MOUNTAIN-PLAINS CONSORTIUM

MPC 22-464 | M. Pawlovich, V. Gayah and I. Guler

FINANCIAL BENEFITS OF PROPOSED ACCESS MANAGEMENT TREATMENTS

F	G	J	
		69th St and Cliff Ave	69th S
		Sioux Falls SD	Si
		no-build	
Costs:		**no-build option**	
	Project Cost	no-build option	$
Benefits:		**no-build option**	
	Traffic Operations	no-build option	$
	Environmental	no-build option	
	Traffic Safety	no-build option	$
Benefit/Cost:			
	Total Benefits:	no-build option	$1
	Total Costs:	no-build option	$2
	Benefit/Cost (B/C):	**no-build option**	
	Incremental B/C:	**no-build option**	

MOUNTAIN-PLAINS CONSORTIUM REGION 8

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Financial Benefits of Proposed Access Management Treatments

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ABSTRACT

Transportation access management is defined as systematic control of the design, spacing, operation, and locations of street connections, interchanges, driveways, and median openings on the roadway with the purpose of providing vehicle access while preserving the efficiency and safety of the entire transportation system. Access management is a proven method for maintaining and improving roadway capacity; traffic flow; and the safety of traffic, pedestrians, and bicyclists on rural and urban highways and streets. No locally calibrated tool existed that captures the complexity of the current and future public benefits of proposed access management for estimating the financial and other benefits and comparing them with the associated financial costs. Therefore, this study had three primary objectives: (1) develop and validate benefits estimation methodology, (2) compile and derive supporting data for benefits estimation methodology, and (3) develop a software tool for benefits estimation. The result is a simple, straightforward benefits estimation methodology focused on benefits related to traffic operations, traffic safety, environmental impacts, and project costs. The methodology is facilitated by the two spreadsheet software tools that implement the benefits estimation and the calculation of traffic safety benefits, with Synchro/SimTraffic utilized for estimation of traffic operations and environmental impacts.

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Acronym	Definition
AADT	Average Annual Daily Traffic
AM	Access Management
B/C	Benefit-to-Cost Ratio
BCA	Benefits Cost Analysis
BES	Benefits Estimation Spreadsheet
BLS	Bureau of Labor Statistics
CH_4	Methane
CMEM	Comprehensive Modal Emissions Model
CMF	Crash Modification Factor
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DOT	Department of Transportation
EB	Empirical Bayes
EPA	Environmental Protection Agency
FHWA	Federal Highway Administration
FI	Fatal and Injury Crashes
HC	Hydrocarbon
HCM	Highway Capacity Manual
HCS	Highway Capacity Software
HSM	Highway Safety Manual
HSMIS	Highway Safety Manual Implementation Spreadsheet
IDCM	Infrastructure Design Criteria Manual
KABC	Fatal and Injury Crashes
LRTP	Long Range Transportation Plan
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
N_2O	Nitrous Oxide
NO_x	Nitrogen Oxides
NR	No Response
O	Property Damage Only Crashes
PDO	Property Damage Only Crashes
PM/PM_x	Particulate Matter
RC	Rapid City
RIRO	Right-In/Right-Out
RML	Rural, Multi-Lane
RTLTW	Rural, Two-Lane, Two-Way
SD	South Dakota
SDDOT	South Dakota Department of Transportation

SDSU	South Dakota State University
SF	Sioux Falls
SO_x	Sulfur Oxides
SPF	Safety Performance Function
TIS	Traffic Impact Study
TRB	Transportation Research Board
TWLTL	Two-Way, Left-Turn Lane
USA	Urban and Suburban Arterial
V/C	Volume-to-Capacity Ratio
VOC	Volatile Organic Compounds
VMT	Vehicle-Miles Travelled
VTPI	Victoria Transport Institute

1. EXECUTIVE SUMMARY

Transportation access management is defined as systematic control of the design, spacing, operation, and locations of street connections, interchanges, driveways, and median openings on the roadway with the purpose of providing vehicle access while preserving the efficiency and safety of the entire transportation system. Access management is a proven method for maintaining and improving roadway capacity; traffic flow; and the safety of traffic, pedestrians, and bicyclists on rural and urban highways and streets. Access management methods include, but are not limited to, increasing the spacing between signals and intersections, managing access to egress from driveways, median treatments (including the use of medians, indirect left-turns, etc.), use of frontage roads, providing turn lanes for heavy traffic movements, and land use policies. Each of these methods has safety and operational impacts (leading to financial and other benefits) as well as associated financial costs for implementing the changes and compensation to landowners for lost property or access. The decision of whether to implement a change often depends on the overall cost as well as the comparison of the cost relative to the expected benefits of the change.

1.1 Problem Description

Currently, no locally calibrated tool exists that captures the complexity of the current and future public benefits of proposed access management for estimating the financial and other benefits and comparing them with the associated financial costs. The benefits may be related to many local conditions including land use and zoning, roadway type and functional classification, traffic volumes, non-motorist volumes and characteristics, and the locations and other characteristics of access points. Given that many outcomes (i.e., safety and traffic operations) are related to human factors that are often unaccounted for in research, estimates for safety effects and operational changes associated with general access management methods can be made based on generally accepted practices. However, application of these practices can be cumbersome and inconsistent.

1.2 Research Objectives

To address these issues, this study had three primary objectives: (1) develop and validate benefits estimation methodology, (2) compile and derive supporting data for benefits estimation methodology, and (3) develop a software tool for benefits estimation.

To address the first objective, initially both a thorough review of the existing literature and extensive interviews of South Dakota access management personnel were conducted to direct the development of a methodology for estimating the financial benefits. Following this, a case study at a location where access management treatments have been implemented was conducted to test the methodology and illustrate the process.

To address the second objective, data needed for refinement of the benefit estimation methodology and development of the spreadsheet software tools were compiled. These data included Synchro/SimTraffic output files (in PDF format) for the traffic operations and environmental impacts estimation and site descriptive geometrics, traffic, and crash information needed for traffic safety estimation per Highway Safety Manual (HSM) procedures.

To address the third objective, the knowledge gained from the literature, interviews, and interactions with the technical panel as well as the data availability were used to develop the spreadsheet software tools. The primary spreadsheet tool addresses the benefits estimation given inputs from analyses related to traffic operations and environmental impacts from Synchro/SimTraffic and to traffic safety from HSM procedures. The secondary spreadsheet tool implements the calculations to estimate safety benefits based on HSM procedures.

1.3 Tasks

Study tasks involved gathering information, preparing, and validating an initial methodology through a case study, developing and refining the software tools, and preparing comprehensive documentation and the final report. Tasks 1 through 5 involved the information gathering through a thorough literature review, extensive interviews with South Dakota access management personnel, and development of an initial benefits estimation methodology based on the literature and interviews. Tasks 6 through 10 involved the further refinement and validation of the benefits estimation methodology as well as implementation of the methodology through initial versions of the spreadsheet tools. It should be noted that Task 8 originally involved development of crash modification factors (CMFs) specific to South Dakota. However, development of CMFs requires sufficient sites to base development upon and, through consultation with the technical panel and technical monitor, the data available were deemed insufficient. Thus, to replace this task, the HSM implementation spreadsheet tool was developed to facilitate traffic safety benefits estimation. Tasks 11 through 13 involved the modification of the software tools to refine them based on technical panel recommendations and comments. Tasks 14 and 15 complete the study with development of the final report and presentation.

1.4 Findings and Conclusions

An extensive literature review was conducted with access management topics related to treatment options and impacts of these on traffic operations, traffic safety, the environment, and the local economy. Primarily, a significant majority of the literature focused on traffic operations and traffic safety impacts. Much less literature mentioned economic impacts with the results inconclusive at times due to the difficulty in measuring these impacts. Even less literature discussed environmental impacts specific to access management; thus, the literature review related to environmental impacts focused more on general transportation network impacts on the environment and health.

Primary treatment options relate to access spacing, driveways and turning movements, and medians. Access spacing covers traffic signal spacing, unsignalized intersection and driveway spacing, and corner clearances. For both traffic signal spacing and unsignalized intersection and driveway spacing, the literature indicates that greater spacing between access points benefits operations and safety by reducing congestion and delay as well as crash frequency and severity. For traffic signals, regularly spaced and relatively infrequent signalized intersections aid traffic mobility and reduces crash occurrence. Inadequate or poor spacing degrades operations and safety. For driveways, the concern is width and throat length as well as ability to make left and right turns easily, which is related to the width and throat length as well as geometric configuration. Driveways can be both too wide and too narrow. When driveways are too wide, problems arise due to uncertainty and confusion for drivers related to path both for ingress and egress. When driveways are too narrow, more significant speed differences between turning vehicles and through traffic becomes a problem. The impacts of poor driveway design are manifested through increased congestion and delay as well as increased incidence of crashes, both for right and left turns. Related to left turns, median treatments such as raised medians limit the locations of left turns, possibly also providing left turn storage refuge. However, this treatment can prove controversial as businesses have opposed the treatment.

Regarding economic impacts and environmental impacts, the literature was sparse. Economic impact literature generally focused on impacts or perceived impacts on businesses. However, the technical panel clarified that the focus for benefits estimation should be on project costs. Thus, though the literature review discussed the business impacts, the topic was moot for software tool development.

Environmental impact literature was not specific to access management but did discuss impacts of poor mobility, congestion, and delay. These impacts manifested in increased travel time, which results in increase fuel consumption and resultant emissions. Some of the travel time was due to congestion and resultant deceleration and acceleration, which again results in increased fuel use and emissions. The literature noted several health impacts for drivers, pedestrians, and area residents.

The interviews involved many South Dakota access management personnel, whether that was their primary duty or a secondary duty, both state and local. Prior to the interview date, the questionnaire developed in collaboration with the technical panel was sent to the interviewees for their review. The questionnaire served primarily as a discussion guide and the project team took notes within the questionnaire. The interviewees helped to identify the access management treatments typically applied in South Dakota. While there were a few treatments identified as being more common, the interviews were heavily weighted toward DOT employees. Thus, the results could be regarded more representative of DOT-owned roads than local roads; however, the most frequent concerns were in common between the state and municipalities. Both groups indicated that access spacing, whether signal/intersection, driveway, or corner clearances, and median treatments were treatments of interest. SDDOT and the City of Sioux Falls have the most active access management programs, likely partially due to their size but also due to administrative support. The City of Brookings indicated an active program and some proactive steps, such as signal spacing planning, but the relative frequency is much less likely due to population and traffic levels. The City of Rapid City also indicated an active interest but that the ability to implement was tempered by developer and business resistance. All four jurisdictions have documents to help direct access management with, again, SDDOT and the City of Sioux Falls having more formalized documents, which makes sense with their more common application of the treatments. The City of Rapid City has a document which was developed with significant input from developers. The City of Brookings referred to zoning ordinances.

Current analysis tools and methods to estimate costs, impacts, and benefits are similar between the jurisdictions, again with an increasing level of sophistication based on frequency and strength of the access management program. Each jurisdiction performs analysis related to safety and traffic operations, whether in-house or through use of consultants, factoring these against project costs, perhaps with use of a benefit-cost (B/C) analysis. Common tools mentioned for safety analysis included the HSM, including safety performance functions (SPFs) and crash modification factors (CMFs), and the online CMF Clearinghouse. Use of severity-based crash valuations varied slightly, somewhat dependent on the availability and categorization of severity. All four jurisdictions indicated limited economic impact and environmental impact analyses; though statements regarding the importance of the former due to developer and business resistance were commonly made. Also, there are concerns that landowners and businesses perceive access management as leading to decreased property values and decreased sales/revenue for retail stores. All four jurisdictions also indicated that a tool to help them effectively estimate benefits would be helpful.

Related to benefits estimation, the overall financial impacts of access management treatments can be broken down into the impacts of these treatments on the following specific areas: safety performance, traffic operations, environmental impacts, and project costs (economic impacts). For traffic safety, the most common measure is observed crash frequency over some time period, typically either three or five years. Crash frequency can be broken down into various crash severities (fatalities, serious or minor injuries, property damage only) and collision types (rear-end, sideswipe, angle, run-off-road). Change in predicted crash frequency, estimated using HSM procedures, was used to quantify the safety performance of proposed access management treatments. For traffic operations, a variety of measures are used to quantify operational performance on a surface street network, including vehicle delay, total travel time, total travel distance, congestion levels, and queue lengths. Total travel time captures both delay and the time a vehicle spends traveling but is not delayed. Total vehicular travel time, estimated using Synchro/SimTraffic, was used to quantify the operational impacts of access management treatments. This metric captures several unique impacts of access management treatments, including both changes to delay incurred at individual facilities and additional time vehicles spend on the roadway due to increased travel distances. For environmental impacts, vehicular emissions are typically used to quantify environmental impacts caused by transportation systems. These emissions typically include carbon-related emissions (CO or CO_2), nitrogen related emissions (NO_X) or volatile organic compounds (VOC) for overall network effects and particulate matter (PM_X) for more localized impacts. As the majority of these emissions are based on the burning of fossil fuels, fuel consumption is often used as a surrogate. Total fuel consumption, estimated using Synchro/SimTraffic, was used to quantify environmental impacts of access management strategies. Economic impacts are generally quantified after the treatment implementation. Metrics that have been used in this manner include total sales from local businesses, survey responses to local business owners, change in sales tax receipts, and property values. However, SDDOT clarified that project cost is the metric to use. Using these metrics of comparative crash frequency, total travel time, fuel used, and project cost, a simple, straightforward equation to estimate financial impact was developed:

$$\begin{aligned} Financial\ impact \\ &= \beta_T \times Annual\ travel\ time + \beta_C \times Annual\ crash\ frequency \\ &+ \beta_F \times Annual\ fuel\ consumption + Total\ Project\ Costs \end{aligned}$$

where β_T is the dollar value associated with one unit (hour) of vehicle travel time, β_C is the dollar value associated with one crash, and β_F is the dollar value associated with one unit (gallon) of fuel consumed. This equation was implemented and validated through use of a case study using data from an implemented access management project in southeast Sioux Falls.

To facilitate estimation of benefits, a software tool called the Benefits Estimation Spreadsheet (BES) was developed with Microsoft Excel. This software tool accepts inputs for project costs as well as traffic operations, environmental impacts, and traffic safety metrics determined through use of other software. For traffic operations and environmental impacts, the recommended software for determining the metrics is Synchro/SimTraffic. Personnel trained in use of Synchro/SimTraffic should develop the appropriate network for determination of these metrics, which are provided in output PDF files from the software. For traffic safety, an accompanying software tool named the Highway Safety Manual Implementation Spreadsheet (HSMIS) facilitates HSM calculations to determine the traffic safety-related metrics. The BES calculates values for linear interpolation of entered start and end year values for determination of benefits over the project lifetime. From these values, dollar values based on the unit costs are calculated for further determination of present values. Finally, benefit/cost (B/C) values and incremental B/C values are calculated for comparative purposes. Results are provided on a separate worksheet to facilitate printing and sharing. The HSMIS calculates SPF, CMF, and other values. Results transferred to the BES software include the summed $N_{predicted}$ for both injury (KABC) and property damage only (O) crashes available near the top of the data entry worksheet.

The result is a simple, straightforward benefits estimation methodology focused on benefits related to traffic operations, traffic safety, environmental impacts, and project costs. The methodology is facilitated by the two spreadsheet software tools that implement the benefits estimation and the calculation of traffic safety benefits, with Synchro/SimTraffic utilized for estimation of traffic operations and environmental impacts.

1.5 Recommendations

This project primarily involved the development of a straightforward benefits estimation methodology that was then implemented in two separate software tools. Thus, the recommendations primarily focus on use of the software (both BES and HSMIS) and expanded use of related software

(Synchro/SimTraffic). SDDOT could also benefit from development of an access management treatment database and future development of South Dakota-specific or regional CMFs.

1.5.1 Use BES – Access Management and Beyond

Use of the Benefits Estimation Spreadsheet (BES), both for access management analysis as well as beyond as appropriate, is recommended.

The BES was developed to facilitate analysis of potential benefits and comparison of project alternatives based on the typical comparative measures of traffic operations, traffic safety, environmental impacts, and project costs. For access management, the tool enables the consolidation of results from separate analyses using standard procedures related to these measures, along with project costs, for a combined financial analysis over a project timeframe using accepted economic analysis procedures related to present value, benefit/cost, and incremental benefit/cost. For access management analysis purposes, the measures are appropriate as determined in collaboration with the technical panel. However, these same measures often apply to other types of projects; thus, use of the BES beyond access management is possible as appropriate.

1.5.2 Use HSMIS – Access Management and Beyond

Use of the Highway Safety Manual Implementation Spreadsheet (HSMIS), both for access management analysis as well as beyond as appropriate, is recommended.

The HSMIS was developed to facilitate analysis of traffic safety using the HSM 2010 procedures. Traffic safety is one aspect of the access management analysis process. However, other types of projects consider safety impacts; thus, use of the HSMIS beyond access management is possible as appropriate.

1.5.3 Expand Use of Synchro/SimTraffic within SDDOT

SDDOT should consider expanded use of Synchro/SimTraffic.

Through collaboration with the technical panel as well as interaction with interviewees, it was clear that use of Synchro/SimTraffic within SDDOT is perhaps limited. Whereas this may serve the needs of SDDOT, training of additional personnel who may then use Synchro/SimTraffic should be considered.

1.5.4 Future Development of South Dakota-specific CMFs

Once SDDOT has a more expansive set of access management treatments, development of South Dakota-specific CMFs should occur.

Currently, the number of implemented South Dakota access management projects is limited with site-to-site idiosyncrasies complicating development of SD-specific CMFs. However, with an expanded number of projects, CMF development becomes more plausible. Partnering with adjacent states that may have similarly limited treatments might allow a set of regionally developed CMFs related to access management.

2. INTRODUCTION

2.1 Problem Description

Transportation access management is defined as systematic control of the design, spacing, operation, and locations of street connections, interchanges, driveways, and median openings on the roadway with the purpose of providing vehicle access while preserving the efficiency and safety of the entire transportation system. Access management is a proven method for maintaining and improving roadway capacity; traffic flow; and the safety of traffic, pedestrians, and bicyclists on rural and urban highways and streets (Gluck et al., 2010). Improvements to operational efficiency and safety reduces transportation costs. Reductions in delay and improvements to traffic flow also reduces vehicle emissions, reducing the environmental impacts of transportation. Research has shown that access management related improvements to traffic operations and safety have a positive impact on the local economy (Benz et al., 2015).

Access management methods include, but are not limited to, increasing the spacing between signals and intersections, managing access to egress from driveways, median treatments (including the use of medians, indirect left-turns, etc.), use of frontage roads, providing turn lanes for heavy traffic movements, and land use policies. Examples of these methods can be found throughout South Dakota in both rural and urban settings. Figure 2.1 shows examples of Google Earth images of access

Figure 2.1 Access Management Examples in Brookings, SD (Google Earth Street View)

management in Brookings, SD. Each of these methods has safety and operational impacts (leading to financial and other benefits) as well as associated financial costs for implementing the changes and compensation to landowners for lost property or access. The decision of whether to implement a change often depends on the overall cost as well as the comparison of the cost relative to the expected benefits of the change. These benefits include the current and future benefits to both the public and the agency making the changes. Also, the project must fit within the overall budget of the agency making the changes.

Currently, no locally calibrated tool exists that captures the complexity of the current and future public benefits of proposed access management for estimating the financial and other benefits and comparing them with the associated financial costs. The benefits may be related to many local conditions, including land use and zoning, roadway type and functional classification, traffic volumes, pedestrian and bicyclist volumes and characteristics, and the locations and other characteristics of access points. Given that many outcomes (i.e., safety and traffic operations) are related to human factors that are often unaccounted for in research, estimates of safety effects and operational changes associated with general access management methods provided in the Highway Safety Manual (AASHTO, 2010) and the Access Management Manual (Williams et al., 2014). Also, more specific, complete estimates of the effects of access management methods on public benefits that are locally calibrated are desired when making decisions related to the value of the investment.

2.2 Research Objectives

This study has the following main objectives:

Develop and Validate Benefits Estimation Methodology

Develop and validate a methodology for estimating the benefits to safety, operational efficiency, environment, and economic vitality resulting from several proposed access management treatments.

Through a review of the existing literature, and using the discussion and information obtained from the interviews, the research team will develop a methodology for estimating the financial benefits of several proposed access treatments and test/validate the methodology using urban and rural case studies. The list of treatments considered will be determined by the research team in consultation with the project panel. The case studies will be at locations where access management treatments have been implemented. The estimated results will then be compared with the observed outcomes to validate the methodology. Further details on how this will be accomplished are presented under tasks 2-7.

Compile and Derive Supporting Data for Benefits Estimation Methodology

Compile and derive data needed to support the benefit estimation methodology.

The data needed to support the benefit estimation methodology will be compiled from multiple sources: SDDOT, the City of Sioux Falls, and the City of Rapid City; a safety analysis presented in Task 8; and the literature review. The data will be recorded in Excel, Synchro files, and the final comprehensive documentation for the software. The data management plan provides descriptions of the data, types of data, data ownership, and protections that will be used for the data that will be compiled for this project.

Develop a Software Tool for Benefits Estimation

Build, demonstrate, and document a software tool to estimate the benefit of proposed access management improvements.

Based on the literature review, interviews, and interactions with the project technical panel, the researchers will develop a software tool that implements the methodology identified in the first two project objectives. The software will be tested by estimating the benefits of the proposed access management treatments identified in the two case studies. Comprehensive documentation of the software, including the assumptions made, values used, instructions for using the software (including procedures for software configuration and maintenance), will be developed as part of Task 12. A short tutorial for the software and a pamphlet for marketing the software to engineers and planners in South Dakota will also be developed in Task 12. Further discussion regarding the development, demonstration, and documentation of the software is provided under tasks 7-15.

3. FINDINGS AND CONCLUSIONS

Findings and conclusions resulting from the study are covered in the following sections.

3.1 Literature Review

The roadway system represents a major investment, both public and private, and valuable resource that enables mobility and accessibility to users (Koepke & Levinson, 1992; Gluck & Lorenz, 2010). The roadway system is not only comprised of both streets and highways but also accesses to public and private property (Koepke & Levinson, 1992; Gluck & Lorenz, 2010). Safe and efficient operation of the system is essential. To achieve this, management of access from adjacent, abutting properties and developments is critical (Gluck & Lorenz, 2010; Schultz et al., 2007). Appropriate access management maintains a reasonable balance between mobility and accessibility and involves a holistic view of the roadway and surrounding land use environment. Inadequate access can be frustrating to both business owners and their customers while inappropriate or excessive access can lead to traffic congestion, delays, crashes, and resultant economic and environmental impacts (Schultz et al., 2007; Albrecht & Plazak, 1998; Brown & Dixon, 2015). Resulting economic costs due to wasted time, fuel consumption, and premature mortality are estimated to be in the billions of dollars. Effective access management improves efficiency and safety, reduces environmental impacts, and increases economic vitality of communities while decreasing roadway rehabilitation costs (SDDOT, 2016).

Access management involves "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" (TRB, 2003), including median treatments, auxiliary lanes, and appropriate traffic signal spacing. Well-implemented access management provides a safe and efficient roadway network by specifying acceptable access by applying traffic engineering principles. Access standards should be incorporated into legislation, and design should match the standards, after careful planning of access related to land use and zoning policies. Access planning and design should incorporate both the public and private sector components of the roadway access system.

To address the first study goal, the current literature related to access management benefits was reviewed. In addition, South Dakota access management professionals, both state and local, were interviewed. The literature review initially describes common access management techniques, including traffic safety and operations benefits followed by discussion of economic and environmental impacts. Various access management techniques are available, including access spacing, traffic signal spacing, unsignalized access spacing, corner clearances, driveway width and throat, turning movements, and median treatments. The specific benefits of each of these are discussed in the following sections.

For a more extended discussion, please see Appendix A, sections A.1, A.2, A.3, and A.4.

3.1.1 Access Spacing

Access spacing consists of four primary techniques: traffic signal spacing, unsignalized access spacing, corner clearances, and interchange crossroad spacing. Guidelines for access spacing should consider allowable access levels appropriate to roadway classification, roadway speeds, and operating environments. Access location criteria for the State of South Dakota are shown in Figure 3.1. One method to increase spacing between accesses is to encourage access consolidation, which reduces conflict points and separates conflict areas. Access consolidation can be accomplished through various means, including limiting individual business access points, encouraging shared accesses, and encouraging interparcel circulation.

Access Class	Signal Spacing Distance (mile)	Median Opening Spacing (mile)	Minimum Unsignalized Access Spacing (feet)	Access Density	Denial of Direct Access When Other Available
Interstate	N/A	N/A	N/A	N/A	Yes
Expressway	½	½	2640	at half-mile increments	Yes
Free Flow Urban	½	½ F, ¼ D	1320	at quarter-mile increments	Yes
Intermediate Urban	½	½ F, ¼ D	660	at eighth-mile increments	Yes
Urban Developed	¼	¼	100	2 accesses/block face	Yes
Urban Fringe	¼	½ F, ¼ D	1000	5 accesses/side/mile	Yes
Rural	N/A	N/A	1000	5 accesses/side/mile	Yes

Figure 3.1 South Dakota Access Location Criteria (SDDOT, 2022)

An increase in access point frequency or density along a roadway generally correlates with a higher crash rate by increasing potential conflicts (Rodegerdts et al., 2004; Williamson & Zhou, 2014; Gluck et al., 1999; FHWA, 1998; Shadewald & Prem, 2003; Eisele & Frawley, 2005; Huang et al., 2014; Preston et al., 1998; Peng, 2004; Chimha, 2004; O'Shea et al., 2000; Drummond et al., 2002; Deng et al., 2006; Stover et al., 1982; Levinson & Gluck, 1997; BRW, 1998; Millard, 1993). Doubling the frequency of access points corresponds to a 20% to 40% increase in crash rate. Research has determined, as shown in Figure 3.2, crash rates climb with the frequency of unsignalized or signalized access points per mile. Conversely, arterial traffic flow and safety improves through conflict density reduction, increased distance for anticipation and recovery from turning maneuvers, and improved opportunities for turning lane designs as access spacing is increased (Papayannoulis et al., 1999).

Representative Accident Rates by Access Density - Urban and Suburban Areas				
Unsignalized Access Points per Mile	Accident Rates (accidents per millions VMT)			
	Signalized Access Points per Mile			
	≤ 2	2.01 - 4.00	4.01 - 6.00	> 6
≤ 20	2.6	3.9	4.8	6.0
20.01 - 40	3.0	5.6	6.9	8.1
40.01 - 60	3.4	6.9	8.2	9.1
> 60	3.8	8.2	8.7	9.5
All	3.1	6.5	7.5	8.9

Figure 3.2 Accident Rates by Access Density (Fitzpatrick & Wooldridge, 2001; Gluck et al., 1999)

Direct access along arterial streets from businesses and residences causes speed and capacity reductions, with more congestion as access points increase (FHWA, 2003; Eisele & Frawley, 2005). Capacity reductions have been reported to be as much as 2.5 mph for every 10 access points up to a 10 mph reduction for 40 access points per mile (FHWA, 2003; Gluck et al., 1999; Shadewald & Prem, 2003; Frawley & Eisele, 2000; HCM, 2010). These values only reflect access points along the directional side of the arterial; however, opposing side access points should be considered where the impact may be significant. Given this, there exist the potential to improve operations, flow, and service level by reduction of access points, with urban arterials with high access control shown to function 30% to 50% better than similar facilities with little control (Rodegerdts et al., 2004; CDOT, 1985). However, access control applied along corridor sections may impact adjacent intersections, which could degrade arterial operational performance (Rodegerdts et al., 2004).

For a more extended discussion, please see Appendix A, section A.4.1.

3.1.2 Traffic Signal Spacing

Traffic signal spacing is critical as traffic signals significantly impact traffic flow and safety. Signals that are closely or irregularly spaced reduce travel speeds and generate excessive stops, leading to poor traffic flow and safety through more crashes. Appropriate signal spacing depends on the speed and traffic flow, but studies have shown that signal densities greater than 2 per mile have a significant impact on congestion and safety (FHWA, 2003; Schultz et al., 2010; Gross et al., 2018; Gluck et al., 1999). Decreasing signal density by increasing signal spacing improves traffic flow, reduces congestion and crashes, and improves air quality (FHWA, 2003). Additionally, uniformly spaced signals with optimal frequency/density again results in improved efficiency and safety (Schultz et al., 2010; Gross et al., 2018).

Increasing signal spacing reduces crash incidence (FHWA, 2003; Gluck et al., 1999; Avelar et al., 2013; Stover, 1996) as shown in Figure 3.3.

Signals Per Mile	Crashes Per Million VMT
Under 2	3.53
2 to 4	6.89
4 to 6	7.49
6 +	9.11

Figure 3.3 Correlation of Signal Density with Increased Crash Rate (FHWA, 2003)

Research has shown significant impacts of traffic signal spacing on operations, specifically related to speed and travel time (FHWA, 2003; Fitzpatrick & Wooldridge, 2001; Gluck et al., 1999). Each additional traffic signal per mile reduces speed around 2 to 3 mph. As detailed in Figure 3.4 and using two traffic signals per mile as base, each additional signal decreases travel time.

Percent Increases in Travel Times as Signal Density Increases	
Signals per Mile	**Increase in Travel Time (%)***
2	0
3	9
4	16
5	23
6	29
7	34
8	39

*** Compared with 2 signals per mile.**

Figure 3.4 Signal Density Impacts on Travel Time
(Fitzpatrick & Wooldridge, 2001; Gluck et al., 1999)

For a more extended discussion, please see Appendix A, section A.4.2.

3.1.3 Unsignalized Access Spacing

Unsignalized accesses, which include public street intersections and private driveways, are far more prevalent than signalized accesses and serve neighborhoods and businesses. Access management attempts to manage driveway frequency through various means, including location of accesses, limitation of number of accesses per parcel, provision of alternative access, and encouragement of joint or shared access (Gattis et al., 2010; ISU, 2022).

Studies have shown significant impacts on the safety performance of roadways (FHWA, 2003; Williamson & Zhou, 2014; Schultz et al., 2010; Gluck et al., 1999; Eisele & Frawley, 2005; Avelar et al., 2013; Papayannoulis et al, 1999; AASHTO, 2011; Dixon & Avelar, 2015; Brown & Tarko, 1999; Mouskos et al., 1999; Flintsch et al., 2008). Crash rates have been shown to increase with greater frequency of driveways and intersections, with each additional access elevating crash frequency potential, as shown in Figure 3.5.

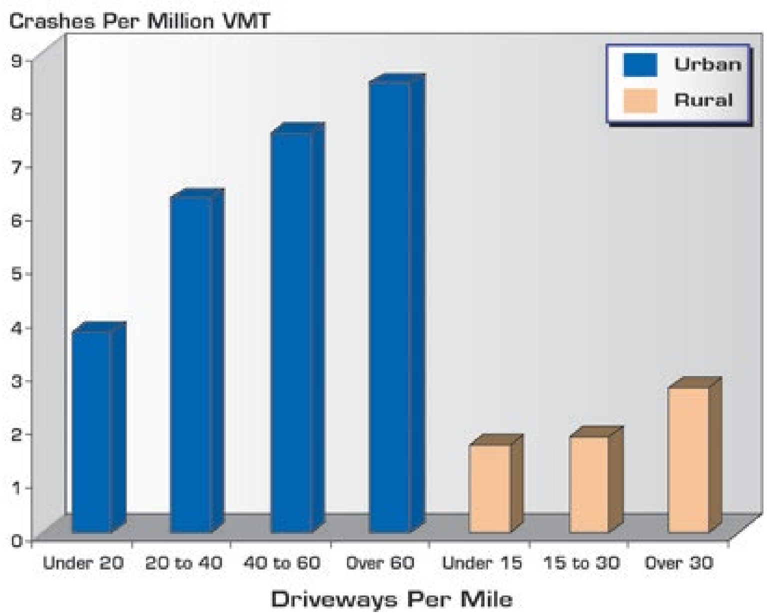

Figure 3.5 Correlation of Driveway Density with Increased Crash Rate (FHWA, 2003)

With regard to conflicts between vehicles, these usually result either from slowed turning vehicles or queued vehicles due to an access point. Longer driveway separations eliminate conflicts and confusion due to overlapping driveway operations, simplifying turning maneuvers, and decreasing crashes (Schultz et al., 2010; Layton et al., 1998). Regarding congestion, reduced driveways are clearly advisable with the presence of slow-moving vehicles due to numerous access points impacting free flow speeds significantly (FHWA, 2003).

For a more extended discussion, please see Appendix A, section A.4.3.

3.1.4 Corner Clearance

Corner clearance is the minimum distance required between an intersection and the nearest crossroad intersection, including driveways (SDDOT, 2022; Gross et al., 2018; Gluck et al., 1999; Schultz et al., 2010; FHWA, 1998; Levinson & Gluck, 2000; AASHTO, 2011; ISU, 2022; Le et al., 2018). Minimum corner clearances are meant to protect intersection functional integrity. Driveways should be located outside the functional area of an intersection which extends beyond the physical intersection limits. An intersection functional area includes the longitudinal limits of auxiliary lanes and areas upstream of an intersection where deceleration, maneuvering, and queueing take place and areas downstream of an intersection where driveways could generate queues extending into intersections due to conflicts. However, corner clearances are limited by the property frontage available.

Accesses located within the functional area of an intersection complicate movements due to the existent natural intersection conflicts being complicated by additional driveway-related ingress/egress conflicts (Schultz et al., 2010). Access management provides criteria to increase corner clearance, including driveway closure, consolidation, or relocation to side roads or to the furthest property line edge; turn lane provision; turn movement prohibition; and establishment of larger minimum corner lots size (Rodegerdts et al., 2004; SDDOT, 2022; Gluck et al., 1999; FHWA, 1998; Levinson & Gluck, 2000; Le et al., 2018).

Studies have shown that accesses within the functional area of intersections are correlated with increased crashes and crash severities (Gluck et al., 1999; Schultz et al., 2010; Avelar et al., 2013; Le et al., 2018; Rakha et al., 2008; Butorac & Wen, 2004), with commercial accesses particularly problematic. Driveway obstruction is a significant problem resulting from poor corner clearance, and intersections with multiple inadequate corner clearances are more crash prone (Gluck et al., 1999; Schultz et al., 2010). Factors relevant to increasing corner clearance include the standard intersection design criteria, including perception-reaction distance, weaving distance, transition distance, and storage requirements (Schultz et al., 2010; Butorac & Wen, 2004). Intersections with corner clearance that adhere to standards have fewer crashes and lower crash severities (Schultz et al., 2010).

Signalized intersection corner clearances significantly impact driveway opening capacity (Ghods et al., 2012). Additionally, reduced corner clearances reduce the flow rate depending on the actual distance to driveway, the ingress and egress volumes, and the driveway design (Rodegerdts et al., 2004; McCoy & Heimann, 1990).

For a more extended discussion, please see Appendix A, section A.4.4.

3.1.5 Driveway Width and Throat

Related to driveway frequency and spacing, driveway width impacts the speed differential of through traffic and turning traffic (ISU, 2022). Narrow driveways slow turning vehicles markedly and increase speed differential with through vehicles. Conversely, extra wide driveways, possibly without discernable boundaries, create uncertainty about vehicle paths and create operational and safety concerns. A properly designed driveway creates a clear area for turning traffic to exit the roadway quickly with resulting improvement in traffic flow and safety. Related to this, driveway throat is the distance from the edge of the traveled way to the driveway point where conflicting traffic movements are encountered. Access management attempts to negate driveway queues that extend into the public roadway. Proper design of throat length, internal circulation, and internal circulation within a site can minimize queues.

For a more extended discussion, please see Appendix A, section A.4.5.

3.1.6 Turning Movements

Arterial conflicts due to accesses are generated by vehicles turning into (entering) these accesses or out of (exiting) the accesses. Turning movements can be either right turns from the lane adjacent to the business or left turns from the lane on the other side of the arterial road centerline. Right turns typically have minimal impact on capacity and crashes when compared with left turns as right turns do not conflict with opposing traffic. Left turns, especially from shared use lanes, pose more significant problems at both driveways and intersections by increasing conflicts, delays, and crashes and complicating traffic signal timing and coordination. Access management typically separates or limits turning movements using turn lanes and turn prohibitions. Additionally, reduction in corridor access point density is related.

Right-turn movements into driveways generally only cause issues when vehicles are slowed to enter or when vehicles are queued due to a turning vehicle. Right-turn lanes were found to reduce rear-end crashes by 30%, reduce crash injury severity, and decrease costs by 26%. Interestingly, rear-end crashes at driveways, compared with intersections, were found to have 1.3 to 1.9 times the relative risk. Right-turn movements from through traffic have a clear impact on delay to this traffic and this delay increases exponentially as additional vehicles are impacted (FHWA, 2003), as shown in Figure 3.6.

Right-Turning Vehicles Per Hour	Through Vehicles Impacted (%)
Under 30	2.4
31 to 61	7.5
61 to 90	12.2
90 and up	21.8

Figure 3.6 Right-Turn Movement Impacts (FHWA, 2003)

Research indicates that right-turn maneuvers from a two-lane arterial at unsignalized driveway or intersection can result in delay from 0 to 6 seconds per through vehicle (Potts et al., 2007). Right-turn movements in the same situation on a four-lane arterial result in delay from 0 to 1 second per through vehicle (Potts et al., 2007). Driveway grades influenced these values with flatter grades having less impact (Gattis & Duncan, 2009). Added access points, especially commercial driveways, contribute noticeably to increased congestion and reduced capacity of the outside lane (Potts et al., 2007). The addition of right-turn lanes diminishes the impact of right-turn maneuvers and therefore increases traffic flow and improves operations.

