messages
Intersection Data			
Area type	Urban		.
Number of legs	4		4SG intersection type
Traffic control type	Signalized		.
Lighting present?	Yes		.
Red-light cameras present?	Yes		.
Daily pedestrian volume crossing all legs (peds/day)	3200		.
Maximum number of lanes crossed by a pedestrian	4		.
Number of bus stops within 1,000 ft of intersection	1		.
School(s) present within 1,000 ft of intersection?	No		.
Alcohol sales establishments within 1,000 ft	2		.
Street Data	*Major*	*Minor*	.
Street configuration	One-way	One-way	1x1 intersection configuration
Annual average daily traffic (AADT), veh/day	24000	10500	.
Number of through lanes	4	2	.
Number of approaches with left-turn lanes	1	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	0	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	0	0	.

Calibration Factors

Calibration Factors	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.020	0.020
Adjustment factor for bicyclists (f_{bike})	0.012	0.012
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.046	0.046

Manner of Collision Proportions

2x2 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors

Crash Modification Factors	F+I	PDO
Total-vehicle crash CMFs		
Lighting	0.911	0.911
Red-light cameras	0.788	0.788
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.433	1.433
Vehicle-pedestrian crash CMFs		
Bus stops	2.780	
Schools	1.000	
Alcohol sales establishments	1.120	

EXERCISE 9: TWO-WAY ARTERIAL PROJECT

Location: A two-way six-lane divided arterial street project with three homogenous segments, one four-leg signalized intersection, and one three-leg stop-controlled intersection
Study year: 2016 **Area type:** Urban
Crash data description: No crash data

INPUT DATA (Segments)

Basic Roadway Data

	Segment 1	*Segment 2*	*Segment 3*
Number of lanes	6	6	6
Segment length (mi)	0.7	0.3	0.5
Posted speed limit (mph)	45	45	45
Highway-rail grade crossings	0	0	1
Automated speed enforcement	no	no	no
Cross-Section Data			
Lane width (ft)	11	10	10
Outside shoulder width (ft)	4	3	3
Inside shoulder width (ft)	1	1	1
Median width (ft)	8	5	5
Median type	curb	curb	curb
Roadside Data			
Roadside fixed-object offset (ft)	15	10	8
Roadside fixed-object density	50/mile	80/mile	80/mile
Driveway Data			
Major commercial driveways	2	1	2
Major industrial driveways	1	0	0
Minor driveways	15	6	15
Traffic Data			
AADT (in 2016)	65,000	55,000	55,000

Crash Data

Not available

INPUT DATA (Intersections)

Basic Roadway Data

	Intersection 1	*Intersection 2*
Intersection traffic control mode	signal	unsignalized
Approaches (legs)	4	3
Lighting	present	not present
Number of minor-street lanes	4	2
Left-turn lanes (major street)	two approaches	one approach
Left-turn lanes (minor street)	none	none
Right-turn channelization	On major street	On major street
Red-light camera	no	no

Traffic Control

Left-turn operational mode	Protected/permitted	–
Right-turn-on-red prohibition	2 approaches	–
U-turn prohibition	2 approaches	–
Traffic Data		
Minor-street AADT (in 2016)	25,000	5,000
Pedestrian Data		
Level of pedestrian activity	High	–
Number of schools	1	–
Number of bus stops	2	–
Alcohol sales establishments	1	–
Refuge Island	On major-street median (n_{lanesx} = 4)	–

Crash Data

Not available

OUTPUT SUMMARY

What is the total predicted number of crashes? *65.040*

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	7.808	10.437	18.245
Multiple-vehicle crashes	6.767	9.653	
Single-vehicle crashes	0.631	0.784	
Vehicle-pedestrian crashes	0.268		
Vehicle-bicycle crashes	0.143		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.091	1.091
Single-vehicle crashes	1.060	1.060

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.101	0.526	2.047	5.134

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		6D	.
Segment length, mi		0.7	.
Annual average daily traffic (AADT), veh/day		65000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	2	**3 major comm. driveways per mile.**
	Major industrial	1	**1 major industrial driveways per mile.**
	Minor	15	**21 minor driveways per mile.**
Cross Section Data			
Lane width, ft		11	.
Outside shoulder width, ft		4	.
Median width, ft		8	.
Median barrier present?		No	.
Roadside Data			
Roadside fixed object count		35	**50 objects per mile.**
Average roadside fixed object offset, ft		15	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.022	1.022	1.022	1.022
Outside shoulder width	0.931	0.931	0.931	0.931
Median width	1.041	1.041	1.041	1.041
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.030		1.030	
Major industrial driveways	1.005		1.005	
Minor driveways	1.064		1.064	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.070		1.070

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	2
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.969	4.064	7.033
Multiple-vehicle crashes	2.506	3.684	
Single-vehicle crashes	0.304	0.380	
Vehicle-pedestrian crashes	0.103		
Vehicle-bicycle crashes	0.055		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.160	1.160
Single-vehicle crashes	1.289	1.289

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.038	0.200	0.778	1.952

Input Data		*Value*	*Advisory Messages*
Basic Roadway Data			
Area type		Urban	.
Segment type		6D	.
Segment length, mi		0.3	.
Annual average daily traffic (AADT), veh/day		55000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**3 major comm. driveways per mile.**
	Major industrial	0	.
	Minor	6	**20 minor driveways per mile.**
Cross Section Data			
Lane width, ft		10	.
Outside shoulder width, ft		3	.
Median width, ft		5	.
Median barrier present?		No	.
Roadside Data			
Roadside fixed object count		24	**80 objects per mile.**
Average roadside fixed object offset, ft		10	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.045	1.045	1.045	1.045
Outside shoulder width	0.958	0.958	0.958	0.958
Median width	1.059	1.059	1.059	1.059
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.048		1.048	
Major industrial driveways	0.989		0.989	
Minor driveways	1.055		1.055	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.216		1.216

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	3
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	5.708	7.827	13.535
Multiple-vehicle crashes	4.877	7.169	
Single-vehicle crashes	0.527	0.658	
Vehicle-pedestrian crashes	0.198		
Vehicle-bicycle crashes	0.106		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	1.354	1.354
Single-vehicle crashes	1.338	1.338

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.074	0.385	1.496	3.753

Input Data	*Value*	*Advisory Messages*
Basic Roadway Data		
Area type	Urban	.
Segment type	6D	.
Segment length, mi	0.5	.
Annual average daily traffic (AADT), veh/day	55000	.
Number of highway-rail grade crossings present	1	**2 crossings per mile.**
Posted speed limit, mi/h	45	.
Automated speed enforcement present?	No	.
Access Data		
Driveway count — Major commercial	2	**4 major comm. driveways per mile.**
Major industrial	0	.
Minor	15	**30 minor driveways per mile.**
Cross Section Data		
Lane width, ft	10	.
Outside shoulder width, ft	3	.
Median width, ft	5	.
Median barrier present?	No	.
Roadside Data		
Roadside fixed object count	24	**48 objects per mile.**
Average roadside fixed object offset, ft	8	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.045	1.045	1.045	1.045
Outside shoulder width	0.958	0.958	0.958	0.958
Median width	1.059	1.059	1.059	1.059
Median barrier	1.000	1.000	1.000	1.000
Highway-rail grade crossing	1.081	1.081	1.081	1.081
Major commercial driveways	1.073		1.073	
Major industrial driveways	0.989		0.989	
Minor driveways	1.114		1.114	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.168		1.168

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	10.831	7.903	18.733
Total-vehicle crashes	9.001	7.903	
Vehicle-pedestrian crashes	1.508		
Vehicle-bicycle crashes	0.321		

Combined CMF

	F+I	PDO
Total-vehicle crashes	1.142	1.142
Vehicle-pedestrian crashes	6.275	

Severity distribution for F+I crashes

K	A	B	C
0.043	0.416	2.410	7.962

Input Data

Intersection Data

	Value	Advisory Messages
Area type	Urban	.
Number of legs	4	**4SG intersection type**
Traffic control type	Signalized	.
Lighting present?	Yes	.
Red-light cameras present?	No	.
Daily pedestrian volume crossing all legs (peds/day)	3200	.
Maximum number of lanes crossed by a pedestrian	4	.
Number of bus stops within 1,000 ft of intersection	2	.
School(s) present within 1,000 ft of intersection?	Yes	.
Alcohol sales establishments within 1,000 ft	1	.

Street Data

	Major	Minor	
Street configuration	Two-way	Two-way	**2x2 intersection configuration**
Annual average daily traffic (AADT), veh/day	60000	25000	.
Number of through lanes	6	4	.
Number of approaches with left-turn lanes	2	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	2	.
Number of U-turn movements prohibited	2	0	.
Number of approaches with right-turn channelization	1	0	.

Calibration Factors

	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.049	0.049
Adjustment factor for bicyclists (f_{bike})	0.019	0.019
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.094	0.094

Manner of Collision Proportions

2x2 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors

Total-vehicle crash CMFs

	F+I	PDO
Lighting	0.911	0.911
Red-light cameras	1.000	1.000
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	0.960	0.960
U-turn prohibition	0.922	0.922
Right-turn channelization	1.243	1.243
Number of lanes	1.139	1.139

Vehicle-pedestrian crash CMFs

	F+I
Bus stops	4.150
Schools	1.350
Alcohol sales establishments	1.120

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	2
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	4.656	2.838	7.494
Total-vehicle crashes	3.981	2.838	
Vehicle-pedestrian crashes	0.348		
Vehicle-bicycle crashes	0.327		

Combined CMF

	F+I	PDO
Total-vehicle crashes	1.000	1.000
Vehicle-pedestrian crashes	6.275	

Severity distribution for F+I crashes

K	A	B	C
0.026	0.574	1.401	2.655

Input Data

Intersection Data

Input Data	Value	Advisory Messages
Area type	Urban	.
Number of legs	3	3ST intersection type
Traffic control type	Two-way stop	.
Lighting present?	No	.
Red-light cameras present?	No	.
Daily pedestrian volume crossing all legs (peds/day)	3200	.
Maximum number of lanes crossed by a pedestrian	4	.
Number of bus stops within 1,000 ft of intersection	2	.
School(s) present within 1,000 ft of intersection?	Yes	.
Alcohol sales establishments within 1,000 ft	1	.

Street Data

Street Data	Major	Minor	#N/A
Street configuration	Two-way	Two-way	2x2 intersection configuration
Annual average daily traffic (AADT), veh/day	55000	5000	.
Number of through lanes	6	2	.
Number of approaches with left-turn lanes	2	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	2	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	1	0	.