Left turns, especially from shared use lanes, pose more significant problems at both driveways and intersections by increasing conflicts, delays, and crashes and complicating traffic signal timing and coordination (FHWA, 1998; Fitzpatrick et al., 2013a; Fitzpatrick et al., 2013b). Crashes involving left-turning vehicles comprise more than two-thirds of driveway-related crashes (FHWA, 1998). Due to this, numerous studies have shown substantial reductions in crashes, particularly rear-end crashes due to left-turning vehicle movements, related to installation of left-turn lanes (FHWA, 2003; Gluck et al., 1999; Schultz et al., 2010; FHWA, 1998; Levinson & Gluck, 2000; Fitzpatrick et al., 2013b; Harwood et al., 2002; Potts et al., 2004; Parker et al., 1983; McCoy and Malone, 1989; ITE, 1985; Cribbins et al., 1967; Hauer, 1988). This reduction has often been reported as 50%, with a range of 18% to 77%, with rear-end collisions reduced from 60% to 88%. The reductions are primarily due to removal of the turning vehicles from the through lanes and improved sight distance for turning maneuvers. Addition of left-turn lanes has been shown to improve capacity from 25% to 33% and improve related delay reductions (FHWA, 2003; FHWA, 1998; Fitzpatrick et al., 2013b; S/K, 2000).

For a more extended discussion, please see Appendix A, section A.4.6.

3.1.7 Medians

Accommodation, prohibition, and diversion or separation of left-turn movements can be accomplished through median treatments. Median treatments are an effective means for access regulation but are often quite controversial (FHWA, 2003; Rodegerdts et al., 2004; FHWA, 1998; Carter et al., 2005). The primary concerns are the limitation of direct access and the perception of reduced business opportunity. The primary decision for median design is whether to install a continuous two-way left-turn lane (TWLTL) or a non-traversable median on an undivided roadway or to replace a TWLTL with a non-traversable median.

Both TWLTL and non-traversable median treatments remove left turns from through traffic and consequently improve operations and safety. TWLTLs provide continuous access and operational flexibility and are generally favored by businesses (SDDOT, 2022; Carter et al., 2005). Non-traversable medians create a divided cross section, which provides traffic flow and improves safety (SDDOT, 2022; Gross et al., 2018; Gluck et al., 1999; Ghods et al., 2012; Carter et al., 2005; Self, 2003).

Numerous studies and syntheses have reported that median installations, regardless of type, improve safety when compared with undivided roadways with similar volumes and driveway density (FHWA, 2003; Gluck et al., 1999; Avelar et al., 2013). Two-way left-turn lanes (TWLTLs) have been shown to have average crash rates significantly lower than undivided roadways (Schultz et al., 1994; FHWA, 2003; TRB, 2003; Gluck et al., 1999; Schultz et al., 2010; Levinson & Gluck, 2000; Gattis et al., 2005). Additionally, raised medians further reduce crash rates and crash severity when compared with TWLTLs (Schultz et al., 1994; FHWA, 2003; TRB, 2003; Gluck et al., 1999; Schultz et al., 2010; Eisele & Frawley, 2005; Avelar et al., 2013; Levinson & Gluck, 2000; Eisele et al, 2004; Ghods et al., 2012; Gattis et al., 2005; Squires & Parsonson, 1989; Margiotta & Chatterjee, 1995; Schultz & Lewis, 2006; CTRE, 2006a; Stover & Koepke, 2002; CTRE, 2006b; Parsonson et al, 2000; Stover, 1994). As shown in Figure 3.7, raised medians experience lower crash rates than TWLTLs and both have lower rates than undivided roadways. Further detail is shown in Figure 3.8.

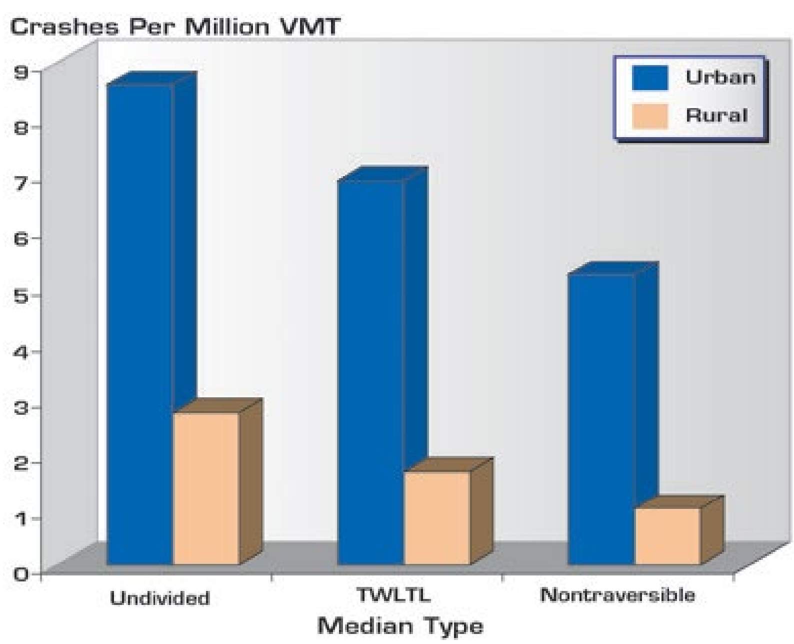

Figure 3.7 Median Type Crash Rate Comparison (FHWA, 2003)

Representative Accident Rates by Type of Median			
Total Access Points per Mile*	Accident Rates (accidents per millions VMT)		
	Median Type		
	Undivided	Two-Way Left-Turn Lane	Nontraversable Median
Urban and Suburban Areas			
≤ 20	3.8	3.4	2.9
20.01 - 40	7.3	5.9	5.1
40.01 - 60	9.4	7.9	6.8
> 60	10.6	9.2	8.2
All	9.0	6.9	5.6
Rural			
≤ 15	2.5	1.0	0.9
15.01 - 30	3.6	1.3	1.2
>30	4.6	1.7	1.5
All	3.0	1.4	1.2

Figure 3.8 Accident Rates by Median Type (Fitzpatrick & Wooldridge, 2001; Gluck et al., 1999)

After replacement of a TWLTL with a raised median, reductions in sideswipe, rear-end, right-angle, left-turn, head-on, and pedestrian crashes are often noted (Schultz et al., 1994; Gluck et al., 1999).

Provision of medians, whether raised or TWLTL, yield similar delays to arterial traffic but significantly lower delays than undivided roadways (Bonneson & McCoy, 1997; Ghods et al., 2012;

Bonneson & McCoy, 1998; Ballard & McCoy, 1988). Replacing a TWLTL with a raised median can result in increased travel time (Eisele & Frawley, 2005).

For a more extended discussion, please see Appendix A, section A.4.7.

3.1.8 Economic Impacts

Changes to transportation infrastructure can have economic impacts on surrounding businesses and also impact land value. However, congestion and reduced safety translate into significant social and economic costs, with costs of capacity, wasted time, crashes, excess fuel consumption, and increased

emissions translating to annual economic burdens of billions of dollars (Stover & Koepke, 2000; Levy et al., 2010; Stover, 1996; Shrank & Lomax, 2007; VTPI, 2009). Communities without effective access management often engage in cyclical roadway investments involving continual improvements and relocation where these changes increase activity and, in time, necessitate additional improvements to address decline in capacity and safety (Koepke & Levinson, 1992). Access management, when carefully conceived and well-implemented, avoids this cycle and can save public funds, time, and lives by preserving capacity and maintaining suitable access and avoidance of massive reconstruction (Koepke & Levinson, 1992). The cost savings due to reduced frequency and severity of crashes alone can more than offset the installation cost of access management treatments (Schultz et al., 1994). Application of access management techniques to reduce and separate access points, manage turning movements, and coordinate between businesses results in a visually pleasing, more functional corridor that protects business and public investments (FHWA, 2006).

The financial benefits related to safety can be estimated using established costs based on the number and severity of crashes that occur (Council et al., 2005; Donnell et al., 2016). The financial costs related to traffic operations can be estimated using the difference in the average delay (or total delay) and the value of time, which has been found to be 50% of the average wage rates for an area when traffic is not congested and 100% to 150% of the average wage rates for an area in congested traffic conditions (Litman, 2007; Litman, 2015). Costs related to environmental impacts are less easily calculated and include benefits for which monetary value is not easily assigned (e.g., changes to the overall health of the public). Based on the limited economic analysis related to access management, the costs related to the local economy are likely to have either no impact or a slight decrease in the overall cost to the public and businesses.

For a more extended discussion, please see Appendix A, section A.5.

3.1.9 Environmental Impacts

With roadway traffic the dominant form of transportation in the United States, vehicle travel has a large impact on the environment by emitting air pollutants through exhaust, evaporation, use of air conditioners, and stirring of fugitive dust by vehicle passage (US EPA, 1996). Transportation activity contributes a major source of carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs) or other hydrocarbons (HCs), nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) (US EPA, 1996; Rubin & Nolan, 2010; Zhang & Batterman, 2013; TRB, 2002; Van Woensel et al., 2001), which are the dominant source of air pollutants in many areas. Studies have indicated that as much as 45% of released pollutants in the U.S. are due to vehicle emissions (Ahn et al. 2002; NRC, 1995). Transportation activities account for a significant portion of carbon dioxide (CO_2) emissions in the U.S., releasing roughly 33% of the total CO_2, with roadway vehicles contributing 80% of those emissions (Barth & Boriboonsomsin, 2008; IPCC, 2007).

These air pollutants have environmental, health, and welfare impacts, including respiratory and other illnesses, such as chronic cough, phlegm, wheezing, chest illness, and bronchitis (US EPA, 1996, McCubbin, 1995). Air pollutants impact the morbidity and mortality of drivers, commuters, and people living in close proximity to roadways (Levy et al., 2010; Zhang & Batterman, 2013; WHO, 2005; HEI, 2009; Grahame & Schlesinger, 2010; White et al., 2005; Samet, 2007; Adar & Kaufman, 2007; Li & Nel, 2006; Delfino et al, 2008). Epidemiological studies link vehicle emission exposure to several cardiovascular health impacts (Levy et al., 2010; Grahame & Schlesinger, 2010) and a significant number of estimated premature deaths. These premature deaths have an estimated cost in the billions of dollars and are projected to increase (Levy et al., 2010).

An initial review of the research literature failed to yield any research on the impacts of access management on the environment. However, it is well established that reducing travel times and congestion, and reductions in the number of braking and acceleration maneuvers, lead to reductions in greenhouse gas emissions (Van Woensel et al., 2001; Ahn et al. 2002; Barth & Boriboonsomsin*, 2008*). Reductions in greenhouse gases improve both the environment and public health (Levy et al., 2010; Zhang & Batterman, 2013; Van Woensel et al., 2001; Grahame & Schlesinger, 2010). Thus, improvements to traffic flow in reductions of overall network travel time and reductions in speed variation lead to decreased emissions. Given that access management treatments increase trip lengths but decrease the overall travel times, there is a balance between traffic flow/speeds and travel distances (and an associated impact on the environment).

For a more extended discussion, please see Appendix A, section A.6.

3.2 Interviews

With the help of the technical panel, the researchers identified key staff from the South Dakota Department of Transportation (SDDOT), the City of Brookings, the City of Rapid City, and the City of Sioux Falls for interviews. These personnel included those in management, engineering, and planning, an access management specialist, and legal representatives. The staff were contacted to schedule interviews, primarily in person.

3.2.1 Interview Process

For the interviews, a questionnaire was developed using modifications from a prior questionnaire developed with assistance from the technical panel (see Appendix B, section B.5). The questionnaire was aimed at identifying current and needed functionality for estimating the financial benefits of access management treatments and the data required for the analysis and functionality. The questionnaire was provided via e-mail to each participant prior to the scheduled interviews to assist them with interview preparation. After each interview, notes were compiled and sent back to each interviewee for comment and clarification. The raw notes of the interviews are available in Appendix B.

In total, 24 staff were interviewed, seven from cities and 17 from SDDOT, with the list of the interviewees included with the individual agency summaries following the summary section. The interviewees provided context for access management as it is currently applied in South Dakota, issues related to managing access (real or perceived), and preliminary thought on the usefulness of a tool that can be used to estimate the financial benefits of access management in South Dakota.

3.2.2 Interview Results

In particular, the interviewees helped to identify the access management treatments typically applied in South Dakota. While there were a few treatments identified as being more common, the interviews were heavily weighted toward DOT employees. Thus, the results could be regarded more representative of DOT-owned roads than local roads; however, the most frequent concerns were in common between the state and municipalities. Both groups indicated that access spacing, whether signal/intersection, driveway, or corner clearances, and median treatments were treatments of interest. SDDOT and the City of Sioux Falls have the most active access management programs, likely partially due to their size but also because of administrative support. The City of Brookings indicated an active program and some proactive steps, such as signal spacing planning, but the relative frequency is much less likely due to population and traffic levels. The City of Rapid City also indicated active interest but that the ability to implement was tempered by developer and business resistance. All four jurisdictions have documents to help direct access management with, again, SDDOT, and the City of Sioux Falls having more formalized documents as makes sense with their more common application of the treatments. The City of Rapid City has a document that was developed with significant input from developers. The City of Brookings referred to zoning ordinances. All four jurisdictions also indicated that a tool to help them effectively estimate benefits would be helpful. Individual jurisdictional interview results are available in Appendix B.

3.2.3 Tools/Methodologies to Estimate Costs, Impacts, and Benefits

Current analysis tools and methods to estimate costs, impacts, and benefits are similar between the jurisdictions, again with an increasing level of sophistication based on frequency and strength of the access management program. Each jurisdiction performs analysis related to safety and traffic operations, whether in-house or through use of consultants, factoring these against project costs, perhaps with use of a benefit-cost (B/C) analysis. Common tools mentioned for safety analysis included the Highway Safety Manual (HSM), including safety performance functions (SPFs) and crash modification factors (CMFs), and the online CMF Clearinghouse. Use of severity-based crash valuations varied slightly, being somewhat dependent on the availability and categorization of severity. For example, the City of Sioux Falls mentioned using South Dakota valuations on state road projects and Minnesota valuations on local roads. The City of Rapid City expressed concern with the validity of state crash data with respect to certain non-spatial attributes. Common tools for traffic operation evaluations included Synchro/SimTraffic software and the Highway Capacity Manual (HCM) and associated Highway Capacity Software (HCS). SDDOT performs traffic impact studies (TIS) and traffic analysis studies within the central office. The City of Brookings mentioned review of the Manual on Uniform Traffic Control Devices (MUTCD) for requirements and guidelines. All four jurisdictions indicated limited economic impact and environmental impact analyses; though statements regarding the importance of the former due to developer and business resistance were commonly made. Also, there are concerns that landowners and businesses perceive access management as leading to decreases in property values and decreased sales/revenue for retail stores. Through the interviews, it was indicated that these concerns have led to the city council in Rapid City making decisions related to limiting and removing median barriers (i.e., the council was concerned that the median barriers decreased sales revenues and lowered property values, leading to decreased tax revenues for the city). Again, all four jurisdictions also indicated that a tool to help them effectively estimate benefits would be helpful.

From a legal standpoint, it was indicated that the typical value of interest is the direct financial impacts of specific businesses or landowners, not the overall benefit to the communities. Also, any limitation of access to property is potentially legally problematic due to South Dakota's laws, which state that all landowners have the right to reasonable access. The law itself is subject to interpretation, and has been the focus of lawsuits (e.g., Schliem v. State Department of Transportation, 2016).

The interviews also indicated that few, if any, previous justifications for access management in South Dakota have estimated the financial benefits of the proposed treatments. Instead, justification has been made using safety (based on point estimates of the change in safety, based on the HSM) or traffic operations (improvements in traffic flow and reductions in delay, based on before-after studies). The majority of the interviewees indicated that having a tool that could estimate potential financial benefits for proposed access management treatments would be a valuable addition to the engineering tools available for decision making.

3.2.4 Data Elements

Regarding the data availability and value of these data, there seems to be less commonality between the availability than the commonality of the perception of value, as shown in the following three tables (Tables 3.1, 3.2, and 3.3 where NR = no response). The City of Sioux Falls indicated many readily available data elements, primarily in the geometrics/site characteristics elements, and many more possibly available elements, again within the geometrics/site characteristics but also within the traffic operations elements, as shown in Tables 3.1 and 3.2. SDDOT indicated fewer readily available data elements with some variables being unavailable or of uncertain availability. The City of Rapid City had fewer readily available and many more unavailable elements. The City of Brookings seemed to indicate that traffic counts were available but perhaps little else. Again, this may be indicative of the size and traffic volumes for each jurisdiction and the related activity of an access management program. Regarding the value, much more agreement exists on the value of each data element, especially when comparing the City of Sioux Falls with the SDDOT. Regarding safety/crash-related variables, as shown in Table 3.3, there are apparently many elements that are not available and also not regarded as highly valuable. This may be due to some uncertainty as to what data are available or a perception that crash data are less reliable, as indicated by a couple of municipalities.

3.2.5 Estimates of Financial Impacts of Treatments

Throughout the jurisdictions, no values for estimates pertaining to the safety, operational, environmental, or economic impacts, nor the project costs of access management treatments, were provided. The interviewees indicated more analyses related to safety and operations concerns, which likely means they use crash severity valuations as part of their analysis but perhaps more subjective level-of-service results for the traffic operations. Past project reports, available online and through the jurisdictions for further information, might be utilized to generate estimates. There have been past considerations of potential environmental impacts but primarily from a possibility of consideration.

Table 3.1 Site Characteristics – Availability and Value – Combined Jurisdictions

	SF	RC	DOT	SF	RC	DOT
Site Characteristics	**Availability**			**Value**		
Geometrics/Site Characteristics						
Site						
Type (corridor, segment, intersection)	Readily	Readily	Readily	High	High	High
Length/width/influence area	Possibly	Possibly	Readily	High	High	Medium
Land Use	Readily	Readily	Not	High	High	Low
Functional Classification	Readily	Readily	Readily	High	High	High
Access Classification	Readily	Not	Readily	High	High	High
Intersection Spacing	Possibly	Possibly	From maps	High	High	High
Sight Distance	Possibly	Not	Not	High	Medium	High
Lanes						
Number	Readily	Readily	Readily	High	High	High
Width	Readily	Not	Readily	High	Low	Medium
Type (Thru, Left, Right)	Readily	Not	Intersections	High	Medium	High
Storage/Lane Length (turn)	Readily	Not	Not	High	Low	High
Acceleration/deceleration	Readily	Not	Not	High	Low	High
Access Points						
Number	Possibly	Not	Not	High	High	High
Type(s)	Possibly	Not	Not	Medium	High	Medium
Distances Between	Readily	Not	Not	Medium	High	High
Entering/departure Grades	Possibly	Not	Not	Low	Low	Medium
Shared/unshared	Possibly	Not	Not	Medium	Medium	Medium
Approach Lane Width	Possibly	Not	Not	Low	Low	Medium
Throat Width	Possibly	Not	Not	Medium	Medium	Medium
Traffic Control (at access point)	Possibly	Not	Not	Low	Low	Low
Corner Clearances	Possibly	Not	Not	Not	High	High
U-Turn Provision	Possibly	Not	Not	Medium	Low	High
Median						
Type	Readily	Not	Readily	High	Medium	High
Width	Readily	Not	Readily (state)	High	Low	High
Frontage/backage Roads	Readily	Possibly	Readily	High	Low	Medium
Roundabouts/Alternative Intersections	Readily	Not	Readily	High	Low	Medium

One primary study, the W 12th St project in Sioux Falls, had a more rigorous economic impact study performed but it is unclear whether these data or results remain available.

3.2.6 Software Tool Elements

Staff indicated much interest in various aspects of the software tool as indicated in the questionnaire, with primary interest in the numerical (tabular) summary tables, the benefit-cost analysis, and the comparative worksheets. Interest in the graphs/charts was lower and likely based more on the value of displays as opposed to analytical value. Within the numerical (tabular) summary tables, staff had much interest in the safety impacts and project costs, mildly less interest in the traffic operations and environmental impacts, and even a little less in the economic impacts. Staff indicated that cost savings gained from the project are important and that the locality of the cost savings should be underscored. Additionally, staff indicated that having a simple rating system would be good. Finally, the software needs to be user-centered and easy to use, with understandable output.

Table 3.2 Traffic Operations – Availability and Value – Combined Jurisdictions

			SF	RC	DOT	SF	RC	DOT
Traffic Operations			**Availability**			**Value**		
Operations								
	Traffic Control		NR	NR	NR	NR	NR	NR
	Signal							
		Number	Readily	Readily	Readily	High	Low	High
		Spacing	Readily	Not	Not	High	High	High
		Left-Turn Protection	Readily	Possibly	Not	High	High	High
	Conflict Points		Possibly	NR	NR	High	NR	NR
	Conflict Density		Possibly	NR	NR	High	NR	NR
	Capacity Analysis							
		Delay	Readily	Not	NR	High	High	NR
		Travel Time	Readily	Not	NR	High	High	NR
		Level-of-Service (LOS)	Readily	Not	NR	High	High	NR
	Non-motorists (pedalcyclists, pedestrians)							
		Types	Possibly	Not	NR	High	Medium	NR
		Volumes	Possibly	Not	NR	High	Medium	NR
Traffic								
	Volumes							
		AADT	Readily	Readily	Readily	High	High	High
		% Truck	Possibly	Not	Readily	High	Low	High
		% Bus	Possibly	Not	Readily	High	Low	Medium
		% Passenger Vehicle	Possibly	Not	Readily	High	Low	Medium
	Peak Hour Factor		NR	Possibly	Readily	NR	Low	High
	Speed							
		Limit	Possibly	Not	Readily	Medium	High	NR
		Operating	Possibly	Not	Not	Medium	High	NR

NR = no response

3.3 Benefits Estimation Methodology

The overall financial impacts of access management treatments can be broken down into the impacts of these treatments on the following specific areas: safety performance, traffic operations, environmental impacts, and project costs (economic impacts).

The metrics commonly used to assess the impacts of access management treatments (or other strategies) in each of these areas, as well as those used for this project, are discussed below. The metrics from each of these areas are combined using known/prescribed monetary equivalents to estimate overall financial impacts.

Table 3.3 Traffic Safety – Availability and Value – Combined Jurisdictions

	SF	RC	DOT	SF	RC	DOT
Traffic Safety	**Availability**			**Value**		
Crash - basic						
Frequency	Locational	Not	NR	High	NR	NR
Severity	Locational	Not	NR	High	High	NR
Rate	Locational	Not	NR	High	NR	NR
Spatial Location (Spacing/Clustering)	Locational	Not	NR	High	High	NR
Crash – extended						
Collision Type (Manner of Crash/Collision Impact)	NR	Not	NR	NR	High	NR
Time of Day/Day of Week	NR	Not	NR	NR	NR	NR
Type of Roadway Junction/Feature	NR	Not	NR	NR	NR	NR
Location of First Harmful Event	NR	Not	NR	NR	NR	NR
Traffic Controls	NR	Not	NR	NR	NR	NR
Sequence of Events	NR	Not	NR	NR	NR	NR
Vehicle						
Vehicle Configuration	NR	Not	NR	NR	Low	NR
Initial Direction of Travel	NR	Not	NR	NR	NR	NR
Vehicle Action	NR	Not	NR	NR	Medium	NR
Driver						
Contributing Circumstances	NR	Not	NR	NR	High	NR
Vision Obscured	NR	Not	NR	NR	Low	NR
Driver Age	NR	Not	NR	NR	Low	NR
Driver Impairment	NR	Not	NR	NR	Low	NR
Driver Distraction	NR	Not	NR	NR	Low	NR
Environment						
Surface Conditions	NR	Not	NR	NR	Low	NR
Weather Conditions	NR	Not	NR	NR	Low	NR
Light Conditions	NR	Not	NR	NR	Low	NR
Non-Motorist						
Type	NR	Not	NR	NR	NR	NR
Location (prior to impact)	NR	Not	NR	NR	NR	NR
Action	NR	Not	NR	NR	NR	NR
Contributing Circumstances	NR	Not	NR	NR	NR	NR

NR = no response

3.3.1 Benefits Estimation Metrics

For traffic safety, the most common measure is observed crash frequency over a given time period, typically either three or five years. Crash frequency can be broken down into various crash severities (fatalities, serious or minor injuries, property damage only) and collision types (rear-end, sideswipe, angle, run-off-road). However, crashes are rare events and subject to significant variability due to impacts, including driver behavior. Surrogate safety measures seek to assess safety performance without observing actual crashes, including conflict-based and risk-based measures. Conflict-based measures observe the frequency of vehicle conflicts (i.e., near-crash events where crash occurrence was avoided due to evasive action) during a given time period. Risk-based measures relate observable traffic metrics (e.g., traffic flow, average speed) to collision risk. Conflict-based surrogates typically require detailed vehicle trajectory information for application while the risk-based measures are highly site specific (e.g., a unique model must be estimated for each site).

For this project, the research team proposes change in predicted crash frequency to quantify safety performance of proposed access management treatments. Crash frequency changes will be estimated using HSM procedures, which involve SPF calculation and adjustments using CMFs per the 2010 HSM.

For traffic operations, a variety of measures are used to quantify operational performance on a surface street network, including vehicle delay, total travel time, total travel distance, congestion levels, and queue lengths. Vehicle delay is the most common measure and is measured on various elements (e.g., roadway segments or intersections). Vehicle delay reflects the additional travel time incurred due to traffic congestion or traffic control. Total travel time captures both delay and the time a vehicle spends traveling but is not delayed. Total travel distance accounts for the directness of a trip, which may be impacted by alternate access management designs (e.g., left-turn prohibitions, right in/right out [RIRO], U-turns, frontage roads). Congestion levels are measured on individual facilities and are typically provided as a ratio of actual volume-to-capacity ratio (v/c). Queue length is another indicator of congestion on individual facilities.

For this project, the research team proposes to use total vehicular travel time to quantify the operational impacts of access management treatments. This metric captures several unique impacts of access management treatments, including both changes to delay incurred at individual facilities and additional time vehicles spend on the roadway due to increased travel distances. Total travel time will be estimated using existing traffic analysis software, specifically Synchro and SimTraffic.

For environmental impacts, vehicular emissions are typically used to quantify environmental impacts caused by transportation systems. These emissions typically include carbon-related emissions (CO or CO_2), nitrogen related emissions (NO_X), or volatile organic compounds (VOC) for overall network effects and particulate matter (PM_X) for more localized impacts. As the majority of these emissions are based on the burning of fossil fuels, fuel consumption is often used as a surrogate.

For this project, the research team proposes to use total fuel consumption to quantify environmental impacts of access management strategies. Total fuel consumption will be estimated using existing traffic analysis software, specifically Synchro and SimTraffic.

Economic impacts are generally quantified after the treatment implementation. Metrics that have been used in this manner include total sales from local businesses, survey responses to local business owners, change in sales tax receipts, and property values. These metrics typically provide an indication of the long-term impacts. Short-term impacts are typically measured by accessibility or exposure measures, such as traffic volume passing storefronts. This latter metric is particularly useful for businesses that rely heavily on pass-by traffic, such as gas stations or fast-food restaurants. However, for this project, SDDOT indicated that this aspect is for the businesses to determine and that SDDOT is primarily concerned with project costs. Thus, project costs represent the cost to implement an access management strategy and would also play a significant role in its overall financial impact. For this reason, the estimated cost will also be included as a part of this project.

3.3.2 Benefits Estimation Assessment Methodology

The results of the literature review and survey of key staff in SDDOT (Tasks 2 and 3) reveal that the impacts of access management treatments are highly specific to the site at which they are implemented. The same treatment can have vastly different safety, operational, environmental, and economic impacts depending on the implementation site characteristics, including prevailing traffic flow patterns among other variables. This is true both within the implementation site as well as within the extended traffic network. Thus, the research team proposes a methodology that addresses this site-specific nature to accurately quantify the overall financial impacts of access management treatments. The proposed method is outlined below.

The proposed method relies on the combination of traffic analysis software and common safety analysis methods (i.e., SPFs and CMFs to estimate the financial impacts of access management treatments. Traffic analysis software will be used to quantify operational, environmental, and economic impacts (specifically, total distance traveled, total fuel consumed, and traffic volumes passing storefronts). SPFs and CMFs will be used to predict safety performance. These impacts will be combined using known or predefined factors to convert safety, operational, environmental, and economic impacts to monetary units. Finally, these converted costs will be merged with project costs for a final impact in financial terms.

The research team specifically proposes the use of the Synchro/SimTraffic software, since interviews with members of the SDDOT staff reveals that the Synchro software has been previously used for operational studies in South Dakota. While Synchro itself does not directly provide some of the necessary outputs to assess all financial impacts of access management strategies (e.g., fuel consumption), this information can be obtained using the SimTraffic add-on that runs using the general Synchro files. This software is particularly useful as it can capture the network-wide effects of access management strategies, such as additional/reduced distance traveled due to fewer/more access points on the roadway. Such impacts are not possible when applying methods that focus on one roadway element at a time, such as the Highway Capacity Software (HCS).

The traffic analysis software provides the needed metrics for only designated time periods (usually with a length of one hour). The research team proposes performing the analysis for each of the AM and PM peak hours and at least one off-peak hour to obtain a comprehensive assessment of the potential impacts of the access management strategy. A unique Synchro file will be needed for each potential access management alternative and time period being considered. Thus, if two potential strategies with three time periods are considered, then a total of six files (2 alternatives x 3 time periods) will be recommended.

The research team strongly advises that the analysis area coded within the Synchro traffic software be large enough to truly capture the impacts of any access management treatment. For example, many access management strategies require vehicles to use alternative routes. To fully capture the operations, economic, and environmental impacts of these strategies, the alternative routes need to be included in the analysis file so the impact of the additional traffic volumes induced on these routes by the access management strategies are included.

To assess safety performance, existing SPFs and CMFs from the HSM, research literature, or FHWA CMF Clearinghouse will be used to estimate the expected crash frequency for the proposed access management treatment. First, SPFs will be applied to estimate crash frequency under baseline conditions. The type of SPF (and associated baseline conditions) will depend on the roadway element being considered (roadway segment or intersection) and roadway type (two-lane rural, multi-lane rural, urban/suburban arterial, freeway). Once the SPF is applied, CMFs will be used to adjust the estimate for site-specific features (deviations from the baseline conditions, including the presence of any access management treatments). CMFs less than 1.0 suggest that the associated feature decreases crash frequency, while CMFs greater than one suggest the associated feature increases crash frequency. The CMFs can be obtained from the HSM or FHWA CMF Clearinghouse, which provides a growing list of CMFs that are suitable for use.

The final outcomes will be combined using known/prescribed monetary equivalents for each of the metrics outlined above. Since crash frequencies are typically estimated on an annual basis while the traffic analysis metrics are estimated for single hourly periods, the outcomes must first be adjusted to a common analysis interval. For simplicity, the research team proposes to use a one-year period as the analysis interval. When using this interval, the crash frequency estimates from the SPFs and CMFs can be used as is. The outputs from the traffic analysis software will have to be adjusted to annual measures. This can be done by first using the outputs for each of the designated time periods into daily values (by breaking the day into a number of equivalent AM peak hours, PM peak hours, and off-peak hours) and then converting these daily measures into annual values. The final estimate of financial impact can be estimated using the following equation:

$$\begin{aligned} Financial\ impact \\ &= \beta_T \times Annual\ travel\ time + \beta_C \times Annual\ crash\ frequency \\ &+ \beta_F \times Annual\ fuel\ consumption + Total\ Project\ Costs \end{aligned}$$

where β_T is the dollar value associated with one unit (hour) of vehicle travel time, β_C is the dollar value associated with one crash, and β_F is the dollar value associated with one unit (gallon) of fuel consumed.

3.3.3 Benefits Estimation Case Study

To illustrate the benefits estimation assessment methodology, a case study was developed using Cliff Avenue and 69th Street in Sioux Falls, SD. As part of the case study development, initial versions of the Highway Safety Manual Implementation Spreadsheet (HSMIS) and Benefits Estimation Spreadsheet (BES) were developed. For a more extended discussion, please see Appendix C.

3.4 Benefits Estimation Spreadsheet (BES)

To facilitate the estimation of benefits, the BES software tool was developed with Microsoft Excel. This software tool accepts inputs for project costs as well as traffic operations, environmental impacts, and traffic safety metrics determined through use of other software. For traffic operations and environmental impacts, the recommended software for determining the metrics is Synchro/SimTraffic. Personnel trained in use of Synchro/SimTraffic should develop the appropriate network for determination of these metrics, which are provided in output PDF files from the software. For traffic safety, an accompanying software tool for facilitating HSM calculations to determine the traffic safety-related metrics. This tool is described in the following section.

Development of the BES proceeded from the literature review and interview process and also considering the benefits estimation methodology. User interactions and desire for a simple interface with straightforward steps were of primary concern. As such, a simple process involving limited data entry for each project alternative (e.g., “no-build,” “build 1,” “build 2,” etc.) was developed. The steps for data entry include eight (8) primary steps involving data entry of each set of metrics for each alternative and review of the results. These steps are:

1. Identify individual alternatives
2. Enter anticipated project costs (dollars)
3. Enter traffic operations (congestion/delay)
4. Enter environmental impacts (emissions)
5. Enter traffic safety (annual predicted crash frequency)
6. Iterate for each alternative
7. Update unit costs (as appropriate)
8. Review results

Inputs for steps 2 through 5 for each alternative are obtained from project alternative development, Synchro/SimTraffic analysis output, and HSM calculations utilizing the companion software.

As data are entered, the spreadsheet calculates values for linear interpolation of entered start and end year values for determination of benefits over the project lifetime. From these values, dollar values based on the unit costs are calculated for further determination of present values. Finally, benefit/cost (B/C) values and incremental B/C values are calculated for comparative purposes. Results are provided on a separate worksheet to facilitate printing and sharing.

A more detailed description and user instructions, including an example of use, is contained within Appendix D.

3.5 Highway Safety Manual Implementation Spreadsheet (HSMIS)

To facilitate the estimation of traffic safety metrics, a software tool was developed with Microsoft Excel. This software tool, the Highway Safety Manual Implementation Spreadsheet (HSMIS), facilitates the calculations involved with procedures as detailed in HSM 2010 chapters 10, 11, and 12, which relate to rural, two-lane, two-way (RTLTW) roadways, rural, multi-lane (RML) roadways, and urban and suburban arterials (USA), respectively. For an example of calculations involved in the HSM procedure, please refer to Appendix C, section C.4.

Development of the HSMIS, matching BES development, considered user interactions, and desire for a simple interface with straightforward steps were of primary concern. As such, a simple process involving limited data entry for each project portion (e.g., “intersection,” “north approach,” “east approach,” etc.) was developed. The steps for data entry include five (5) primary steps involving data entry of project portion characteristics (e.g., traffic, geometrics, and historical crashes). These steps are:

1. Identify individual project portion(s)
2. Enter site characteristics
3. Iterate for each project portion
4. Obtain Results for BES
5. Iterate for each period and alternative

Inputs for step 2 for each project portion should be readily accessible based on the alternative development process as the data for the step include volumes and lengths, site descriptive characteristics (e.g., geometrics and such), and observed crashes. For the HSMIS, a separate spreadsheet file for each alternative, containing perhaps several project portions per HSM procedures, is advised.

As data are entered the spreadsheet calculates SPF, CMF, and other values. Results transferred to the BES software include the summed $N_{predicted}$ for both injury (KABC) and property damage only (O) crashes available near the top of the data entry worksheet.

A more detailed description and user instructions, including an example of use, is contained within Appendix E.

4. RECOMMENDATIONS

This project primarily involved the development of a straightforward benefits estimation methodology that was then implemented in two separate software tools. Thus, the recommendations primarily center on use of the software (both BES and HSMIS) and expanded use of related software (Synchro/SimTraffic). SDDOT could also benefit from development of an access management treatment database and future development of South Dakota-specific or regional CMFs.

4.1 Use BES – Access Management and Beyond

Use of the Benefits Estimation Spreadsheet (BES), both for access management analysis as well as beyond as appropriate, is recommended.

The BES was developed to facilitate analysis of potential benefits and comparison of project alternatives based on the typical comparative measures of traffic operations, traffic safety, environmental impacts, and project costs.

For access management, the tool enables the consolidation of results from separate analyses using standard procedures related to these measures, along with project costs, for a combined financial analysis over a project timeframe using accepted economic analysis procedures related to present value, B/C, and incremental B/C. For example, a typical access management analysis would involve:

- Assessment of traffic operation impacts on total vehicle delay by developing a model of the traffic network in Synchro/SimTraffic. This model would be developed for the existing site conditions for both present and future levels of traffic. Similarly, the model would be adjusted to model each alternative, both present and future. Output from these models would be entered into the BES within which the economic impacts would be automatically calculated across the project timeframe using SDDOT-determined travel time values ($ per hour).
- Assessment of environmental impacts on total fuel used using the same Synchro/SimTraffic models developed for traffic operations. Output from these models would be entered into the BES, within which the economic impacts would be automatically calculated across the project timeframe using SDDOT-determined fuel used values ($ per gallon).
- Assessment of traffic safety impacts on total crashes split by severity, whether injury crashes (including fatal crashes) or property damage only crashes. The HSM procedures would be used to determine these values with these HSM procedures facilitated by the companion software noted in the following section. The values would be entered into the BES, within which the economic impacts would be automatically calculated across the project timeframe using SDDOT-determined crash costs by severity level ($ per crash).

For access management analysis purposes, the measures are appropriate as determined in collaboration with the technical panel.

However, these same measures often apply to other types of projects; thus, use of the BES beyond access management is possible as appropriate. That is, oftentimes other SDDOT projects involve traffic operation, environmental, and traffic safety impacts; thus, the BES could be used to assess the economic impacts of projects other than access management.

4.2 Use HSMIS – Access Management and Beyond

Use of the Highway Safety Manual Implementation Spreadsheet (HSMIS), both for access management analysis as well as beyond as appropriate, is recommended.

The HSMIS was developed to facilitate analysis of traffic safety using the HSM 2010 procedures. Traffic safety is one aspect of the access management analysis process that, without the HSMIS, can become a tedious process of formula application, table value determination, and calculation. Thus, expanded use of the HSMIS for access management analyses would shorten analytical time and provide consistency of results.