Calibration Factors

Calibration Factors	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.051	0.051
Adjustment factor for bicyclists (f_{bike})	0.048	0.048
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.043	0.043

Manner of Collision Proportions

2x2 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors

Total-vehicle crash CMFs

	F+I	PDO
Lighting	1.000	1.000
Red-light cameras	1.000	1.000
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.000	1.000

Vehicle-pedestrian crash CMFs

	F+I
Bus stops	4.150
Schools	1.350
Alcohol sales establishments	1.120

Crash Totals Tabulation

Empirical Bayes adjustment type:
None

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	61.663
VP+VB:	3.377
F+I:	31.972
PDO:	33.069
Total:	65.040

Total Predicted Crash Frequency, crashes / year

	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	14.150	20.506	1.462	1.823	15.612	22.329	0.569	0.304
Intersections:					12.982	10.740	1.856	0.648
Total:	14.150	20.506	1.462	1.823	28.594	33.069	2.425	0.952

Segment Site Information				Predicted crash frequency, crashes / year					
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I
1	2016	6D		6.767	9.653	0.631	0.784	0.268	0.143
2	2016	6D		2.506	3.684	0.304	0.380	0.103	0.055
3	2016	6D		4.877	7.169	0.527	0.658	0.198	0.106

Intersection Site Information				Predicted crash frequency, crashes / year			
				Total-vehicle		Vehicle-pedestrian	Vehicle-bicycle
Number	Year	Type	Configuration	F+I	PDO	F+I	F+I
1	2016	4SG	Two-way	9.001	7.903	1.508	0.321
2	2016	3ST	Two-way	3.981	2.838	0.348	0.327

EXERCISE 10: ONE-WAY ARTERIAL PROJECT

Location: A one-way three-lane arterial street project with three homogenous segments and two four-leg street intersections
Study year: 2016 **Area type:** Urban
Crash data description: No crash data

INPUT DATA (Segments)

Basic Roadway Data

	Segment 1	*Segment 2*	*Segment 3*
Number of lanes	3	3	3
Segment length (mi)	0.2	0.1	0.3
Posted speed limit (mph)	30	30	30
Bike lanes	present	present	none
Automated speed enforcement	no	no	no
Cross-Section Data			
Lane width (ft)	10	11	10
Right shoulder width (ft)	0	0	3
Parallel parking	no	no	no
Angle parking	yes, left side	yes, left side	yes, left side
Roadside Data			
Roadside fixed-object offset (ft)	10	10	6
Roadside fixed-object density	20/mile	30/mile	20/mile
Driveway Data			
Major commercial driveways	1	1	2
Minor driveways	8	4	15
Traffic Data			
AADT (in 2016)	25,000	23,000	21,000

Crash Data

Not available

INPUT DATA (Intersections)

Basic Roadway Data

	Intersection 1	*Intersection 2*
Intersection traffic control mode	signal	signal
Legs	4	4
Lighting	present	not present
Minor street	two-way	one-way
Red-light camera	no	no
Number of minor-street lanes	4	2
Left-turn lanes (major street)	one approach	one approach
Left-turn lanes (minor street)	none	none
Right-turn channelization	on major street	on minor street
Right-turn-on-red prohibition	none	none

Traffic Data

Minor-street AADT (in 2016)	12,000	5,000

Pedestrian Data

Level of pedestrian activity	High	Medium-high
Number of schools	1	1
Number of bus stops	2	3
Alcohol sales establishments	0	1
Refuge islands	None (n_{lanesx} = 4)	None (n_{lanesx} = 4)

Crash Data

Not available

OUTPUT SUMMARY

What is the total predicted number of crashes? …………………………... *35.421*

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	3.130	5.952	9.082
Multiple-vehicle crashes	2.505	5.517	
Single-vehicle crashes	0.319	0.435	
Vehicle-pedestrian crashes	0.211		
Vehicle-bicycle crashes	0.097		

Combined CMF

	F+I	PDO
Multiple-vehicle crashes	3.519	3.519
Single-vehicle crashes	3.134	3.134

Severity distribution for F+I crashes

K	A	B	C
0.078	0.709	1.244	1.100

Input Data		Value	Advisory Messages
Basic Roadway Data			
Area type		Urban	.
Segment type		3O	.
Segment length, mi		0.2	.
Bicycle lanes present?		Yes	.
Annual average daily traffic (AADT), veh/day		25000	.
Posted speed limit, mi/h		30	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	1	**5 major comm. driveways per mile.**
	Minor	8	**40 minor driveways per mile.**
Cross Section Data			
Lane width, ft		10	.
Right shoulder width, ft		0	.
Roadside Data			
On-street parallel parking length on right side, mi		0	.
On-street angle parking length on right side, mi		0	.
On-street parallel parking length on left side, mi		0	.
On-street angle parking length on left side, mi		0.2	.
Roadside fixed object count		4	**20 objects per mile.**
Average roadside fixed object offset, ft		10	.

Calibration Factors	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.024	0.024
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors	F+I Multiple	F+I Single	PDO Multiple	PDO Single
Right shoulder width	1.084	1.084	1.084	1.084
On-street parallel parking	1.000	1.000	1.000	1.000
On-street angle parking	2.682	2.682	2.682	2.682
Major commercial driveways	1.055		1.055	
Minor driveways	1.148		1.148	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.078		1.078

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	2
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	1.544	2.985	4.530
Multiple-vehicle crashes	1.232	2.768	
Single-vehicle crashes	0.159	0.217	
Vehicle-pedestrian crashes	0.105		
Vehicle-bicycle crashes	0.048		

Combined CMF

	F+I	PDO
Multiple-vehicle crashes	3.844	3.844
Single-vehicle crashes	3.248	3.248

Severity distribution for F+I crashes

K	A	B	C
0.035	0.319	0.632	0.559

Input Data

Input Data	Value	Advisory Messages
Basic Roadway Data		
Area type	Urban	.
Segment type	3O	.
Segment length, mi	0.1	.
Bicycle lanes present?	Yes	.
Annual average daily traffic (AADT), veh/day	23000	.
Posted speed limit, mi/h	30	.
Automated speed enforcement present?	No	.
Access Data		
Driveway count — Major commercial	1	10 major comm. driveways per mile.
Driveway count — Minor	4	40 minor driveways per mile.
Cross Section Data		
Lane width, ft	11	.
Right shoulder width, ft	0	.
Roadside Data		
On-street parallel parking length on right side, mi	0	.
On-street angle parking length on right side, mi	0	.
On-street parallel parking length on left side, mi	0	.
On-street angle parking length on left side, mi	0.1	.
Roadside fixed object count	3	30 objects per mile.
Average roadside fixed object offset, ft	10	.

Calibration Factors

Calibration Factors	Value	Default Values
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.024	0.024
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors

Crash Modification Factors	F+I Multiple	F+I Single	PDO Multiple	PDO Single
Right shoulder width	1.084	1.084	1.084	1.084
On-street parallel parking	1.000	1.000	1.000	1.000
On-street angle parking	2.682	2.682	2.682	2.682
Major commercial driveways	1.152		1.152	
Minor driveways	1.148		1.148	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.117		1.117

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Street number	
Street name	
Segment number	3
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	3.883	7.622	11.505
Multiple-vehicle crashes	3.062	7.033	
Single-vehicle crashes	0.432	0.589	
Vehicle-pedestrian crashes	0.267		
Vehicle-bicycle crashes	0.122		

Combined CMF

	F+I	*PDO*
Multiple-vehicle crashes	3.572	3.572
Single-vehicle crashes	3.048	3.048

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.040	0.360	1.271	2.212

Input Data	_Value_	_Advisory Messages_
Basic Roadway Data		
Area type	Urban	.
Segment type	3O	.
Segment length, mi	0.3	.
Bicycle lanes present?	No	.
Annual average daily traffic (AADT), veh/day	21000	.
Posted speed limit, mi/h	30	.
Automated speed enforcement present?	No	.
Access Data		
Driveway count — Major commercial	2	**7 major comm. driveways per mile.**
Driveway count — Minor	15	**50 minor driveways per mile.**
Cross Section Data		
Lane width, ft	10	.
Right shoulder width, ft	3	.
Roadside Data		
On-street parallel parking length on right side, mi	0	.
On-street angle parking length on right side, mi	0	.
On-street parallel parking length on left side, mi	0	.
On-street angle parking length on left side, mi	0.3	.
Roadside fixed object count	6	**20 objects per mile.**
Average roadside fixed object offset, ft	6	.

Calibration Factors	_Value_	_Default Values_
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.024	0.024
Adjustment factor for bicyclists (f_{bike})	0.011	0.011
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099	0.099

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Right shoulder width	1.020	1.020	1.020	1.020
On-street parallel parking	1.000	1.000	1.000	1.000
On-street angle parking	2.682	2.682	2.682	2.682
Major commercial driveways	1.086		1.086	
Minor driveways	1.202		1.202	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.114		1.114

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	1
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	2.158	4.743	6.901
Total-vehicle crashes	1.087	4.743	
Vehicle-pedestrian crashes	1.001		
Vehicle-bicycle crashes	0.070		

Combined CMF

	F+I	*PDO*
Total-vehicle crashes	1.300	1.300
Vehicle-pedestrian crashes	5.603	

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.004	0.080	0.765	1.310

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Urban		.
Number of legs	4		**4SG intersection type**
Traffic control type	Signalized		.
Lighting present?	Yes		.
Red-light cameras present?	No		.
Daily pedestrian volume crossing all legs (peds/day)	3200		.
Maximum number of lanes crossed by a pedestrian	4		.
Number of bus stops within 1,000 ft of intersection	2		.
School(s) present within 1,000 ft of intersection?	Yes		.
Alcohol sales establishments within 1,000 ft	0		.
Street Data	*Major*	*Minor*	.
Street configuration	One-way	Two-way	**1x2 intersection configuration**
Annual average daily traffic (AADT), veh/day	24000	12000	.
Number of through lanes	3	4	.
Number of approaches with left-turn lanes	1	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	0	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	1	0	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.020	0.020
Adjustment factor for bicyclists (f_{bike})	0.012	0.012
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.046	0.046

Manner of Collision Proportions

2x2 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	*F+I*	*PDO*
Total-vehicle crash CMFs		
Lighting	0.911	0.911
Red-light cameras	1.000	1.000
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.428	1.428
Vehicle-pedestrian crash CMFs		
Bus stops	4.150	
Schools	1.350	
Alcohol sales establishments	1.000	

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	
Agency	
Date	
Location	

Site Information

Major street name	
Minor street name	
Intersection number	2
Analysis year	2016

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	PDO	Total
Total crashes	1.271	2.132	3.403
Total-vehicle crashes	0.659	2.132	
Vehicle-pedestrian crashes	0.579		
Vehicle-bicycle crashes	0.033		

Combined CMF

	F+I	PDO
Total-vehicle crashes	1.223	1.223
Vehicle-pedestrian crashes	6.275	

Severity distribution for F+I crashes

K	A	B	C
0.002	0.046	0.206	1.018

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Urban		.
Number of legs	4		4SG intersection type
Traffic control type	Signalized		.
Lighting present?	No		.
Red-light cameras present?	No		.
Daily pedestrian volume crossing all legs (peds/day)	1500		.
Maximum number of lanes crossed by a pedestrian	4		.
Number of bus stops within 1,000 ft of intersection	3		.
School(s) present within 1,000 ft of intersection?	Yes		.
Alcohol sales establishments within 1,000 ft	1		.
Street Data	*Major*	*Minor*	.
Street configuration	One-way	One-way	1x1 intersection configuration
Annual average daily traffic (AADT), veh/day	22000	5000	.
Number of through lanes	3	2	.
Number of approaches with left-turn lanes	1	0	.
Number of left-turn movements with protected phasing	0	0	.
Number of right-turn movements prohibited on red	0	0	.
Number of U-turn movements prohibited	0	0	.
Number of approaches with right-turn channelization	0	1	.

Calibration Factors	*Value*	*Default Values*
Local calibration factor (*C*)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.020	0.020
Adjustment factor for bicyclists (f_{bike})	0.012	0.012
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.046	0.046

Manner of Collision Proportions

2x2 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552

1x2 or 1x1 intersections	3ST, F+I	3ST, PDO	3SG, F+I	3SG, PDO	4ST, F+I	4ST, PDO	4SG, F+I	4SG, PDO
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	*F+I*	*PDO*
Total-vehicle crash CMFs		
Lighting	1.000	1.000
Red-light cameras	1.000	1.000
Left-turn signal phasing	1.000	1.000
Right-turn-on-red	1.000	1.000
U-turn prohibition	1.000	1.000
Right-turn channelization	1.000	1.000
Number of lanes	1.223	1.223
Vehicle-pedestrian crash CMFs		
Bus stops	4.150	
Schools	1.350	
Alcohol sales establishments	1.120	

Crash Totals Tabulation

Empirical Bayes adjustment type:
None

Clear tables

Sort rows

Calculate

Facility Totals	
MV+SV:	32.888
VP+VB:	2.533
F+I:	11.988
PDO:	23.434
Total:	35.421

Total Predicted Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	6.799	15.318	0.910	1.241	7.709	16.559	0.582	0.267
Intersections:					1.746	6.875	1.581	0.103
Total:	6.799	15.318	0.910	1.241	9.454	23.434	2.163	0.370

Segment Site Information				Predicted crash frequency, crashes / year					
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I
1	2016	3O		2.505	5.517	0.319	0.435	0.211	0.097
2	2016	3O		1.232	2.768	0.159	0.217	0.105	0.048
3	2016	3O		3.062	7.033	0.432	0.589	0.267	0.122

Intersection Site Information				Predicted crash frequency, crashes / year			
				Total-vehicle		Vehicle-pedestrian	Vehicle-bicycle
Number	Year	Type	Configuration	F+I	PDO	F+I	F+I
1	2016	4SG	One-way	1.087	4.743	1.001	0.070
2	2016	4SG	One-way	0.659	2.132	0.579	0.033

APPENDIX C. SPREADSHEET PROGRAM AND USER MANUAL

INTRODUCTION

The safety prediction models developed in NCHRP Project 17-58 (*1*, *2*) apply to two-way urban and suburban arterials with six or more lanes, one-way urban and suburban arterials, and intersections on these types of arterials. These models were developed for inclusion in the next edition of the *Highway Safety Manual* (HSM) (*3*). Because the models are complex in form and require numerous calculations to implement, an Excel®-based spreadsheet program was developed to assist analysts in implementing the safety prediction models.

This *User Guide* provides instructions for using the spreadsheet program to implement the calculations in the draft Chapter 12 of the HSM (*2*). All variable names and definitions in the spreadsheet program are consistent with those in the draft Chapter 12 of the HSM. Hence, it is recommended that the analyst read the draft Chapter 12 of the HSM before using the spreadsheet program, and refer back to the Chapter when clarification is needed on variable definitions and procedures for measuring or counting variable values.

BASIC OPERATION

The spreadsheet program can be used on a computer with Microsoft Office® 2007 or newer versions. This User Guide provides instructions on using the spreadsheet program to analyze individual sites (arterial segments or intersections), tabulate results for a facility consisting of multiple sites, and conduct an empirical Bayes (EB) analysis.

Enabling Macro Content

The spreadsheet program uses macros for several of its calculation and organization tasks. Hence, it is essential that Excel be configured such that macros are not always disabled. Macro security settings are located in the Trust Center (see Figure 1), which is accessed by choosing the File tab on the upper-left portion of the Excel screen and choosing “Options”. The spreadsheet program will not function properly if the highest macro security setting, “Disable all macros without notification”, is chosen. If “Disable all macros with notification” or “Disable all macros except digitally signed macros” is chosen, the yellow bar shown in Figure 2 will appear when the program is opened. Click on the “Enable Content” button to enable macros. If the last macro security option, “Enable all macros”, is chosen, the yellow bar will not appear and macros will function.

Worksheet Organization

When the spreadsheet program is opened, the Welcome screen shown in Figure 3 will appear. This screen provides a basic overview of the program and brief description of the color scheme used for the cells. The five tabs below the Welcome message are used to access the five worksheets that are provided in the program. The first of these worksheets is the Welcome screen. The next three worksheets, “Two-way segments”, “One-way segments”, and “Intersections”, are the input data worksheets that are used to analyze individual sites on the urban or suburban arterial facility of interest. The last worksheet, “Totals”, is used to obtain crash totals for the entire facility as well as to conduct a site-specific or project-level EB analysis based on the procedures described in Appendix A of the HSM.