However, safety impacts are often considered for other types of SDDOT projects; thus, use of the HSMIS to estimate traffic safety impacts beyond access management is possible as appropriate.

4.3 Expand Use of Synchro/SimTraffic within SDDOT

SDDOT should consider expanded use of Synchro/SimTraffic.

Through collaboration with the technical panel and interaction with interviewees, it was clear that use of Synchro/SimTraffic within SDDOT is perhaps limited. Whereas this may serve the needs of SDDOT, training of additional personnel who may then use Synchro/SimTraffic should be considered. With expanded use of the BES for access management purposes, SDDOT should consider training of personnel involved with access management analysis. Alternatively, SDDOT could decide to enable collaboration of access management personnel with more knowledgeable Synchro/SimTraffic users for development of models assessing traffic operations and environmental impacts.

4.4 Future Development of South Dakota-specific CMFs

Once SDDOT has a more expansive dataset of access management treatments, development of South Dakota-specific CMFs should occur.

Currently, the number of implemented South Dakota access management projects is limited with site-to-site idiosyncrasies complicating development of SD-specific CMFs. However, with an expanded number of projects, CMF development becomes more plausible. Depending on future application of access management treatments, achieving sufficient projects for analysis may take years. However, SDDOT could consider partnering with adjacent states that may have similarly limited treatments, with a combined set of treatments allowing development of regionally applicable CMFs related to access management.

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APPENDIX A: EXTENDED LITERATURE REVIEW

A.1 Introduction

The roadway system represents a major investment, both public and private, and a valuable resource that enables mobility and accessibility to users *(1, 2)*. The roadway system is not only comprised of both streets and highways but also accesses to public and private property *(1, 2)*. It is essential to operate the roadway system safely and efficiently *(1, 2)* and, to do this, management of access to the roadway system from adjacent, abutting properties and developments is critical *(2, 3)*. Access management can help maintain a reasonable balance between the often conflicting objectives of mobility and accessibility. Access management involves a holistic view of the roadway and surrounding land use environment, including location, spacing, design, and operation of any access to the roadway.

However, both property owners and roadway users have rights; the former have "a right to reasonable access" (accessibility) to the roadway system and the latter have "a right to freedom of movement (mobility), safety, and efficient expenditure of public funds" *(2)*. These two rights can often conflict as balancing the service for through traffic (mobility) while simultaneously providing property access (accessibility), as shown in Figures A.1 and A.2, is difficult *(4)*. Streets and highways providing high

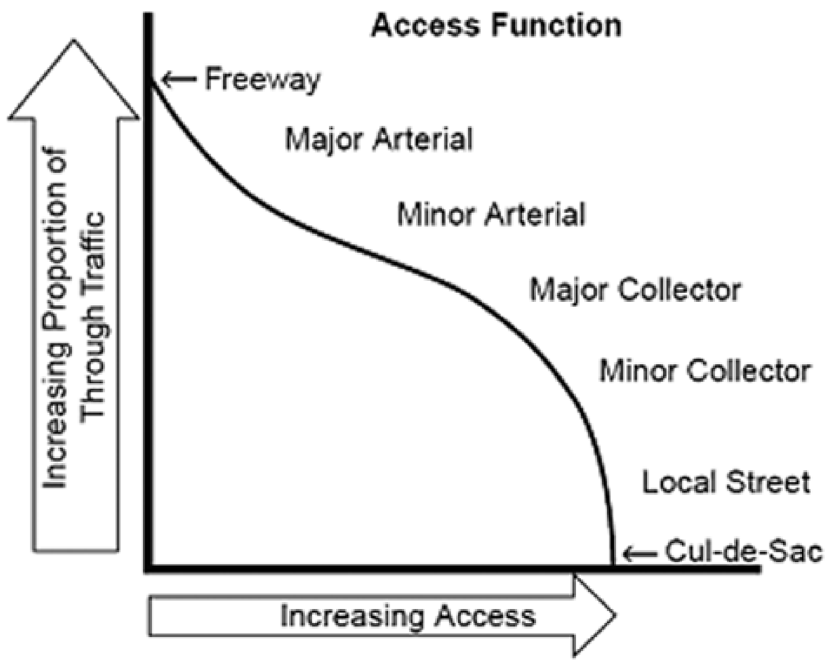


Figure A.1 Conceptual roadway functional hierarchy *(2)*

mobility should provide less access, whereas those considered local should provide more access. In between are road classifications that require standards to define allowable access while ensuring free flow of traffic and crash minimization *(5)*. Inadequate access can be frustrating to both business owners and their customers while inappropriate or excessive access can lead to traffic congestion, delays, crashes, and resultant economic and environmental impacts *(3, 4, 6)*.

Due to increasing traffic volumes coupled with rising construction costs, transportation agencies are more interested in alternate techniques and projects, such as access management, to effectively address the

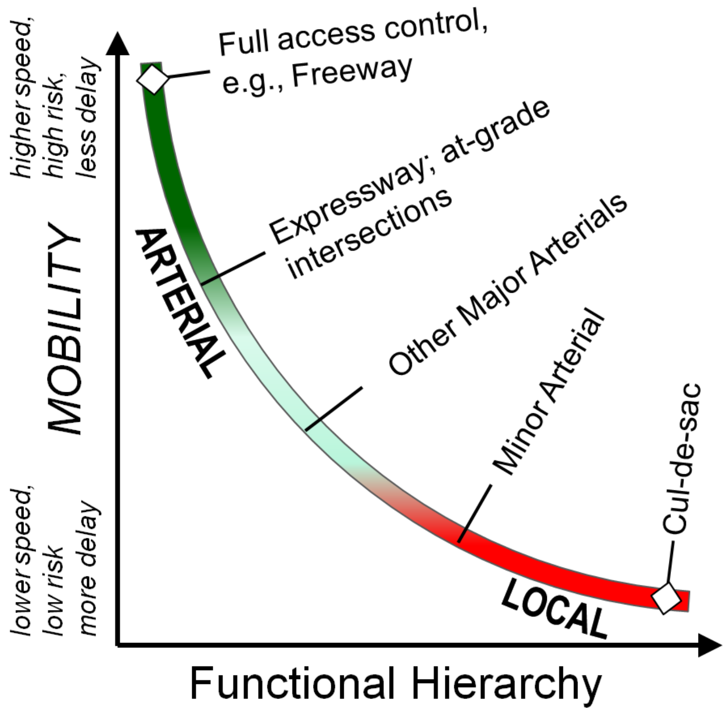


Figure A.2 Access Control Hierarchy *(7)*

problems resulting from traffic congestion *(3, 5, 6, 8, 9)*. These transportation agencies are seeking to increase mobility along arterials by providing higher operating speeds and level of service while providing appropriate access *(10)*. Effective access management implementation has been shown to improve efficiency of arterial roads through increased capacity and reduced congestion, delay, and travel times and improve safety through reduced crashes or crash severity *(3, 11-18)*.

However, implementation of access management techniques without a long-term commitment can become a cyclical problem, as shown in Figure A.3 *(19, 20)*. When first constructed, conventional streets and highways generally have few driveways and low crash experience. However, as development occurs and traffic increases, more driveways are added and crash frequency and rate climbs. This generates the need or the demand for improvements or reconstruction to maintain traffic but reduce delay. However, implementation of these improvements often leads to additional development and traffic that likely results in increased congestion, delay, travel times, and crashes if effective access management to preserve the integrity of the roadway system has not occurred. This again generates the need for improvements, which for developed areas can be quite costly and disruptive to both the public and area businesses. However, appropriately implemented access management avoids this cycle by considering accessibility options throughout the cycle; thus, continually improving traffic safety and operations. *(14, 21, 22)*.

In summary, state and local governments can use access management to improve traffic flow, preserve capacity, and ensure safe operation on both rural and urban roadways. The result of effective access management can include lower costs, increased efficiency, improved safety, reduced environmental impacts, and increased economic vitality of the businesses and communities *(23)*.

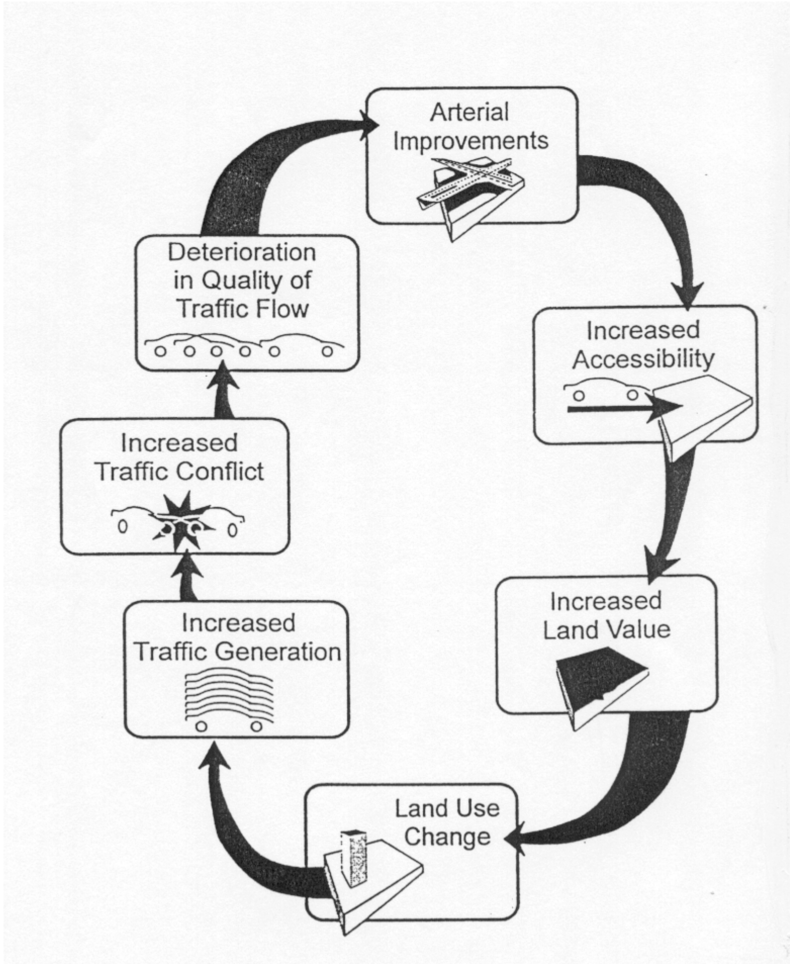


Figure A.3 Transportation-Land Use Cycle *(19)*

A.2 Access Management

Access management involves the careful management of the roles that roadways serve in providing both mobility to through traffic and providing access to property and land use, as shown in Figure A.1 *(8, 19, 24)*. Management occurs through "the systematic control of the location, spacing, design, and operation of driveways, median openings, interchanges, and street connections to a roadway" *(25)*. This includes median treatments and auxiliary lanes as well as the appropriate spacing of traffic signals, whether these are at intersections or driveways. Through use of access management, transportation agencies seek to provide vehicular access to adjacent land use while preserving the safety and efficiency of the transportation system. System efficiency is generally measured by capacity and speed while safety is measured by frequency and rate of crashes *(1, 2, 4, 8, 11, 25-32)*.

Well-implemented access management balances the dual role of roadways to provide safe and efficient use of the network by specifying acceptable spacing and combinations of access through application of traffic engineering principles *(1, 19, 21, 33)*. Access standards should be set and incorporated into legislation, and designs should match these standards *(1)*. Access management involves careful planning of access and reduction of potential conflict points through land use and zoning policies to increase the flow of traffic and reduce crash rate and severity *(4, 5, 7, 11, 34)*. Evaluation of the suitability of sites for particular types of development as well as related site access is a central theme with anticipation and prevention of safety and congestion problems as sub-themes *(1, 19)*. Along with these, access management also involves the "continuity and connectivity of the roadway network" *(15, 35)*. Access management may be implemented through two basic legal powers, police power and eminent domain. The former allows restriction of individual actions in the interest of public welfare and provides sufficient authority for most access management applications (e.g., highway operations, driveway location, driveway design, and access denials). The latter allows acquisition of property for public use with compensation for the loss and eminent domain must be cited for certain access management applications (e.g., building local service roads, buying abutting property, acquiring additional right-of-way, and taking access rights). Denial of direct access can usually be accomplished through police power if alternate reasonable access is available. However, access management can be most effective when planners, engineers, and developers all work together rather than applying these powers *(1, 26)*.

To this end, access planning and design should incorporate both the public and private sector components of the access system, including the public and private roadways and the land use itself *(1)*. Neglecting or ignoring one component would "merely transfer rather than alleviate problems" *(1)*. Access management involves application of techniques which involve established traffic engineering and roadway design principles, namely conflict point limitation, conflict area separation, acceleration and deceleration impact reduction, turning vehicle separation from through traffic, intersection spacing improvement, and adequacy of on-site storage. *(1, 5, 7)*. For example, to limit conflict points and separate conflict areas, transportation agencies can increase the spacing between accesses, specifically signalized accesses but also unsignalized intersections and driveways, install median treatments to limit left turns, use frontage or backage roads, or establish land use policies to limit access *(5)*.

The "foundation of any access management program" *(25)* is definition and application of the road classification system, as indicated in Figures A.1 and A.2, transitioning from full access control freeways to limited access control cul-de-sacs *(19, 36)*. Classification of roadways is based upon functional criteria reflecting their importance to mobility *(19)*. For each roadway classification, allowable access levels are defined, including access spacing criteria. Normal traffic engineering and design principles are then applied to each access. To encourage compliance, transportation agencies should develop and adopt of access management policies, guidelines, and procedures which cover these topics *(19, 36)*.

NCHRP 548 *(26)* restates much of these concepts within a list of principle access management methods, including: acquisition of access rights; access management regulations; policies, directives, and guidelines; land development regulations; geometric design; and development review and impact assessment. Transportation agencies may acquire access rights, and this is an effective and long-term solution. This solution is usually applied to major roadways such as freeways, expressways, and others. Access management regulations can be applied to define or control access spacing and manifest agency legal police power through access codes, administrative rules, or local ordinances. Adoption of specific access management policies, directives, or guidelines address non-regulatory aspects to control design and operations to protect the public welfare. Land development regulations are generally local and address access management through land use, development review, and permitting. These again seek to protect the public welfare but more specifically the roadway user. Geometric design elements that encourage or enforce access management techniques such as limiting conflict points can be set forth in design manuals. These design elements may be tied to the road classification to promote access management. Development review and access management encourages consistent application of access management, fostering communication and understanding.

Consistent with the prior discussion, South Dakota initiated a review of the state's highway access control process during the early 2000s *(14, 28)*. The principle purpose of this review was to update South Dakota's policies from the 1970s "to develop improved access policies, design guidelines, and procedures for applying them." These improved policies, guidelines, and procedures were intended to "provide an improved and consistent basis for managing highway access to":

- improve safety through minimization of crash frequency, severity, and cost;
- preserve highway and road investments by preserving the functional integrity;
- provide consistency and predictability of approach; and
- improve coordination and consistency between state and local agencies.

The principles of the South Dakota Department of Transportation (SDDOT) Access Management Policy *(28)* are:

- Protect the public's investment in the highway system by preserving its functional integrity through the use of modern access management practices.
- Coordinate with local jurisdictions to ensure that the state's access policy and criteria are addressed early in decisions affecting land use.
- Provide advocacy, educational and technical assistance to promote access management practices among local jurisdictions.
- Undertake proactive corridor preservation through coordinated state/local planning and selective investment in access rights.
- Provide a consistent statewide management of the state highway system.
- Maintain and apply access criteria based upon best engineering practices to guide driveway location and design.
- Establish and maintain an access classification system that defines the planned level of access for different highways in the state.
- Establish procedures for determining developer responsibilities for paying for improvements that address the safety and capacity impacts for major development.
- Enhance existing regulatory powers and statutory authority to ensure safe and efficient access.
- Permit exceptions to the SDDOT's access criteria only where retrofit techniques have been applied.

These principles are consistent with the literature.

A.3 Problem Statement

The consensus from literature is that access management, when applied effectively, helps maintain the functional integrity of the roadway network and maintaining traffic operations and safety. An additional and growing consideration is the environmental impacts of traffic through emissions and fuel consumption. Conversely, inadequate and ineffective access management factors greatly into operational deterioration by eroding the ability of a roadway to serve traffic and surrounding land use. Ill-managed access management can lead to an overabundance of driveways that are improperly located and designed driveways, poorly spaced and coordinated signalization, and insufficient storage for turning vehicles. These problems degrade the character and capacity of the roadway and contribute to increased congestion, delay, crashes, driver confusion, and environmental concerns *(1, 8, 11, 19, 24)*. Additional symptoms of poor access management include: numerous brake light activations by through vehicles, neighborhoods disrupted by through traffic choosing alternate routes, requests to widen a route or build a bypass, decreases in property values, and increased commuting time, fuel consumption, and related vehicle emissions *(7, 19)*. Economic costs due to wasted time, fuel consumption, and premature mortality resulting from congestion is estimated to be in the billions of dollars *(37)*. In South Dakota, driveway-related crashes result in a loss of approximately $36.5 million each year *(28)*. NCHRP 420 (33) reports that over 55% of arterial crashes are access related with the percentage in urban areas higher at 65% to 75% *(7)*. In summary, poorly managed roads are an inefficient use of taxpayer funds *(24)*. However, business owners, city officials, chambers of commerce, and transportation agencies remain concerned about the impact of retrofit access management projects on business vitality, especially for commercial or retail land use *(6, 38)*. Businesses that depend on pass-by traffic (e.g., gas stations) are greatly concerned regarding the potential reductions in revenue resulting from access management implementation *(5)*. Therefore, a need exists to better assess potential application of access management practices, especially for roadways experiencing issues *(1)*.

However, no locally calibrated tool currently exists that captures the complexity of the current and future public benefits of proposed access management for estimating the financial and other benefits and comparing them with the associated financial costs. The benefits may be related to many local conditions, including land use and zoning, roadway type and functional classification, roadway network structure, traffic volumes, pedestrian and bicyclist volumes and characteristics, and the locations and other characteristics of access points. Given that many outcomes (i.e., safety and traffic operations) are related to human factors that are often unaccounted for in research, estimates of safety effects and operational changes associated with general access management methods are provided in the *Highway Safety Manual* (HSM) *(39)* and the *Access Management Manual (25)*. Also, more specific, complete estimates of the effects of access management methods on public benefits that are locally calibrated are desired when making decisions related to the value of the investment.

Given the potential improvements to safety, traffic operations, environment, and the local economy, access management has the potential to be a useful tool for engineers and planners. However, the exact benefits that could be obtained in South Dakotas' cities and towns is unclear. The safety estimates from previous research are unlikely to apply to South Dakota conditions. The impacts of access management on traffic operations have been shown to be estimable using traffic simulation software. The economic benefits of access management has not received extensive attention in the research literature, but has been shown to have positive impacts when properly applied. Therefore, this study seeks to 1) provide estimates of the safety impacts of specific access management methods and 2) provide a tool that compares the expected financial benefits (from safety and traffic operations improvements) to the expected costs. Also, other factors such as indirect impacts on the economy and the benefits to the environment will be incorporated into a decision-making process that can guide access management application decisions (including financial benefits, when possible).

To begin to address the study goals, the current literature related to access management benefits was reviewed. In addition, South Dakota access management professionals, both state and local, were interviewed. The literature review initially describes common access management techniques, including traffic safety and operations benefits followed by discussion of economic and environmental impacts. Each of these sections will provide some focus on specific access management techniques, including access spacing, signal spacing, unsignalized access spacing, median treatments, corner clearances, frontage/backage roads and others. Following the literature review, a summary of the interview process focuses on information specific to South Dakota transportation agencies from SDDOT and the cities of Sioux Falls, Rapid City, and Brookings, SD.

A.4 Description and Benefits

Access management could have several benefits, including traffic safety, traffic operations, economic impacts, and environmental impacts. An effective access management program can preserve capacity by reducing congestion and delay and improve safety through reduced crashes or crash severity, which then may minimize costly remedial roadway improvements *(1, 4-6, 8, 12, 24-26, 33, 40-47)*. Faster and safer travel is one result. Due to this faster, less congested travel, the environment can improve due to reduced delay-induced fuel consumption and resulting emission reductions (4, 12, 26, 40, 43) and avoidance of more environmentally damaging methods of mitigation *(4)*. Of course, with some access management techniques, increased travel distances may offset these gains somewhat. Another is reduced expenditure of public funds on road reconstruction, protecting public investment and freeing financial resources for other public needs *(1, 4, 24, 41)*. With construction costs rising, access management can replace or postpone more expensive capital expenditure options; however, these savings may be somewhat offset by compensation to landowners for property or access right acquisition and the actual costs of access remediation but supported by reduced displacement of businesses and homes and reduced comparative acquisition of additional right-of way *(4)*. Studies have also shown that retail business along corridors with managed access gained increased vitality and a healthier climate by allowing customers to reach the business within a reasonable time *(4, 6, 12, 28, 33, 41, 42, 45, 48, 49)*. One source *(19)* summarized the benefits of access management to many different users of the roadway as follows:

- Motorists – fewer crashes, reduced travel time, reduced travel delay, and lower fuel consumption
- Pedestrians and bicyclists – fewer driveways mean fewer conflicts with vehicles, pedestrian refuge in medians, and fewer pedestrian and cyclist deaths and injuries
- Bus riders – reduced travel time and improved schedule reliability
- Property owners – preserved private investment and limited through traffic in residential areas
- General public – more stabilized land use patterns, more coordinated land use and transportation decisions, preserved public investment in major thoroughfares, fewer crash-related deaths and injuries, reduced loss in property damage, reduced vehicular emissions, and maintained livable communities

To achieve these benefits, various access management techniques are available *(4, 12, 28)*. These techniques are implemented for a range of reasons and have differing impacts and levels of acceptance or resistance. Consolidation of access is design to limit the density of driveways and intersections and provide adequate spacing between access points. Traffic signal spacing seeks to promote the flow of traffic through a signalized corridor. Control of medians and openings and provision of right- and left-turn lanes seek to prevent or separate turning movements that negatively impact the flow of through traffic.

Another source *(32)* provides a table, shown in Figure A.4, which has these same techniques (now referred to as "strategies") but provides a match with applicable access management principles. The table also includes a priority level as determined through input from a panel of state and local representatives and availability of data, but this prioritization was specific to consideration in the study and thus removed. Finally, that same source *(32)*, reorganizes the prior table and adds an indication, shown in Figure A.5, of whether a particular strategy achieves a particular safety objective, whether it is limitation, separation, or reduction of conflicts.

The traffic safety benefits of access management have been shown by numerous studies, with studies consistently demonstrating that well-managed arterials are often significantly safer *(4, 8, 10, 29, 30, 43, 46, 50-52)*. These studies typically find reductions in crashes and crash rates, with both personal injury and property damage only crashes reduced. Though crash rates were not always reduced, crash severity generally was reduced through decreased frequency of the more serious collision types *(3)*. The effects of several access management methods on crash frequency are documented in the crash modification factors/functions (CMFs) in the HSM and the Federal Highway Administrations *CMF Clearinghouse* (CMF Clearinghouse).

Access management has been shown to have several benefits for traffic operations, increasing capacity and reducing travel time and delay *(43)*. Additionally, these benefits include 1) reductions in speed variation *(53)* and 2) total network travel time savings, which outweigh additional travel time for left-turning vehicles from the major road, in most cases *(2, 54)*. Access management projects have raised

AM Strategy	Applicable AM Principles	Priority
Establish unsignalized access spacing criteria.	Limit the number of conflict points. Separate conflict areas.	
Establish signal spacing criteria.	Locate signals to favor through movements. Limit the number of conflict points. Separate conflict areas.	
Establish spacing criteria for interchange crossroads.	Limit the number of conflict points. Separate conflict areas.	
Establish spacing criteria for median openings/crossovers.	Limit the number of conflict points. Separate conflict areas.	
Establish corner clearance criteria.	Preserve the functional area of intersections. Separate conflict areas.	
Provide median and accommodate left turns and U-turns.	Limit the number of conflict points. Separate conflict areas. Manage left-turn movements.	
Provide left-turn lane.	Remove turning vehicles from through-traffic lanes.	
Close or modify median opening and accommodate left turns and U-turns.	Limit the number of conflict points. Separate conflict areas. Manage left-turn movements.	
Provide TWLTL.	Remove turning vehicles from through-traffic lanes.	
Provide right-turn lane.	Remove turning vehicles from through-traffic lanes.	
Provide frontage/backage road.	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	
Provide internal cross connectivity.	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	

TWLTL = two-way left-turn lane; 1 = highest priority; 2 = secondary priority.

Figure A.4 Access Management Strategy Prioritization *(32)*

AM Principle	AM Strategy/Policy	Limit Conflicts	Separate Conflicts	Reduce Conflicts
Access spacing	Unsignalized access spacing	—	X	—
Access spacing	Traffic signal spacing	—	X	—
Access spacing	Interchange crossroad spacing	—	X	—
Access spacing	Corner clearance	—	X	—
Roadway cross section	Median type: TWLTL	—	—	X
Roadway cross section	Median type: nontraversable median	X	—	—
Roadway cross section	Median type: Replace TWLTL with nontraversable median	X	X	—
Roadway cross section	Directional median opening	X	—	—
Roadway cross section	Median opening spacing	—	X	—
Property access	Frontage/backage roads	X	X	—
Property access	Internal cross connectivity	X	X	—

TWLTL = two-way left-turn lane; X = the strategy/policy can achieve the specified safety objective.
—The strategy/policy does not accomplish the specified safety objective.

Figure A.5 Access Management Strategies Paired with Principles *(32)*

corridor peak hour service levels through increased operating speed and reduced congestion *(4)*. While access management treatments may result in increased travel distances, the increase in overall traffic speeds and decreased variation in traffic speeds typically leads to lower overall travel times, although this may not be true in some cases. The specific benefits related to differences in total network travel time are specific to each application and local traffic conditions, and the majority of research is based on case studies that use simulation software to analyze specific conditions *(2, 54, 55)*.

Several key factors have been identified as impacting the operations and safety performance of arterial highways that can be influenced by access management *(56, 57)*. These factors include access spacing, signal density and coordination, corner clearances, proximity to interchanges, driveway design and geometric design elements, median configuration, and land use. Specific impacts of these are discussed in the following.

A.4.1 Access Spacing

Access spacing is used to separate conflicts and consists of four primary techniques: traffic signal spacing, unsignalized access (including intersections and driveways) spacing, corner clearances, and interchange crossroad spacing *(32, 58)*. Guidelines for access spacing should consider allowable access levels appropriate to roadway classification, roadway speeds, and operating environments *(1)*. Each state likely has its own access spacing criteria with South Dakota's access location criteria shown in Figure A.6. These access spacing guidelines can be applied to new developments and to significant retrofits of

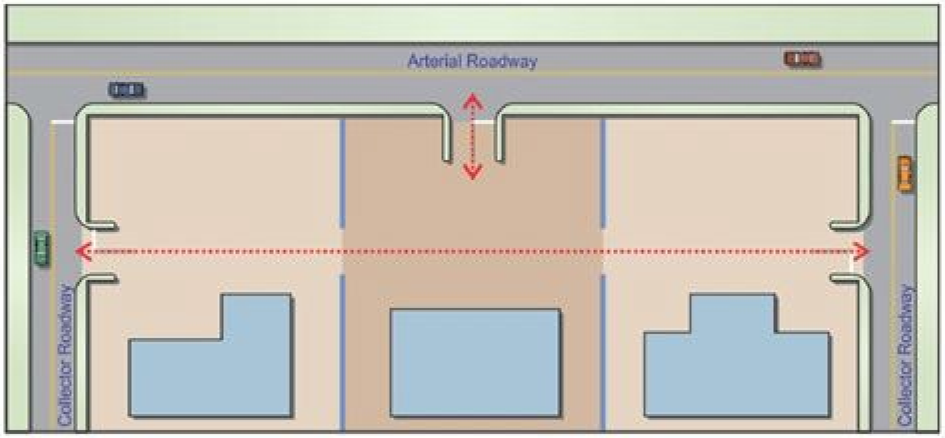
Access Class	Signal Spacing Distance (mile)	Median Opening Spacing (mile)	Minimum Unsignalized Access Spacing (feet)	Access Density	Denial of Direct Access When Other Available
Interstate	N/A	N/A	N/A	N/A	Yes
Expressway	½	½	2640	at half-mile increments	Yes
Free Flow Urban	½	½ F, ¼ D	1320	at quarter-mile increments	Yes
Intermediate Urban	½	½ F, ¼ D	660	at eighth-mile increments	Yes
Urban Developed	¼	¼	100	2 accesses/block face	Yes
Urban Fringe	¼	½ F, ¼ D	1000	5 accesses/side/mile	Yes
Rural	N/A	N/A	1000	5 accesses/side/mile	Yes

Figure A.6 South Dakota Access Location Criteria *(28)*

existing developments *(1)*. For the latter, when no reasonable alternative access option exists, non-conforming spacing may be necessary for land parcels that have existing access *(1)*.

One method to increase spacing between accesses is to encourage access consolidation *(28)*. Access consolidation reduces conflict points and separate conflict areas, with the latter of these facilitating possible right-turn lanes. These changes result in improved traffic flow and reduced crash frequency. Access consolidation can be accomplished by limiting businesses to a single ingress/egress point, encouraging shared accesses and inter-parcel circulation.

Inter-parcel circulation, also known as internal cross connectivity, promotes the implementation of shared access driveways with cross-access easements between adjacent properties *(32)*, as shown in Figure A.7. Internal cross connectivity allows vehicles to circulate between properties without reentering the arterial roadway. Access sharing, facilitated by internal cross connectivity, improves arterial capacity and decreases crash occurrence through reduced and separated conflict points. Additionally, the increased spacing between accesses along the arterial facilitates the addition of auxiliary deceleration and acceleration lanes, further improving operations and safety.

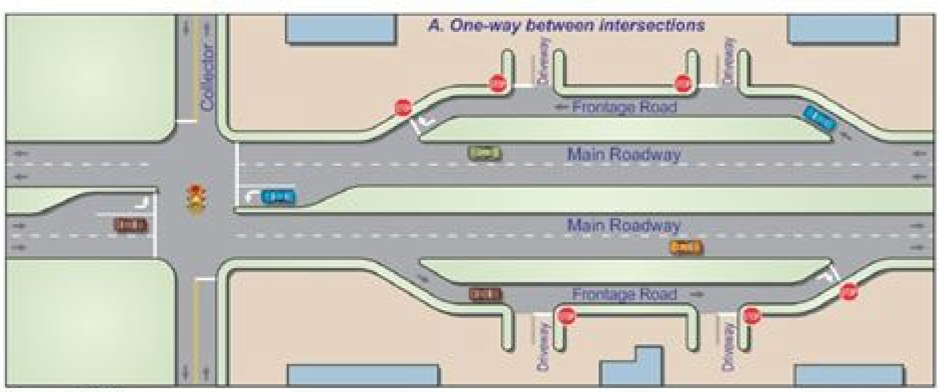


Source: FHWA.

Figure A.7 Internal Cross Connectivity *(32)*

Another method to increase access spacing is to close accesses where possible. Again, this might involve limiting businesses to a single ingress/egress point, but it may also involve relocating corner business accesses to the non-arterial road. Another option is to acquire access rights, but this option is typically more contentious. Both access consolidation and access closures should involve communication and flexibility, which may result in discussion of service roads to reduce access points from the arterial but continue direct access to businesses.

Service roads are either frontage roads or backage roads. Frontage roads, shown in Figure A.8, are generally aligned parallel to an arterial and located between the arterial and the businesses the frontage road serves *(32, 33, 59)*. Frontage roads provide access management by providing direct access to properties by first separating the business access-related traffic from the arterial through traffic at limited locations, usually adjacent intersections. The typical result is improved traffic flow and reduced frequency and severity of conflicts and crashes. Additionally, the increased spacing between accesses along the arterial facilitates the addition of auxiliary deceleration and acceleration lanes, further improving operations and safety. A backage road serves a similar purpose with location behind the business as the primary difference. Both can be configured for either one-way or two-way operation *(32, 33, 59)*.



Source: FHWA.

Figure A.8 Frontage Road *(32)*

An increase in access point frequency or density along a roadway generally correlates with a higher crash rate by increasing potential conflicts *(11, 30, 33, 38, 42, 45, 46, 50, 60-68)*. Specific roadway geometrics found to vary the impacts of accesses on roadways include lane width, turn lane presence, median type, operational speed, traffic volumes and characteristics, and land use. Studies have shown a strong relationship between access point density increases and crashes *(11, 46, 62)*. Doubling the frequency of access points corresponds to a 20% to 40% increase in crash rate. Research has determined, as shown in Figure A.9, crash rates climb with the frequency of unsignalized or signalized access points per mile.

Representative Accident Rates by Access Density - Urban and Suburban Areas				
Unsignalized Access Points per Mile	Accident Rates (accidents per millions VMT)			
	Signalized Access Points per Mile			
	≤ 2	2.01 - 4.00	4.01 - 6.00	> 6
≤ 20	2.6	3.9	4.8	6.0
20.01 - 40	3.0	5.6	6.9	8.1
40.01 - 60	3.4	6.9	8.2	9.1
> 60	3.8	8.2	8.7	9.5
All	3.1	6.5	7.5	8.9

Figure A.9 Accident Rates by Access Density *(27, 33)*

Conversely, arterial traffic flow and safety improves through conflict density reduction, increased distance for anticipation and recovery from turning maneuvers, and improved opportunities for turning lane designs as access spacing is increased *(69)*.

Direct access along arterial streets from businesses and residences causes speed and capacity reductions, with more congestion as access points increase *(5, 45)*. Capacity reductions have been reported to be as much as 2.5 mph for every 10 access points up to a 10 mph reduction for 40 access points per mile *(5, 33, 42, 52, 70)*. These values only reflect access points along the directional side of the arterial; however, opposing side access points should be considered where the impact may be significant. Given this, there exists the potential to improve operations, flow, and service level by reduction of access points, with urban arterials with high access control shown to function 30% to 50% better than similar facilities with little control *(11, 71)*. However, access control applied along corridor sections may have impacts on adjacent intersections, which could degrade arterial operational performance *(11)*.

A.4.2 Traffic Signal Spacing

Proper traffic signal spacing, as one special case of access spacing, is critical due to the impact traffic signals have on traffic flow and safety *(28, 32, 33)*. Signal spacing should consider both public and private entrances *(1)*. Most of the delay motorists experience in urban environments is due to traffic signals *(28, 33)*. Signals constrain capacity, especially during peak travel periods, and can result in queueing and spillback. Signals that are randomly located, ineffectively coordinated, or improperly timed cause delay throughout the day. Signals that are closely or irregularly spaced, as shown in Figure A.10, reduce travel speeds and generate excessive stops. All these lead to poor traffic flow and safety by contributing to more crashes.

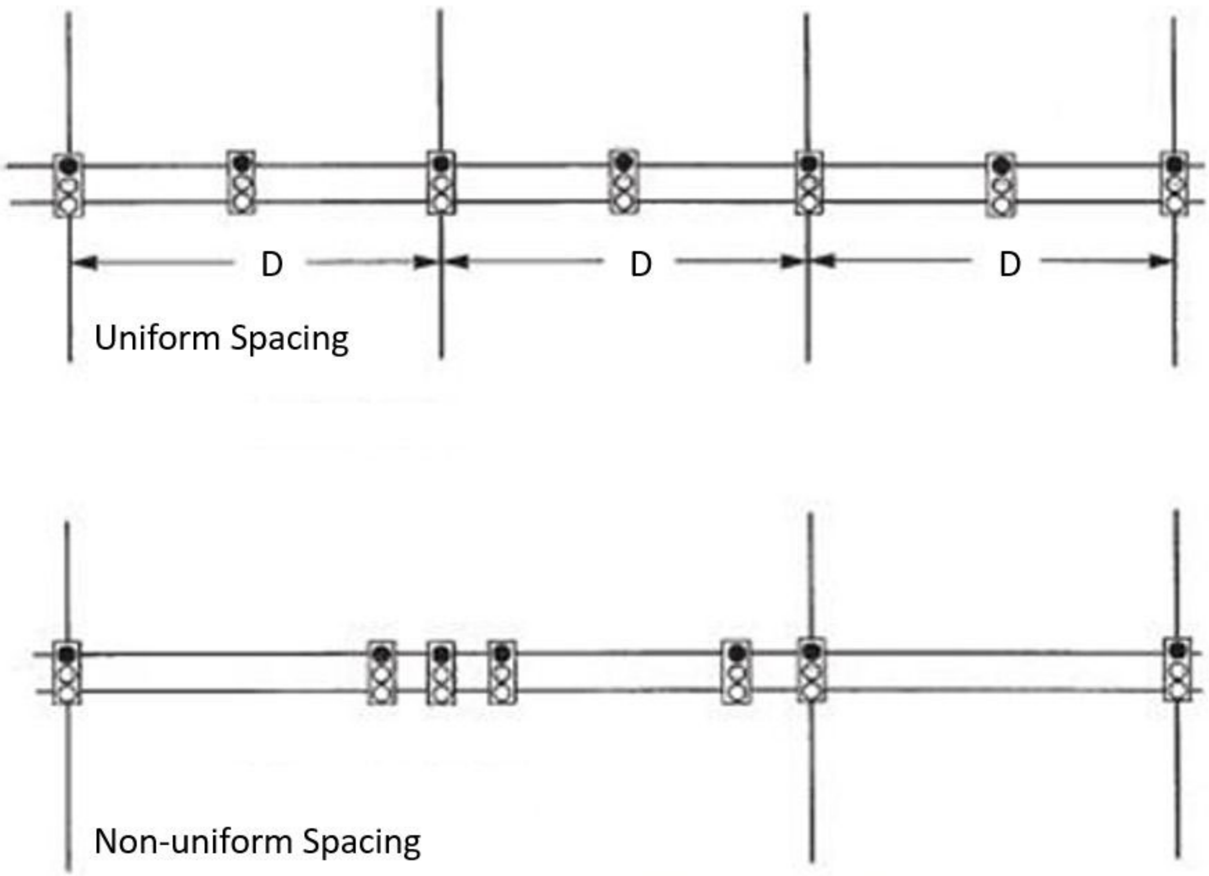


Figure A.10 Traffic Signal Spacing *(32, 33)*

Appropriate signal spacing depends on the speed and traffic flow, but studies have shown that signal densities greater than 2 per mile have a significant impact on congestion and safety *(5, 31, 32, 33)*. Decreasing signal density by increasing signal spacing improves traffic flow, reduces congestion and crashes, and improves air quality *(5)*. In addition to the frequency or density of traffic signals, uniformity of signal spacing, as shown in Figure A.10, is also critical. Uniformly spaced signals with optimal frequency/density again results in improved efficiency and safety *(31, 32)*. To maintain traffic flow, additional signals, including driveway signalization, should be located where impedance of progressive movement of traffic is minimal *(1, 28)*. Analysis of the impacts should consider cycle length, prevailing speed, and signal warrants.