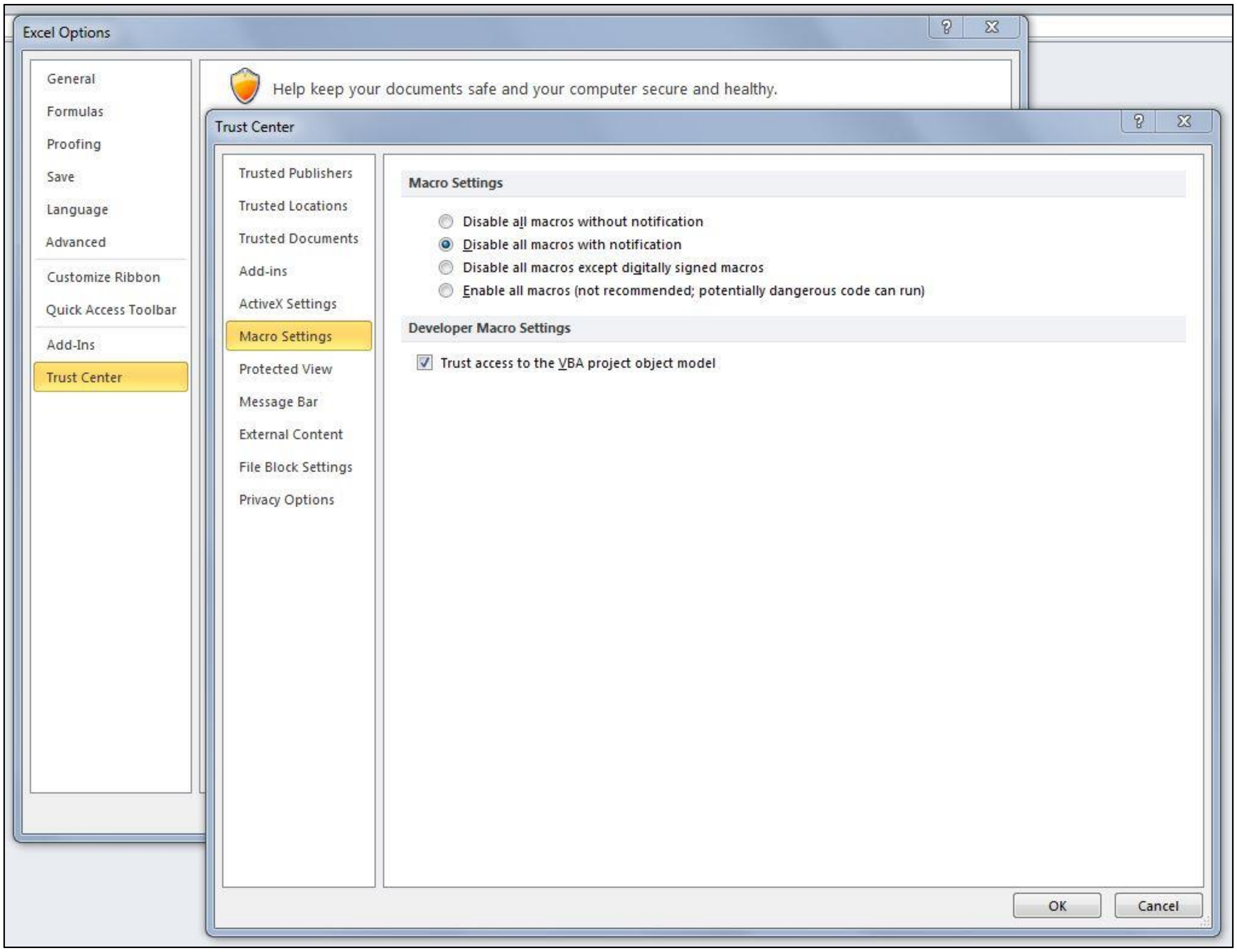


Figure 1. Macro Security Settings in Excel

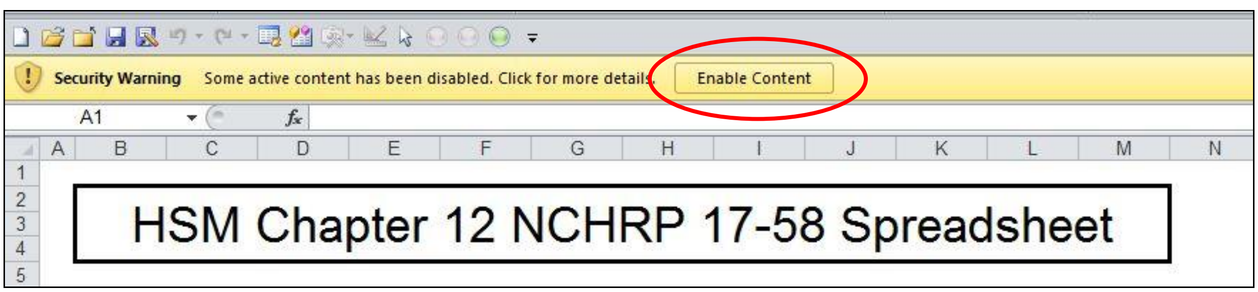
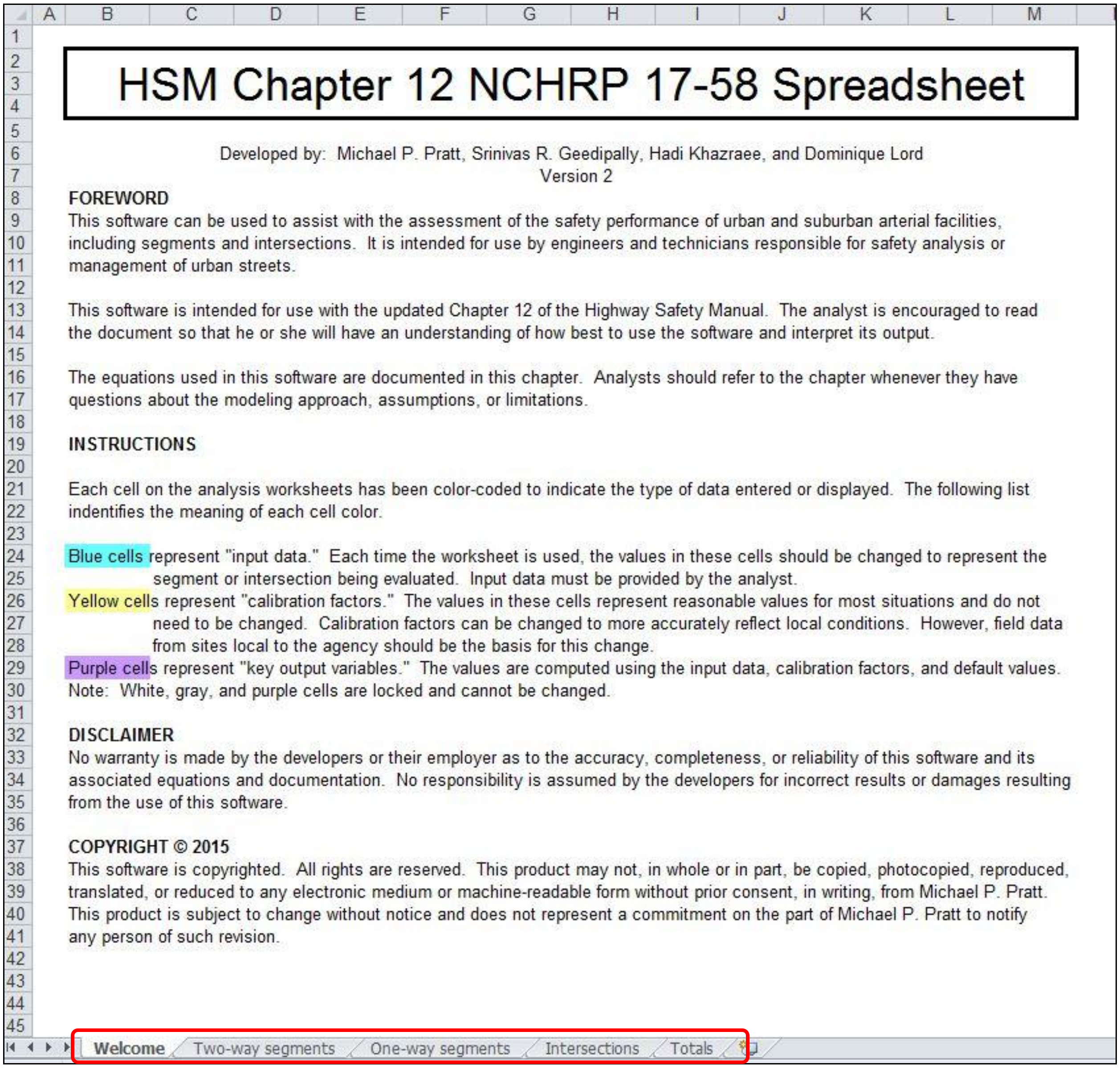


Figure 2. Enabling Macros in Excel



HSM Chapter 12 NCHRP 17-58 Spreadsheet

Developed by: Michael P. Pratt, Srinivas R. Geedipally, Hadi Khazraee, and Dominique Lord
Version 2

FOREWORD
This software can be used to assist with the assessment of the safety performance of urban and suburban arterial facilities, including segments and intersections. It is intended for use by engineers and technicians responsible for safety analysis or management of urban streets.

This software is intended for use with the updated Chapter 12 of the Highway Safety Manual. The analyst is encouraged to read the document so that he or she will have an understanding of how best to use the software and interpret its output.

The equations used in this software are documented in this chapter. Analysts should refer to the chapter whenever they have questions about the modeling approach, assumptions, or limitations.

INSTRUCTIONS

Each cell on the analysis worksheets has been color-coded to indicate the type of data entered or displayed. The following list indentifies the meaning of each cell color.

Blue cells represent "input data." Each time the worksheet is used, the values in these cells should be changed to represent the segment or intersection being evaluated. Input data must be provided by the analyst.
Yellow cells represent "calibration factors." The values in these cells represent reasonable values for most situations and do not need to be changed. Calibration factors can be changed to more accurately reflect local conditions. However, field data from sites local to the agency should be the basis for this change.
Purple cells represent "key output variables." The values are computed using the input data, calibration factors, and default values.
Note: White, gray, and purple cells are locked and cannot be changed.

DISCLAIMER
No warranty is made by the developers or their employer as to the accuracy, completeness, or reliability of this software and its associated equations and documentation. No responsibility is assumed by the developers for incorrect results or damages resulting from the use of this software.

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Welcome | Two-way segments | One-way segments | Intersections | Totals

Figure 3. Welcome Screen

Cell Color Scheme

In the various worksheets, color shading is used to assist the analyst in understanding which cells may be manipulated and which cannot be disrupted. The spreadsheet program uses numerous equations and macros to perform the calculations needed to implement the safety prediction models, and cells containing these calculations are locked to prevent inadvertent alteration that would lead to erroneous results.

Input Data Cells

Input data cells are shaded blue, like the "General Information" and "Site Information" cells shown in Figure 4. The analyst will routinely change the values in these cells to describe the site being analyzed and to examine changes in predicted crash frequency that may occur if input parameters are altered. The required content for these cells is described in greater detail in the next section of this Guide.

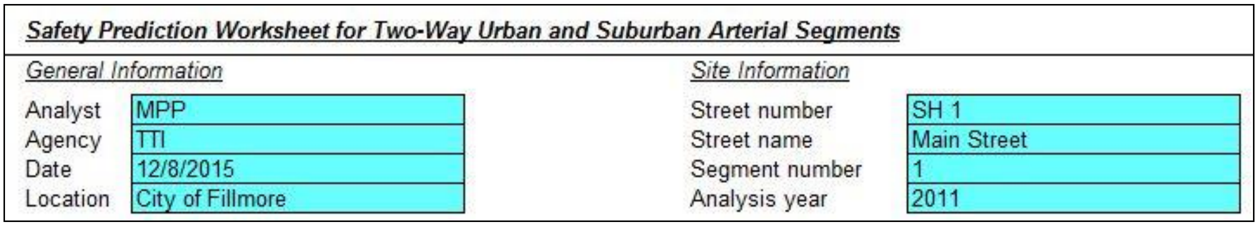

Figure 4. Input Data Cells – Blue Shading

Some input data cells describe characteristics that can only be described in discrete quantities. For example, area type can only be described as urban or suburban for the facilities included in the scope of the safety prediction models contained in the spreadsheet program. When the analyst selects one of these cells, a drop-down menu will appear as shown in Figure 5. The analyst may choose one of the options in the menu or type one of the allowed options into the cell. If the analyst enters a value that is not valid for the input data cell, an error message will appear as shown in Figure 6.

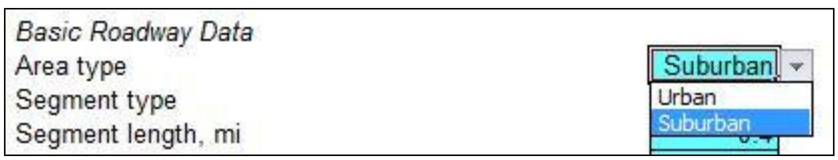

Figure 5. Drop-Down Menus

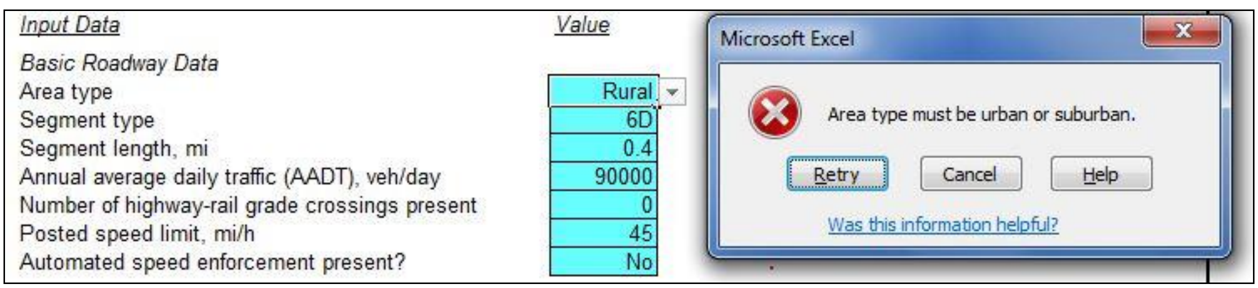

Figure 6. Input Data Cell Error Message

Some input data cells are accompanied by advisory messages that will appear in red to the right of the cell. These messages may provide clarifications on certain data inputs, warnings if model parameter ranges have been exceeded, or warnings if an invalid value has been entered into the input data cell. All three of these situations are visible in Figure 7. For the described two-way arterial segment, the segment type was entered as "8D", or eight-lane divided. The analyst indicated that the segment length is 0.4 mi and there are 18 roadside fixed objects present, so an advisory message explains that the object density is "45 objects per mile". The analyst entered a median width of 0 ft, which is not consistent with an eight-lane divided cross section, so a warning message indicates that the analyst "must enter nonzero median width". The posted speed limit is 30 mi/h, and the pedestrian and bicyclist adjustment factors (f_{ped} and

f_{bike}) that are needed for some calculations are not available for that speed, so the advisory message indicates that the factors must be estimated ("Estimated ped/bike factors").

Input Data		Value	Advisory Messages
Basic Roadway Data			
Area type		Suburban	.
Segment type		8D	.
Segment length, mi		0.4	.
Annual average daily traffic (AADT), veh/day		90000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		30	Estimated ped/bike factors.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	0	.
	Major industrial	0	.
	Minor	0	.
Cross Section Data			
Lane width, ft		11	.
Outside shoulder width, ft		1.5	.
Median width, ft		0	Must enter nonzero median width.
Median barrier present?		Yes	.
Roadside Data			
Roadside fixed object count		18	45 objects per mile.
Average roadside fixed object offset, ft		7	.

Figure 7. Advisory Messages for Input Data Cells

Calibration Factor Cells

Calibration factor cells are shaded yellow as shown in Figure 8. These cells contain parameters like the local calibration factor *C* and the pedestrian and bicyclist adjustment factors f_{ped} and f_{bike}. These calibration factors affect key calculation results in each of the input data worksheets. The analyst can change the values entered into calibration factor cells, but should do so only based on analysis of field data from the jurisdiction containing the sites of interest. The original values in the calibration factor cells are the factors and model coefficients that were derived from the research conducted in NCHRP Project 17-58. It is expected that these cells may need to be altered on occasion based on a jurisdiction's data trends, but they should not need to be altered during the course of a routine analysis exercise.

Calibration Factors	Value
Local calibration factor (C)	1.000
Adjustment factor for pedestrians (f_{ped})	0.029
Adjustment factor for bicyclists (f_{bike})	0.007
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000

Figure 8. Calibration Factor Cells

Key Output Variable Cells

Key output variable cells are shaded purple as shown in Figure 9. These cells contain key output quantities, such as the total predicted crash frequency, combined CMF (product of all individual CMFs), and severity distribution for fatal-and-injury crashes. These cells are locked and cannot be altered, but are shaded to denote their importance.

Output Summary	*Predicted crash frequency, crashes / year*		
	F+I	*PDO*	*Total*
Total crashes	4.145	5.039	9.184
Multiple-vehicle crashes	2.878	3.872	
Single-vehicle crashes	0.948	1.167	
Vehicle-pedestrian crashes	0.257		
Vehicle-bicycle crashes	0.062		

Figure 9. Key Output Variable Cells

Other Types of Cell Shading

Some cells are shaded white or gray as shown in Figure 10. These cells contain intermediate calculations that may be of interest to the analyst, but do not represent the final analysis result. The white cells in Figure 10 contain the computed values for each individual CMF on a two-way segment. The analyst may need to inspect these values to determine which site characteristics contribute most to a high or low predicted crash frequency. White cells are also visible in Figure 9, showing the tabulation of predicted crash frequency by severity (fatal-and-injury or property-damage-only) and crash type (multiple-vehicle, single-vehicle, vehicle-pedestrian, or vehicle-bicycle).

Crash Modification Factors	*F+I*		*PDO*	
	Multiple	*Single*	*Multiple*	*Single*
Lane width	1.022	1.022	1.022	1.022
Outside shoulder width	1.000	1.000	1.000	1.000
Median width	1.011	1.011	1.011	1.011
Median barrier	0.600	1.967	0.600	1.967
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	0.932		0.932	
Major industrial driveways	0.989		0.989	
Minor driveways	0.947		0.947	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.180		1.180

Figure 10. Other Cells

A small number of gray cells exist in the spreadsheet program. These cells are shaded gray to indicate that they are not applicable. For example, Figure 10 shows that the cells for single-vehicle driveway CMFs and the multiple-vehicle roadside fixed object CMF are gray. These cells are not applicable because the driveway CMFs do not apply to single-vehicle crashes and the roadside fixed object CMF does not apply to multiple-vehicle crashes.

Some input data cells are configured to be shaded different colors depending on whether they are needed. For example, as shown in Figure 11, the input data cell for average roadside fixed object offset is typically shaded blue. However, if the analyst enters 0 for roadside fixed object count, the average roadside fixed object offset cell shading turns white and its text turns gray. This change denotes the fact that an average roadside fixed object offset need not be provided if no such objects are present.

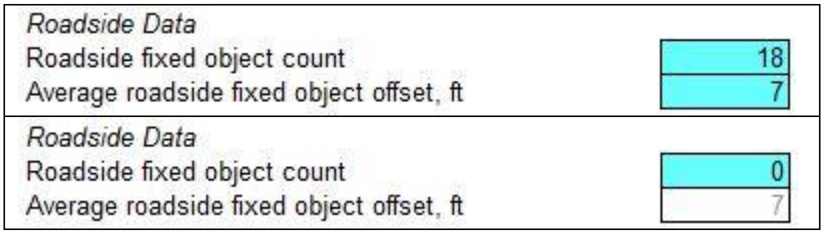

Figure 11. Automated Cell Shading

Analysis Sequence

To conduct a safety analysis of an urban or suburban arterial facility, the analyst would complete the following steps:

1. Identify the facility of interest. The facility will likely consist of multiple sites, where a site is a homogeneous two-way arterial street segment, a homogeneous one-way arterial street segment, or a signalized or stop-controlled intersection of two streets.
2. Determine the analysis period of interest. The analysis period will consist of one or more years.
3. Analyze the first site on the facility using the relevant input data worksheet.
4. Transfer the data and calculations from the input data worksheet to the Totals worksheet.
5. Repeat steps 3 and 4 for each year in the analysis period (if there are multiple years).
6. Repeat steps 3-5 for each site on the facility (if there are multiple sites).
7. Enter crash count data into the Totals worksheet (if an EB adjustment is desired).
8. Calculate the predicted crash frequency (if EB adjustment is not applied) or expected crash frequency (if EB adjustment is applied) for the entire facility using the Totals worksheet.

The analysis procedure is described in greater detail in the next parts of this Guide, which describe the input data worksheets and the Totals worksheet.

Input Data Worksheets

The spreadsheet program contains input data worksheets for describing and analyzing individual sites. There are three worksheets, which correspond to the three facility types that were addressed in NCHRP Project 17-58. These facility types include two-way urban and suburban arterial street segments with six or more lanes, one-way urban and suburban arterial streets, and intersections on these streets.

All three input data worksheets have the three command buttons that are shown in Figure 12. These buttons serve the following purposes:

- Add to Totals worksheet: Click this button to transfer the data and calculations from the input data worksheet to the Totals worksheet. If the site has already been described for the specified year, and the data and calculations have already been transferred to the Totals worksheet, an error message will appear (see Figure 13) and the data will not transfer. The data will be added to the bottommost empty row in the relevant data table (segment or intersection) on the Totals worksheet; if this row is filled, an error message will appear (see Figure 14) to indicate that the data table is full, and the data will not transfer.
- Restore equations: Some of the input data cells and calibration factor cells contain equations, though these cells are unlocked. For example, the Date cell in the General Information input data cells contains an equation that gives today's date, but the analyst can overwrite the equation-computed date with a different date if desired. Click this button to restore the equations in the cells.
- Reset input cells: Click this button to populate the input data cells with a set of pre-chosen values. These values describe a fictitious site. This function is useful if the analyst is finished analyzing a site and desires to start a new analysis without retaining data describing the previous site.