More specific to traffic signal spacing, increasing signal spacing reduces crash incidence *(5, 33)* with a review of crash data from several states and previous studies determining the converse *(5, 33, 56, 72)*, as shown in Figure A.11.

Signals Per Mile	Crashes Per Million VMT
Under 2	3.53
2 to 4	6.89
4 to 6	7.49
6 +	9.11

Figure A.11 Correlation of Signal Density with Increased Crash Rate *(5)*

Research has shown significant impacts of traffic signal spacing on operations, specifically related to speed and travel time *(5, 27, 33)*. Each additional traffic signal per mile reduces speed around two to three mph. As detailed in Figure A.12 and using two traffic signals per mile as base, each additional signal decreases travel time.

Percent Increases in Travel Times as Signal Density Increases	
Signals per Mile	**Increase in Travel Time (%)***
2	0
3	9
4	16
5	23
6	29
7	34
8	39

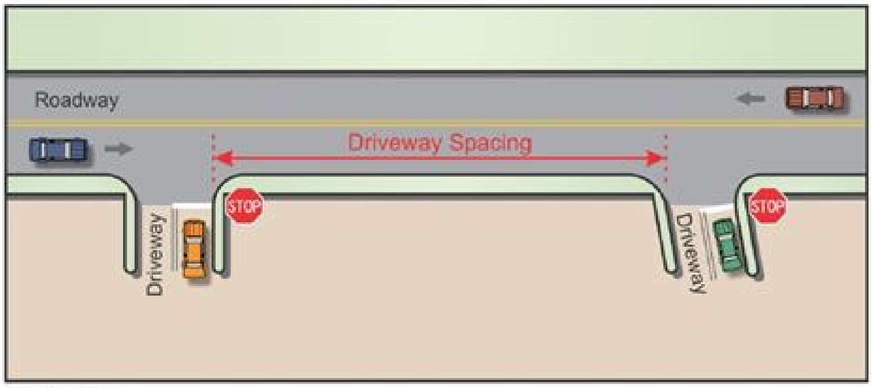
* Compared with 2 signals per mile.

Figure A.12 Signal Density Impacts on Travel Time *(27, 33)*

A.4.3 Unsignalized Access Spacing

Unsignalized access includes both public street connections as well as private driveways. These accesses are far more prevalent than signalized accesses and serve as the primary ingress/egress points for neighborhoods and businesses. Private property has the right of access to public roadways; however, this right is not unlimited *(73)*. Instead, this right of access is balanced against the public good and general welfare of the traveling public. Access management attempts to manage driveway frequency through various means, including location of accesses, limitation of number of accesses per parcel, provision of alternative access, and encouragement of joint or shared access *(73, 74)*. Management of driveways is more restrictive for arterials as these are designed for greater mobility and less access.

Unsignalized access spacing impacts traffic flow and safety through frequency of conflicts and separation of conflict areas *(32)*. Vehicle ingress/egress along roadways often slows through traffic and the speed differential between through and turning traffic increases crash potential *(32)*. Public agencies exert much control over intersection spacing and, nominally, these should be spaced regularly at sufficient distances. However, driveway spacing, shown in Figure A.13, is generally less well regulated, with disproportionately higher frequency of crashes *(32, 75)*.



Source: FHWA.

Figure A.13 Unsignalized Driveway Spacing *(32)*

Corridors without appropriately managed access often result in inadequate spacing, whereas well-managed corridors usually have good spacing as shown in Figure A.14. Inappropriate or inadequate driveway

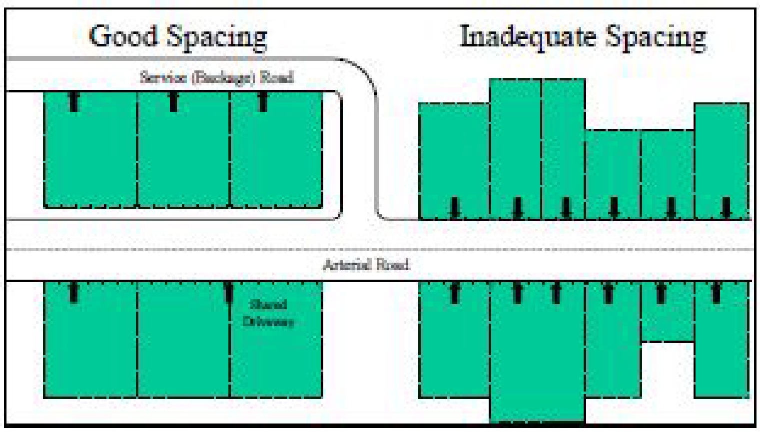


Figure A.14 Good and Inadequate Driveway Spacing *(74)*

spacing, due to both frequency and separation, increases conflicts and driver confusion *(3, 5, 33, 74, 76)*. Conversely, fewer driveways that are further separated allow for more orderly ingress/egress to land parcels, which improves traffic flow and safety for both motorists and non-motorists *(5, 38)*. Traffic operational factors that favor increased driveway spacing include weaving and merging distances, stopping sight distances, acceleration rates, and turn lane storage distances and, from a spacing perspective, driveways should be considered as intersections *(1, 28)*. Spacing guidelines should consider these traffic operational factors but be balanced with land use and economic reasons and reflect access categories, roadway speeds, and traffic generator size.

Regarding unsignalized access spacing, studies have shown significant impacts on the safety performance of roadways *(5, 30, 31, 33, 45, 56, 69, 75, 77-81)*. Crash rates have been shown to increase with greater frequency of driveways and intersections, with each additional access elevating crash frequency potential, as shown in Figure A.15. Fully access-controlled roadways have lower crash rates but arterial roadways with dense spacing often have double or triple the crash rates of those with widely spaced accesses. Driveways and intersections are natural points of conflict, whether between vehicles or between vehicles and pedestrians. With regard to conflicts between vehicles, these usually result either from slowed turning vehicles or queued vehicles due to an access point. Numerous potential conflicts also exist between vehicles and pedestrians, with potentially disastrous results when conflicts occur *(82)*. Furthermore, the trend of increased crash rate occurs whether the environment is urban or rural, with commercial and industrial driveways consistently influential *(5, 56)*. However, for the rural environment, the impact may be related to the clustering of driveways, with clustered driveways experiencing fewer crashes than isolated driveways. Longer driveway separations eliminate conflicts and confusion due to overlapping driveway operations, simplifying turning maneuvers, and decreasing crashes *(34, 82)*. With regard to congestion, reduced driveways are clearly advisable with the presence of slow-moving vehicles due to numerous access points impacting free flow speeds significantly *(5)*.

A.4.4 Corner Clearance

Corner clearance is the minimum distance required between an intersection and the nearest crossroad intersection, including driveways *(28, 32-34, 38, 59, 75, 83, 84)*, as shown in Figure A.16. Minimum

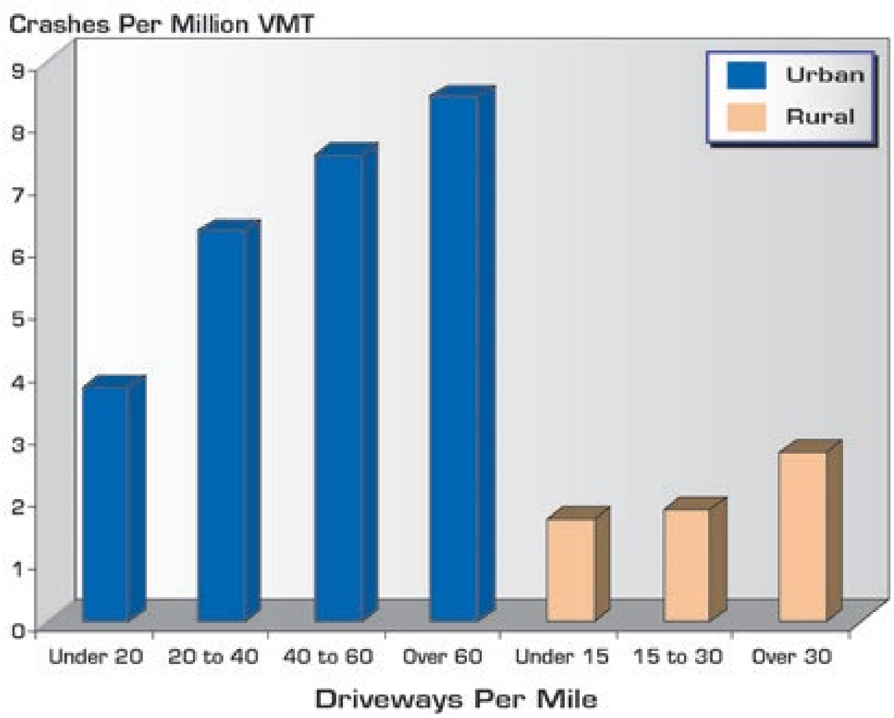


Figure A.15 Correlation of Driveway Density with Increased Crash Rate *(5)*

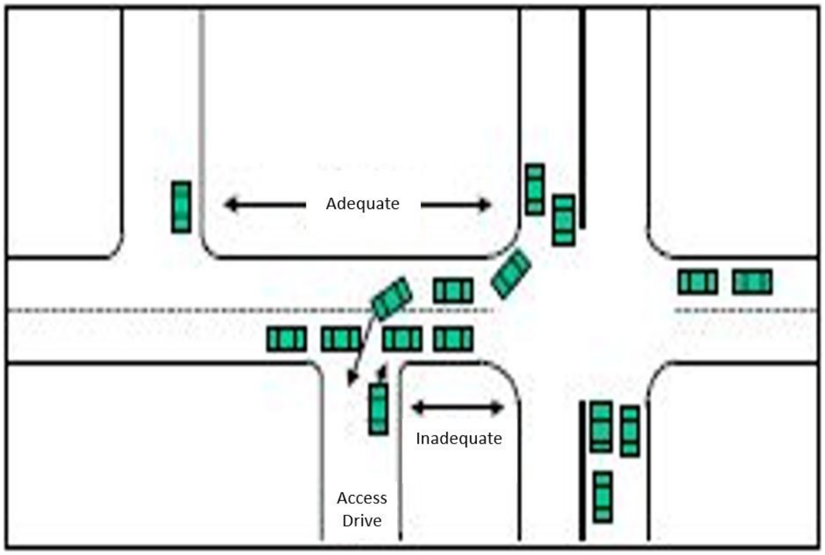


Figure A.16 Corner Clearance *(83)*

corner clearances are meant to protect the functional integrity of intersections and, as such, driveways should be located outside the functional area of an intersection, as shown in Figure A.17. The functional

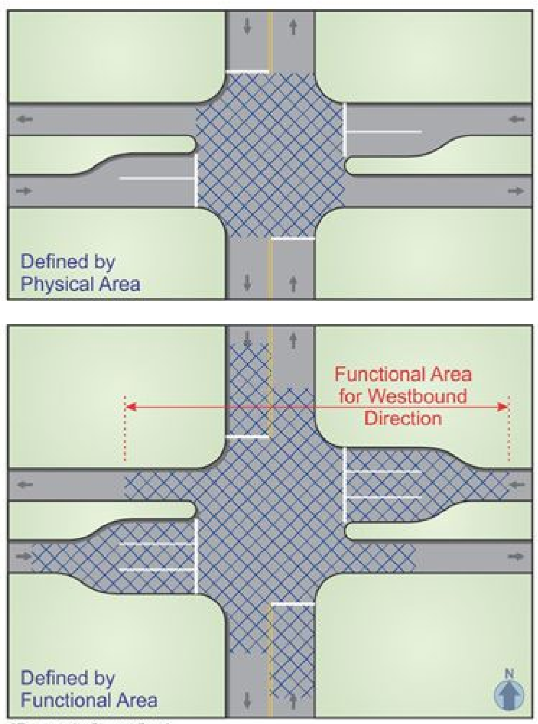


Figure A.17 Intersection Functional Area *(32)*

area of an intersection extends beyond the physical intersection limits to include the longitudinal limits of auxiliary lanes, the area upstream of an intersection where deceleration, maneuvering, and queueing take place, and the area downstream of an intersection where driveways could generate queues extending into intersections due to conflicts *(28, 32, 33, 59, 73, 75, 83)*. However, corner clearances are limited by the property frontage available and improvement or retrofit is not always practical *(33, 38, 59)*.

Accesses located within the functional area of an intersection complicate movements due to the existent natural intersection conflicts being complicated by additional driveway-related ingress/egress conflicts *(34)*. Operational and safety problems resulting from inadequate corner clearances include mutual blockage of movement for through and driveway traffic, inability of entering or exiting driveway traffic to enter left-turn lanes, insufficient distance for traffic entering an arterial street, inadequate weaving maneuver distances, and confusion and conflicts related to right-turn signal interpretation *(25, 28, 33, 34, 38, 59, 84)*. These problems equate to reduced capacity through increased congestion and delay and decreased safety through increased crashes near intersections.

Access management provides criteria to increase corner clearance including driveway closure, consolidation, or relocation to side roads or to the furthest property line edge; turn lane provision; turn movement prohibition; and establishment of larger minimum corner lots size *(11, 28, 33, 38, 59, 84)*. Adequate corner clearances are most easily established prior to land subdivision and approval of site development *(33, 59)*. Providing adequate corner clearances through these means reduces conflict frequency and provides more time and space for vehicle turning and merging movements *(38)*.

Studies have shown that accesses within the functional area of intersections are correlated with increased crashes and crash severities *(33, 34, 56, 84-86)*, with commercial accesses particularly problematic. Driveway obstruction is a significant problem resulting from poor corner clearance, and intersections with multiple inadequate corner clearances are more crash prone *(33, 34)*. Factors relevant to increasing corner clearance include the standard intersection design criteria, including perception-reaction distance, weaving distance, transition distance, and storage requirements *(34, 86)*. Intersections with corner clearance that adhere to standards have fewer crashes and lower crash severities *(34)*.

Signalized intersection corner clearances significantly impact driveway opening capacity *(87)*. Additionally, reduced corner clearances reduce the flow rate depending on the actual distance to a driveway, the ingress and egress volumes, and the driveway design *(11, 88)*.

A.4.5 Driveway Width and Throat

Related to driveway frequency and spacing, driveway width impacts the speed differential of through traffic and turning traffic *(89)*. Turning vehicles that are forced to slow markedly to enter a driveway increase the differential and increase the likelihood of crashes with faster moving following through vehicles. As this speed differential increases, the chance of severe crashes also grows. Older urban arterial streets tend to have many narrow driveways that only safely accommodate one vehicle, either an entering or exiting vehicle. Another common situation involves driveways that are too wide, possibly also without discernable boundaries or curbs, creating uncertainty about vehicle paths leading to operational and safety concerns. The more driveways, either too narrow or too wide, along a corridor, the more the concerns are magnified. However, a properly designed driveway creates a clear area for turning traffic to exit the roadway quickly with resulting improvement in traffic flow and safety.

Driveway throat, as shown in Figure A.18, is the distance from the edge of the traveled way to the driveway point where conflicting traffic movements are encountered *(73)*. Other terms for driveway throat include driveway connection depth, reservoir length, stacking distance, and storage length. A major objective of access management is to negate driveway queues that extend into the public roadway through traffic *(73)*. Proper design of throat length, internal circulation, and internal circulation within a site can minimize queues. Conversely, queueing for exiting traffic, though this does not impact operation of the public roadway, is impacted by throat length as well as number of egress lanes and traffic control at the public intersection. The exiting queues can impact site circulation and operations within the parking lot *(73)*.

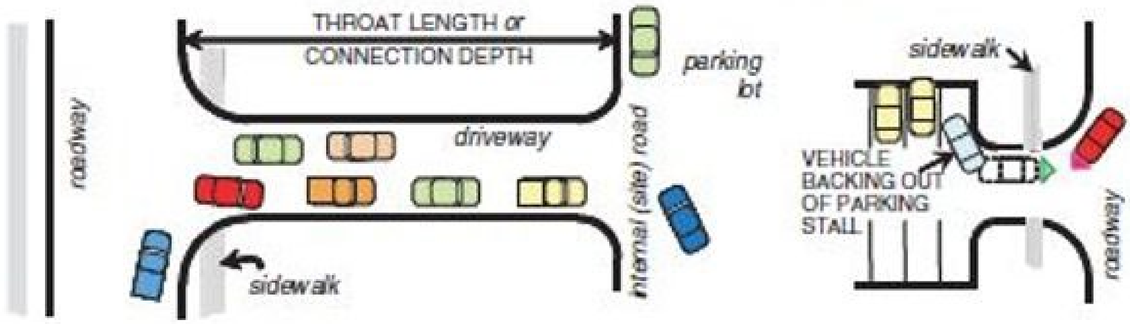


Figure A.18 Driveway Throat *(73)*

Adequate throat length, as shown in Figure A.19, allows vehicles to stack (queue) in the driveway throat rather than on the public roadway, avoid interaction with vehicles entering or leaving parking stalls, and reduce driver confusion, traffic conflicts, and crashes *(90)*.

However, insufficient throat length along with poor site planning, as shown in Figure A.20, causes any entering vehicle queues to extend into the arterial, interrupting traffic flow and creating potential for crashes *(90)*. Deeper lots not only allow for extended throat lengths but also allow for buffer space between developments, off-street parking, and the arterial *(74)*. These deep lots, along with minimum driveway spacing requirements, shared driveways, restrictions on multiple driveways, access via service roads, and internal cross connectivity, can facilitate access spacing impacts.

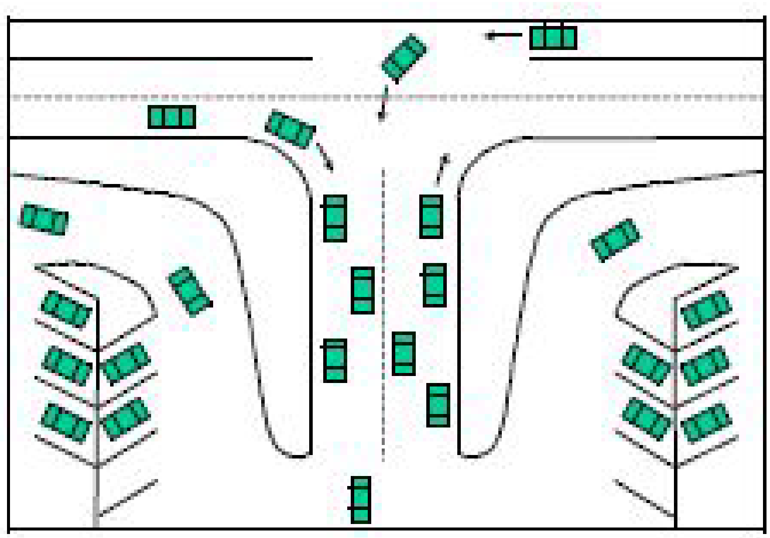


Figure A.19 Adequate Throat Length *(90)*

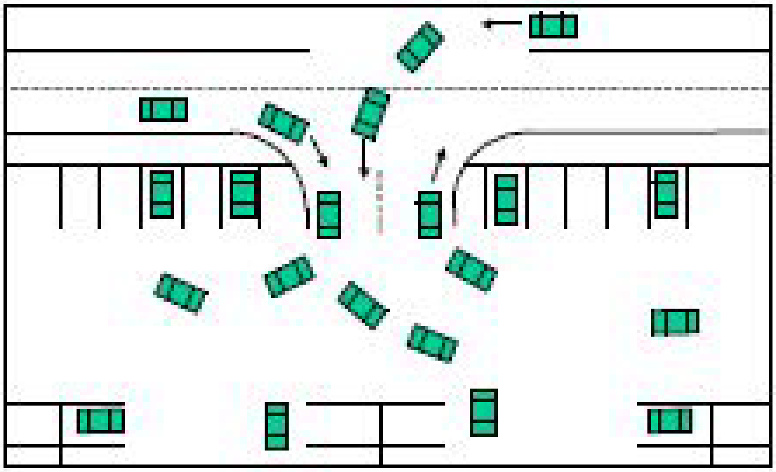


Figure A.20 Insufficient Throat Length *(90)*

A.4.6 Turning Movements

Arterial conflicts due to accesses are generated by vehicles turning into (entering) these accesses or out of (exiting) the accesses. Turning movements can be either right turns from the lane adjacent to the business or left turns from the lane on the other side of the arterial road centerline.

Right turns typically have minimal impact on capacity and crashes when compared with left turns as right turns do not conflict with opposing traffic. Due to this, provision of right-turn deceleration lanes has a less substantial impact on traffic flow and safety improvement *(5)*. These lanes also reduce the potential for rear-end collisions due to slowed turning vehicles and improve arterial capacity by removing these vehicles from the through traffic lanes *(91)*.

Right turn movements into driveways generally only cause issues when vehicles are slowed to enter or when vehicles are queued due to a turning vehicle. Usually, the conflicts resulting from right turns result in relatively minor rear-end crashes *(92)*. Right turn lanes were found to reduce rear-end crashes by 30%, reduce crash injury severity, and decrease costs by 26%. Interestingly, rear-end crashes at driveways, compared with intersections, were found to have 1.3 to 1.9 times the relative risk.

Right-turn movements from through traffic have a clear impact on delay to this traffic, and this delay increases exponentially as additional vehicles are impacted *(5)*, as shown in Figure A.21. Research

Right-Turning Vehicles Per Hour	Through Vehicles Impacted (%)
Under 30	2.4
31 to 61	7.5
61 to 90	12.2
90 and up	21.8

Figure A.21 Right-Turn Movement Impacts *(5)* indicates that right-turn maneuvers from a two-lane arterial at unsignalized driveway or intersection can result in delay from 0 to 6 seconds per through vehicle *(91)*. Right-turn movements in the same situation on a four-lane arterial result in delay from 0 to 1 second per through vehicle *(91)*. Driveway grades influenced these values with flatter grades having less impact *(93)*. Added access points, especially commercial driveways, contribute noticeably to increased congestion and reduced capacity of the outside lane *(91)*. The addition of right-turn lanes diminishes the impact of right-turn maneuvers and therefore increase traffic flow and improve operations.

Left turns, especially from shared use lanes, pose more significant problems at both driveways and intersections by increasing conflicts, delays, and crashes and complicating traffic signal timing and coordination *(38, 94, 95)*. Under typical urban and suburban conditions, shared lane capacity might be reduced 40% to 60% as compared with a dedicated through lane due to left-turning vehicles blocking through traffic while waiting to turn *(33)*. As a result, left-turn treatments factor greatly into access management considerations and, depending on site specifics, may be accommodated, prohibited, diverted, or separated *(33, 38)*.

Left turns are typically accommodated by separating these movements from through movements with protected left-turn lanes, increasing capacity and safety along the arterial *(5, 33, 38, 95)*. Provision of left-turn lanes separates through and turning traffic; decreases delay and increases capacity by providing an area for deceleration and queueing outside the through lane; and reduces conflicts and associated crashes *(95)*. Many factors based on these gains should be considered before installing a left-turn lane, one of which is location.

Another consideration for left-turn treatment is types and location of access points. Access points can allow all movements or can restrict certain movements such as for right in/right out or right or left in/right out accesses. Access points for left-turn egress should conform with traffic signal spacing requirements and for median breaks involving major traffic generators *(1)*. Midblock left-turn lane treatments directly affect capacity and crash rates *(47)*. If midblock left turns are prohibited due to significant capacity or safety issues, indirect turns might be considered to facilitate traffic movement and access while reducing congestion and improving capacity and safety *(5)*.

Crashes involving left-turning vehicles comprise more than two-thirds of driveway-related crashes *(38)*. Due to this, numerous studies have shown substantial reductions in crashes, particularly rear-end crashes due to left-turning vehicle movements, related to installation of left-turn lanes *(5, 33, 34, 38, 59, 95-102)*. This reduction has often been reported as 50%, with a range of 18% to 77%, with rear-end collisions reduced of 60% to 88%. The reductions are primarily due to removal of the turning vehicles from the through lanes and improved sight distance for turning maneuvers. However, adequate storage is essential. For rural conditions, adding left-turn lanes at rural, two-lane highway intersections can reduce crashes as well *(97, 98)*.

Left-turn movements substantially improve roadway operations as the capacity of a shared left-turn and through lane is about 40% to 60% of a standard through lane *(5, 33, 38)*. However, addition of left-turn lanes has been shown to improve capacity from 25% to 33% and related delay reductions *(5, 38, 95, 103)*. Operations studies have indicated that removing left-turning vehicles from through traffic, whether through provision of left-turn lanes or prohibition of left turns, reduces delay *(59)*.

A.4.7 Medians

Accommodation, prohibition, and diversion or separation of left-turn movements can be accomplished through median treatments. These median treatments are an effective means for access regulation, improving safety, and reducing delay, but are often quite controversial with owners of abutting businesses commonly in opposition *(5, 11, 38, 104)*. The primary concerns are the limitation of direct access and, at least, the perception of reduced business.

The primary decision for median design is whether to install a continuous two-way left-turn lane (TWLTL) or a non-traversable median on an undivided roadway or to replace a TWLTL with a non-traversable median, either raised or depressed, as shown in Figure A.22 *(5, 33, 38, 59, 105)*. Selection of an alternative depends on factors related to policy, land use, and traffic, which include roadway classification and associated access management policy; land use type and intensity; opportunities for left turn rerouting on the supporting street system; existing driveway spacing and geometric design and traffic control features; volumes, speeds, and crashes; and potential costs for each alternative *(59)*.

Both TWLTL and non-traversable median treatments remove left turns from through traffic and consequently improve operations and safety. TWLTLs provide continuous access and operational flexibility and are generally favored by businesses *(28, 104)*. Non-traversable medians create a divided cross section, which provide better midblock traffic flow and improve safety *(28, 32, 33, 87, 104, 106)*. These non-traversable medians physically separate opposing traffic flows and reduce left-turn conflicts, as shown in Figure A.23 *(32, 33, 87)*. Non-traversable medians also provide pedestrian refuge at intersections, reduce driver workload through more clearly identifiable options, and comparatively reduce crash frequency and severity *(32, 87)*. However, adjacent intersections may be impacted by an increased number of U-turns as drivers exiting a driveway could only turn right even when desiring to turn left *(11, 104)*. These U-turn movements improve operations and safety *(11, 32, 33)*.

Median openings along an arterial are needed at signalized intersections and unsignalized intersections with collector streets. They may also occur where necessary but should be designed to minimize traffic flow impact and to be conducive to future signalization. Deceleration and storage for left-turn movements, if designed properly to separate slower turning vehicles from through traffic and prohibit ingress/egress from driveways within the functional area of an intersection, is an effective means for improved operations and crash reductions *(1, 107)*.

Numerous studies and syntheses have reported that median installations, regardless of type, improve safety when compared with undivided roadways with similar volumes and driveway density *(5, 33, 56)*. TWLTLs have been shown to have average crash rates significantly lower than undivided roadways *(3, 5, 25, 33, 34, 59, 108)*. Additionally, raised medians further reduce crash rates and crash severity when compared with TWLTLs *(3, 5, 25, 33, 34, 45, 56, 59, 76, 87, 108-117)*. As shown in Figure A.24, raised medians experience lower crash rates than TWLTLs and both have lower rates than undivided roadways. This relationship is shown with further detail in Figure A.25.

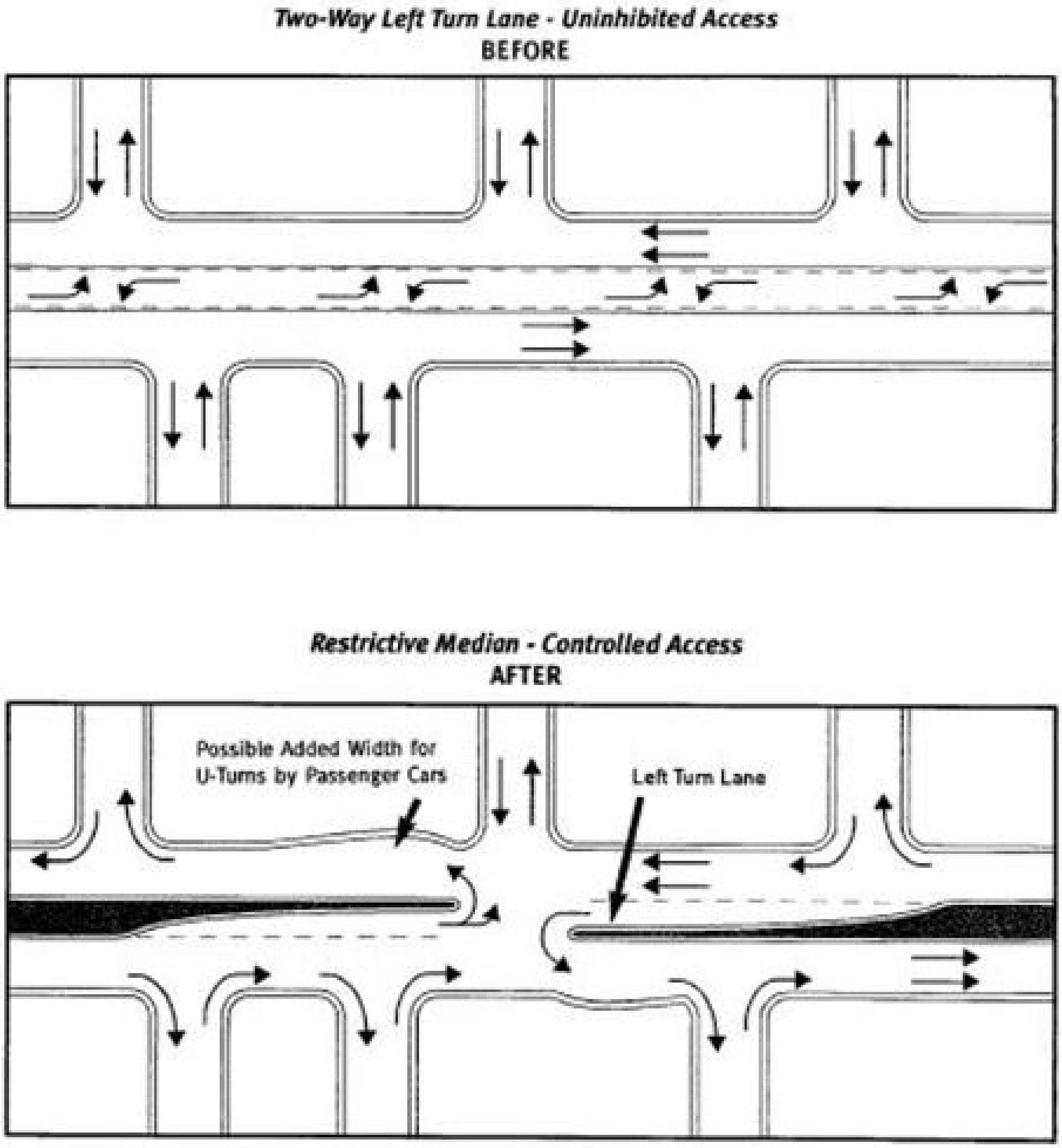


Figure A.22 TWLTL vs. Restrictive Median *(33)*

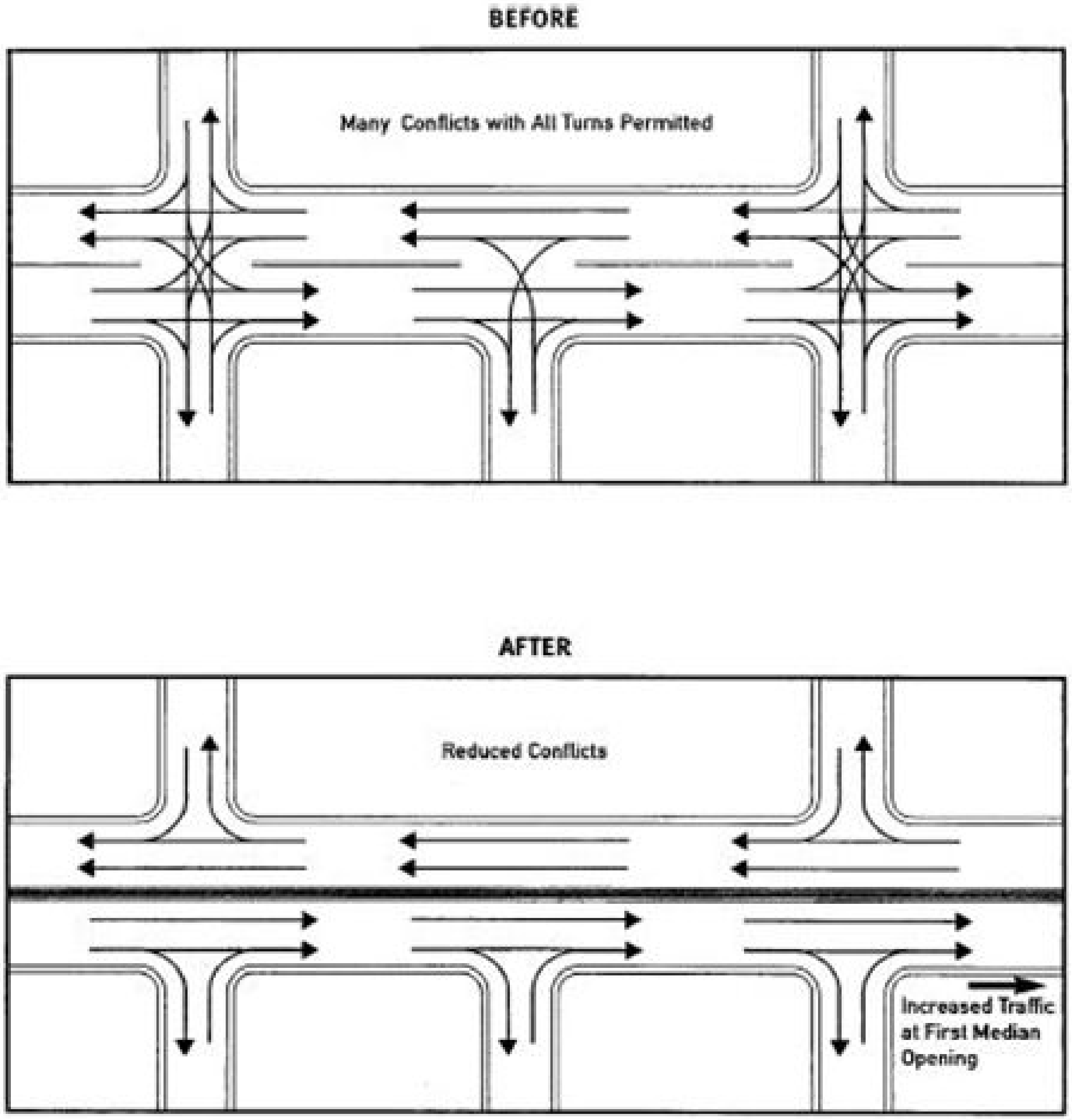


Figure A.23 Median Left-Turn Conflict Comparison *(32, 33)*

After replacement of a TWLTL with a raised median, reductions in sideswipe, rear-end, right-angle, left-turn, head-on, and pedestrian crashes are often noted *(3, 33)*. Appropriate median design is needed, however, to avoid shifting movements and crashes to intersections *(33, 34)*. Median designs, which provide for U-turns, have been shown to be safer than left turns due to reduced conflict frequency and severity, and U-turns that have been shifted to intersections do not have a large negative impact *(56, 97, 104, 113, 118)*. Finally, as compared with both undivided and TWLTL configurations, raised medians provide positive safety benefits for pedestrians by providing refuge and reducing pedestrian-involved crashes and associated fatalities markedly *(5, 82, 115)*.

Provision of medians, whether raised or TWLTL, yield similar delays to arterial traffic but have significantly lower delays than undivided roadways *(47, 87, 119, 120)*. Replacing a TWLTL with a raised median can result in increased travel time *(45)*. Hourly traffic conflict rates decreased for directional median openings as compared with full median openings *(121, 122)*. Raised medians are beneficial for "speeds greater than 45 mph, when the 24-hour design volume meets or exceeds 24,000 vehicles, when intersection queues are great or cannot be fully dissipated, or when the intersection demand/capacity ratio exceeds 0.9" *(87)*.

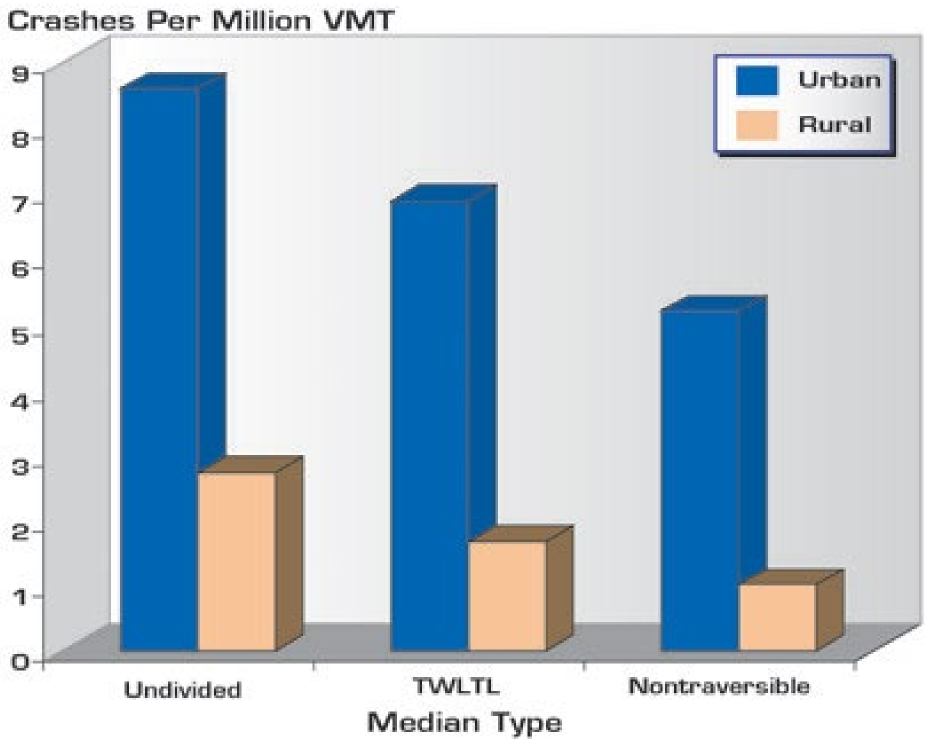


Figure A.24 Median Type Crash Rate Comparison *(5)*

Representative Accident Rates by Type of Median			
Total Access Points per Mile*	Accident Rates (accidents per millions VMT)		
	Median Type		
	Undivided	Two-Way Left-Turn Lane	Nontraversable Median
Urban and Suburban Areas			
≤ 20	3.8	3.4	2.9
20.01 - 40	7.3	5.9	5.1
40.01 - 60	9.4	7.9	6.8
> 60	10.6	9.2	8.2
All	9.0	6.9	5.6
Rural			
≤ 15	2.5	1.0	0.9
15.01 - 30	3.6	1.3	1.2
>30	4.6	1.7	1.5
All	3.0	1.4	1.2

Figure A.25 Accident Rates by Median Type *(27, 33)*

A.5 Economic Impacts

Changes to transportation infrastructure can have economic impacts on surrounding businesses and also impact land value. However, congestion and reduced safety translate into significant social and economic costs, with costs of capacity, wasted time, crashes, excess fuel consumption, and increased emissions translating to annual economic burdens of billions of dollars *(19, 37, 123, 124, 125, 126)*. Communities without effective access management often engage in cyclical roadway investments involving continual improvements and relocation where these changes increase activity and, in time, necessitate additional improvements to address decline in capacity and safety *(1)*. Access management, when carefully conceived and well-implemented, avoids this cycle and can save public funds, time, and lives by preserving capacity and maintaining suitable access and avoidance of massive reconstruction *(1)*. The cost savings due to reduced frequency and severity of crashes alone can more than offset the installation cost of access management treatments *(3)*. Application of access management techniques to reduce and separate access points, manage turning movements, and coordinate between businesses results in a visually pleasing, more functional corridor that protects business and public investment *(29)*.

Most of the literature on impacts of transportation infrastructure on land and property values focuses on public transportation investments *(127)*. Few studies consider the economic impacts of access management; however, those that do are most often based on case studies and do not provide general trends that can be expected. The economic impact of access management strategies are typically quantified using sales data and surveys of business owners to understand their perceptions of the infrastructure changes.

NCHRP Report 420 Impacts of Access Management Techniques provides a short discussion on how access management treatments might influence economic activity *(33)*. This report suggests that property values are determined based on a location's accessibility (i.e., the ease at which someone is able to get to or leave that location) and exposure (i.e., how many vehicles pass by that location). Exposure is less important to larger or unique sites—like a regional shopping mall—since these tend to attract traffic from a wide geographic area. However, sites that tend to rely heavily on pass-by traffic—like gas stations or fast food restaurants—are more impacted by reductions in exposure.

Implementation of access management, particularly installation of raised medians or other significant changes, is generally opposed by adjacent businesses *(4-6, 29, 38, 44, 52, 97, 103, 128-131)*. Business owners and managers are understandably skeptical and hesitant regarding potential detriments, in the form of reduced sales, due to access changes to their business. This skepticism can easily turn into political opposition. Businesses that serve pass-by traffic such as gas stations and fast food restaurants are particularly concerned, and not without cause. They are particularly concerned with changes in direct access through changes, such as driveway consolidation or raised median installation, with the latter perceived as having a large, negative impact on customers, sales, and property values. However, perceptions are often worse than reality, and numerous studies have shown that access management improves traffic operations and safety while maintaining or improving the business environment. Surveys and studies conducted for multiple corridors in Iowa, Florida, and Texas support this as business owners have indicated no sales decline and perhaps some improvement *(5, 6, 8, 29, 33, 38, 49, 128-130, 132-135)*. Additionally, the turnover rate for businesses impacted by access management in Iowa and Minnesota was similar to or lower than surrounding, non-impacted areas. Conversely, without access management, effective business access is already greatly reduced due to congestion, delay, and effective, traffic-related turn restrictions *(29)*. Customers, drivers, and truckers, when surveyed, have generally reacted well to access management projects that have improved traffic flow and safety despite some inconvenience *(4, 6, 8, 29, 33, 38, 59, 130, 132)*. Additionally, studies have shown that customers will adjust their patterns to continue patronizing specific establishments. When surveyed, business owners have supported this viewpoint that customers rank access as much less important than service and quality *(47, 52)*. However, it should be noted that access management treatments, especially those denying direct left-turn access, will require alternate routes and additional travel distance or time *(97)*. This delay should factor into access management implementation.

NCHRP Report 420 also provides a short discussion on how to measure these economic impacts due to median alternatives, since it is generally expected that this type of access management treatment would result in the largest economic impact of commonly used access management strategies. For example, the implementation of a physical median is expected to increase exposure due to improved roadway capacities. However, this is offset by the reduced accessibility of being able to enter a site that is cut off from the median and rerouting of vehicles that would have otherwise been able to make a left turn into the site. The net effect is often unknown. Restricting left turns along a median are also likely to reduce accessibility to businesses and properties along the affected arterial, although the overall combined impacts due to both exposure and accessibility depend strongly on changes in business conditions, traffic volumes, population, and other factors. While *NCHRP Report 420* provides guidelines on how to measure the maximum effect of a median closure as a function of the number of left turns entering an establishment and the proportion of these turns that represent pass-by traffic, it does not offer any insights to any net benefits that might exist.

Some case studies provide insights into the net economic impacts of various median alternatives *(136-138)*. Several different variables are considered, including the types of businesses and land uses that will be impacted by left-turn restrictions, along with the gross sales figures and employment trends. One of the earliest studies was conducted in three cities in Texas: Baytown, San Antonio and Pleasonton. These studies observed a general decline in sales (except for automotive type and general retail-type businesses) after median closures with no associated advantages to businesses located near the median opening. A case study in Ft Lauderdale, Florida, provided survey results that indicated most residents and customers favored a raised median after its implementation, although they were initially against it *(139)*. Two case studies in Atlanta, Georgia, also showed that while some individual businesses experienced loss of sales due to raised medians, there were very few overall negative impacts *(109)*. *NCHRP Project 25-4* evaluated the economic impacts of restricting left turns using revenue data from 9,200 businesses. This work found that gas stations, food stores, and personal service businesses did suffer sale losses, while general service businesses and durable goods retailers were not affected *(140)*. A study conducted in Utah showed that the raised medians increased the corridor-wide retail sales, whereas the perceptions of business owners were typically negative *(129)*. In a survey conducted before and after raised median construction in Texas, 86% of business owners reported no negative impact on their businesses *(141)*. Similarly, North Carolina State conducted a survey of 789 business near raised medians along with a control group and showed there was no statistically significant difference in revenue for most businesses except for single-location local businesses *(128)*. A separate study evaluated the reactions of businesses in Florida to the conversion of two-way left-turn lanes to raised medians *(142)*. In the study, 151 businesses along 10 separate locations where two-way left-turn lanes were converted to raised medians participated in interviews. The perceptions of the businesses in regard to the feasibility of truck deliveries, safety, and property access, general access to the businesses, traffic congestion, and the impact on the number of customers were assessed. The results indicated that the majority of businesses preferred the accessibility of two-way left turn-lanes, although raised medians were preferred for safety reasons as long as there was an adequate number of median openings.

Other studies have considered access management strategies on a corridor in a holistic manner, rather than only considering raised medians. For example, the Access Management Awareness Program in Iowa reported on access management projects that included driveway consolidations, corner clearance, and raised medians. This report found that only a few individual businesses reported sales losses; however, the majority of business did not suffer any losses *(8)*. In a study conducted in King County, Washington, surveys were conducted on business owners on six corridors with access management strategies ranging from no access control to fully controlled with right-in, right-out, and consolidated driveways *(143)*. The results show that most businesses reported a negative impact on revenue. The most comprehensive evaluation of the economic impacts of access management used data collected in the Houston-Galveston Area Council in Texas *(48)*. Three separate corridors where multiple access management treatments were implemented, including hooded left-turn bays, added travel lanes, raised medians, etc., were considered. Both retail and residential developments along principal arterials were studied, comparing taxable sales receipts and other economic factors with the period before access management was implemented and with the adjacent ZIP code zones. The economic data were collected through public accounts of taxable sales receipts. In general, for the three corridors considered an increase in sales was observed. Compared with a control zone, two corridors experienced a higher increase in sales, whereas one corridor experienced a lower increase in sales. The findings indicated that the economic activity for the corridors with access management either remained steady or increased with the implementation of access management projects *(48)*.

The financial benefits related to safety can be estimated using established costs based on the number and severity of crashes that occur *(144, 145)*. The financial costs related to traffic operations can be estimated using the difference in the average delay (or total delay) and the value of time, which has been found to be 50% of the average wage rates for an area when traffic is not congested and 100% to 150% of the average wage rates for an area in congested traffic conditions *(146, 147)*. Costs related to environmental impacts are less easily calculated and include benefits for which monetary value is not easily assigned (e.g., changes to the overall health of the public). Based on the limited economic analysis related to access management, the costs related to the local economy are likely to have either no impact or a slight decrease in the overall cost to the public and businesses.

A.6 Environmental Impacts

With roadway traffic the dominant form of transportation in the United States, vehicle travel has a large impact on the environment by emitting air pollutants through exhaust, evaporation, use of air conditioners, and stirring of fugitive dust by vehicle passage *(148)*. Transportation activity contributes a major source of carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs) or other hydrocarbons (HCs), nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) *(148-152)*, which are the dominant sources of air pollutants in many areas. Studies have indicated that as much as 45% of released pollutants in the U.S. are due to vehicle emissions *(153, 154)*. Transportation activities account for a significant portion of CO_2 emissions in the U.S., releasing roughly 33% of the total CO_2, with roadway vehicles contributing 80% of those emissions *(155, 156)*. In 1994, as shown in Figure A.26 and Figure A.27, highway traffic contributed significant amounts and

Pollutant	Quantity Emitted (1994, thousand short tons)	Percentage of total Emissions of that Pollutant[42]
Carbon Monoxide (CO)	61,070	62.3%
Nitrogen Oxides (NO_x)	7,530	31.9%
Volatile Organic Compounds (VOCs)	6,295	27.2%
Sulfur Dioxide (SO_2)	295	1.4%
Particulate Matter (PM-10)	311	0.7%
Lead (Pb)	1.4	28.3%

Figure A.26 U.S. Vehicle Operations Contribution to Nationwide Emissions *(148)*

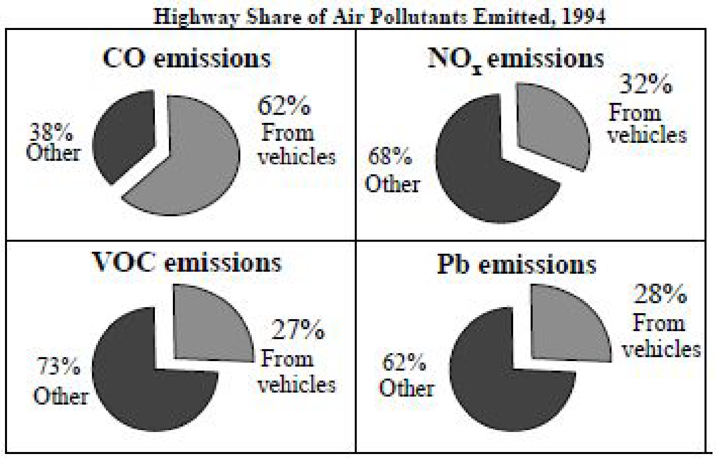


Figure A.27 U.S. Vehicle Operations Share of Air Pollutant Emissions *(148)*

percentages of emissions nationwide. Furthermore, highway traffic contributed to emissions of additional air pollutants regarded as greenhouse gases, including methane (CH_4) and nitrous oxide (N_2O), as shown in Figure A.28, and significantly to emissions of toxics, including benzene, butadiene, and formaldehyde, as shown in Figures A.29 and Figure A.30.

Pollutant	Quantity Emitted (1990, thousand metric tons)
Methane (CH_4)	201
Nitrous Oxide (N_2O)	87

Figure A.28 Air Pollutant Emissions from U.S. Vehicle Operations *(148)*

Pollutant	Quantity Emitted (1990, short tons)	Percent of total Emissions of that Pollutant
Benzene	217,765	45%
Butadiene	41,883	41%
Formaldehyde	101,722	37%

Figure A.29 Quantities of Toxics Emitted by U.S. Vehicle Operations *(148)*

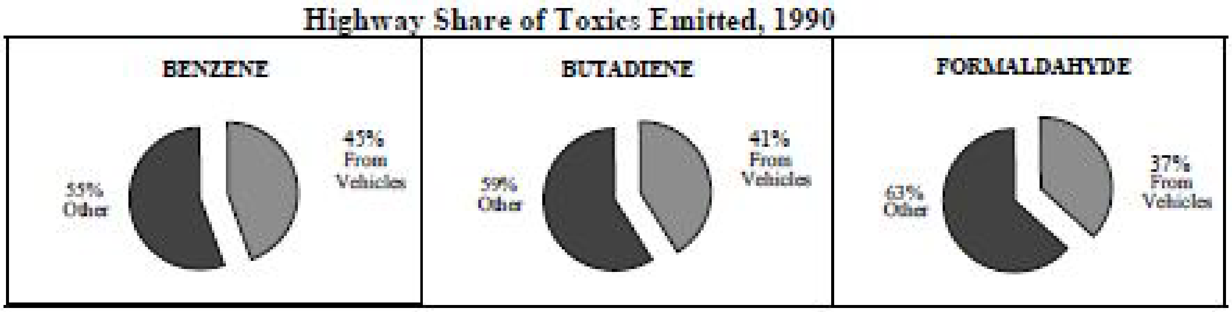


Figure A.30 Share of Toxics Emitted by U.S. Vehicle Operations *(148)*

Clearly, transportation contributes significantly to air pollutant emissions. As such, vehicle fuel consumption and emissions are critical considerations related to traffic, and significant efforts have been made to reduce pollutants, including improvements in vehicle efficiency and use of carbon-neutral alternative fuels *(149, 153, 155)*.

These air pollutants have environmental, health, and welfare impacts such as respiratory and other illnesses, including chronic cough, phlegm, wheezing, chest illness, and bronchitis *(148, 157)*. Air pollutants impact the morbidity and mortality of drivers, commuters, and people living in close proximity to roadways *(37, 150, 158-165)*. Epidemiological studies link vehicle emission exposure to several cardiovascular health impacts *(37, 160)* and significant, estimated premature deaths, as shown in Figure A.31. These premature deaths have an estimated cost in the billions of dollars and are projected to increase *(37)*.

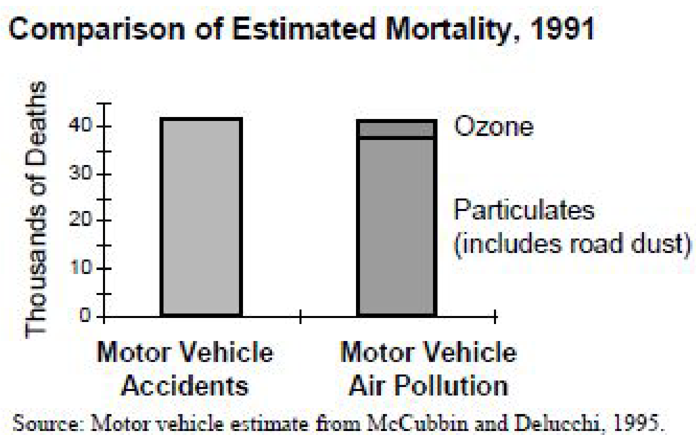


Figure A.31 Motor Vehicle Air Pollutants Deaths *(148, 157)*

Many variables impact energy and emission rates of vehicles, including travel-, weather-, vehicle-, roadway-, traffic-, and driver-related *(153)*. Travel-related factors include distance and trip frequency. Vehicle-related factors include engine size and condition and presence of a functioning catalytic converter and air conditioner. Driver-related factors include behavior and aggressiveness differences. These factors in combination with roadway factors can influence traffic flow and impacts resulting from congestion. Traffic congestion degrades ambient air quality through increased emissions by lowering average speeds, which result in travel time increases and lengthened exposure per vehicle *(150, 152)*. Emissions produced at low speeds increase exponentially. The lowered speeds also diminish turbulence-related dispersion of vehicle-related pollutants, increasing pollutant concentrations. Additionally, congestion results in stop-and-go vehicle operations that again increase emissions as compared with smooth traffic flow *(150)*. Nationwide estimates of traffic emissions attributable to congested conditions are significant and associated with approximately 3,000 premature deaths in 2005 *(37)*. Clearly, emissions can be reduced through improved traffic operations and consequent reduction of congestion and fuel consumption *(155)*. Access management is known to improve operations.

An initial review of the research literature failed to yield any research on the impacts of access management on the environment. However, it is well established that reducing travel times, reducing congestion, and reductions in the number of braking and acceleration maneuvers lead to reductions in greenhouse gas emissions *(152, 153, 155)*. Reductions in greenhouse gases improves both the environment as well as the public's health *(37, 150, 152, 160)*. Thus, improvements to traffic flow in reductions of overall network travel time and of the reductions in speed variation leads to decreased emissions. Given that access management treatments increase trip lengths but decrease the overall travel times, there is a balance between the traffic flow/speeds and travel distances (and an associated impact on the environment).

Furthermore, a review of the research literature did not reveal many guidelines on how to specifically measure the environmental impacts of access management treatments. *NCHRP Report 420 Impacts of Access Management Techniques* provides a short discussion on how access management treatments are likely to influence environmental outcomes (i.e., vehicle-created emissions). This report indicated that access management treatments could cause changes in traffic volumes on specific roadway segments or driveways and average travel speeds and cause additional travel distance (due to re-routing), all of which may have environmental impacts. Environmental outcomes would generally improve as traffic volumes are reduced or average speeds are increased due to the access management treatment, while they are likely to get worse as total VMT increases. One would have to carefully consider these specific changes in traffic volumes, speeds, and travel distances together to determine if the net impact is positive or negative.

A general review of the research literature suggests there are several ways to quantify the environmental impacts of transportation activities. These can be generally classified into two categories: microscopic and meso/macroscopic. Microscopic methods seek to relate the speed profile of an individual vehicle to its fuel consumption or emissions *(166-168)*. This is typically done by using known relationships between required engine power to maintain a specific speed profile and amount of emissions generated or fuel consumed during different driving modes (accelerating, decelerating, cruising, and idling). Examples include the Comprehensive Modal Emissions Model (CMEM), the project-level version of EPA MOVES, and the Virginia Tech Comprehensive Power-Based Fuel Consumption Model. Although these microscopic models are very accurate, they generally require highly detailed information to be applied (e.g., trajectories of all vehicles traveling on a transportation network). Thus, they are typically implemented within simulation platforms that are capable of predicting the movement of every vehicle within a network. However, one recent study applied CMEM to high-resolution traffic data obtained from pavement detectors *(155)*. Various access management strategies can be tested within the simulation environment to estimate the relative differences between them with respect to environmental impacts.

Macroscopic models have also been proposed to relate emissions to aggregate traffic measure (e.g., link volume, average travel speed, vehicle miles or vehicle hours traveled) *(169-171)*. Examples include the Akcelik model, MEET, and the county-level version of the EPA MOVES, which is an update of a previous set of models called MOBILE. While these models require fewer inputs than traditional models, they do not accurately relate the different driving modes to current traffic patterns and thus provide an oversimplified relationship that is not as accurate *(172)*. Mesoscopic models offer a compromise between the two approaches, by using average traffic metrics along with aggregated measures associated with the different driving modes (e.g., total number of stops, total time vehicles spent stopped) *(173, 174)*. However, these aggregated measures must be known to use the mesoscopic models, and well-defined relationships between these and other traffic parameters do not currently exist. These macroscopic and mesoscopic methods are generally implemented jointly with traffic planning or simulation models that provide the necessary outputs. For example, the outputs of different scenarios (or access management treatments) can be obtained and then inputted into the macroscopic or mesoscopic models to compare the relative differences in environmental impacts. Previous studies have used queuing-based models (175) or large-scale planning estimates of VMT *(37)*.

A.7 References

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APPENDIX B: EXTENDED INTERVIEW PROCESS AND RESULTS

B.1 Interview Summary. South Dakota Department of Transportation (SDDOT)

B.1.1 Meeting Dates:

- April 10th, 2018
- April 16th, 2018 (morning)
- April 16th, 2018 (afternoon)
- April 23rd, 2018

B.1.2 Meeting Locations:

- SDDOT Central Office (Pierre) – Roadway Design, Safety, and Traffic Data (April 10th)
- SDDOT Western Area (Pierre and remote) (April 16th morning)
- SDDOT Central Office (Pierre and remote) (April 16th afternoon)
- SDDPS Brookings Office (April 23rd)

B.1.3 Interviewed Staff:

- April 10th, 2018
  - Neil Schochenmaier, Engineering Supervisor (Road Design)
  - Andy Vandel, Highway Safety Engineer
  - Rocky Hook, Transportation Inventory Management Program Manager (highway system and traffic data)
  - Thomas Herman, Engineer (Roadway Design)
- April 16th, 2018 (morning)
  - Stacy Bartlett, Access Management Engineering (Pierre and Rapid City Regions)
  - Dean VanDeWiele, Area Engineer (Pierre)
  - Doug Sherman, Area Engineer (Winner)
  - Mike Carlson, Area Engineer (Rapid City)
  - Steve Gramm, Planning Engineer (Project Development)
- April 16th, 2018 (afternoon)
  - Joel Jundt, Deputy Secretary
  - Joel Gengler, Program Manager (ROW)
  - Ben Orsbon, Federal Programs Coordinator
- April 23rd, 2018
  - Brooke White, Access Management Engineer (Aberdeen and Mitchell Regions)
  - Matt Brey, Area Engineer (Watertown)
  - Brad Letcher, Area Engineer (Huron)
- April 30th, 2018
  - Karla Engle, SDDOT Legal Counsel

B.1.4 Interviewer(s):

  - Michael Pawlovich, SDSU Faculty/Researcher (April 10th, 16th (remotely from Sioux Falls), and 23rd)
  - Rouzbeh Ghabchi, SDSU Faculty/Researcher (April 16th (remotely from Sioux Falls))

B.1.5 Introduction

The State of South Dakota has a population of roughly 882,000, growing from a population of approximately 755,000 in 2000 and 814,000 in 2010. The South Dakota Department of Transportation (SDDOT) has a strong interest in access management, as evidenced by continual reevaluation and development of access management guidelines and policies. SDDOT uses the Access Management Manual (2014 TRB) as a basis for access management policies/decisions. Additionally, SDDOT applies many access management techniques on a regular basis with the Road Design Manual containing Chapter 17 – Access Management. The contents of this chapter describe and discuss many access management treatments, including consolidating access, traffic signals, medians and openings, driveways and intersections, continuous two-way left-turn lanes (TWLTLs), and several others.

B.1.6 Treatments

As evidenced by a strong and active commitment to access management, SDDOT has an extensive list of sites with past access management treatments. The following list contains a synopsis of the discussion involving access management treatments within South Dakota.

1. Increasing the spacing between signals and intersections: SDDOT uses highway classifications to define appropriate spacing for signals and intersections, and these distances are provided in Figure 17-1 of the Access Management chapter of the SDDOT Design Manual. Though signal changes or removals occur, staff noted that once a road (intersection) or signal exists, adjustments or removals are difficult Staff stated that more physical removals or relocations would occur if the treatments were better supported. Generally, local governments need an excellent reason, supported by planning and operational studies, to justify signal removals or relocations.

2. Managing the number of driveway access points (e.g., access via alternate roads or shared access points): SDDOT tries to manage driveway access frequency on every project, but many times the treatment is part of a larger project where other treatments are also applied. SDDOT has a process that involves access consideration reports for grading designers. Primarily, SDDOT attempts to consolidate or remove accesses to improve safety and operational efficiency, subject to landowner cooperation, or relocate them to promote more appropriate spacing and, failing that, tries alternate treatments. However, considerations that factor into the success include the availability of alternate access points and the relative costs incurred due to relocation or closure. Additionally, SDDOT has used driveway width increases as trade for elimination of access points.

3. Moving access point to locations farther from an intersection: SDDOT tries to manage corner clearances on every project, but many times the treatment is part of a larger project where other treatments are also applied. SDDOT uses the Access Management Manual (2014 TRB) corner clearance guidance and has rules pertaining to minimum spacing between access points.

4. Right in/right out only movements for access points: SDDOT does implement right in/right only (RIRO) through installation of raised medians. The raised medians are needed to control unauthorized left turns, but this produces difficulties for traffic wanting to turn left. SDDOT has done a few of these treatments in urban areas.

5. Median treatments (e.g., converting a two-way left-turn lane into a raised median): SDDOT implements median treatments where volumes and highway classifications match. One past project along 12th St in Sioux Falls, SD, from Marion Rd to Lyons, had a business impact study done using sales tax receipts before and after.

6. ¾ control medians (left-in allowed, left-out not allowed): SDDOT regards this treatment as being in the toolbox of possible options but has not commonly implemented the treatment.

7. 4-lane highway with deceleration lanes compared with 6-lane highway: SDDOT has not implemented this treatment.

8. Use of frontage roads: SDDOT has used frontage roads but implementation of this treatment is not common now, with some instances being removed or abandoned due to maintenance and side street storage due to inadequate offset cited as reasons.

9. Use of backage/rearage roads: SDDOT does not commonly use backage/rearage roads, instead choosing to work with local jurisdictions and utilizing local infrastructure. These treatments improve flow and safety; however, customers must pass a business then backtrack, in a sense.

10. Providing turn lanes for heavy traffic movements: SDDOT often provides turn lanes for heavy traffic movements, with determination of these generated by traffic counts or initiated by safety concerns. The treatment is commonly studied for ethanol plants and grain elevators.

11. Providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway: SDDOT occasionally provides rural acceleration/deceleration lanes.

12. Approach lane width considerations: SDDOT designs for proper throat length and appropriate radius.

13. Land use policies: Though certainly land use policies impact projects, SDDOT has no jurisdiction beyond the ROW. When land use changes, the landowner should inform the DOT, but there exists no trigger for gaining this knowledge beyond that.

14. Other: Other access management techniques mentioned during the interviews include driveway throat depth, driveway throat width, and aligning accesses. These are somewhat related to access frequency, with the primary need here to facilitate movements in and out of business driveways without traffic backups onto the main road or providing accesses so wide that drivers are confused.

B.1.7 Tools/Methodologies to Estimate Costs, Impacts, and Benefits

SDDOT has an active interest in access management treatments with Chapter 17 of the Road Design Manual specifically addressing the topic. The contents of this chapter describe and discuss many access management treatments, including consolidating access, traffic signals, medians and openings, driveways and intersections, continuous two-way left-turn lanes (TWLTLs), and several others. However, no specific tools or methodologies to estimate costs, impacts, or benefits are mentioned.

- Safety: To estimate safety benefits, SDDOT has guidelines within Chapter 17 but also implements safety analysis use safety performance functions (SPFs) and crash modification factors (CMFs) from the Highway Safety Manual (HSM) and the online CMF Clearinghouse. Safety benefits are calculated, many times isolated to one approach/access or one intersection. Staff indicated that a corridor solution or methodology for assessing access management treatments would be useful. CMFs that have been used by SDDOT related to corner clearances, presence of a median, and conversion of left exit to right-in/right-out (RIRO) situations. Project development personnel may have further details regarding intersection analyses.

- Traffic Operations: SDDOT estimates traffic operations benefits within the central office through a traffic impact study (TIS) and traffic analysis study.

- Economic Impacts: Staff stated that the state does not estimate economic impacts well. However, having a better method of estimation would be beneficial when interacting with local businesses and developers. SDDOT has studied economic impacts previously, with the W 12th St project in Sioux Falls, SD, mentioned several times. This project involved a study to estimate financial impacts through evaluation of before and after sale tax receipts.

- Project Costs: SDDOT project costs are available for specific sites upon request much like the traffic operations data.

- Environmental Impacts: Analysis of environmental impacts of access management are limited.

B.1.8 Data Elements

For the State of South Dakota, many of the data elements queried about through the questionnaire are readily available, but there are numerous variables whose availability is uncertain or was not indicated. Additionally, many of the variables were regarded by staff as highly valuable for purposes of access management treatment evaluation. Many of the highly valuable variables were also indicated as readily available.

Much of the data are available within a geographic information system (GIS) format, obtainable via the GIS coordinator. Related to these data, data dictionaries are also available for roads, intersections, crashes, state inventory, and non-state inventory. The intersection database contains all intersections throughout the state. State highways contain the presence of turn lanes but not the length.

The following sections detail each of these from three data categorization subsets: geometric/site characteristics, traffic operations, and traffic safety.

B.1.8.1 Geometrics/Site Characteristics

With regard to geometrics/site characteristics, shown in Table B.1, staff indicated that many (9) of the data elements within the questionnaire table were readily available. Only a few (4) of the variables were not available, including land use, sight distance, storage/turn lane length, and acceleration/deceleration lanes. The individual availability of each geometric/site characteristic element is shown in Table B.1.

Again, with regard to geometrics/site characteristics, staff indicated that many of the data elements would be highly valuable or of medium value if these data were available. Only land use and traffic control were regarded as of low value. The individual value of each geometric/site characteristic element is shown in Table B.1.

As shown in Table B.1, the coincidence of readily available and high value occurs with several (5) data elements. A few (4) additional data elements are regarded as medium value but readily available. Some other (3) data elements that are regarded as highly valuable are not available.

Table B.1 Site Characteristics – Availability and Value – South Dakota DOT

Site Characteristics	Availability	Value
Geometrics/Site Characteristics		
Site		
Type (corridor, segment, intersection)	Readily	High
Length/width/influence area	Readily	Medium
Land Use	Not	Low
Functional Classification	Readily	High
Access Classification	Readily	High
Intersection Spacing	From maps	High
Sight Distance	Not	High
Lanes		
Number	Readily	High
Width	Readily	Medium
Type (Thru, Left, Right)	Intersections	High
Storage/Lane Length (turn)	Not	High
Acceleration/deceleration	Not	High
Access Points		
Number	Not	High
Type(s)	Not	Medium
Distances Between	Not	High
Entering/departure Grades	Not	Medium
Shared/unshared	Not	Medium
Approach Lane Width	Not	Medium
Throat Width	Not	Medium
Traffic Control (at access point)	Not	Low
Corner Clearances	Not	Not
U-Turn Provision	Not	High
Median		
Type	Readily	High
Width	Readily (state)	High
Frontage/backage Roads	Readily	Medium
Roundabouts/Alternative Intersections	Readily	Medium

B.1.8.2 Traffic Operations

With regard to traffic operations, as shown in Table B.2, staff indicated that primarily the traffic volume, speed limit, and number of traffic signals are readily available. The remaining variables are either not available or information was not provided. The individual availability of each geometric/site characteristic element is shown in Table B.2.

Again, regarding geometrics/site characteristics, staff indicated that the same data elements that were readily available were also highly valuable. However, a couple (2) variables of high value are not available. The individual value of each geometric/site characteristic element is shown in Table B.2.

Table B.2 Traffic Operations – Availability and Value – South Dakota DOT

Traffic Operations	Availability	Value
Operations		
Traffic Control	NR	NR
Signal		
Number	Readily	High
Spacing	Not	High
Left-Turn Protection	Not	High
Conflict Points	NR	NR
Conflict Density	NR	NR
Capacity Analysis		
Delay	NR	NR
Travel Time	NR	NR
Level-of-Service (LOS)	NR	NR
Non-motorists (pedalcyclists, pedestrians)		
Types	NR	NR
Volumes	NR	NR
Traffic		
Volumes		
AADT	Readily	High
% Truck	Readily	High
% Bus	Readily	Medium
% Passenger Vehicle	Readily	Medium
Peak Hour Factor	Readily	High
Speed		
Limit	Readily	NR
Operating	Not	NR

NR = no response

As shown in Table B.2, the coincidence of readily available and high value occurs with four (4) data elements. Two (2) additional data elements regarded as of medium value are also readily available. Other data elements regarded as highly valuable are not available.

B.1.8.3 Traffic Safety

Staff did not specifically speak to the availability of traffic safety data. However, a database of traffic crash data is available through the GIS coordinator.

B.1.9 Estimates of Financial Impacts of Treatments

No estimates of financial impacts of access management treatments were provided. However, construction estimates of project costs are available on a project basis.

B.1.10 Software Tool Elements

Staff indicated much interest in various aspects of the software tool as indicated in the questionnaire, with primary interest in the numerical (tabular) summary tables, the benefit-cost analysis, and the comparative worksheets. Interest in the graphs/charts was lower and likely based more on the value of displays as opposed to analytical value. Within the numerical (tabular) summary tables, staff had much interest in the safety impacts and project costs, mildly less interest in the traffic operations and environmental impacts, and even a little less in the economic impacts. Staff indicated that costs savings gained from the project are important and that the locality of the cost savings should be underscored. Additionally, staff indicated that having a simple rating system would be good. Finally, the software needs to be user-centered and easy to use, with understandable output.

B.2 Interview Summary. City of Sioux Falls, South Dakota

B.2.1 Meeting Date: May 15th, 2018, and May 23rd, 2018

B.2.2 Meeting Location:

City of Sioux Falls Office, Sioux Falls, South Dakota (5/15) and

Crothers Engineering Hall, Brookings, South Dakota (5/23)

B.2.3 Interviewed Staff:

- Shannon Ausen, Civil Engineering w/ Access Mgmt, Capital Improvements Program (CIP), and Long Range Transportation Planning (5/15)
- Sam Trebilcock, Transportation Planner → traffic modelling (5/15)
- Heath Hoftiezer, Traffic Engineer (5/23)

B.2.4 Interviewer:

- Michael Pawlovich, SDSU Faculty/Researcher (5/15 and 5/23)

B.2.5 Introduction

The City of Sioux Falls, South Dakota has a population of roughly 183,000, growing from a population of approximately 124,000 in 2000 and 154,000 in 2010. Beyond the city boundaries, several adjoining communities have experienced significant growth in the past couple decades as well. As part of a vibrant, rapidly growing community, city personnel continually attempt to apply access management principles to proactively foster traffic flow and safety as the community grows. All plan reviews include consideration of access management and the economic impacts are “critically interesting” to Sioux Falls.

Thus far, staff have had support from the city mayor and the commissioner has noted the importance of medians. The city council has not been vocal about the topic and developers basically seem to accept access management provisions and primarily request more right-in/right-out (RIRO) access points. Essentially, this equates to good administrative support with encouragement to be development friendly without compromising the base tenets. Within the standards, access management is not strongly supported so working with developers on variances is easier and fosters a cooperative environment. Retrofitting access has become the main issue with mutual access easements one very strong tool.

Staff view land use policies as vital to successful implementation of access management. As such, the city prepares long-range plans, with the current plan being the 2040 Sioux Falls Long Range Plan, which includes the 2040 Long Range Transportation Plan (LRTP) Road Map. The LRTP has been done several times and contains market studies details and data summaries. Also, the city provides additional comprehensive planning and anticipated future land use maps online as well. Additionally, access management is addressed in chapters 5 and 8 of the City Engineering Design Standards.

B.2.6 Treatments

The following list contains a synopsis of the discussion involving access management treatments in and around the Sioux Falls, South Dakota. The city has an active access management program with requests, considerations, and implementation of the various treatments occurring on a daily basis. Per the numbering of these treatments, staff indicated that numbers 2 (access point frequency/density) and 5 (median treatments) are most common with 13 (land use policies) being vital. The city posts many of its project studies and reports online and has an extensive spreadsheet of sites that is updated annually with crash and traffic volume data.

Regarding specific access management treatments, again the city considers some form of access management on a daily basis, whether through requests or through each plan review. The frequency and number for each access management treatment in the questionnaire are as follows:

1. Increasing the spacing between signals and intersections: 1 per month, monthly
2. Managing the number of driveway access points (e.g., access via alternate roads or shared access points): 1 per day, daily
3. Moving access point to locations farther from an intersection: 1 per day, daily
4. Right in/right out only movements for access points: 1 per day, daily
5. Median treatments (e.g., converting a two-way left-turn lane into a raised median): 1 project, yearly

   For median treatments, the city has studied before-and-after and has generally found a 30% reduction in crashes and an increase in capacity of 5,000 to 10,000 vehicles per day. Speeds have typically been found to increase as well. An HDR study has determined results from median treatment installations to match national results.

   The spreadsheet the city maintains lists many corridors with three (3) primary median types: none, TWLTL, and raised. Specifically mentioned during the interview were two high volume corridors: W 12th Street and 41st Street. W 12th Street, from Marion to Westport, has existing raised medians. For 41st Street, raised medians are planned for 2022 construction in two stages, first from Marion to Shirley then from Shirley to Kiwanis.