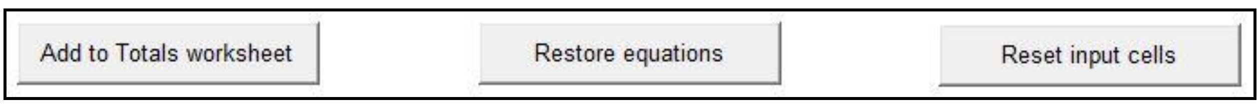

Figure 12. Command Buttons on Input Data Worksheets

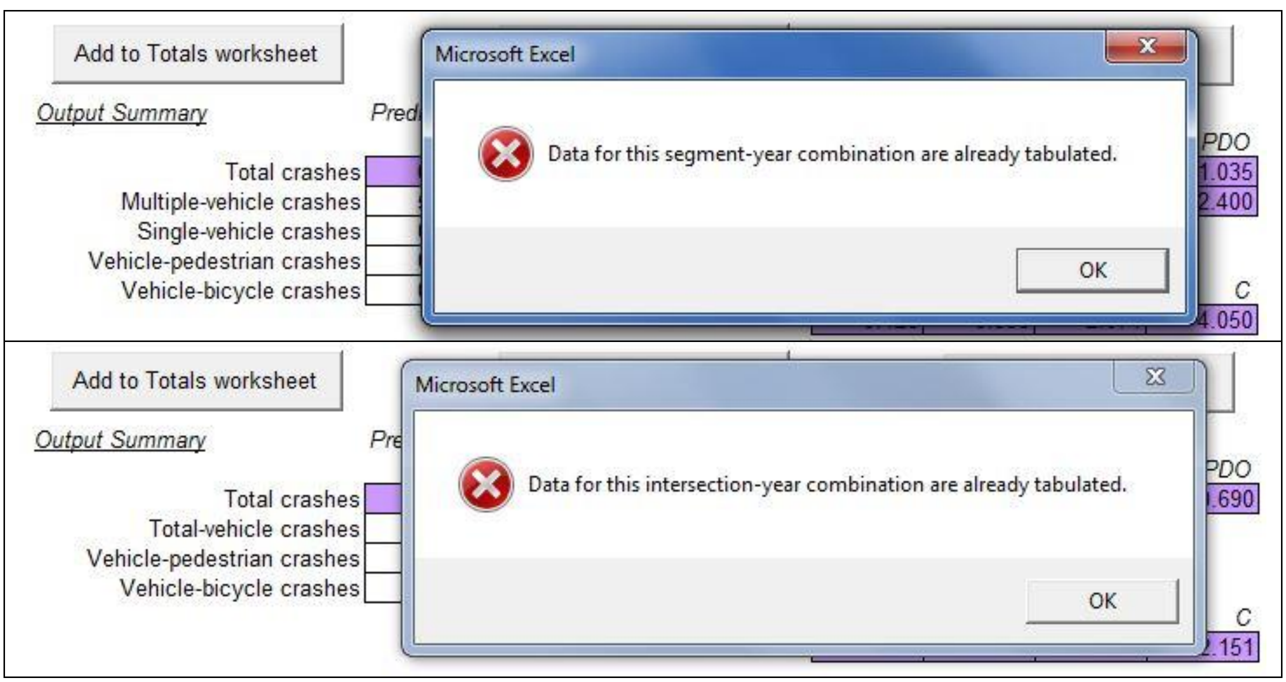

Figure 13. Data Transfer Error Messages – Duplicate Data

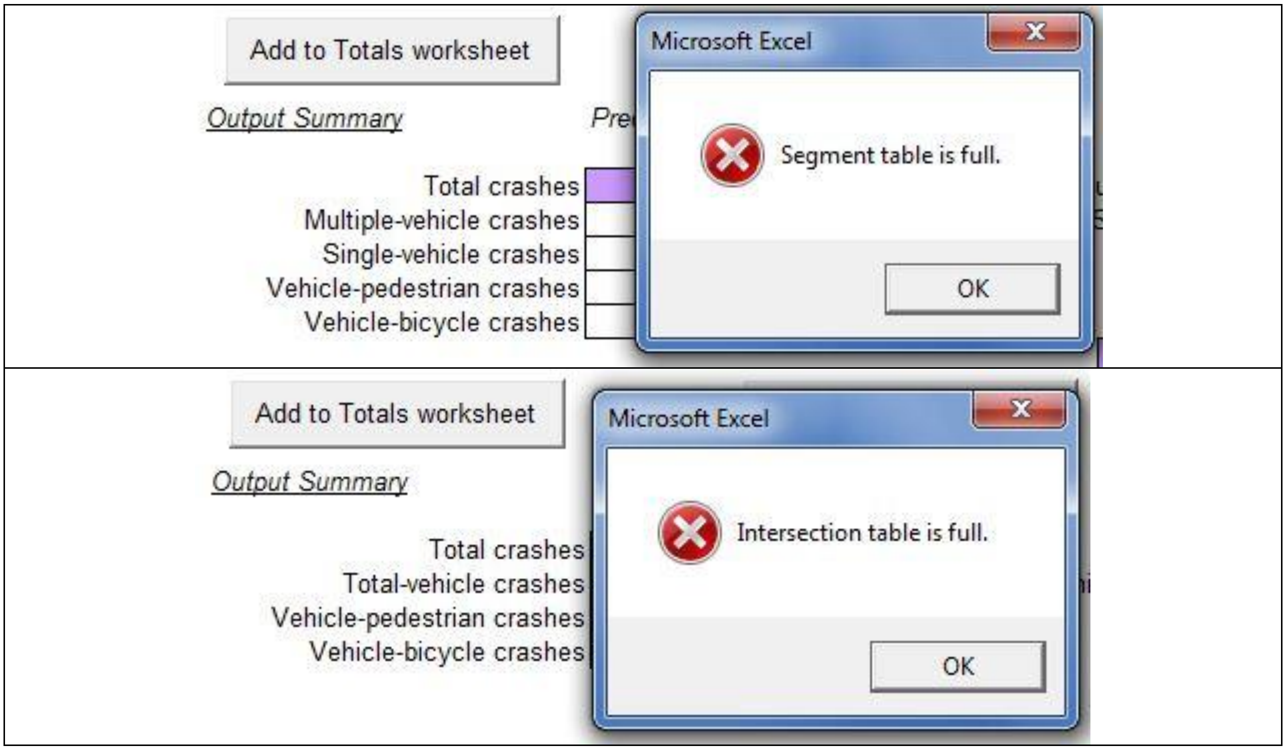

Figure 14. Data Transfer Error Messages – Full Data Table

Each of the input data worksheets consists of a main work area that is denoted by a bold-bordered box. The main work area contains all input data cells, calibration factor cells, and output cells. The worksheets also have numerous boxes containing calibration coefficients and some intermediate calculations in the space to the right of the main work area. It is not anticipated that the analyst would need to use the boxes to the right of the main work area. Some of these boxes contain cells that are shaded yellow because they are populated with calibration coefficients for the various equations. These coefficients were derived in NCHRP Project 17-58, and the analyst should not alter them without significant justification based on detailed analysis of field data from the jurisdiction of interest.

Two-Way Segments

The general information and site information input data cells are shown in the top portion of Figure 15. Cells are provided for the analyst to enter analyst's name, agency, date (this cell is populated with an equation that computes the current date), location, street number, street name, segment number, and analysis year. To avoid the error message shown in Figure 13, it is essential to change the segment number every time a new site at a facility is being analyzed, and to change the analysis year every time a new year is being analyzed.

The input data cells on the Two-Way Segments worksheet are shown in Figure 16. The analyst must provide data to describe the basic roadway characteristics, access characteristics, cross-sectional characteristics, and roadside characteristics.

Safety Prediction Worksheet for Two-Way Urban and Suburban Arterial Segments

General Information		Site Information	
Analyst	MPP	Street number	SH 1
Agency	TTI	Street name	Main Street
Date	12/9/2015	Segment number	1
Location	City of Fillmore	Analysis year	2011

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year	F+I	PDO	Total
Total crashes	6.785	8.556	15.341
Multiple-vehicle crashes	5.492	7.389	
Single-vehicle crashes	0.948	1.167	
Vehicle-pedestrian crashes	0.225		
Vehicle-bicycle crashes	0.120		

Combined CMF	F+I	PDO
Multiple-vehicle crashes	1.035	1.035
Single-vehicle crashes	2.400	2.400

Severity distribution for F+I crashes

K	A	B	C
0.128	0.533	2.074	4.050

Figure 15. Two-Way Segments General Information Cells and Output Summary

Input Data		Value	Advisory Messages
Basic Roadway Data			
Area type		Suburban	.
Segment type		6D	.
Segment length, mi		0.4	.
Annual average daily traffic (AADT), veh/day		90000	.
Number of highway-rail grade crossings present		0	.
Posted speed limit, mi/h		45	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	6	15 major comm. driveways per mile.
	Major industrial	1	3 major industrial driveways per mile.
	Minor	7	18 minor driveways per mile.
Cross Section Data			
Lane width, ft		11	.
Outside shoulder width, ft		1.5	.
Median width, ft		13	.
Median barrier present?		Yes	.
Roadside Data			
Roadside fixed object count		18	45 objects per mile.
Average roadside fixed object offset, ft		7	.

Figure 16. Two-Way Segments Input Data Cells

The following basic roadway characteristics are needed:

- Area type: Specify if the area surrounding the site is urban or suburban.
- Segment type: Select the appropriate code – 6U for six-lane undivided segments, 6D for six-lane divided segments, 7T for six-lane segments with a two-way left-turn lane, or 8D for eight-lane divided segments. These codes are consistent with those used in the HSM.
- Segment length: Enter the segment length, in miles.

- Annual average daily traffic: Enter the AADT, in vehicles per day.
- Number of highway-rail grade crossings present: Enter the number of highway-rail grade crossings that are present on the segment.
- Posted speed limit: Select the posted speed limit, in miles per hour.
- Automated speed enforcement: Indicate whether automated speed enforcement is used on the segment.

The following access characteristics are needed:

- Driveway count – major commercial: Enter the count of major commercial driveways on the segment.
- Driveway count – major industrial: Enter the count of major industrial driveways on the segment.
- Driveway count – minor: Enter the count of minor driveways (of any land use type) on the segment.

All driveway counts represent the number of full driveways, which are driveways that accommodate all entering and exiting turning movements. Driveways that are channelized to allow only right-turn entry and exit movements should be counted as half-driveway.

The following cross-sectional characteristics are needed:

- Lane width: Enter the lane width, in feet.
- Outside shoulder width: Enter the outside shoulder width, in feet. The outside shoulder is the shoulder to the right of drivers with respect to the direction of travel.
- Median width: Enter the median width, in feet. This quantity is not needed if an undivided or two-way left-turn lane segment type (6U or 7T) is specified.
- Median barrier present: Indicate whether a non-traversable median barrier is present. This quantity is not needed if an undivided or two-way left-turn lane segment type (6U or 7T) is specified.

The following roadside characteristics are needed:

- Roadside fixed object count: Enter the number of fixed objects that are present on the roadside (not including the median). Fixed objects that are located within 70 feet of one another longitudinally along the street are counted as a single object.
- Average roadside fixed object offset: Enter the average offset between travel lanes and fixed objects, in feet. The edge of the travel lanes is defined as the marked edgeline, or a line 2 feet from the face of the curb if no marked edgeline exists. This quantity is not needed if no roadside fixed objects are present.

If necessary, the analyst can enter values for the following calibration factors:

- Local calibration factor.
- Adjustment factor for pedestrians.

- Adjustment factor for bicyclists.
- Severity distribution calibration factor.

Computed values for the individual CMFs are provided in the lower portion of the worksheet (see Figure 17). The output summary on the top portion of the worksheet (see Figure 15) provides the predicted crash frequency, combined CMFs (product of individual CMFs), and severity distribution for the segment in the analysis year.

Calibration Factors	Value	Default Values
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians (f_{ped})	0.015	0.015
Adjustment factor for bicyclists (f_{bike})	0.008	0.008
Severity distribution calibration factor ($C_{sdf,tws}$)	1.000	1.000

Crash Modification Factors	F+I Multiple	F+I Single	PDO Multiple	PDO Single
Lane width	1.022	1.022	1.022	1.022
Outside shoulder width	1.000	1.000	1.000	1.000
Median width	1.011	1.011	1.011	1.011
Median barrier	0.600	1.967	0.600	1.967
Highway-rail grade crossing	1.000	1.000	1.000	1.000
Major commercial driveways	1.576		1.576	
Major industrial driveways	1.016		1.016	
Minor driveways	1.041		1.041	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.180		1.180

Figure 17. Two-Way Segments Calibration Factor Cells and CMF Calculations

One-Way Segments

The general information and site information input data cells are shown in the top portion of Figure 18. Cells are provided for the analyst to enter analyst's name, agency, date (this cell is populated with an equation that computes the current date), location, street number, street name, segment number, and analysis year. To avoid the error message shown in Figure 13, it is essential to change the segment number every time a new site at a facility is being analyzed, and to change the analysis year every time a new year is being analyzed.

The input data cells on the One-Way Segments worksheet are shown in Figure 19. The analyst must provide data to describe the basic roadway characteristics, access characteristics, cross-sectional characteristics, and roadside characteristics.

Safety Prediction Worksheet for One-Way Urban and Suburban Arterial Segments

General Information		Site Information	
Analyst	MPP	Street number	SH 1
Agency	TTI	Street name	Main Street
Date	12/9/2015	Segment number	1
Location	City of Fillmore	Analysis year	2011

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year	F+I	PDO	Total
Total crashes	1.638	3.295	4.933
Multiple-vehicle crashes	1.244	2.986	
Single-vehicle crashes	0.227	0.309	
Vehicle-pedestrian crashes	0.114		
Vehicle-bicycle crashes	0.052		

Combined CMF	F+I	PDO
Multiple-vehicle crashes	1.370	1.370
Single-vehicle crashes	1.297	1.297

Severity distribution for F+I crashes			
K	A	B	C
0.024	0.222	0.536	0.856

Figure 18. One-Way Segments General Information Cells and Output Summary

Input Data		Value	Advisory Messages
Basic Roadway Data			
Area type		Suburban	.
Segment type		3O	.
Segment length, mi		0.4	.
Bicycle lanes present?		No	.
Annual average daily traffic (AADT), veh/day		17500	.
Posted speed limit, mi/h		30	.
Automated speed enforcement present?		No	.
Access Data			
Driveway count	Major commercial	6	15 major comm. driveways per mile.
	Minor	7	18 minor driveways per mile.
Cross Section Data			
Lane width, ft		11	.
Right shoulder width, ft		1.5	.
Roadside Data			
On-street parallel parking length on right side, mi		0	.
On-street angle parking length on right side, mi		0	.
On-street parallel parking length on left side, mi		0	.
On-street angle parking length on left side, mi		0	.
Roadside fixed object count		18	45 objects per mile.
Average roadside fixed object offset, ft		7	.

Figure 19. One-Way Segments Input Data Cells

The following basic roadway characteristics are needed:

- Area type: Specify if the area surrounding the site is urban or suburban.
- Segment type: Select the appropriate code – 2O, 3O, or 4O for two-lane, three-lane, or four-lane segments, respectively. These codes are consistent with those used in the HSM.
- Segment length: Enter the segment length, in miles.

- Bicycle lanes present: Indicate if bicycle lanes are present on the segment.
- Annual average daily traffic: Enter the AADT, in vehicles per day.
- Posted speed limit: Select the posted speed limit, in miles per hour.
- Automated speed enforcement: Indicate whether automated speed enforcement is used on the segment.