6. ¾ control medians (left-in allowed, left-out not allowed): 1 project, yearly

7. 4-lane highway with deceleration lanes compared to 6-lane highway: not applicable to Sioux Falls
8. Use of frontage roads: 1 project, yearly
9. Use of backage/rearage roads: 1 project, yearly

   Backage routes exist along W 12th St and the city has tried them in other places as well.

10. Providing turn lanes for heavy traffic movements: 1 project, yearly
11. Providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway: 1 project, yearly
12. Approach lane width considerations: 1 per day, daily
13. Land use policies: 1 per day, daily
14. Other - consolidate driveways from 2 to 1, for example: 1 per day, daily

Unfortunately, at this point, no specific projects were identified for each of these, potentially due to a multiplicity of treatment applications for each project. However, the materials available online might provide these details.

B.2.7 Tools/Methodologies to Estimate Costs, Impacts, and Benefits

In general, the City of Sioux Falls performs detailed analyses regarding projects, which, as mentioned previously, always considers access management treatment implementation and installation. Staff analyze safety and traffic operations using standard tools and with the assistance of a consultant, either HDR, Inc. or HRGreen, Inc. Specific tools used for each category are detailed in the following:

- Safety: To estimate safety benefits, both HDR and HRGreen perform safety studies for the city. For state system roads, state crash numbers and valuations are used. For non-state system roads, Minnesota valuations are used with categories of Fatal, Major, Minor, Possible/Unknown, PDO (state), and PDO (non-state). The extensive spreadsheet of treatments that the city maintains contains a long crash history for several primary corridors.

- Traffic operations: Related to traffic operations, the city primarily uses Synchro/SimTraffic with the Highway Capacity Manual (HCM)/Highway Capacity Software (HCS), CORSIM, VISSIM, and TranSIM used little if at all. An emerging software called Vistro used by large cities was mentioned but is not used by Sioux Falls or, apparently, in South Dakota at this time. For South Dakota DOT-related projects, HCM/HCS is sometimes used for right turns from Synchro, but the results are questionable as HCS often returns a failed result. Past Synchro data may be obtainable by site. If not, the data could be recreated.

- Economic impacts: The city has not performed a study, but staff have observed that, in general, more traffic equates to more business. Those businesses that maintain their establishments to meet customer demand are successful and those that do not go out of business. Business concern for projects exists as each week at least a couple calls are received from businesses or developers who want more specific counts.

- Project costs: The city maintains information regarding project costs, and these are obtainable by site or project.

- Environmental impacts: Within the city, environmental impacts are generally only considered on South Dakota DOT-related projects.

B.2.8 Data Elements

For the City of Sioux Falls, South Dakota, many of the data elements queried about through the questionnaire were available, whether readily or possibly, at least through the city. The exception to this seems to be crash details beyond frequency, severity, rate, and spatial location. Most of the variables were regarded by staff as highly valuable for purposes of access management treatment evaluation, and many of these were also readily available, validating the commitment to access management. The following sections detail each of these from three data categorization subsets: geometric/site characteristics, traffic operations, and traffic safety.

B.2.8.1 Geometrics/Site Characteristics

With regard to geometrics/site characteristics, staff indicated that about half of the data elements within the questionnaire table were readily available with the other half possibly available, at least via the city. The individual availability of each geometric/site characteristic element is shown in Table B.3.

Again, regarding geometrics/site characteristics, staff indicated that most of the data elements would be highly valuable and many more of medium value if these data were available. The individual value of each geometric/site characteristic element is shown in Table B.3.

Table B.3 Site Characteristics – Availability and Value – City of Sioux Falls, SD

Site Characteristics	Availability	Value
Geometrics/Site Characteristics		
Site		
Type (corridor, segment, intersection)	Readily	High
Length/width/influence area	Possibly	High
Land Use	Readily	High
Functional Classification	Readily	High
Access Classification	Readily	High
Intersection Spacing	Possibly	High
Sight Distance	Possibly	High
Lanes		
Number	Readily	High
Width	Readily	High
Type (Thru, Left, Right)	Readily	High
Storage/Lane Length (turn)	Readily	High
Acceleration/deceleration	Readily	High
Access Points		
Number	Possibly	High
Type(s)	Possibly	Medium
Distances Between	Readily	Medium
Entering/departure Grades	Possibly	Low
Shared/unshared	Possibly	Medium
Approach Lane Width	Possibly	Low
Throat Width	Possibly	Medium
Traffic Control (at access point)	Possibly	Low
Corner Clearances	Possibly	Medium
U-Turn Provision	Possibly	Medium
Median		
Type	Readily	High
Width	Readily	High
Frontage/backage Roads	Readily	High
Roundabouts/Alternative Intersections	Readily	High

As shown in Table B.3, the coincidence of readily available and high value occurs with several data elements (13). Four (4) additional data elements are regarded as high value but possibly available.

B.2.8.2 Traffic Operations

With regard to traffic operations, staff indicated that about half of the data elements within the questionnaire table were readily available with the other half possibly available, at least via the city. The individual availability of each traffic operations element is shown in Table B.4.

Table B.4 Traffic Operations – Availability and Value – City of Sioux Falls, SD

Traffic Operations	Availability	Value
Operations		
Traffic Control	NR	NR
Signal		
Number	Readily	High
Spacing	Readily	High
Left-Turn Protection	Readily	High
Conflict Points	Possibly	High
Conflict Density	Possibly	High
Capacity Analysis		
Delay	Readily	High
Travel Time	Readily	High
Level-of-Service (LOS)	Readily	High
Non-motorists (pedalcyclists, pedestrians)		
Types	Possibly	High
Volumes	Possibly	High
Traffic		
Volumes		
AADT	Readily	High
% Truck	Possibly	High
% Bus	Possibly	High
% Passenger Vehicle	Possibly	High
Peak Hour Factor	NR	NR
Speed		
Limit	Possibly	Medium
Operating	Possibly	Medium

NR = no response

Again, with regard to traffic operations, staff indicated that most of the data elements would be highly valuable and only a couple of medium value if these data were available. The individual value of each traffic operations element is shown in Table B.4.

As shown in Table B.4, the coincidence of readily available and high value occurs with several data elements (7). Several (7) additional data elements were regarded as high value but possibly available.

Staff indicated that reliability is becoming a better tool to measure with the recent U.S. Transportation Bill dictating reliability as a performance measure. For Sioux Falls, reliability of travel times is a good measure but performance measurement can be problematic.

B.2.8.3 Traffic Safety

As shown in Table B.5, staff indicated that crash data availability varies based on location with some readily available, other possibly available, and some not available. Staff noted that the basic crash data were highly valuable but did not comment on many variables, other than to describe the variables as generally readily available but questionably reliable with greater subjectivity, indicating less reliability.

Table B.5 Traffic Safety – Availability and Value, City of Sioux Falls, SD

Traffic Safety		Availability	Value
Crash - basic			
	Frequency	Locational	High
	Severity	Locational	High
	Rate	Locational	High
	Spatial Location (Spacing/Clustering)	Locational	High
Crash – extended			
	Collision Type (Manner of Crash/Collision Impact)	NR	NR
	Time of Day/Day of Week	NR	NR
	Type of Roadway Junction/Feature	NR	NR
	Location of First Harmful Event	NR	NR
	Traffic Controls	NR	NR
	Sequence of Events	NR	NR
Vehicle			
	Vehicle Configuration	NR	NR
	Initial Direction of Travel	NR	NR
	Vehicle Action	NR	NR
Driver			
	Contributing Circumstances	NR	NR
	Vision Obscured	NR	NR
	Driver Age	NR	NR
	Driver Impairment	NR	NR
	Driver Distraction	NR	NR
Environment			
	Surface Conditions	NR	NR
	Weather Conditions	NR	NR
	Light Conditions	NR	NR
Non-Motorist			
	Type	NR	NR
	Location (prior to impact)	NR	NR
	Action	NR	NR
	Contributing Circumstances	NR	NR

NR = no response

Staff noted that better tools are needed for review of crash data. Formerly the state had access to the Crash Magic collision diagramming tool but this has been replaced with another tool, which may not satisfy city needs for quick and easy retrieval.

Additionally, staff noted that Sioux Falls had switched to a new crash data collection system in early 2018. The switch was made by the police department without consultation with engineering and the implications are still under review.

B.2.9 Estimates of Financial Impacts of Treatments

The city did not provide values for estimates pertaining to the safety, operational, environmental, or economic impacts nor the project costs of access management treatments. However, as noted previously, the city uses different values for safety impact costs, depending on whether the project is on a state or non-state road. Staff commented that operational impacts could include delay time cost, but some issue regarding "too high" versus "probably not high enough" was mentioned. The city has mused about environmental costs, particularly those regarding fuel use, fuel efficiency, and emissions, but there is not much support for these. Economic impacts were extensively studied for the W 12th St project several years ago. The city might have the project costs for specific sites. From these project costs, specific treatment installation costs could be derived.

B.2.10 Software Tool Elements

Staff did not indicate any particular preference for the software tool features.

B.3 Interview Summary. City of Rapid City, South Dakota

B.3.1 Meeting Date: April 9th, 2018

B.3.2 Meeting Location: City of Rapid City Office, Rapid City, South Dakota

B.3.3 Interviewed Staff:

- Kip Harrington, City Planner
- Steve Frooman, City Engineer

B.3.4 Interviewer:

- Michael Pawlovich, SDSU Faculty/Researcher

B.3.5 Introduction

The City of Rapid City, South Dakota, has a population of roughly 73,000, growing from a population of approximately 59,000 in 2000 and 65,000 in 2010. As such, city personnel attempt to apply access management principles along major arterials to proactively foster traffic flow and safety as the community grows. However, staff noted that developers often attempt to gain approval for projects via the city council without including access management principles. The city has an Infrastructure Design Criteria Manual (IDCM), which includes access management techniques and criteria but, as described by the staff, this document was written with significant developer involvement and input. Thus, in the view of the staff, the IDCM is developer friendly.

The city attempts to implement several access management techniques with most, if not all, projects. Examples of these techniques the city promotes includes limiting the number of accesses to developments, increasing intersection corner clearances, and minimizing access widths. There have been successes for each of these, but staff members clearly view access management implementation as a tenuous proposition. Attempts to implement these techniques, however, are normally unsuccessful with staff stating that there had not been any successful access management proposals in the prior two years, though several had been attempted. Additionally, staff cited examples of removal of medians (Eglin Ave and E. St. Patrick) and access exceptions (county jail loading docks) as the reverse of access management principles in the city.

The Rapid City Comprehensive Plan discusses growth, land use, and reinvestment and mentions access management. This plan covers future land use, major streets, other topics, and addresses specific neighborhoods and implementation. Additionally, the Rapid City Downtown Area Master Plan addresses access management at least minimally.

B.3.6 Treatments

The following list contains a synopsis of the discussion involving access management treatments in and around the City of Rapid City, South Dakota. Per the numbering of these treatments, staff indicated that numbers 1 (signal/intersection spacing), 2 (access point frequency/density), and 3 (corner clearances) are tried most frequently, with varying minimal levels of success. Staff also indicated that numbers 5 (median treatments) and 12 (approach lane widths) are good options but these have not been implemented. Details regarding staff views and examples regarding each treatment are detailed in the following:

1. Increasing the spacing between signals and intersections

   The city considers this treatment with every application but the attempt to is largely unsuccessful. The IDCM has a standard of 90 feet, which, in the opinion of the staff, is already too short. However, this standard is not commonly upheld with exceptions of 50 feet indicated.

2. Managing the number of driveway access points (e.g., access via alternate roads or shared access points)

   The city has had some success with this treatment for certain streets (e.g., Mall Drive) if a plan for the corridor already exists, but successful application of this is not frequent.

3. Moving access point to locations farther from an intersection

   The city has had some success with this treatment as driveways have been moved 20 to 30 feet at times. Staff said that some developers are conscious of the issue and assist by moving or placing driveways as far from corners as possible. Some developers bargain access distance against number of access points.

4. Right in/right out only movements for access points

   The city does not often request this treatment, but developers sometimes bargain for the treatment when denied normal access. The city does not favor the treatment as undesirable movements are difficult to control unless a raised median has been installed.

5. Median treatments (e.g., converting a two-way left turn lane into a raised median)

   The city has had one recent treatment on Mount Rushmore Rd and one older treatment on Omaha St, both state highways. The staff expressed the opinion that two-way left-turn lanes (TWLTLs) become hazardous "suicide lanes" at higher volumes. Also, the city has considered the application of unusually lengthy medians with landscaping radiating from intersections to create de-facto right in/right out accesses for the first couple hundred feet. However, some hesitancy exists due to maintenance concerns regarding the landscaping and a severely wide pavement width requirement (20 feet) within the IDCM. Some developers have tried to narrow this width to 12 feet through exceptions while others have tried widening the width to 24 feet (e.g., 2 lanes). Staff stated that the city could do better with consideration and implementation.

6. ¾ control medians (left-in allowed, left-out not allowed)

   Staff cited one instance of this treatment at Haynes and Nollwood, which came out of the Arterial Street Safety Study. They also mentioned a recent discussion regarding a W Main and Jackson intersection project. However, this project has been discussed for the past two to three or more years as multiple adjacent landowners have not come to consensus regarding the various ideas/options.

7. 4-lane highway with deceleration lanes compared with 6-lane highway

   Staff have indicated that they would be interested in implementing these but that there is not a lot of need for them. Staff cited an example of Omaha (SD44), which has medians with six lanes that may be expanded to the west. Another example cited was W Main where a crash involving a left-turning motorcycle was struck by an oncoming vehicle after pulling into oncoming traffic from behind a truck. This crash prompted the Arterial Street Safety Study.

8. Use of frontage roads

   The city does not use frontage roads much.

9. Use of backage/rearage roads

   The city does not use backage roads much but sometimes implements similar treatments.

10. Providing turn lanes for heavy traffic movements

    The city has no standard within city ordinances or requirements (e.g., the IDCM) but the SDDOT Road Design Manual is used. Staff members question the manual's applicability to urban situations.

11. Providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway

    Staff cited examples including US16 south of Rapid City where corridor studies were conducted in the early 2000s and I-90 near Sturgis, SD, where a deceleration lane was lengthened due to the massive number of motorcycles during the annual Sturgis Rally. Staff indicated concerns with this treatment if the full length was not allowed by geometric constraints.

12. Approach lane width considerations

    The city noted nothing regarding this treatment.

13. Land use policies

    The city has a land use policy and plan but it needs to be applied better.

14. Other

    Staff indicated interest in use of expanded throat depths (i.e., distance from the curb line to the first parking spot) to prevent backups onto the street. No examples were mentioned.

    Staff noted issues with extremely wide driveway throats.

B.3.7 Tools/Methodologies to Estimate Costs, Impacts, and Benefits

In general, the City of Rapid City performs relatively minimal analysis regarding access management treatment implementation and installation. Staff analyze safety and traffic operations using standard tools, but these tools have only recently updated. The city does use a benefit-cost (B/C) assessment to assess the project, presumably using the safety and traffic operations analysis output, but receives pushback from developers regarding project costs. Specific tools used for each category are detailed in the following:

- Safety

  To estimate safety benefits, the city often consults the CMF Clearinghouse. Staff indicated that the HSM is less useful as it has not been updated, whereas the CMF Clearinghouse is updated. The city has tried to estimate benefits on corridors where several ideas were proffered and, for example, had one project where a TWLTL was removed to improve pedestrian safety.

- Traffic Operations

  Related to traffic operations, the city does not have the HCS and had only recently obtained the HCM. However, the city has had Synchro version 7 and recently updated to version 10.

- Economic Impacts

  For economic impacts, the city has no specific numbers, but staff pointed out that many negative, implausible claims are made. For example, along Omaha St. where a raised median was installed, many business relocations were attributed to the installation. However, staff feels that the car dealers that moved may have done so anyway as, for example, one of the dealers moved to another location where raised medians exist. Additionally, a grocery store location along the corridor closed but other locations with the same grocery chain also closed.

- Project Costs

  Project costs are considered for every project using a B/C assessment. Staff members feel that the city is often accused of raising project costs by requiring developers to expend additional effort.

- Environmental Impacts

  The city does not really consider environmental impacts as, though Rapid City is a non-attainment area for particulates, this is due to the nearby mining and not the transportation or traffic impacts.

B.3.8 Data Elements

For the City of Rapid City, South Dakota, many of the data elements queried about through the questionnaire were simply unavailable, at least through the city. However, there were several variables regarded by staff as highly valuable for purposes of access management treatment evaluation that were also readily available. The following sections detail each of these from three data categorization subsets: geometric/site characteristics, traffic operations, and traffic safety.

B.3.8.1 Geometrics/Site Characteristics

With regard to geometrics/site characteristics, staff indicated that many of the data elements within the questionnaire table were not available, at least through the city. However, a small number (4) were readily available, including site type (corridor, segment, or intersection), land use, functional classification, and number of lanes. Another, slightly smaller numbers (3) were possibly available, including site length/width/influence area, intersection spacing, and presence of frontage/backage/rearage roads. The individual availability of each geometric/site characteristic element is shown in Table B.6. A further comment was that a point database exists of the entire metro area for land use characteristics.

Table B.6 Site Characteristics – Availability and Value – City of Rapid City, SD

Site Characteristics	Availability	Value
Geometrics/Site Characteristics		
Site		
Type (corridor, segment, intersection)	Readily	High
Length/width/influence area	Possibly	High
Land Use	Readily	High
Functional Classification	Readily	High
Access Classification	Not	High
Intersection Spacing	Possibly	High
Sight Distance	Not	Medium
Lanes		
Number	Readily	High
Width	Not	Low
Type (Thru, Left, Right)	Not	Medium
Storage/Lane Length (turn)	Not	Low
Acceleration/deceleration	Not	Low
Access Points		
Number	Not	High
Type(s)	Not	High
Distances Between	Not	High
Entering/departure Grades	Not	Low
Shared/unshared	Not	Medium
Approach Lane Width	Not	Low
Throat Width	Not	Medium
Traffic Control (at access point)	Not	Low
Corner Clearances	Not	High
U-Turn Provision	Not	Low
Median		
Type	Not	Medium
Width	Not	Low
Frontage/backage Roads	Possibly	Low
Roundabouts/Alternative Intersections	Not	Low

Conversely, again with regard to geometrics/site characteristics, staff indicated that many of the data elements would be highly valuable or of medium value if these data were available. The highly valuable data included site descriptors (type [corridor, segment, intersection], length/width/influence area, land use, functional classification, access classification, and intersection spacing); lane descriptors (number); and access point descriptors (number, type[s], distances between, and corner clearances). The data elements of medium value included site descriptors (sight distance), lane descriptors (type [thru, left, right]), access point descriptors (whether shared/unshared, throat width), and median (type). The remaining data elements were regarded as low value. The individual value of each geometric/site characteristic element is shown in Table B.6.

As shown in Table B.6, the coincidence of readily available and high value occurs with relatively few data elements (4), namely some (3) site descriptors (type [corridor, segment, intersection], land use, functional classification) and one (1) lane descriptor (number). Two (2) additional data elements that are regarded as high value but possibly available are site descriptors (length/width/influence area and intersection spacing). Many other data elements that are regarded as highly valuable are not available.

B.3.8.2 Traffic Operations

With regard to traffic operations, staff indicated that many of the data elements within the questionnaire table were not available, at least through the city. However, two (2) were readily available, including number of signals and traffic volume (AADT). Another two (2) more were possibly available, including left-turn protection at signals and peak hour factor. The individual availability of each traffic operations element is shown in Table B.7.

Table B.7 Traffic Operations – Availability and Value – City of Rapid City, SD

Traffic Operations	Availability	Value
Operations		
Traffic Control	NR	NR
Signal		
Number	Readily	Low
Spacing	Not	High
Left-Turn Protection	Possibly	High
Conflict Points	NR	NR
Conflict Density	NR	NR
Capacity Analysis		
Delay	Not	High
Travel Time	Not	High
Level-of-Service (LOS)	Not	High
Non-motorists (pedalcyclists, pedestrians)		
Types	Not	Medium
Volumes	Not	Medium
Traffic		
Volumes		
AADT	Readily	High
% Truck	Not	Low
% Bus	Not	Low
% Passenger Vehicle	Not	Low
Peak Hour Factor	Possibly	Low
Speed		
Limit	Not	High
Operating	Not	High

NR = no response

Conversely, again with regard to traffic operations, staff indicated that many of the data elements would be highly valuable or of medium value if these data were available. The highly valuable data included signal descriptors (spacing and left-turn protection), capacity analysis descriptors (delay, travel time, and level-of-service [LOS]), volume descriptors (AADT), and speed descriptors (limit, operations). The data elements of medium value included non-motorists (pedalcyclists, pedestrians) descriptors (types, volumes). The remaining data elements were regarded as low value, as shown in Table B.7.

As shown in Table B.7, the coincidence of readily available and high value occurs with one (1) data element, namely traffic volume (AADT). One (1) additional data element is regarded as high value but possibly available, namely signal left-turn protection. Other data elements regarded as highly valuable are not available.

B.3.8.3 Traffic Safety

Staff indicated that crash data from the state is reliable with regard to location but unreliable in the details or attributes, with examples provided (e.g., non-motorist information). The city is working to transfer PDF crash reports to GIS but is not current. Data needed for an analysis can be obtained from the state. The availability of traffic safety or crash data from the city is minimal, as shown in Table B.8.

Table B.8 Traffic Safety – Availability and Value – City of Rapid City, SD

Traffic Safety		Availability	Value
Crash - basic			
	Frequency	Not	NR
	Severity	Not	High
	Rate	Not	NR
	Spatial Location (Spacing/Clustering)	Not	High
Crash – extended			
	Collision Type (Manner of Crash/Collision Impact)	Not	High
	Time of Day/Day of Week	Not	NR
	Type of Roadway Junction/Feature	Not	NR
	Location of First Harmful Event	Not	NR
	Traffic Controls	Not	NR
	Sequence of Events	Not	NR
Vehicle			
	Vehicle Configuration	Not	Low
	Initial Direction of Travel	Not	NR
	Vehicle Action	Not	Medium
Driver			
	Contributing Circumstances	Not	High?
	Vision Obscured	Not	Low
	Driver Age	Not	Low
	Driver Impairment	Not	Low
	Driver Distraction	Not	Low
Environment			
	Surface Conditions	Not	Low
	Weather Conditions	Not	Low
	Light Conditions	Not	Low
Non-Motorist			
	Type	Not	NR
	Location (prior to impact)	Not	NR
	Action	Not	NR
	Contributing Circumstances	Not	NR

NR = no response

However, staff noted that, if available, some of the variables would be highly valuable (crash severity, crash spatial location (spacing/clustering), collision type (manner of crash/collision impact), and possibly driver contributing circumstances. One more was regarded as being of medium value, namely vehicle action. The remaining data elements were viewed as low value. The individual value of each traffic safety element is shown in Table B.8.

B.3.9 Estimates of Financial Impacts of Treatments

The city feels that they have no reliable estimates pertaining to the safety, operational, environmental, or economic impacts nor the project costs of access management treatments.

B.3.10 Software Tool Elements

Staff indicated strong interest (essential to the software) in safety, economic, and project aspects of any proposed software with slightly less need for traffic operation impacts and much less interest in environmental impacts (mildly useful). This general trend of interest translated across numerical (tabular) features, graphing/charting features, and benefit-cost analysis of access management treatments. Staff members favored numerical (tabular) tables for their use and analysis but noted that graphs/charts are highly useful for public or council meetings. Staff really liked (essential) the thought of summary tables for each project/alternative both including and relative to the base case (no treatment).

B.4 Interview Summary. City of Brookings, South Dakota

B.4.1 Meeting Date: April 18, 2018

B.4.2 Meeting Location: City of Brookings Office, Brookings, South Dakota

B.4.3 Interviewed Staff:

- Jackie Lanning, City Engineer
- Mike Struck, Community Development

B.4.4 Interviewer:

- Michael Pawlovich, SDSU Faculty/Researcher

B.4.5 Introduction

The City of Brookings, South Dakota, has a population of roughly 24,000, growing from a population of approximately 19,000 in 2000 and 22,000 in 2010. As such, city personnel attempt to apply access management principles to proactively foster traffic flow and safety as the community grows. The city uses its zoning ordinance document to manage access by, for example, encouraging 125-foot offsets from intersections (corner clearances), limiting commercial access points to one access per 150 feet, with a maximum of two accesses per lot with exceptions considered for larger areas, and offsets from property corners at intersections governed by road classification.

B.4.6 Treatments

The following list contains a synopsis of the discussion involving access management treatments in and around the City of Brookings, South Dakota. Details regarding staff views and examples regarding each treatment are detailed in the following:

1. Increasing the spacing between signals and intersections

   The city indicated that block lengths have been increasing thus requiring secondary accesses to property. The city is coordinating with HDR to map out future signal locations. The recent US14/6th St project on the east side of Brookings was done in coordination with the South Dakota DOT with many access management techniques implemented. Other signal locations follow

HDR recommendations. This is somewhat complicated by the piecemeal manner of development due to many, smaller developers.

2. Managing the number of driveway access points (e.g., access via alternate roads or shared access points)

   Access points are defined within the Brookings zoning ordinance document. The city follows this document, attempting to eliminate existing accesses, possibly by relocating the access to a side street. They also encourage shared accesses where feasible.

3. Moving access points to locations farther from an intersection

   Increasing corner clearances is also defined within the Brookings zoning ordinance document. The city encourages this treatment when a project occurs, citing a gas station (Pump 'N Pack) at the corner of Main and Graeber. Staff again noted the recent US14/6th St project as an example of this treatment and noted Darin Johnson with SDDOT in Sioux Falls, South Dakota, as the contact for the project.

4. Right in/right out only movements for access points

   The city does not implement this treatment often. Staff again noted the recent US14/6th St project as an example of this treatment but also noted another possible location at 6th St and 12th Ave. The city encourages the treatment at other locations, noting 20th St and Medary at McClemon's (the Depot) as an example.

5. Median treatments (e.g., converting a two-way left-turn lane into a raised median)

   Staff again noted the recent US14/6th St project as an example of this treatment and noted that developers also choose to use median treatments as enhancements to development entrances.

6. ¾ control medians (left-in allowed, left-out not allowed)

   Staff again noted the recent US14/6th St project as an example of this treatment with the city initiating a study and the results convincing project designers to implement.

7. 4-lane highway with deceleration lanes compared with 6-lane highway

   The city has not used this treatment.

8. Use of frontage roads

   Staff again noted the recent US14/6th St project as an example of this treatment but as an example of removal of frontage roads from the vicinity of a major intersection.

9. Use of backage/rearage roads

   The city has not used this treatment.

10. Providing turn lanes for heavy traffic movements

    Staff stated that this treatment is occasionally used; however, several examples were provided. Staff indicated that the use of this treatment was defined by turning volumes and considered for intersections with traffic backups or to facilitate right-turn movements. Examples provided include 2nd St S and Main Ave, Lefever Dr south of Cenex, Main Ave & 26th St S, Main Ave & 8th St S, 22nd Ave SB, 12th St & 20th St S, and possibly Main Ave & 22nd St S.

11. Providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway

    Staff indicated that this was not applicable.

12. Approach lane width considerations

    The city generally provides wide radii at intersections.

13. Land use policies

    The city primarily relies on its zoning ordinance document.

14. Other

    No additional treatments types were indicated.

B.4.7 Tools/Methodologies to Estimate Costs, Impacts, and Benefits

The City of Brookings primarily utilizes consultant services from HDR, Inc. to perform the analyses regarding proposed access management implementations. The consultant analyzes potential safety and crash impacts, reviews Manual on Uniform Traffic Control Devices (MUTCD) requirements, and performs traffic operations analyses using the Highway Capacity Manual (HCM), Highway Capacity Software (HCS), and Synchro. Additionally, in one instance at the intersection of 15th St S and 7th Ave S, the consultant conducted an environmental impacts study. The city provides the traffic counts.

B.4.8 Data Elements

For the City of Brookings, South Dakota, no indication of the availability of the data elements queried about through the questionnaire was provided. Staff did indicate that traffic counts are provided for analyses; thus, the city must have traffic counts available.

B.4.9 Estimates of Financial Impacts of Treatments

The city indicated no reliable estimates pertaining to the safety, operational, environmental, or economic impacts nor the project costs of access management treatments. However, staff did indicate that values can be retrieved from documents pertinent the provided examples of treatments.

B.4.10 Software Tool Elements

Staff did not indicate any specific desire for particular software tool features.

B.5 Questionnaire

The questionnaire provided to interviewees prior to the interview session is shown on the subsequent pages. The questionnaire primarily served to direct the interview session with discussion and conversation following the questionnaire topics.

Financial Benefits of Proposed Access Management Treatments
Project SD2016-05
Questionnaire

Access Management Questionnaire

Instructions: As part of a South Dakota Department of Transportation (SDDOT) study titled "Financial Impacts of Proposed Access Management Treatments," the research team is interested in your insights on a variety of topics related to access management via interview. The purpose of the interview is to determine the functionality needed to estimate the financial benefits of access management treatments and the data required to provide that functionality. The results will guide the development of a software tool that engineers and planners can use to evaluate the financial benefits of proposed access management treatments.

An interview will be scheduled to solicit your feedback. To prepare for the interview and maximize the value of information obtained in it, please consider this list of questions. Thank you for your time and thoughtful consideration.

Thank you for your help.

Michael Pawlovich, Lecturer

E-mail: Michael.Pawlovich@sdstate.edu

Phone: (605) 688-6936

1. How often has your agency considered or applied any of the following access management treatments in the past (# of instances) and how recently (month/year)?

#	Treatment Type	# of Instances	How Recently?
1	Increasing the spacing between signals and intersections		
2	Managing the number of driveway access points (e.g., access via alternate roads or shared access points)		
3	Moving access point to locations farther from an intersection		
4	Right in/right out only movements for access points		
5	Median treatments (e.g., converting a two-way left turn lane into a raised median)		
6	¾ Control Medians (left-in allowed, left-out not allowed)		
7	4-lane highway with deceleration lanes compared to 6-lane highway		
8	Use of frontage roads		
9	Use of backage/rearage roads		
10	Providing turn lanes for heavy traffic movements		
11	Providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway		
12	Approach Lane Width Considerations		
13	Land Use Policies		
14	Other (please specify):		
15			
16			

Additional comments:

2. If your agency has considered or applied any access management treatments in the past, please identify any tools or methodologies used to estimate costs, impacts, or benefits. Please describe how the output/results from the tools or methodologies were used to assess the following bulleted categories. Please specifically discuss the assessment of the financial benefits related to each bulleted category.

   - Safety (e.g., Highway Safety Manual (HSM), Crash Modification Factors (CMFs))

   - Traffic Operations (e.g., Highway Capacity Manual (HCM)/Software (HCS), simulation tools/software (e.g., Synchro/SimTraffic, CORSIM, Vissim, TranSIM)

   - Economic Impacts (e.g., taxable sales receipts, business retention/departure)

   - Project Costs (e.g., benefit/cost)

   - Environmental Impacts (e.g., fuel used, fuel efficiency, emissions)

* For each of these categories, please provide a sample of any report that documents the procedures that were used.

3. If your agency has considered or applied any access management treatments in the past, please supply site information in the table below using the Treatment Type #s from question 1. Please recognize that a request for site characteristic or analysis data (per the tables for question 5) may follow.

Treatment Type #	Location	Year	Additional Comments
1	**Sioux Falls, SD (example) Minnesota Ave from W 6th St to W Russell St**	**2013**	**initiated due to corridor delay and business access complaints**

* Please use and attach additional pages if needed.

4. Through this project, the research team is developing a software tool to estimate the impacts of various access management treatments. The following tables list data elements that may be inputs for this tool. To help direct tool development, please indicate, in your opinion, how available (not, possibly, readily) and valuable (low, medium, high), these data are. (next 3 tables)

	Availability				**Value**		
Site Characteristics	**Not**	**Possibly**	**Readily**		**Low**	**Medium**	**High**
Geometrics/Site Characteristics							
Site							
Type (corridor, segment, intersection)							
Length/width/influence area							
Land Use							
Functional Classification							
Access Classification							
Intersection Spacing							
Sight Distance							
Lanes							
Number							
Width							
Type (Thru, Left, Right)							
Storage/Lane Length (turn)							
Acceleration/deceleration							
Access Points							
Number							
Type(s)							
Distances Between							
Entering/departure Grades							
Shared/unshared							
Approach Lane Width							
Throat Width							
Traffic Control (at access point)							
Corner Clearances							
U-Turn Provision							
Median							
Type							
Width							
Frontage/backage/rearage Roads							
Roundabouts/Alternative Intersections							

Additional comments:

Traffic Operations			Availability				Value	
			Not	Possibly	Readily		Low	Medium	High
Operations									
	Traffic Control								
	Signal								
		Number							
		Spacing							
		Left-Turn Protection							
	Conflict Points								
	Conflict Density								
	Capacity Analysis								
		Delay							
		Travel Time							
		Level-of-Service (LOS)							
	Non-motorists (pedalcyclists, pedestrians)								
		Types							
		Volumes							
Traffic									
	Volumes								
		AADT							
		% Truck							
		% Bus							
		% Passenger Vehicle							
	Peak Hour Factor								
	Speed								
		Limit							
		Operating							

Additional comments:

Traffic Safety	Availability				Value		
	Not	Possibly	Readily		Low	Medium	High
Crash - basic							
Frequency							
Severity							
Rate							
Spatial Location (Spacing/Clustering)							
Crash - extended							
Collision Type (Manner of Crash/Collision Impact)							
Time of Day/Day of Week							
Type of Roadway Junction/Feature							
Location of First Harmful Event							
Traffic Controls							
Sequence of Events							
Vehicle							
Vehicle Configuration							
Initial Direction of Travel							
Vehicle Action							
Driver							
Contributing Circumstances							
Vision Obscured							
Driver Age							
Driver Impairment							
Driver Distraction							
Environment							
Surface Conditions							
Weather Conditions							
Light Conditions							
Non-Motorist							
Type							
Location (prior to impact)							
Action							
Contributing Circumstances							

Additional comments:

5. The software tool will require estimates of the following parameters to estimate the financial impacts of the access management treatments. Which of these parameters do you have reliable estimates for (yes), and which would you prefer the research team estimate as a part of this project (no)? If you have reliable estimates, please provide these along with the units for which they apply – e.g., cost/mile (units = mile), cost/foot (units = feet). (next 2 tables)

			Have Reliable Estimates		**If Yes, Estimated Cost**	**Units**
			Yes	**No**		
Safety Impacts						
	Costs of traffic crashes resulting in a:					
		Fatality				
		Serious Injury				
		Minor Injury				
		Property Damage Only				
Operational Impacts						
	Cost associated with travel time (i.e., cost associated with 1 additional vehicle-hour of travel)					
		Passenger vehicles				
		Commercial vehicles				
	Cost of travel distance (i.e., cost associated with 1 additional vehicle-mile of travel)					
		Passenger vehicles				
		Commercial vehicles				
Environmental Impacts						
	Cost of travel distance (i.e., cost associated with 1 additional vehicle-mile of travel)					
		Passenger vehicles				
		Commercial vehicles				
	Cost associated with a vehicle stopping maneuver (i.e., cost of an additional 1 vehicle-stop)					
		Passenger vehicles				
		Commercial vehicles				
	Cost associated with vehicle fuel use or emissions (i.e., cost associated with one additional unit for each)					
		Fuel used (gal)				
		Fuel efficiency decline (mpg)				
		HC (hydrocarbon) emissions (g)				
		CO (carbon monoxide) emissions (g)				
		NOx (nitrogen oxides) emissions (g)				
Economic Impacts						
	Cost associated with change in pass-by traffic to local businesses (i.e., cost associated with one fewer pass-by trip due to access management treatment)					

Additional comments:

			Have Reliable Estimates		If Yes, Estimated Cost	Units
			Yes	No		
Project Costs						
	Treatment					
	1	Cost of increasing the spacing between signals and intersections				
	2	Cost of managing the number of driveway access points (e.g., using access via alternate roads or using shared access points)				
	3	Cost of moving access point to locations farther from an intersection				
	4	Cost of right in/right out only movements for access points				
	5	Cost of median treatments (e.g., converting a two-way left turn lane into a raised median)				
	6	Cost of ¾ control medians (left-in allowed, left-out not allowed)				
	7	Cost of 4-lane highway with deceleration lanes compared to 6-lane highway				
	8	Cost of use of frontage roads				
	9	Cost of use of backage roads				
	10	Cost of providing turn lanes for heavy traffic movements				
	11	Cost of providing acceleration/deceleration lanes on rural highways at locations where large vehicles commonly access the highway				
	12	Cost of approach lane width considerations				
	13	Cost of land use policies				
	14	Cost of other (please specify):				
	15					

Additional comments:

6. If a software tool were available for estimating the financial benefits for various access management treatments, what outputs would your agency find useful? Some expected outputs are provided in the following table. Please rate these from Not Useful (1) to Essential (5). If you have additional suggestions, please describe and rate them as well.

Project/Alternatives Worksheet(s)			**1**	**2**	**3**	**4**	**5**
	Numerical (tabular) summary tables detailing financial impacts by category:						
		Safety impacts					
		Traffic operations impacts					
		Economic impacts					
		Environmental impacts					
		Project costs					
	Graphs/charts displaying data from the numerical (tabular) tables by category:						
		Safety impacts					
		Traffic operations impacts					
		Economic impacts					
		Environmental impacts					
		Project costs					
	Benefit-Cost analysis of access management treatments summarized by category						
		Safety impacts					
		Traffic operations impacts					
		Economic impacts					
		Environmental impacts					
		Project costs					
Comparative Worksheet for Analysis of Multiple Projects/Alternatives by Summarized Category			**1**	**2**	**3**	**4**	**5**
	Summary table with each project/alternative including base case (no treatment)						
	Summary table with each project/alternative relative to the base case (no treatment)						
Other output functionality suggestions:			**1**	**2**	**3**	**4**	**5**

Additional comments:

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APPENDIX C: CASE STUDY – CLIFF AVENUE AND 69TH STREET, SIOUX FALLS, SD

This case study example focuses on the comparison of two access management scenarios along Cliff Avenue in Sioux Falls, South Dakota, a "no-build" (i.e., existing conditions) and a "build" (i.e., build preferred). The study area encompasses eleven (11) intersections, including:

- primary intersection: Cliff Avenue & 69th Street
- along the north segment from Cliff Avenue & 69th Street
  - Cliff Avenue & Jane Lane
  - Cliff Avenue & Apartment Access (South Pointe Apts.) (not in Synchro)
- along the west segment from Cliff Avenue & 69th Street
  - 69th Street & Apartment Access (Diamond Valley Apts.)
- along the east segment from Cliff Avenue & 69th Street
  - 69th Street & West Driveway ("removed" during implementation)
  - 69th Street and Middle Driveway
  - 69th Street & East Driveway
  - 69th Street & Charger Avenue
- along the south segment from Cliff Avenue & 69th Street
  - Cliff Avenue & Sunrise Place
  - Cliff Avenue & Retail/Access/USF Driveway
  - Cliff Avenue & 73rd Street

However, for purposes of the case study analysis, the study area essentially condensed to the primary intersection and the four (4) approaches radiating outward from the primary intersection.

Two infrastructure scenarios are considered: existing conditions and build preferred conditions. Each of these are detailed in the following sections.

C.1 Existing Conditions

For the existing conditions scenario, no access management treatments are considered for current or future analyses, i.e., this is the "no-build" scenario. Conditions prior to construction are shown in Figure C.1, which was obtained from Google Earth (imagery date of 3/9/2015). There are indications of the West Driveway along 69th St east of Cliff Avenue about 300 feet from the intersection, both on the south and north sides of 69th. The conditions for the site prior to construction appear to be:

- For the intersection of Cliff Ave and 69th Street
  - 4-leg, signalized intersection (4SG)
  - North Approach (SB)
    - 2 through lanes (1 approach, 1 departure)
    - 1 left turn lane
    - 1 right turn lane
  - East Approach (WB)
    - 4 through lanes (2 approach, 2 departure)
    - 1 left turn lane (offset)
  - South Approach (NB)
    - 2 through lanes (1 approach, 1 departure)

- 1 left turn lane

Figure C.1 Project Area, 2015 *(Google Earth, imagery date 3/9/2015)*

- West Approach (EB)
  - 4 through lanes (2 approach, 2 departure)
  - 1 left turn lane
  - Raised median

Judging from the intersection configuration, signalization was likely protected/permissive phasing for the left turns and pedestrian traffic was judged as reasonably low.

- For the segments radiating from the intersection
  - North Segment
    - Length: 900 feet
    - 3-lane arterial (3T) with two-way left-turn lane (TWLTL)
    - No on-street parking
    - Roadside fixed objects present at roughly 40 fixed objects per mile with a 4-foot offset
    - TWLTL width of roughly 12 feet
    - Lighting present
  - East Segment
    - Length: 1300 feet
    - 4-lane, undivided arterial (4U)
    - No on-street parking
    - Roadside fixed objects present at roughly 40 fixed objects per mile with a 4-foot offset
    - Undivided segment with no median width
    - Lighting present
  - South Segment
    - Length: 1300 feet
    - 2-lane, undivided arterial (2U)
    - No on-street parking
    - Roadside fixed objects present at roughly 40 fixed objects per mile with a 30-foot offset
    - Undivided segment with no median width
    - Lighting not present
  - West Segment
    - Length: 600 feet
    - 4-lane, divided arterial (4U)
    - No on-street parking
    - Roadside fixed objects present at roughly 40 fixed objects per mile with a 4-foot offset
    - Divided segment with 18-foot median with raised section
    - Lighting present

C.2 Build Preferred Conditions

For the build preferred conditions scenario, access management treatments were applied to current and future analyses, i.e., this is the "build" scenario. The access management treatments that were applied include: 1) Raised medians added along the north, east, and south segments and 2) Due to the raised medians, access control added along the north, east, and south segments, resulting in right-in-right-out (RIRO).

Conditions after construction are shown in Figure C.2, which was obtained from GoogleEarth (imagery date of 6/1/2016). The West driveway along 69th St east of Cliff Avenue about 300 feet from the intersection is gone. The conditions for the site after construction appear to be:

- For the intersection of Cliff Ave and 69th Street
  - 4-leg, signalized intersection (4SG)

- North Approach (SB)
  - 4 through lanes (2 approach, 2 departure)
  - 2 left turn lanes
  - 1 right turn lane

Figure C.2 Project Area, 2016 (Google Earth, imagery date 6/1/2016)

- East Approach (WB)
  - 4 through lanes (2 approach, 2 departure)
  - 2 left turn lanes

        - 1 right turn lane
    - South Approach (NB)
        - 4 through lanes (2 approach, 2 departure)
        - 2 left turn lanes
        - 1 right turn lane
    - West Approach (EB)
        - 4 through lanes (2 approach, 2 departure)
        - 2 left turn lanes
        - 1 right turn lane

    Judging from the intersection configuration, the signalization likely involves protected phasing for the left turns and pedestrian traffic was judged as reasonably medium-low.

- For the segments radiating from the intersection
    - North Segment
        - Length: 900 feet
        - 4-lane, divided arterial (4D)
        - No on-street parking
        - Roadside fixed objects present at roughly 40 fixed objects per mile with a 24-foot offset
        - Divided segment with 24-foot median with raised section
        - Lighting present
    - East Segment
        - Length: 1300 feet
        - 4-lane, divided arterial (4D)
        - No on-street parking
        - No roadside fixed objects present
        - Divided segment with 24-foot median with raised section
        - Lighting present
    - South Segment
        - Length: 1300 feet
        - 4-lane, divided arterial (4D)
        - No on-street parking
        - Roadside fixed objects present at roughly 49 fixed objects per mile with a 24-foot offset
        - Divided segment with 18-foot median with raised section
        - Lighting present
    - West Segment
        - Length: 600 feet
        - 4-lane, divided arterial (4D)
        - No on-street parking
        - Roadside fixed objects present at roughly 9 fixed objects per mile with a 30-foot offset
        - Divided segment with 24-foot median with raised section
        - Lighting present

C.3 Benefits Estimation Analysis

Based on the "no-build" and "build" characteristics, both for current year and future year, benefits were estimated for traffic safety, traffic operations, and environmental impacts. Project costs were obtained through consultation with the City of Sioux Falls, SD. Safety benefits were estimated for the changing traffic and design conditions using Highway Safety Manual (HSM) procedures. Synchro/SimTraffic data were provided that covered the primary intersection and four (4) radiating approaches. For each of the scenarios, two time periods were provided for current and future traffic conditions: an AM peak and a PM peak period. Using the Synchro/SimTraffic output, estimation of benefits resulting from traffic operation differences and environmental impact differences were calculated using the proposed methodology.

C.3.1 Safety Benefits Estimation

To estimate average crash frequencies, HSM procedures were implemented based on the existing (no-build) conditions for both the current traffic (2007) and future traffic (2028) as well as for the build conditions for current and future traffic. Geometric conditions were used to determine the appropriate safety performance functions (SPFs) and crash modification factors (CMFs) based on site type. Per HSM procedures, these values were used to calculate the predicted crashes and modified using the empirical based (EB) procedure with the observed crash frequency incorporated to obtain the expected crashes per the HSM procedure. From this, the metrics shown in Table C.1 were obtained. Example HSM calculations are shown in at the end of Appendix C along with a discussion of actual crash history for the site.

Table C.1 Expected Average Crash Frequency (Crashes/Year) Metrics

Scenario - Year	Intersection	Segments	Total
No-build (existing) - 2007	0.904	0.973	1.877
No-build (existing) - 2028	2.745	4.332	7.077
Build - 2007	0.765	0.702	1.467
Build - 2028	2.521	2.723	5.244

Thus, it appears that implementation of the proposed access management treatment is expected to reduce crashes in the build-out year 2028 by 1.833 crashes. However, the crash reduction gains would not only be realized in 2028 but also in the interim. To account for this, the expected crash frequencies for both scenarios were calculated for each interim year using linear interpolation from year 2008 through year 2028 as shown in Table C.2.

Over the 21-year timeframe, as shown in Table C.2, this results in a reduction of 24.263 crashes.

C.3.2 Traffic Operations and Environmental Benefits Estimation

Synchro files for the different combinations of infrastructure scenarios and time periods were used to obtain the required operational and environmental metrics. The metrics that were considered include:

- Total vehicle travel time
- Total fuel consumption

These metrics were obtained by transferring the Synchro files obtained from South Dakota into the SimTraffic software, which produced the output provided in Appendix C. Figures C.3, C.4, and C.5 illustrate the steps taken to obtain these values. This requires outputting the Synchro file to the SimTraffic module (Figure C.3), generating an output report once the SimTraffic module is run (Figure C.4), and pulling out the required metrics from the output report (Figure C.5).

Per Figure C.3, to transfer the Synchro file to SimTraffic for detailed simulation metrics, a user would click the “SimTraffic” button under the “Transfer” menu (as denoted by the red circle).

Per Figure C.4, the required outputs from SimTraffic are obtained by selecting the “Create Reports” button under the “Reports” menu once the simulation has been run. Within a pop-up window, the “Other” and “Total Travel Time” options should be selected (red circle), then “Total only, Run Number” (blue circle).

Per Figure C.5, the appropriate values are obtained from the report, including total travel time (hr) (red circle) and fuel used (gal) (blue circle). Using these values from each scenario, calculations are done.

Table C.2 Annual Expected Average Crash Frequency (Crashes/Year)

Year		no-build	build	difference
2008	1	2.125	1.647	-0.478
2009	2	2.372	1.827	-0.546
2010	3	2.620	2.007	-0.613
2011	4	2.867	2.186	-0.681
2012	5	3.115	2.366	-0.749
2013	6	3.363	2.546	-0.817
2014	7	3.610	2.726	-0.884
2015	8	3.858	2.906	-0.952
2016	9	4.106	3.086	-1.020
2017	10	4.353	3.266	-1.088
2018	11	4.601	3.445	-1.155
2019	12	4.848	3.625	-1.223
2020	13	5.096	3.805	-1.291
2021	14	5.344	3.985	-1.359
2022	15	5.591	4.165	-1.426
2023	16	5.839	4.345	-1.494
2024	17	6.087	4.525	-1.562
2025	18	6.334	4.704	-1.630
2026	19	6.582	4.884	-1.697
2027	20	6.829	5.064	-1.765
2028	21	7.077	5.244	-1.833
	sum:	96.617	72.354	-24.263

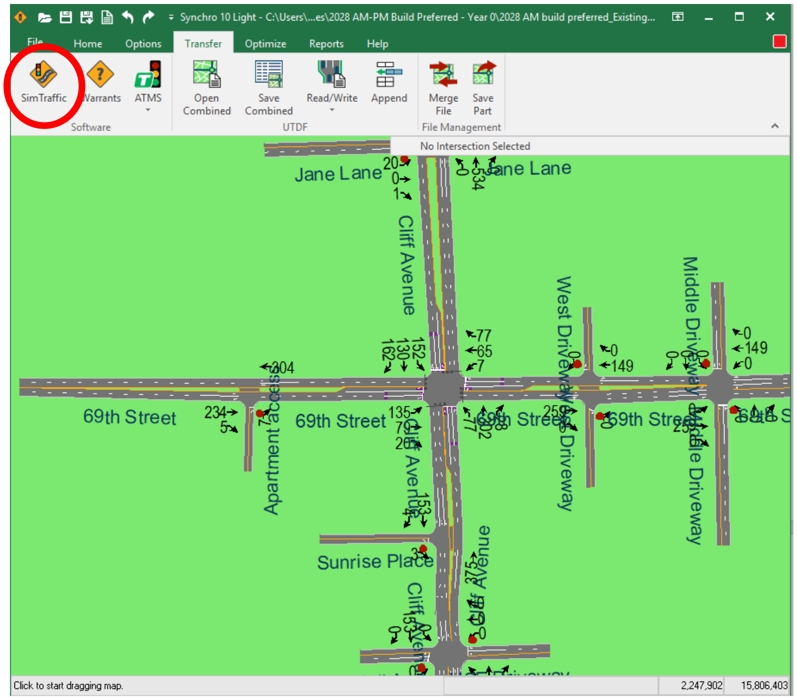


Figure C.3 Transferring Synchro File to SimTraffic

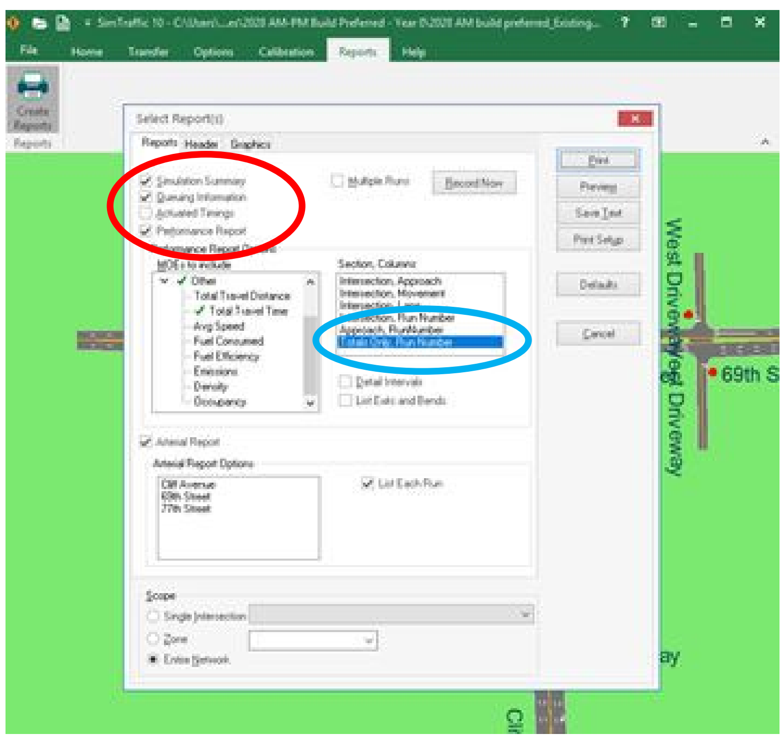
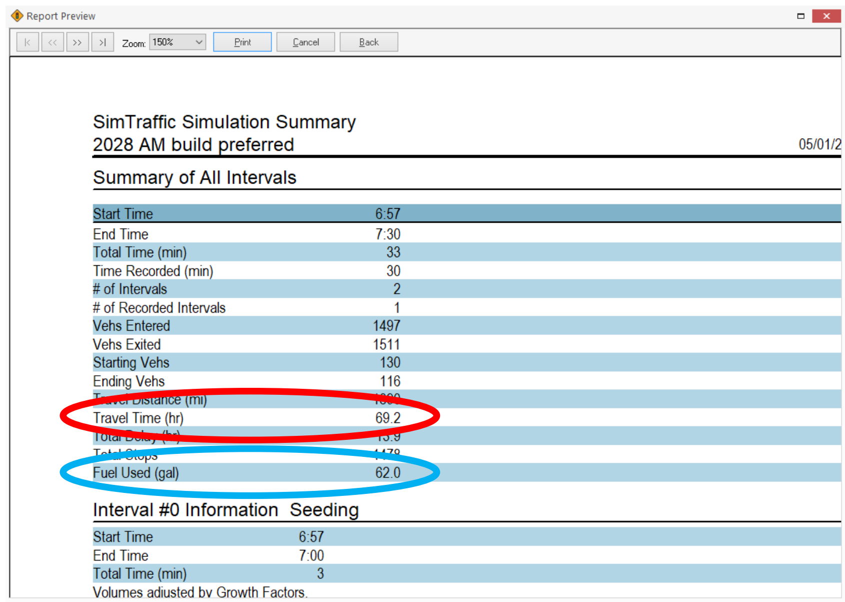


Figure C.4 Obtaining Required Outputs from SimTraffic


Report Preview

Zoom: 150% Print Cancel Back

SimTraffic Simulation Summary
2028 AM build preferred 05/01/2

Summary of All Intervals

Start Time	6:57
End Time	7:30
Total Time (min)	33
Time Recorded (min)	30
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	1497
Vehs Exited	1511
Starting Vehs	130
Ending Vehs	116
Travel Distance (mi)	[illegible]
Travel Time (hr)	69.2
Total Delay (hr)	13.9
Total Stops	1478
Fuel Used (gal)	62.0

Interval #0 Information Seeding

Start Time	6:57
End Time	7:00
Total Time (min)	3

Volumes adjusted by Growth Factors.

Figure C.5 Sample SimTraffic Output

These steps were repeated for each infrastructure scenario/time period combination and the metrics shown in Table C.3 were obtained.

A comparison of the existing conditions vs. build preferred option suggests that the implementation of the proposed access management treatments can reduce travel time significantly during both the AM and PM peak periods. This is also associated with an overall decrease in fuel consumption by vehicles traveling during this time period.

Table C.3 Travel Time and Fuel Used Metrics

Scenario/Peak Period - Year	Total travel time (veh-hr)	Fuel used (gal)
No-build (existing)/AM - 2007	138.7	114.3
No-build (existing)/PM - 2007	149.0	129.4
No-build (existing)/AM - 2028	2020.0	587.3
No-build (existing)/PM - 2028	1969.4	585.2
Build/AM - 2007	131.3	118.8
Build/PM - 2007	139.6	126.8
Build/AM - 2028	1377.8	532.4
Build/PM - 2028	1466.3	550.5

The estimates of operational and environmental impacts are performed for just two peak periods during a typical year, whereas crash costs are provided on an annual basis. To make the two values more comparable, operational and environmental impacts should be converted to an annual value. To do so, we assume that there are 250 working days in the year and ignore any impacts during off-peak periods (including weekends) since no traffic analysis is available for these periods. The metrics shown in Table C.4 are then obtained.

Table C.4 Annualized Travel Time and Fuel Used Metrics

Differences	Total travel time (veh-hr)	Fuel used (gal)
AM - 2028	-642.2	-54.9
PM - 2028	-503.1	-34.7
Daily Difference	-1,145.3	-89.6
Annual Difference	-286,325.0	-22,400.0

Thus, it appears that the implementation of the proposed access management treatment is expected to save travelers 286,325 vehicle-hours of travel time in the build-out year 2028 and save 22,400 gallons of fuel use. However, these reductions would not only be realized in 2028 but also in the interim. To account for this, the total travel time and fuel used for both scenarios were calculated for each interim year using linear interpolation from year 2008 through year 2028 as shown in Table C-5 and Table C-6.

Over the 21-year timeframe, as shown in Table C-5, this results in a reduction of 3,191,575 vehicle-hours.

Over the 21-year timeframe, as shown in Table C-6, this results in a reduction of 241,650 gallons of fuel used.

C.3.3 Project Costs

For project costs, the City of Sioux Falls provided an $8.5 million cost for the entire project along Cliff Ave. from Jane Lane south to 85th St and outward east-west along 69th St. However, this entire project was greater than the extents of the access management project site; thus, the city estimated a cost of $2.5 million for the area along Cliff Ave. from Jane Lane south to 73rd St and outward east-west along 69th St. Thus, the project cost for the access management treatments is assumed to be $2.5 million as we have no further details as to access management-specific treatment costs.

Table C.5 Annual Expected Travel Time (veh-hr) Differences

Year		no-build	build	difference
2008	1	115,992.9	98,358.3	-17,634.5
2009	2	160,060.7	128,991.7	-31,069.0
2010	3	204,128.6	159,625.0	-44,503.6
2011	4	248,196.4	190,258.3	-57,938.1
2012	5	292,264.3	220,891.7	-71,372.6
2013	6	336,332.1	251,525.0	-84,807.1
2014	7	380,400.0	282,158.3	-98,241.7
2015	8	424,467.9	312,791.7	-111,676.2
2016	9	468,535.7	343,425.0	-125,110.7
2017	10	512,603.6	374,058.3	-138,545.2
2018	11	556,671.4	404,691.7	-151,979.8
2019	12	600,739.3	435,325.0	-165,414.3
2020	13	644,807.1	465,958.3	-178,848.8
2021	14	688,875.0	496,591.7	-192,283.3
2022	15	732,942.9	527,225.0	-205,717.9
2023	16	777,010.7	557,858.3	-219,152.4
2024	17	821,078.6	588,491.7	-232,586.9
2025	18	865,146.4	619,125.0	-246,021.4
2026	19	909,214.3	649,758.3	-259,456.0
2027	20	953,282.1	680,391.7	-272,890.5
2028	21	997,350.0	711,025.0	-286,325.0
	sum:	11,690,100.0	8,498,525.0	-3,191,575.0

C.3.4 Combined Benefits Estimation

To fully compare the financial impacts of the proposed treatment, the values in Table C.7 can be used to combine the operational, environmental, safety, and project costs.

As is clear, the largest contributor of cost, as least for this site, is travel time savings. This is true even at a modest cost of travel time of $3.75/hour. Sources of travel time cost estimates suggest using 50% of median wage for drivers and 25% of median wage for passengers (BCA, VTPI). For South Dakota, the U.S. Bureau of Labor Statistics indicated that the May 2019 median hourly wage was $16.71 and the mean hourly wage was $20.63 (BLS). Thus, a relatively conservative value was used for this example and the state is encouraged to determine an appropriate value. Additionally, the cost per gallon of fuel used is roughly the current cost of a gallon of ethanol blend unleaded in the city of Brookings, SD, as noted by Dr. Pawlovich during his daily drives to and from work (last noted 11/14/2020).

C.3.5 References

Benefits Cost Analysis (BCA). http://bca.transportationeconomics.org/benefits/travel-time. Accessed 11/14/2020.

Victoria Transport Institute (VTPI). https://www.vtpi.org/tca/tca0502.pdf. Accessed 11/14/2020.

Bureau of Labor Statistics (BLS). https://www.bls.gov/oes/2019/may/oes_sd.htm#00-0000. Accessed 11/14/2020.

Table C.6 Annual Expected Fuel Use (gallons) Differences

Year		no-build	build	difference
2008	1	71,982.1	71,367.9	-614.3
2009	2	83,039.3	81,335.7	-1,703.6
2010	3	94,096.4	91,303.6	-2,792.9
2011	4	105,153.6	101,271.4	-3,882.1
2012	5	116,210.7	111,239.3	-4,971.4
2013	6	127,267.9	121,207.1	-6,060.7
2014	7	138,325.0	131,175.0	-7,150.0
2015	8	149,382.1	141,142.9	-8,239.3
2016	9	160,439.3	151,110.7	-9,328.6
2017	10	171,496.4	161,078.6	-10,417.9
2018	11	182,553.6	171,046.4	-11,507.1
2019	12	193,610.7	181,014.3	-12,596.4
2020	13	204,667.9	190,982.1	-13,685.7
2021	14	215,725.0	200,950.0	-14,775.0
2022	15	226,782.1	210,917.9	-15,864.3
2023	16	237,839.3	220,885.7	-16,953.6
2024	17	248,896.4	230,853.6	-18,042.9
2025	18	259,953.6	240,821.4	-19,132.1
2026	19	271,010.7	250,789.3	-20,221.4
2027	20	282,067.9	260,757.1	-21,310.7
2028	21	293,125.0	270,725.0	-22,400.0
	sum:	3,833,625.0	3,591,975.0	-241,650.0

Table C.7 Cost Values

Cost category	Unit	Value	Dollars per unit	Total
Operations	Veh-hour	-3,191,575.00	$3.75	-$11,968,406
Environmental	Gallons of fuel	-241,650.00	$2.00	-$483,300
Safety	Crashes	-24.263	$31,200	-$757,006
Project costs	$	$2.5 million[a]	$2,500,000	$2,500,000
			Total financial impact:	-$10,708,712

[a] Estimated value of project for S Cliff Ave from Jane Lane to 73rd St and out along 69th Street (from Shannon Ausen, P.E., City of Sioux Falls, 10/9/2019)

C.4 Case Study: Highway Safety Manual (HSM) Calculations

Following are the HSM manual calculations for each portion of the case study site.

C.4.1 North Segment 2007 (no-build): 3-lane, Arterial Including a Center TWLTL (3T)

Safety Performance Functions (SPFs)

$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$
$$= \exp(-12.40 + 1.41 \times \ln(10{,}600) + \ln\left(\frac{900}{5280}\right))$$ (coefficients from Table 12-3)
$$= \mathbf{0.333}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$
$$= \exp(-5.74 + 0.54 \times \ln(10{,}600) + \ln\left(\frac{900}{5280}\right))$$ (coefficients from Table 12-5)
$$= \mathbf{0.082}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all\\ driveway\\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$
$$= (0.102)(0)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.032)(0)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.110)(0)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.015)(0)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.053)(1)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.010)(0)\left(\frac{10{,}600}{15{,}000}\right)^1 + (0.016)(0)\left(\frac{10{,}600}{15{,}000}\right)^1$$ (coefficients from Table 12-7)
$$= 0 + 0 + 0 + 0 + 0.037 + 0 + 0$$
$$= \mathbf{0.037}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy} = 0.333 + 0.082 + 0.037 = \mathbf{0.452}\ \boldsymbol{crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.034$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.166)(40)(0.034) + (1 - 0.034)$$

$$= \mathbf{1.192}$$

Median Width: TWLTL and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571)$$

= **0.934**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 1.192 \times 1.000 \times 0.934 \times 1.000$$

$$= \mathbf{1.113}$$

Predicted Crashes ($N_{predicted}$)

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$

$$= 0.452 \times 1.113$$

$$= \mathbf{0.503}\ \boldsymbol{crashes/year}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 0.503 \times 0.013$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.007}\ \boldsymbol{crashes/year}$$

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

$= 0.503 \times 0.007$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$$= \mathbf{0.004}\ \boldsymbol{crashes/year}$$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.503 + 0.007 + 0.004)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{0.513}\ \boldsymbol{crashes/year}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$

$$= 0.333 \times 1.113$$

$$= \mathbf{0.370} \ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.082 \times 1.113$$

$$= \mathbf{0.091} \ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.037 \times 1.113$$

$$= \mathbf{0.042} \ \boldsymbol{crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(0.66)(0.370)} = 0.804$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.804)(0.370) + (1 - 0.804)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.347} \ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(1.37)(0.091)} = 0.889$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.889)(0.091) + (1 - 0.889)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.081} \ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.10)(0.042)} = 0.956$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.956)(0.042) + (1 - 0.956)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.040} \ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.347 + 0.081 + 0.040$$

$$= \mathbf{0.467} \ \boldsymbol{crashes/year}$$

C.4.2 North Segment 2028 (no-build): 3-lane, Arterial Including a Center TWLTL (3T)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.40 + 1.41 \times \ln(31{,}000) + \ln\left(\frac{900}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{1.511}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.74 + 0.54 \times \ln(31{,}000) + \ln\left(\frac{900}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.146}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all\\ driveway\\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$= (0.102)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.032)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.110)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.015)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.053)(1)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.010)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.016)(0)\left(\frac{31{,}000}{15{,}000}\right)^1$ (coefficients from Table 12-7)

$= 0 + 0 + 0 + 0 + 0.110 + 0 + 0$

$= \mathbf{0.110}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 1.511 + 0.146 + 0.110 = \mathbf{1.766}\ \boldsymbol{crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.034$

$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$

$= (0.166)(40)(0.034) + (1 - 0.034)$

$= \mathbf{1.192}$

Median Width: TWLTL and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571)$

= **0.934**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.192 \times 1.000 \times 0.934 \times 1.000$

$= \mathbf{1.113}$

<u>Predicted Crashes ($N_{predicted}$)</u>

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 1.766 \times 1.113$

$= \mathbf{1.966}\ \boldsymbol{crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 1.966 \times 0.013$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.026}\ \boldsymbol{crashes/year}$

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

$= 1.966 \times 0.007$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.014}\ \boldsymbol{crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (1.966 + 0.026 + 0.014)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{2.005}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 1.511 \times 1.113$

$$= \mathbf{1.682}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.146 \times 1.113$$

$$= \mathbf{0.162}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.110 \times 1.113$$

$$= \mathbf{0.122}\ \boldsymbol{crashes/year}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1-w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(0.66)(1.682)} = 0.474$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.474)(1.682) + (1-0.474)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.929}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(1.37)(0.162)} = 0.818$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.818)(0.162) + (1-0.818)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.133}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.10)(0.122)} = 0.882$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.882)(0.122) + (1-0.882)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.108}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.929 + 0.133 + 0.108$$

$$= \mathbf{1.169}\ \boldsymbol{crashes/year}$$

C.4.3 North Segment 2007 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp\left(-12.34 + 1.36 \times \ln(10{,}600) + \ln\left(\frac{900}{5280}\right)\right) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.222}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp\left(-5.05 + 0.47 \times \ln(10{,}600) + \ln\left(\frac{900}{5280}\right)\right) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.085}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

$$= (0.033)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{10{,}600}{15{,}000}\right)^{1.106} \text{ (coefficients from Table 12-7)}$$

$$= 0 + 0 + 0 + 0 + 0.012 + 0 + 0$$

$$= \mathbf{0.012}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.222 + 0.085 + 0.012 = \mathbf{0.320}\ \boldsymbol{crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 36 fixed objects/mile and fixed-object offset (O_{fo}) = 24 feet; thus, from Table 12-20,

$f_{offset} = 0.057 + (0.049 - 0.057)\left(\frac{24-20}{25-20}\right) = 0.051$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$= (0.051)(36)(0.036) + (1 - 0.036)$

$= \mathbf{1.030}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.030 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.941}$

Predicted Crashes ($N_{predicted}$)

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.320 \times 0.941$

$= \mathbf{0.301\ crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.301 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.006\ crashes/year}$

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

$= 0.301 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.002\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.301 + 0.006 + 0.002)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.308\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.222 \times 0.941$

$$= \mathbf{0.209}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.085 \times 0.941$$

$$= \mathbf{0.080}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.012 \times 0.941$$

$$= \mathbf{0.012}\ \boldsymbol{crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.209)} = 0.784$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.784)(0.209) + (1 - 0.784)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.218}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.080)} = 0.936$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.936)(0.080) + (1 - 0.936)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.075}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.012)} = 0.984$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.984)(0.012) + (1 - 0.984)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.011}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.218 + 0.075 + 0.011$$

$$= \mathbf{0.304}\ \boldsymbol{crashes/year}$$

C.4.4 North Segment 2028 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-12.34 + 1.36 \times \ln(31{,}000) + \ln\left(\frac{900}{5280}\right)) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.956}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.05 + 0.47 \times \ln(31{,}000) + \ln\left(\frac{900}{5280}\right)) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.141}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all\\driveway\\types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.033)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} \text{ (coefficients from Table 12-7)}$$

$$= 0 + 0 + 0 + 0 + 0.040 + 0 + 0$$

$$= \mathbf{0.040}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.956 + 0.141 + 0.040 = \mathbf{1.138}\ \boldsymbol{crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 36 fixed objects/mile and fixed-object offset (O_{fo}) = 24 feet; thus, from Table 12-20,

$f_{offset} = 0.057 + (0.049 - 0.057)\left(\frac{24-20}{25-20}\right) = 0.051$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$
$$= (0.051)(36)(0.036) + (1 - 0.036)$$
$$= \mathbf{1.030}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$
$$= 1.000 \times 1.030 \times 1.000 \times 0.914 \times 1.000$$
$$= \mathbf{0.941}$$

<u>Predicted Crashes ($N_{predicted}$)</u>

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$
$$= 1.138 \times 0.941$$
$$= \mathbf{1.070\ \mathit{crashes/year}}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 1.070 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.020\ \mathit{crashes/year}}$$

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

$= 1.070 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$$= \mathbf{0.005\ \mathit{crashes/year}}$$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (1.070 + 0.020 + 0.005)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{1.096\ \mathit{crashes/year}}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$
$$= 0.956 \times 0.941$$

$$= \mathbf{0.900}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.141 \times 0.941$$

$$= \mathbf{0.133}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.040 \times 0.941$$

$$= \mathbf{0.038}\ \boldsymbol{crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1-w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.900)} = 0.457$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.457)(0.900) + (1-0.457)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.547}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.133)} = 0.898$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.898)(0.133) + (1-0.898)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.119}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.038)} = 0.950$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.950)(0.038) + (1-0.950)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.036}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.547 + 0.119 + 0.036$$

$$= \mathbf{0.702}\ \boldsymbol{crashes/year}$$

C.4.5 East Segment 2007 (no-build): 4-lane, Undivided Arterial (4U)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-11.63 + 1.33 \times \ln(375) + \ln\left(\frac{1300}{5280}\right)) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.006}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-7.99 + 0.81 \times \ln(375) + \ln\left(\frac{1300}{5280}\right)) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.010}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.182)(0)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.058)(1)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.198)(0)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.026)(1)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.096)(0)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.018)(0)\left(\frac{375}{15{,}000}\right)^{1.172} + (0.029)(0)\left(\frac{375}{15{,}000}\right)^{1.172} \text{ (coefficients from Table 12-7)}$$

$$= 0 + 0.001 + 0 + 0.000 + 0 + 0 + 0$$

$$= \mathbf{0.001}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.006 + 0.010 + 0.001 = \mathbf{0.017}\ \boldsymbol{crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.037$

$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$

$= (0.166)(40)(0.037) + (1 - 0.037)$

$= \mathbf{1.209}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.365 \times (1.0 - 0.72 \times 0.517 - 0.83 \times 0.483)$

= **0.917**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.209 \times 1.000 \times 0.917 \times 1.000$

$= \mathbf{1.109}$

<u>Predicted Crashes ($N_{predicted}$)</u>

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.017 \times 1.109$

$= \mathbf{0.019\ \mathit{crashes/year}}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.019 \times 0.009$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.000\ \mathit{crashes/year}}$

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

$= 0.019 \times 0.002$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.000\ \mathit{crashes/year}}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.019 + 0.000 + 0.000)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.019\ \mathit{crashes/year}}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.006 \times 1.109$

$$= \mathbf{0.006\ crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.010 \times 1.109$$

$$= \mathbf{0.011\ crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.001 \times 1.109$$

$$= \mathbf{0.001\ crashes/year}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1 + k \times \sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.01)(0.006)} = 0.994$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.994)(0.006) + (1 - 0.994)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.006\ crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.91)(0.011)} = 0.990$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.990)(0.011) + (1 - 0.990)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.011\ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(0.81)(0.001)} = 0.999$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.999)(0.042) + (1 - 0.999)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.001\ crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.006 + 0.011 + 0.001$$

$$= \mathbf{0.019\ crashes/year}$$

C.4.6 East Segment 2028 (no-build): 4-lane, Undivided Arterial (4U)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-11.63 + 1.33 \times \ln(18{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{1.000}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-7.99 + 0.81 \times \ln(18{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.233}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

$= (0.182)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.058)(1)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.198)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.026)(1)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.096)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.018)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.172} + (0.029)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.172}$ (coefficients from Table 12-7)

$= 0 + 0.072 + 0 + 0.032 + 0 + 0 + 0$

$= \mathbf{0.104}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 1.000 + 0.233 + 0.104 = \mathbf{1.337}\ \boldsymbol{crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.037$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.166)(40)(0.037) + (1 - 0.037)$$

$$= \mathbf{1.209}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.365 \times (1.0 - 0.72 \times 0.517 - 0.83 \times 0.483)$$

= **0.917**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 1.209 \times 1.000 \times 0.917 \times 1.000$$

$$= \mathbf{1.109}$$

<u>Predicted Crashes ($N_{predicted}$)</u>

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$

$$= 1.337 \times 1.109$$

$$= \mathbf{1.483\ crashes/year}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 1.483 \times 0.009$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.013\ crashes/year}$$

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

$= 1.483 \times 0.002$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$$= \mathbf{0.003\ crashes/year}$$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (1.483 + 0.013 + 0.003)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{1.499\ crashes/year}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$

$$= 1.000 \times 1.109$$

$$= \mathbf{1.109}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.233 \times 1.109$$

$$= \mathbf{0.259}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.104 \times 1.109$$

$$= \mathbf{0.115}\ \boldsymbol{crashes/year}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.01)(1.109)} = 0.472$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.472)(1.109) + (1 - 0.472)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.523}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.91)(0.259)} = 0.809$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.809)(0.259) + (1 - 0.809)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.209}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(0.81)(0.115)} = 0.915$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.915)(0.115) + (1 - 0.915)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.105}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.523 + 0.209 + 0.105$$

$= \mathbf{0.838}\ \boldsymbol{crashes/year}$

C.4.7 East Segment 2007 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.34 + 1.36 \times \ln(375) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{0.003}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.05 + 0.47 \times \ln(375) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.026}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.033)(0)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.011)(1)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.005)(1)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.018)(0)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{375}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{375}{15{,}000}\right)^{1.106}$$ (coefficients from Table 12-7)

$= 0 + 0.000 + 0 + 0.000 + 0 + 0 + 0$

$= \mathbf{0.000}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 0.003 + 0.026 + 0.000 = \mathbf{0.029}\ \boldsymbol{crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: no fixed objects present (none); thus, $CMF_{2r} = \mathbf{1.000}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.000 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.914}$

<u>Predicted Crashes ($N_{predicted}$)</u>

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.029 \times 0.914$

$= \mathbf{0.027}\ \boldsymbol{crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.027 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.001}\ \boldsymbol{crashes/year}$

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

$= 0.027 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.000}\ \boldsymbol{crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.027 + 0.001 + 0.000)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.027}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$

$$= 0.003 \times 0.914$$

$$= \mathbf{0.003\ crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.026 \times 0.914$$

$$= \mathbf{0.023\ crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.000 \times 0.914$$

$$= \mathbf{0.000\ crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.003)} = 0.996$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.996)(0.003) + (1 - 0.996)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.003\ crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.023)} = 0.980$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.980)(0.023) + (1 - 0.980)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.023\ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.000)} = 1.000$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (1.000)(0.000) + (1 - 1.000)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.000}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.003 + 0.023 + 0.000$