The following access characteristics are needed:

- Driveway count – major commercial: Enter the count of major commercial driveways on the segment.
- Driveway count – minor: Enter the count of minor driveways (of any land use type) on the segment.

All driveway counts represent the number of full driveways, which are driveways that accommodate all entering and exiting turning movements. Driveways that are channelized to allow only right-turn entry and exit movements should be counted as half-driveway.

The following cross-sectional characteristics are needed:

- Lane width: Enter the lane width, in feet.
- Right shoulder width: Enter the right shoulder width, in feet.

The following roadside characteristics are needed:

- On-street parallel parking length on right side: Enter the length of parallel parking present on the right side of the segment in the direction of travel, in miles.
- On-street angle parking length on right side: Enter the length of angle parking present on the right side of the segment in the direction of travel, in miles.
- On-street parallel parking length on left side: Enter the length of parallel parking present on the left side of the segment in the direction of travel, in miles.
- On-street angle parking length on left side: Enter the length of angle parking present on the left side of the segment in the direction of travel, in miles.
- Roadside fixed object count: Enter the number of fixed objects that are present on the roadside (not including the median). Fixed objects that are located within 70 feet of one another longitudinally along the street are counted as a single object.
- Average roadside fixed object offset: Enter the average offset between travel lanes and fixed objects, in feet. The edge of the travel lanes is defined as the marked edgeline, or a line 2 feet from the face of the curb if no marked edgeline exists. This quantity is not needed if no roadside fixed objects are present.

If necessary, the analyst can enter values for the following calibration factors:

- Local calibration factor.
- Adjustment factor for pedestrians.
- Adjustment factor for bicyclists.

- Severity distribution calibration factor.
- Probability of fatality given a crash involving fatality or incapacitating injury has occurred.

Computed values for the individual CMFs are provided in the lower portion of the worksheet (see Figure 20). The output summary on the top portion of the worksheet (see Figure 18) provides the predicted crash frequency, combined CMFs (product of individual CMFs), and severity distribution for the segment in the analysis year.

Calibration Factors	Value		Default Values	
Local calibration factor (C)	1.000		1.000	
Adjustment factor for pedestrians (f_{ped})	0.024		0.024	
Adjustment factor for bicyclists (f_{bike})	0.011		0.011	
Severity distribution calibration factor ($C_{sdf,ows}$)	1.000		1.000	
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.099		0.099	
Crash Modification Factors	F+I		PDO	
	Multiple	Single	Multiple	Single
Right shoulder width	1.052	1.052	1.052	1.052
On-street parallel parking	1.000	1.000	1.000	1.000
On-street angle parking	1.000	1.000	1.000	1.000
Major commercial driveways	1.259		1.259	
Minor driveways	1.035		1.035	
Automated speed enforcement	1.000	1.000	1.000	1.000
Roadside fixed objects		1.233		1.233

Figure 20. One-Way Segments Calibration Factor Cells and CMF Calculations

Intersections

The general information and site information input data cells are shown in the top portion of Figure 21. Cells are provided for the analyst to enter analyst's name, agency, date (this cell is populated with an equation that computes the current date), location, major street name, minor street name, intersection number, and analysis year. To avoid the error message shown in Figure 13, it is essential to change the intersection number every time a new site at a facility is being analyzed, and to change the analysis year every time a new year is being analyzed.

For intersections, the major street is defined based on the following rules:

- For 2x2 intersections (intersections of two two-way streets), the major street is the street with the higher volume.
- For 1x2 or 1x1 intersections (intersections where one or both of the streets are one-way), the major street is the one-way street.
- Note that in the case of 3-leg intersections, it is possible for the major street to be the one that ends at the intersection.

Safety Prediction Worksheet for Urban and Suburban Arterial Intersections

General Information

Analyst	MPP
Agency	TTI
Date	12/9/2015
Location	City of Fillmore

Site Information

Major street name	Main Street
Minor street name	Cross Street
Intersection number	1
Analysis year	2011

Add to Totals worksheet | Restore equations | Reset input cells

Output Summary

Predicted crash frequency, crashes / year

	F+I	*PDO*	*Total*
Total crashes	3.064	2.774	5.837
Total-vehicle crashes	2.862	2.774	
Vehicle-pedestrian crashes	0.095		
Vehicle-bicycle crashes	0.107		

Combined CMF

	F+I	*PDO*
Total-vehicle crashes	0.690	0.690
Vehicle-pedestrian crashes	1.000	

Severity distribution for F+I crashes

K	*A*	*B*	*C*
0.015	0.149	0.748	2.151

Figure 21. Intersections General Information Cells and Output Summary

The input data cells on the Intersections worksheet are shown in Figure 22. The analyst must provide data to describe characteristics of the intersection as a whole as well as both intersecting streets.

Input Data	*Value*		*Advisory Messages*
Intersection Data			
Area type	Urban		.
Number of legs	4		**4SG intersection type**
Traffic control type	Signalized		.
Lighting present?	Yes		.
Red-light cameras present?	No		.
Daily pedestrian volume crossing all legs (peds/day)	700		.
Maximum number of lanes crossed by a pedestrian	7		.
Number of bus stops within 1,000 ft of intersection	0		.
School(s) present within 1,000 ft of intersection?	No		.
Alcohol sales establishments within 1,000 ft	0		.
Street Data	*Major*	*Minor*	.
Street configuration	Two-way	Two-way	**2x2 intersection configuration**
Annual average daily traffic (AADT), veh/day	20000	10000	.
Number of lanes	6	4	.
Number of approaches with left-turn lanes	2	2	.
Number of left-turn movements with protected phasing	2	0	.
Number of right-turn movements prohibited on red	2	0	.
Number of U-turn movements prohibited	0	2	.
Number of approaches with right-turn channelization	0	2	.

Figure 22. Intersections Input Data Cells

The following intersection characteristics are needed:

- Area type: Specify if the area surrounding the site is urban or suburban.
- Number of legs: Enter the number of street legs at the intersection (3 or 4).
- Traffic control type: Specify if the traffic control is signalized or two-way stop. Note that an advisory message will provide the intersection category code (3ST, 3SG, 4ST, or 4SG) that is used in the HSM to describe the four combinations of number of legs and traffic control.
- Lighting present: Indicate whether lighting is present at the intersection.
- Red-light cameras present: Indicate whether red-light cameras are used at the intersection. This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.
- Daily pedestrian volume crossing all legs: Enter the daily pedestrian volume, in pedestrians per day. Include all pedestrians crossing at all intersection legs. Note that the HSM refers to this quantity as "PedVol" and provides default values for 3SG and 4SG intersections based on qualitative general levels of pedestrian activity (high, medium-high, medium, medium-low, and low). This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.
- Maximum number of lanes crossed by a pedestrian: Count the total number of lanes (all through lanes plus turn lanes) at each intersection leg, and enter the highest number of lanes observed on the legs. This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.
- Number of bus stops within 1,000 ft of intersection: Enter the number of bus stops present within 1,000 feet of the center of the intersection, across all legs. This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.
- School(s) present within 1,000 ft of intersection: Indicate whether one or more schools are present within 1,000 ft of the center of the intersection. This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.
- Alcohol sales establishments within 1,000 ft: Enter the number of alcohol sales establishments present within 1,000 ft of the center of the intersection, across all legs. This quantity is not needed for two-way stop-controlled intersections. This quantity is not needed for a two-way stop-controlled intersection.

The following street characteristics are needed for each street:

- Street configuration: Specify the street configuration as two-way or one-way. For a 1x2 intersection, the one-way street is defined as the major street.
- Annual average daily traffic: Enter the AADT, in vehicles per day. This quantity is a two-way total, including both arriving and departing vehicles. If different AADTs are present on the two legs of a street, enter the average of the two values. For 2x2 and 1x1 intersections, the major street must have equal or greater AADT than the minor street.
- Number of lanes: Enter the number of lanes (arriving plus departing) present on the street, not including turn lanes that are added by taper in the vicinity of the intersection.

- Number of approaches with left-turn lanes: Indicate the number of approaches on the street that have left-turn lanes. Count a leg if it has one or more left-turn lanes; the number of left-turn lanes on the leg does not matter. This quantity is not needed for the minor street at a signalized intersection or the major street at a two-way stop-controlled intersection.
- Number of left-turn movements with protected phasing: Enter the number of left-turn movements on the street that have protected-only phasing. This quantity is needed only for signalized 2x2 intersections.
- Number of right-turn movements prohibited on red: Enter the number of right-turn movements on the street that are prohibited when the signal indication is red. This quantity is not needed for a two-way stop-controlled intersection.
- Number of U-turn movements prohibited: Enter the number of U-turn movements on the street that are prohibited. This quantity is needed only for signalized 2x2 intersections.
- Number of approaches with right-turn channelization: Enter the number of approaches on the street that have right-turn channelization, or provision of free or yield-controlled right-turn movement. This quantity is not needed for a two-way stop-controlled intersection.

If necessary, the analyst can enter values for the following calibration factors:

- Local calibration factor.
- Adjustment factor for pedestrians for stop-controlled intersections.
- Adjustment factor for bicyclists.
- Severity distribution calibration factors for 2x2 intersections.
- Severity distribution calibration factors for 1x2 and 1x1 intersections.
- Probability of fatality given a crash involving fatality or incapacitating injury has occurred.

Computed values for the individual CMFs are provided in the lower portion of the worksheet (see Figure 23). The output summary on the top portion of the worksheet (see Figure 21) provides the predicted crash frequency, combined CMFs (product of individual CMFs), and severity distribution for the segment in the analysis year.

Totals Worksheet

After the analyst uses the input data worksheets to describe each site on the facility of interest, the Totals worksheet is available to tabulate the predicted crash frequency for the overall facility and also to conduct a site-specific or project-level EB analysis. The analyst transfers data from the input data worksheets to the Totals worksheet by clicking the “Add to Totals worksheet” button near the top of each input data worksheet.

Calibration Factors	Value	Default Values
Local calibration factor (C)	1.000	1.000
Adjustment factor for pedestrians for stop control (f_{ped})	0.049	0.049
Adjustment factor for bicyclists (f_{bike})	0.019	0.019
Severity distribution calibration factor, 2-way ($C_{sdf,twi}$)	1.000	1.000
Severity distribution calibration factor, 1-way ($C_{sdf,owi}$)	1.000	1.000
Probability of fatality given K+A severity ($P_{K\|K+A}$)	0.094	0.094

	Manner of Collision Proportions							
2x2 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.094	0.154	0.120	0.189	0.079	0.098	0.083	0.148
Angle colllision proportion	0.764	0.629	0.676	0.554	0.806	0.707	0.746	0.552
1x2 or 1x1 intersections	*3ST, F+I*	*3ST, PDO*	*3SG, F+I*	*3SG, PDO*	*4ST, F+I*	*4ST, PDO*	*4SG, F+I*	*4SG, PDO*
Rear-end collision proportion	0.100	0.100	0.111	0.143	0.047	0.065	0.030	0.059
Angle colllision proportion	0.300	0.250	0.889	0.571	0.822	0.706	0.837	0.733

Crash Modification Factors	F+I	PDO
Total-vehicle crash CMFs		
Lighting	0.911	0.911
Red-light cameras	1.000	1.000
Left-turn signal phasing	0.740	0.740
Right-turn-on-red	0.960	0.960
U-turn prohibition	0.922	0.922
Right-turn channelization	1.000	1.000
Number of lanes	1.158	1.158
Vehicle-pedestrian crash CMFs		
Bus stops	1.000	
Schools	1.000	
Alcohol sales establishments	1.000	

Figure 23. Intersections Calibration Factor Cells and CMF Calculations

Worksheet Organization

The Totals worksheet is organized with two large data tables like the one shown in Figure 24. The top table is labeled "Segment Site Information" and accommodates up to 15 segment-year combinations. The bottom table is labeled "Intersection Site Information" and accommodates up to 15 intersection-year combinations. For example, if the facility of interest consists of five segments and five intersections, and the analysis period is three years, all 15 rows in each table would be filled. Each table contains the following data:

- Site identification information like site number, analysis year, and site type.
- Predicted crash frequency, which was obtained from the relevant input data worksheet. These cells are shaded white.
- Site-specific observed crash totals. These cells are grayed out if no EB analysis or a project-level EB analysis is conducted, and are shaded blue if a site-specific EB analysis is conducted.
- Predicted or expected crash frequency. These cells are labeled with "Predicted crash frequency" and shown with purple shading in Figure 24 for the case of no EB analysis being conducted. The cells are shaded purple and labeled with "Expected crash

frequency” if a site-specific EB analysis is chosen, and grayed out if a project-level EB analysis is chosen.

- Combined CMF (not shown in Figure 24).
- Site location information (not shown in Figure 24).

Segment Site Information				Predicted crash frequency, crashes / year						Site-specific observed crash totals				Predicted crash frequency, crashes / year					
				Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle		Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle
Number	Year	Type	Street number	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
1	2011	6D	SH 1	5.492	7.389	0.948	1.167	0.225	0.120	7	9	2	3						
1	2011	3O	SH 1	1.244	2.986	0.227	0.309	0.114	0.052	2	3	1	1						

Figure 24. Totals Worksheet, Segments Data Table

The controls for the Totals worksheet are shown in Figure 25. The blue cell contains a drop-down menu where the analyst specifies the type of EB analysis to be conducted (none, site-specific, or project-level). Both EB analysis options can be applied to past periods for which crash counts are available. A site-specific EB analysis requires crashes to be assigned to the appropriate site and year, while a project-level EB analysis allows a facility-wide crash total across all analysis years to be provided. The site-specific EB analysis is more precise but requires more detailed crash data.

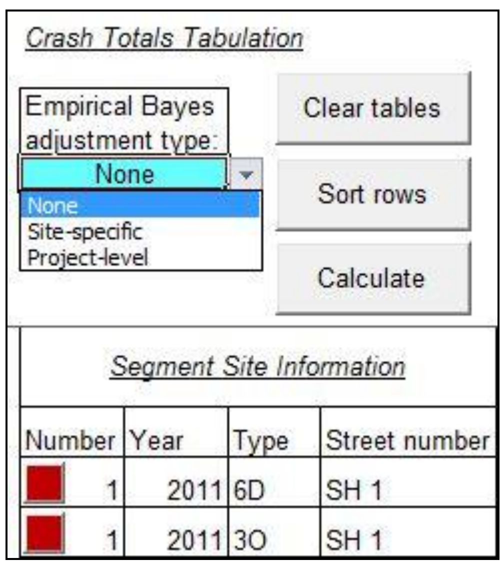

Figure 25. Totals Worksheet Controls

The following three command buttons are provided near the upper-left corner of the Totals worksheet (see Figure 25):

- Clear tables: Click this button to clear all data from the Totals worksheet.
- Sort rows: Click this button to sort the rows in each data table by year, site number, and site type code. This function is particularly useful when the data table is mostly full but has an empty row in the middle of the table that must be reclaimed because the bottom row was filled (see the error message in Figure 14).
- Calculate: Click this button to perform the calculations needed to aggregate crash totals and perform an EB analysis (if chosen).

Each row in the data tables has a square red button in the leftmost cell of the row. Clicking these buttons allows the analyst to (1) return the data in that table row to its origin worksheet (Two-way segments, One-way segments, or Intersections) and/or (2) delete the data in that row of the table.

The Totals worksheet consists of the main data tables that were discussed above; a second set of tables to the right of the main data tables, which contain intermediate calculations; two boxes that contain inverse dispersion parameters that are used for the EB analysis calculations and were derived along with the model coefficients in NCHRP Project 17-58; and an archived data area that contains all relevant site data in case the analyst needs to return these data to the input data worksheets for revision. The boxes for the inverse dispersion parameters contain yellow-shaded cells, as these parameters can be changed, but they should not be changed without significant justification based on detailed analysis of field data from the jurisdiction of interest.

Analysis Options

The Totals worksheet can perform three different types of analysis, which are described in the following paragraphs.

No Empirical Bayes Analysis. This option is denoted as "None" in the drop-down menu shown in Figure 25. With this analysis option, the Totals worksheet provides the predicted crash frequency for the facility as a simple summation of the predicted crash frequencies across the sites. The analyst need not provide crash counts. The crash totals tables on the top of the Totals worksheet will be populated with crash summations as shown in Figure 26. The "Facility Totals" table provides the total crash frequency for the facility, and aggregated by crash type (multiple-vehicle + single-vehicle, vehicle-pedestrian + vehicle-bicycle), severity (fatal-and-injury, property-damage-only). The "Total Predicted Crash Frequency" table provides a more detailed aggregation of crash frequency, broken down by site type (segment or intersection) in addition to crash type and severity. The "Project-Level Observed Crash Totals" table is not used when an EB analysis is not conducted.

Site-Specific Empirical Bayes Analysis. This option is denoted as "Site-specific" in the drop-down menu shown in Figure 25. With this analysis option, the Totals worksheet provides the expected crash frequency for each site-year combination, and also computes the total expected crash frequency for the facility as a summation across all sites and analysis years. The analyst must provide crash counts for every site, as indicated by the blue cells for the columns in the middle portion of the data tables (see Figure 27). Vehicle-pedestrian crash counts need not be provided for stop-controlled intersections because the pedestrian-vehicle crash frequency model applies only to signalized intersections, so the relevant cells for these crash counts are shaded white accordingly. The crash totals tables on the top of the Totals worksheet will be populated with EB-adjusted crash totals, and the "Total Expected Crash Frequency" table will be populated with a more detailed aggregation of crash frequency. The "Project-Level Observed Crash Totals" table is not used when a site-specific EB analysis is conducted.

Facility Totals	
MV+SV:	32.422
VP+VB:	1.425
F+I:	14.989
PDO:	18.858
Total:	33.846

Project-Level Observed Crash Totals		
Crash type	F+I	PDO
Multiple-vehicle crashes on segments:	9	12
Single-vehicle crashes on segments:	3	4
Total-vehicle crashes at **all** intersections:	7	9
Vehicle-pedestrian crashes at **signalized** intersections:	2	

Total Predicted Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	6.737	10.375	1.175	1.476	7.912	11.850	0.339	0.172
Intersections:					5.653	7.007	0.505	0.408
Total:	6.737	10.375	1.175	1.476	13.564	18.858	0.844	0.580

Figure 26. Crash Totals Tables – No Empirical Bayes Analysis

Facility Totals	
MV+SV:	38.068
VP+VB:	2.176
F+I:	18.079
PDO:	22.165
Total:	40.243

Project-Level Observed Crash Totals		
Crash type	F+I	PDO
Multiple-vehicle crashes on segments:	9	12
Single-vehicle crashes on segments:	3	4
Total-vehicle crashes at **all** intersections:	7	9
Vehicle-pedestrian crashes at **signalized** intersections:	2	

Total Expected Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:	7.845	11.560	1.597	2.061	9.442	13.621	0.391	0.200
Intersections:					6.461	8.544	1.106	0.478
Total:	7.845	11.560	1.597	2.061	15.903	22.165	1.498	0.678

Predicted crash frequency, crashes / year						Site-specific observed crash totals				Expected crash frequency, crashes / year						Combine	
Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle		Single-vehicle		Multiple-vehicle		Single-vehicle		Vehicle-pedestrian	Vehicle-bicycle	Multiple-vehicle	
F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I	F+I	PDO
5.492	7.389	0.948	1.167	0.225	0.120	7	9	2	3	6.455	8.569	1.312	1.686	0.270	0.144	1.035	1.035
1.244	2.986	0.227	0.309	0.114	0.052	2	3	1	1	1.390	2.991	0.285	0.375	0.121	0.055	1.370	1.370

Figure 27. Crash Totals Tables – Site-Specific Empirical Bayes Analysis

Project-Level Empirical Bayes Analysis. This option is denoted as "Project-level" in the drop-down menu shown in Figure 25. With this analysis option, the Totals worksheet provides the expected crash frequency for the facility across all analysis years. The analyst must provide crash counts for the facility, as indicated by the blue cells in the "Project-Level Observed Crash Totals" table (see Figure 28). These crash counts are aggregated by crash type and severity and summed across all analysis years. The crash totals tables on the top of the Totals worksheet will be populated with EB-adjusted crash totals. The "Total Predicted Crash Frequency" table is not used when an EB analysis is not conducted.

Facility Totals	
MV+SV:	41.911
VP+VB:	1.330
F+I:	18.864
PDO:	24.377
Total:	43.241

Project-Level Observed Crash Totals		
Crash type	F+I	PDO
Multiple-vehicle crashes on segments:	9	12
Single-vehicle crashes on segments:	3	4
Total-vehicle crashes at **all** intersections:	7	9
Vehicle-pedestrian crashes at **signalized** intersections:	2	

Total Expected Crash Frequency, crashes / year								
	Multiple-vehicle		Single-vehicle		Total-vehicle		Veh-ped	Veh-bike
Site type	F+I	PDO	F+I	PDO	F+I	PDO	F+I	F+I
Segments:								
Intersections:								
Total:								

Figure 28. Crash Totals Tables – Project-Level Empirical Bayes Analysis

REFERENCES

1. Lord, D., S. Geedipally, M. P. Pratt, E. S. Park, S. H. Khazraee, and K. Fitzpatrick. *Safety Prediction Models for Six-Lane and One-Way Urban and Suburban Arterials.* NCHRP Report 17-58. Transportation Research Board, National Academy of Sciences, Washington, D.C., 2016 (forthcoming).
2. Draft Chapter 12 of the *Highway Safety Manual.* NCHRP Project 17-58.
3. *Highway Safety Manual, 1st Edition.* Volume 2. American Association of State Highway and Transportation Officials, Washington, D.C., 2010.