$= \mathbf{0.026}\ \boldsymbol{crashes/year}$

C.4.8 East Segment 2028 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.34 + 1.36 \times \ln(18{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{0.660}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.05 + 0.47 \times \ln(18{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.158}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$= (0.033)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} + (0.011)(1)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} +$
$(0.005)(1)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} + (0.018)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.106} +$
$(0.005)(0)\left(\frac{18{,}000}{15{,}000}\right)^{1.106}$ (coefficients from Table 12-7)

$= 0 + 0.013 + 0 + 0.006 + 0 + 0 + 0$

$= \mathbf{0.020}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 0.660 + 0.158 + 0.020 = \mathbf{0.837}\ \boldsymbol{crashes/year}$

<u>Crash Modification Factors (CMFs)</u>

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: no fixed objects present (none); thus, $CMF_{2r} = \mathbf{1.000}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.000 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.914}$

<u>Predicted Crashes ($N_{predicted}$)</u>

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.837 \times 0.914$

$= \mathbf{0.765}\ \boldsymbol{crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.765 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.015}\ \boldsymbol{crashes/year}$

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

$= 0.765 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.004\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.765 + 0.015 + 0.004)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.783\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.660 \times 0.914$

$= \mathbf{0.603\ crashes/year}$

$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$

$= 0.158 \times 0.914$

$= \mathbf{0.144\ crashes/year}$

$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$

$= 0.020 \times 0.914$

$= \mathbf{0.018\ crashes/year}$

Expected Crashes ($N_{expected}$)

$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.603)} = 0.557$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.557)(0.603) + (1 - 0.557)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.336\ crashes/year}$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.144)} = 0.890$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.890)(0.144) + (1 - 0.890)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.128}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.018)} = 0.976$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.976)(0.018) + (1 - 0.976)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.017}\ \boldsymbol{crashes/year}$

⁑ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.336 + 0.128 + 0.017$

$= \mathbf{0.481}\ \boldsymbol{crashes/year}$

C.4.9 South Segment 2007 (no-build): 2-lane, Undivided Arterial (2U)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-15.22 + 1.68 \times \ln(5{,}100) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{0.102}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.47 + 0.56 \times \ln(5{,}100) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.124}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.158)(0)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.050)(0)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.172)(1)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.023)(1)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.083)(1)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.016)(0)\left(\frac{5{,}100}{15{,}000}\right)^1 + (0.025)(0)\left(\frac{5{,}100}{15{,}000}\right)^1$$ (coefficients from Table 12-7)

$$= 0 + 0 + 0.058 + 0.008 + 0.028 + 0 + 0$$

$$= \mathbf{0.095\ crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.102 + 0.124 + 0.095 = \mathbf{0.321\ crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 30 feet; thus, from Table 12-20, f_{offset} = 0.044 and, from Table 12-21, p_{fo} = 0.059

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.044)(40)(0.059) + (1 - 0.059)$$

$$= \mathbf{1.045}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: no lighting present (none); thus, $CMF_{4r} = \mathbf{1.000}$

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 1.045 \times 1.000 \times 1.000 \times 1.000$$

$$= \mathbf{1.045}$$

Predicted Crashes ($N_{predicted}$)

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$

$$= 0.321 \times 1.045$$

$$= \mathbf{0.335}\ \boldsymbol{crashes/year}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 0.335 \times 0.005$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.002}\ \boldsymbol{crashes/year}$$

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

$= 0.335 \times 0.004$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$$= \mathbf{0.001}\ \boldsymbol{crashes/year}$$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.335 + 0.002 + 0.001)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{0.338}\ \boldsymbol{crashes/year}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$

$$= 0.102 \times 1.045$$

$$= \mathbf{0.107}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.124 \times 1.045$$

$$= \mathbf{0.129}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.095 \times 1.045$$

$$= \mathbf{0.099}\ \boldsymbol{crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(0.84)(0.107)} = 0.918$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.918)(0.107) + (1 - 0.918)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.139}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.81)(0.129)} = 0.905$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.905)(0.129) + (1 - 0.905)(0.25)$ (with 0.25 crashes/year observed)

$= \mathbf{0.141}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(0.81)(0.099)} = 0.926$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.926)(0.099) + (1 - 0.926)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.091}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.139 + 0.141 + 0.091$

$= \mathbf{0.371}\ \boldsymbol{crashes/year}$

C.4.10 South Segment 2028 (no-build): 2-lane, Undivided Arterial (2U)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-15.22 + 1.68 \times \ln(31{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$$= \mathbf{2.122}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.47 + 0.56 \times \ln(31{,}000) + \ln\left(\frac{1300}{5280}\right))$$ (coefficients from Table 12-5)

$$= \mathbf{0.340}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

$$= (0.158)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.050)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.172)(1)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.023)(1)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.083)(1)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.016)(0)\left(\frac{31{,}000}{15{,}000}\right)^1 + (0.025)(0)\left(\frac{31{,}000}{15{,}000}\right)^1$$ (coefficients from Table 12-7)

$$= 0 + 0 + 0.355 + 0.048 + 0.172 + 0 + 0$$

$$= \mathbf{0.575}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 2.122 + 0.340 + 0.575 = \mathbf{3.04}\ \boldsymbol{crashes/year}$$

<u>Crash Modification Factors (CMFs)</u>

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 30 feet; thus, from Table 12-20, f_{offset} = 0.044 and, from Table 12-21, p_{fo} = 0.059

$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$

$= (0.044)(40)(0.059) + (1 - 0.059)$

$= \mathbf{1.045}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: no lighting present (none); thus, $CMF_{4r} = \mathbf{1.000}$

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.045 \times 1.000 \times 1.000 \times 1.000$

$= \mathbf{1.045}$

Predicted Crashes ($N_{predicted}$)

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 3.037 \times 1.045$

$= \mathbf{3.173\ crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 3.173 \times 0.005$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.016\ crashes/year}$

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

$= 3.173 \times 0.004$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.013\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (3.173 + 0.016 + 0.013)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{3.202\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$
$$= 2.122 \times 1.045$$
$$= \mathbf{2.218}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$
$$= 0.340 \times 1.045$$
$$= \mathbf{0.355}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$
$$= 0.575 \times 1.045$$
$$= \mathbf{0.600}\ \boldsymbol{crashes/year}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(0.84)(2.218)} = 0.349$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.349)(2.218) + (1 - 0.349)(0.5)$ (with 0.5 crashes/year observed)

$$= \mathbf{1.100}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.81)(0.355)} = 0.777$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.777)(0.355) + (1 - 0.777)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.331}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$w_{brdwy} = \frac{1}{1+(0.81)(0.600)} = 0.673 \text{ (with k coefficient from Table 12-7)}$$

$$N_{\exp brdwy} = (0.673)(0.600) + (1 - 0.673)(0.0) \text{ (with 0.0 crashes/year observed)}$$

$$= \mathbf{0.404}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 1.100 + 0.331 + 0.404$$

$$= \mathbf{1.835}\ \boldsymbol{crashes/year}$$

C.4.11 South Segment 2007 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-12.34 + 1.36 \times \ln(5{,}100) + \ln\left(\frac{1300}{5280}\right)) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.119}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.05 + 0.47 \times \ln(5{,}100) + \ln\left(\frac{1300}{5280}\right)) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.087}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

$$= (0.033)(0)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.036)(1)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.005)(1)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{5{,}100}{15{,}000}\right)^{1.106} \text{ (coefficients from Table 12-7)}$$

$$= 0 + 0 + 0.011 + 0.002 + 0.005 + 0 + 0$$

$$= \mathbf{0.018}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 0.119 + 0.087 + 0.018 = \mathbf{0.224}\ \boldsymbol{crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 49 fixed objects/mile and fixed-object offset (O_{fo}) = 24 feet; thus, from Table 12-20,

$f_{offset} = 0.057 + (0.049 - 0.057)\left(\frac{24-20}{25-20}\right) = 0.051$ and, from Table 12-21, $p_{fo} = 0.036$

$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$

$= (0.051)(49)(0.036) + (1 - 0.036)$

$= \mathbf{1.053}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.053 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.963}$

Predicted Crashes ($N_{predicted}$)

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.224 \times 0.963$

$= \mathbf{0.215}\ \boldsymbol{crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.215 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.004}\ \boldsymbol{crashes/year}$

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

$= 0.215 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.001}\ \boldsymbol{crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.215 + 0.004 + 0.001)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.221}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.119 \times 0.963$

$= \mathbf{0.114}\ \boldsymbol{crashes/year}$

$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$

$= 0.087 \times 0.963$

$= \mathbf{0.084}\ \boldsymbol{crashes/year}$

$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$

$= 0.018 \times 0.963$

$= \mathbf{0.017}\ \boldsymbol{crashes/year}$

Expected Crashes ($N_{expected}$)

$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.114)} = 0.869$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.869)(0.114) + (1 - 0.869)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.165}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.084)} = 0.933$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.933)(0.084) + (1 - 0.933)(0.25)$ (with 0.25 crashes/year observed)

$= \mathbf{0.095}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.017)} = 0.977$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.977)(0.017) + (1 - 0.977)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.017}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.165 + 0.095 + 0.017$

$= \mathbf{0.277}\ \boldsymbol{crashes/year}$

C.4.12 South Segment 2028 (build): 4-lane, Divided Arterial (4D)

<u>Safety Performance Functions (SPFs)</u>

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.34 + 1.36 \times \ln(31{,}000) + \ln\left(\frac{1300}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{1.382}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.05 + 0.47 \times \ln(31{,}000) + \ln\left(\frac{1300}{5280}\right))$$ (coefficients from Table 12-5)

$$= \mathbf{0.204}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.033)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.036)(1)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.005)(1)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{31{,}000}{15{,}000}\right)^{1.106}$$ (coefficients from Table 12-7)

$$= 0 + 0 + 0.080 + 0.011 + 0.040 + 0 + 0$$

$$= \mathbf{0.132}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 1.382 + 0.204 + 0.132 = \mathbf{1.717}\ \boldsymbol{crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 49 fixed objects/mile and fixed-object offset (O_{fo}) = 24 feet; thus, from Table 12-20,

$f_{offset} = 0.057 + (0.049 - 0.057)\left(\frac{24-20}{25-20}\right) = 0.051$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.051)(49)(0.036) + (1 - 0.036)$$

$$= \mathbf{1.053}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 1.053 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.963}$

<u>Predicted Crashes ($N_{predicted}$)</u>

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 1.717 \times 0.963$

$= \mathbf{1.653\ crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 1.653 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.031\ crashes/year}$

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

$= 1.653 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.008\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (1.653 + 0.031 + 0.008)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{1.692\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 1.382 \times 0.963$

$= \mathbf{1.330\ crashes/year}$

$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$

$= 0.204 \times 0.963$

$= \mathbf{0.196\ crashes/year}$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.132 \times 0.963$$

$$= \mathbf{0.127\ \textit{crashes/year}}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1-w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\ study\\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(1.330)} = 0.363$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.363)(1.330) + (1-0.363)(0.5)$ (with 0.5 crashes/year observed)

$$= \mathbf{0.801\ \textit{crashes/year}}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.196)} = 0.856$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.856)(0.196) + (1-0.856)(0.25)$ (with 0.25 crashes/year observed)

$$= \mathbf{0.204\ \textit{crashes/year}}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.127)} = 0.850$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.850)(0.127) + (1-0.850)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.108\ \textit{crashes/year}}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.801 + 0.204 + 0.108$

$= \mathbf{1.113}\ \boldsymbol{crashes/year}$

C.4.13 West Segment 2007 (no-build): 4-lane, Divided Arterial (4D)

<u>Safety Performance Functions (SPFs)</u>

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.34 + 1.36 \times \ln(5{,}700) + \ln\left(\frac{600}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{0.064}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.05 + 0.47 \times \ln(5{,}700) + \ln\left(\frac{600}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.042}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all\\ driveway\\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$= (0.033)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} +$
$(0.005)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} +$
$(0.005)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106}$ (coefficients from Table 12-7)

$= 0 + 0 + 0 + 0 + 0.006 + 0 + 0$

$= \mathbf{0.006}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 0.064 + 0.042 + 0.006 = \mathbf{0.112}\ \boldsymbol{crashes/year}$

<u>Crash Modification Factors (CMFs)</u>

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.166)(40)(0.036) + (1 - 0.036)$$

$$= \mathbf{1.203}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$$

$$= \mathbf{0.914}$$

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 1.203 \times 1.000 \times 0.914 \times 1.000$$

$$= \mathbf{1.099}$$

<u>Predicted Crashes ($N_{predicted}$)</u>

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$

$$= 0.112 \times 1.099$$

$$= \mathbf{0.123\ crashes/year}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 0.123 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.002\ crashes/year}$$

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

= 0.123 × 0.005 (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.001\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

= 1.00 × (0.123 + 0.002 + 0.001) (where calibration factor, C_r, = 1.00)

$= \mathbf{0.126\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.064 \times 1.099$

$= \mathbf{0.070\ crashes/year}$

$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$

$= 0.042 \times 1.099$

$= \mathbf{0.047\ crashes/year}$

$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$

$= 0.006 \times 1.099$

$= \mathbf{0.007\ crashes/year}$

<u>Expected Crashes ($N_{expected}$)</u>

$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1 + k \times \sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.070)} = 0.915$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.915)(0.070) + (1 - 0.915)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.064\ crashes/year}$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.047)} = 0.961$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.961)(0.047) + (1 - 0.961)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.045}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$w_{brdwy} = \frac{1}{1+(1.39)(0.007)} = 0.991 \text{ (with k coefficient from Table 12-7)}$$

$$N_{\exp brdwy} = (0.991)(0.007) + (1 - 0.991)(0.0) \text{ (with 0.0 crashes/year observed)}$$

$$= \mathbf{0.007}\ \boldsymbol{crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.064 + 0.045 + 0.007$$

$$= \mathbf{0.116}\ \boldsymbol{crashes/year}$$

C.4.14 West Segment 2028 (no-build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-12.34 + 1.36 \times \ln(30{,}000) + \ln\left(\frac{600}{5280}\right)) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.610}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.05 + 0.47 \times \ln(30{,}000) + \ln\left(\frac{600}{5280}\right)) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.093}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.033)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106}$$ (coefficients from Table 12-7)

$$= 0 + 0 + 0 + 0 + 0.039 + 0 + 0$$

$$= \mathbf{0.039}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.610 + 0.093 + 0.039 = \mathbf{0.741}\ \boldsymbol{crashes/year}$$

<u>Crash Modification Factors (CMFs)</u>

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 40 fixed objects/mile and fixed-object offset (O_{fo}) = 4 feet; thus, from Table 12-20,

$f_{offset} = (0.232) + (0.133 - 0.232)\left(\frac{4-2}{5-2}\right) = 0.166$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.166)(40)(0.036) + (1 - 0.036)$$

$$= \mathbf{1.203}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 1.203 \times 1.000 \times 0.914 \times 1.000$$

$$= \mathbf{1.099}$$

Predicted Crashes ($N_{predicted}$)

$$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$$

$$N_{predicted\ br} = N_{spf} \times CMF_{combined}$$

$$= 0.741 \times 1.099$$

$$= \mathbf{0.815}\ \boldsymbol{crashes/year}$$

$$N_{pedr} = N_{br} \times f_{pedr}$$

$= 0.815 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$$= \mathbf{0.015}\ \boldsymbol{crashes/year}$$

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

$= 0.815 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$$= \mathbf{0.004}\ \boldsymbol{crashes/year}$$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.815 + 0.015 + 0.004)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{0.834}\ \boldsymbol{crashes/year}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$$

$$= 0.610 \times 1.099$$

$$= \mathbf{0.670}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.093 \times 1.099$$

$$= \mathbf{0.102}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.039 \times 1.099$$

$$= \mathbf{0.043\ crashes/year}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.670)} = 0.530$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.530)(0.670) + (1 - 0.530)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.356\ crashes/year}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.102)} = 0.919$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.919)(0.102) + (1 - 0.919)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.094\ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.043)} = 0.944$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.944)(0.043) + (1 - 0.944)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.040\ crashes/year}$$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$$= 0.356 + 0.094 + 0.040$$

$$= \mathbf{0.490\ crashes/year}$$

C.4.15 West Segment 2007 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-12.34 + 1.36 \times \ln(5{,}700) + \ln\left(\frac{600}{5280}\right)) \text{ (coefficients from Table 12-3)}$$

$$= \mathbf{0.064}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$$

$$= \exp(-5.05 + 0.47 \times \ln(5{,}700) + \ln\left(\frac{600}{5280}\right)) \text{ (coefficients from Table 12-5)}$$

$$= \mathbf{0.042}\ \boldsymbol{crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times (\frac{AADT}{15{,}000})^{(t)}$$

$$= (0.033)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} + (0.005)(0)\left(\frac{5{,}700}{15{,}000}\right)^{1.106} \text{ (coefficients from Table 12-7)}$$

$$= 0 + 0 + 0 + 0 + 0.006 + 0 + 0$$

$$= \mathbf{0.006}\ \boldsymbol{crashes/year}$$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$$= 0.064 + 0.042 + 0.006 = \mathbf{0.112}\ \boldsymbol{crashes/year}$$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 9 fixed objects/mile and fixed-object offset (O_{fo}) = 30 feet; thus, from Table 12-20, $f_{offset} = 0.044$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.044)(9)(0.036) + (1 - 0.036)$$

$= \mathbf{0.978}$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$= 1.000 \times 0.978 \times 1.000 \times 0.914 \times 1.000$

$= \mathbf{0.894}$

Predicted Crashes ($N_{predicted}$)

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$= 0.112 \times 0.894$

$= \mathbf{0.100\ crashes/year}$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.112 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.002\ crashes/year}$

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

$= 0.112 \times 0.005$ (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.001\ crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.100 + 0.002 + 0.001)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.103\ crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.064 \times 0.894$

$= \mathbf{0.057\ crashes/year}$

$$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$$

$$= 0.042 \times 0.894$$

$$= \mathbf{0.038\ \mathit{crashes/year}}$$

$$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$$

$$= 0.006 \times 0.894$$

$$= \mathbf{0.006\ \mathit{crashes/year}}$$

<u>Expected Crashes ($N_{expected}$)</u>

$$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.057)} = 0.930$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.930)(0.057) + (1 - 0.930)(0.0)$ (with 0.0 crashes/year observed)

$$= \mathbf{0.053\ \mathit{crashes/year}}$$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.038)} = 0.968$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.968)(0.038) + (1 - 0.968)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.037}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.006)} = 0.992$ (with k coefficient from Table 12-7)

$N_{\exp brdwy} = (0.992)(0.006) + (1 - 0.992)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.005}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$= 0.053 + 0.037 + 0.005$

$= \mathbf{0.095}\ \boldsymbol{crashes/year}$

C.4.16 West Segment 2028 (build): 4-lane, Divided Arterial (4D)

Safety Performance Functions (SPFs)

$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

Multiple-Vehicle Non-driveway Collisions

$N_{brmv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-12.34 + 1.36 \times \ln(30{,}000) + \ln\left(\frac{600}{5280}\right))$ (coefficients from Table 12-3)

$= \mathbf{0.610}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT) + \ln(L))$

$= \exp(-5.05 + 0.47 \times \ln(30{,}000) + \ln\left(\frac{600}{5280}\right))$ (coefficients from Table 12-5)

$= \mathbf{0.093}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$$N_{brdwy} = \sum_{\substack{all \\ driveway \\ types}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

$= (0.033)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.011)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.036)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} +$
$(0.005)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.018)(1)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} + (0.003)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106} +$
$(0.005)(0)\left(\frac{30{,}000}{15{,}000}\right)^{1.106}$ (coefficients from Table 12-7)

$= 0 + 0 + 0 + 0 + 0.039 + 0 + 0$

$= \mathbf{0.039\ crashes/year}$

⁂ $N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy}$

$= 0.610 + 0.093 + 0.039 = \mathbf{0.741\ crashes/year}$

Crash Modification Factors (CMFs)

On-Street Parking: no on-street parking (none); thus, $CMF_{1r} = \mathbf{1.000}$

Roadside Fixed Objects: present with estimated fixed-object density (D_{fo}) = 9 fixed objects/mile and fixed-object offset (O_{fo}) = 30 feet; thus, from Table 12-20, $f_{offset} = 0.044$ and, from Table 12-21, $p_{fo} = 0.036$

$$CMF_{2r} = f_{offset} \times D_{fo} \times p_{fo} + (1 - p_{fo})$$

$$= (0.044)(9)(0.036) + (1 - 0.036)$$

$$= \mathbf{0.978}$$

Median Width: undivided and traversable; thus, $CMF_{3r} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})$ (coefficients from Table 12-23)

$$= 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)$$

= **0.914**

Automated Speed Enforcement: no automated speed enforcement (none); thus, $CMF_{5r} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1r} \times CMF_{2r} \times CMF_{3r} \times CMF_{4r} \times CMF_{5r}$

$$= 1.000 \times 0.978 \times 1.000 \times 0.914 \times 1.000$$

$$= \mathbf{0.894}$$

Predicted Crashes ($N_{predicted}$)

$N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$N_{predicted\ br} = N_{spf} \times CMF_{combined}$

$$= 0.741 \times 0.894$$

$$= \mathbf{0.663\ crashes/year}$$

$N_{pedr} = N_{br} \times f_{pedr}$

$= 0.663 \times 0.019$ (with f_{pedr} coefficient from Table 12-8 with speed > 30mph)

$= \mathbf{0.013\ crashes/year}$

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

= 0.663 × 0.005 (with f_{biker} coefficient from Table 12-9 with speed > 30mph)

$= \mathbf{0.003}\ \boldsymbol{crashes/year}$

⁂ $N_{predicted\ rs} = C_r \times (N_{pred\ br} + N_{pedr} + N_{biker})$

$= 1.00 \times (0.663 + 0.013 + 0.003)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.679}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ brmv} = N_{brmv} \times CMF_{combined}$

$= 0.610 \times 0.894$

$= \mathbf{0.545}\ \boldsymbol{crashes/year}$

$N_{predicted\ brsv} = N_{brsv} \times CMF_{combined}$

$= 0.093 \times 0.894$

$= \mathbf{0.083}\ \boldsymbol{crashes/year}$

$N_{predicted\ brdwy} = N_{brdwy} \times CMF_{combined}$

$= 0.039 \times 0.894$

$= \mathbf{0.035}\ \boldsymbol{crashes/year}$

Expected Crashes ($N_{expected}$)

$N_{expected\ total} = N_{\exp brmv} + N_{\exp brsv} + N_{\exp brdwy}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Non-driveway Collisions

$w_{brmv} = \frac{1}{1+(1.32)(0.545)} = 0.582$ (with k coefficient from Table 12-3)

$N_{\exp brmv} = (0.582)(0.545) + (1 - 0.582)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.317}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{brsv} = \frac{1}{1+(0.86)(0.083)} = 0.934$ (with k coefficient from Table 12-5)

$N_{\exp brsv} = (0.934)(0.083) + (1 - 0.934)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.077}\ \boldsymbol{crashes/year}$

Multiple-Vehicle Driveway-Related Collisions

$w_{brdwy} = \frac{1}{1+(1.39)(0.035)} = 0.954$ (with k coefficient from Table 12-7)

$N_{\exp\,brdwy} = (0.954)(0.035) + (1 - 0.954)(0.0)$ (with 0.0 crashes/year observed)

$= \mathbf{0.033}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp\,brmv} + N_{\exp\,brsv} + N_{\exp\,brdwy}$

$= 0.317 + 0.077 + 0.033$

$= \mathbf{0.427}\ \boldsymbol{crashes/year}$

C.4.17 69th St and Cliff Ave Intersection 2007 (no-build): 4-leg, signalized (4SG)

Safety Performance Functions (SPFs)

$N_{spf\ int} = N_{bimv} + N_{bisv}$

Multiple-Vehicle Collisions

$N_{bimv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-10)

$= \exp(-10.99 + 1.07 \times \ln(7{,}850) + 0.23 \times \ln(3{,}308))$

$= \mathbf{1.569}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-12)

$= \exp(-10.21 + 0.68 \times \ln(7{,}850) + 0.27 \times \ln(3{,}308))$

$= \mathbf{0.143}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ int} = N_{bimv} + N_{bisv}$

$= 1.569 + 0.143 = \mathbf{1.712}\ \boldsymbol{crashes/year}$

For pedestrians, general level of pedestrian activity is assumed to be low; thus, from Table 12-15, PedVol (pedestrians/day) = 50 and maximum number of lanes crossed, n_{lanesx}, = 3

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

(coefficients from Table 12-14)

$= \exp\left(-9.53 + 0.40 \times \ln(7{,}850 + 3{,}308) + 0.26 \times \ln\left(\frac{3{,}308}{7{,}850}\right) + 0.45 \times \ln(50) + 0.04 \times 3\right)$

= 0.015 crashes/year

Crash Modification Factors (CMFs)

General

Intersection Left-Turn Lanes: number of approaches with left-turn lanes = 4; thus, from Table 12-24, $CMF_{1i} = \mathbf{0.660}$

Intersection Left-Turn Signal Phasing: number of approaches with protected/permissive signal phasing = 4; thus, from Table 12-25, $CMF_{2i} = (0.99)^4 = \mathbf{0.961}$

Intersection Right-Turn Lanes: number of approaches with right-turn lanes = 4; thus, from Table 12-26, $CMF_{3i} = \mathbf{0.850}$

Right-Turn-on-Red: right-turn-on-red allowed; thus, $CMF_{4i} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{5i} = 1.0 - 0.38 \times p_{ni}$ (coefficients from Table 12-27)

$= 1.0 - 0.38\ (0.235)$

= **0.911**

Red-Light Cameras: no red-light cameras (none); thus, $CMF_{6i} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1i} \times CMF_{2i} \times CMF_{3i} \times CMF_{4i} \times CMF_{5i} \times CMF_{6i}$

$= 0.660 \times 0.961 \times 0.850 \times 1.000 \times 0.911 \times 1.000$

$= \mathbf{0.491}$

Pedestrian

Bus Stop: number of bus stops within 1,000 ft = 0; thus, from Table 12-28, $CMF_{1p} = \mathbf{1.000}$

Schools: number of schools within 1,000 ft = 0; thus, from Table 12-29, $CMF_{2p} = \mathbf{1.000}$

Alcohol Sales Establishments: number of alcohol sales establishments within 1,000 ft = 0; thus, from Table 12-30, $CMF_{3p} = \mathbf{1.000}$

Predicted Crashes ($N_{predicted}$)

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

$N_{predicted\ bi} = N_{spf} \times CMF_{combined}$

$= 1.712 \times 0.491$

$= \mathbf{0.840\ crashes/year}$

$N_{pedi} = N_{pedbase} \times CMF_{ip}$

$= 0.015 \times (1.000 \times 1.000 \times 1.000)$

$= \mathbf{0.015\ crashes/year}$

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

$= 0.840 \times 0.015$ (with f_{biker} coefficient from Table 12-17)

$= \mathbf{0.013}\ \boldsymbol{crashes/year}$

⁂ $N_{predicted\ int} = C_r \times (N_{pred\ bi} + N_{pedi} + N_{bikei})$

$= 1.00 \times (0.840 + 0.015 + 0.013)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{0.868}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ bimv} = N_{bimv} \times CMF_{combined}$

$= 1.569 \times 0.491$

$= \mathbf{0.770}\ \boldsymbol{crashes/year}$

$N_{predicted\ bisv} = N_{bisv} \times CMF_{combined}$

$= 0.143 \times 0.491$

$= \mathbf{0.070}\ \boldsymbol{crashes/year}$

Expected Crashes ($N_{expected}$)

$N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Collisions

$w_{bimv} = \frac{1}{1+(0.39)(0.770)} = 0.769$ (with k coefficient from Table 12-10)

$N_{\exp bimv} = (0.769)(0.770) + (1 - 0.769)(1.0)$ (with 1.0 crashes/year observed)

$= \mathbf{0.823}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{bisv} = \frac{1}{1+(0.36)(0.070)} = 0.975$ (with k coefficient from Table 12-12)

$N_{\exp bisv} = (0.975)(0.070) + (1 - 0.975)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.081}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$= 0.823 + 0.081$

$= \mathbf{0.904}\ \boldsymbol{crashes/year}$

C.4.18 69th St and Cliff Ave Intersection 2028 (no-build): 4-leg, signalized (4SG)

Safety Performance Functions (SPFs)

$N_{spf\ int} = N_{bimv} + N_{bisv}$

Multiple-Vehicle Collisions

$N_{bimv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-10)

$= \exp(-10.99 + 1.07 \times \ln(31{,}000) + 0.23 \times \ln(24{,}000))$

$= \mathbf{10.973}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-12)

$= \exp(-10.21 + 0.68 \times \ln(31{,}000) + 0.27 \times \ln(24{,}000))$

$= \mathbf{0.635}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ int} = N_{bimv} + N_{bisv}$

$= 10.973 + 0.635 = \mathbf{11.607}\ \boldsymbol{crashes/year}$

For pedestrians, general level of pedestrian activity is assumed to be low; thus, from Table 12-15, PedVol (pedestrians/day) = 50 and maximum number of lanes crossed, n_{lanesx}, = 3

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

(coefficients from Table 12-14)

$$= \exp\left(-9.53 + 0.40 \times \ln(31{,}000 + 24{,}000) + 0.26 \times \ln\left(\frac{24{,}000}{31{,}000}\right) + 0.45 \times \ln(50) + 0.04 \times 3\right)$$

= 0.035 crashes/year

Crash Modification Factors (CMFs)

General

Intersection Left-Turn Lanes: number of approaches with left-turn lanes = 4; thus, from Table 12-24, $CMF_{1i} = \mathbf{0.660}$

Intersection Left-Turn Signal Phasing: number of approaches with protected/permissive signal phasing = 4; thus, from Table 12-25, $CMF_{2i} = (0.99)^4 = \mathbf{0.961}$

Intersection Right-Turn Lanes: number of approaches with right-turn lanes = 4; thus, from Table 12-26, $CMF_{3i} = \mathbf{0.850}$

Right-Turn-on-Red: right-turn-on-red allowed; thus, $CMF_{4i} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{5i} = 1.0 - 0.38 \times p_{ni}$ (coefficients from Table 12-27)

$= 1.0 - 0.38\ (0.235)$

= **0.911**

Red-Light Cameras: no red-light cameras (none); thus, $CMF_{6i} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1i} \times CMF_{2i} \times CMF_{3i} \times CMF_{4i} \times CMF_{5i} \times CMF_{6i}$

$= 0.660 \times 0.961 \times 0.850 \times 1.000 \times 0.911 \times 1.000$

$= \mathbf{0.491}$

Pedestrian

Bus Stop: number of bus stops within 1,000 ft = 0; thus, from Table 12-28, $CMF_{1p} = \mathbf{1.000}$

Schools: number of schools within 1,000 ft = 0; thus, from Table 12-29, $CMF_{2p} = \mathbf{1.000}$

Alcohol Sales Establishments: number of alcohol sales establishments within 1,000 ft = 0; thus, from Table 12-30, $CMF_{3p} = \mathbf{1.000}$

Predicted Crashes ($N_{predicted}$)

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

$N_{predicted\ bi} = N_{spf} \times CMF_{combined}$

$= 11.607 \times 0.491$

$= \mathbf{5.697\ crashes/year}$

$N_{pedi} = N_{pedbase} \times CMF_{ip}$

$= 0.035 \times (1.000 \times 1.000 \times 1.000)$

$= \mathbf{0.035\ crashes/year}$

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

$= 5.697 \times 0.015$ (with f_{biker} coefficient from Table 12-17)

$= \mathbf{0.085\ crashes/year}$

⁂ $N_{predicted\ int} = C_r \times (N_{pred\ bi} + N_{pedi} + N_{bikei})$

$= 1.00 \times (5.697 + 0.035 + 0.085)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{5.817}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ bimv} = N_{bimv} \times CMF_{combined}$

$= 10.973 \times 0.491$

$= \mathbf{5.385}\ \boldsymbol{crashes/year}$

$N_{predicted\ bisv} = N_{bisv} \times CMF_{combined}$

$= 0.635 \times 0.491$

$= \mathbf{0.312}\ \boldsymbol{crashes/year}$

<u>Expected Crashes ($N_{expected}$)</u>

$N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1 + k \times \sum_{\substack{all \\ study \\ years}} N_{pred}}$

Multiple-Vehicle Collisions

$w_{bimv} = \frac{1}{1+(0.39)(5.385)} = 0.323$ (with k coefficient from Table 12-10)

$N_{\exp bimv} = (0.323)(5.385) + (1 - 0.323)(1.0)$ (with 1.0 crashes/year observed)

$= \mathbf{2.414}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{bisv} = \frac{1}{1+(0.36)(0.312)} = 0.899$ (with k coefficient from Table 12-12)

$N_{\exp bisv} = (0.899)(0.312) + (1 - 0.899)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.331}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$= 2.414 + 0.331$

$= \mathbf{2.745\ crashes/year}$

C.4.19 69th St and Cliff Ave Intersection 2007 (build): 4-leg, signalized (4SG)

Safety Performance Functions (SPFs)

$N_{spf\ int} = N_{bimv} + N_{bisv}$

Multiple-Vehicle Collisions

$N_{bimv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-10)

$= \exp(-10.99 + 1.07 \times \ln(7{,}850) + 0.23 \times \ln(3{,}038))$

$= \mathbf{1.569\ crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-12)

$= \exp(-10.21 + 0.68 \times \ln(7{,}850) + 0.27 \times \ln(3{,}038))$

$= \mathbf{0.143\ crashes/year}$

⁂ $N_{spf\ int} = N_{bimv} + N_{bisv}$

$= 1.569 + 0.143 = \mathbf{1.712\ crashes/year}$

For pedestrians, general level of pedestrian activity is assumed to be medium-low; thus, from Table 12-15, PedVol (pedestrians/day) = 240 and maximum number of lanes crossed, n_{lanesx}, = 5

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

(coefficients from Table 12-14)

$$= \exp(-9.53 + 0.40 \times \ln(7{,}850 + 3{,}308) + 0.26 \times \ln\left(\frac{3{,}308}{7{,}850}\right) + 0.45 \times \ln(240) + 0.04 \times 7)$$

= 0.036 crashes/year

Crash Modification Factors (CMFs)

General

Intersection Left-Turn Lanes: number of approaches with left-turn lanes = 4; thus, from Table 12-24, $CMF_{1i} = \mathbf{0.660}$

Intersection Left-Turn Signal Phasing: number of approaches with protected signal phasing = 4; thus, from Table 12-25, $CMF_{2i} = (0.94)^4 = \mathbf{0.781}$

Intersection Right-Turn Lanes: number of approaches with right-turn lanes = 4; thus, from Table 12-26, $CMF_{3i} = \mathbf{0.850}$

Right-Turn-on-Red: right-turn-on-red allowed; thus, $CMF_{4i} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{5i} = 1.0 - 0.38 \times p_{ni}$ (coefficients from Table 12-27)

$= 1.0 - 0.38\ (0.235)$

= **0.911**

Red-Light Cameras: no red-light cameras (none); thus, $CMF_{6i} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1i} \times CMF_{2i} \times CMF_{3i} \times CMF_{4i} \times CMF_{5i} \times CMF_{6i}$

$= 0.660 \times 0.781 \times 0.850 \times 1.000 \times 0.911 \times 1.000$

$= \mathbf{0.399}$

Pedestrian

Bus Stop: number of bus stops within 1,000 ft = 0; thus, from Table 12-28, $CMF_{1p} = \mathbf{1.000}$

Schools: number of schools within 1,000 ft = 0; thus, from Table 12-29, $CMF_{2p} = \mathbf{1.000}$

Alcohol Sales Establishments: number of alcohol sales establishments within 1,000 ft = 0; thus, from Table 12-30, $CMF_{3p} = \mathbf{1.000}$

Predicted Crashes ($N_{predicted}$)

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

$N_{predicted\ bi} = N_{spf} \times CMF_{combined}$

$= 1.712 \times 0.399$

$= \mathbf{0.683}\ \boldsymbol{crashes/year}$

$$N_{pedi} = N_{pedbase} \times CMF_{ip}$$

$$= 0.036 \times (1.000 \times 1.000 \times 1.000)$$

$$= \mathbf{0.036}\ \boldsymbol{crashes/year}$$

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

$= 0.683 \times 0.015$ (with f_{biker} coefficient from Table 12-17)

$$= \mathbf{0.010}\ \boldsymbol{crashes/year}$$

⁂ $N_{predicted\ int} = C_r \times (N_{pred\ bi} + N_{pedi} + N_{bikei})$

$= 1.00 \times (0.683 + 0.036 + 0.010)$ (where calibration factor, C_r, = 1.00)

$$= \mathbf{0.729}\ \boldsymbol{crashes/year}$$

Also (needed for $N_{expected}$ calculations):

$$N_{predicted\ bimv} = N_{bimv} \times CMF_{combined}$$

$$= 1.569 \times 0.399$$

$$= \mathbf{0.626}\ \boldsymbol{crashes/year}$$

$$N_{predicted\ bisv} = N_{bisv} \times CMF_{combined}$$

$$= 0.143 \times 0.399$$

$$= \mathbf{0.057}\ \boldsymbol{crashes/year}$$

Expected Crashes ($N_{expected}$)

$$N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$$

$$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$$

where $w = \frac{1}{1+k\times\sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Collisions

$w_{bimv} = \frac{1}{1+(0.39)(0.626)} = 0.804$ (with k coefficient from Table 12-10)

$N_{\exp bimv} = (0.804)(0.626) + (1 - 0.804)(1.0)$ (with 1.0 crashes/year observed)

$$= \mathbf{0.699}\ \boldsymbol{crashes/year}$$

Single-Vehicle Crashes

$w_{bisv} = \frac{1}{1+(0.36)(0.057)} = 0.980$ (with k coefficient from Table 12-12)

$N_{\exp bisv} = (0.980)(0.057) + (1 - 0.980)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.066}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$= 0.699 + 0.066$

$= \mathbf{0.765}\ \boldsymbol{crashes/year}$

C.4.20 69th St and Cliff Ave Intersection 2028 (build): 4-leg, signalized (4SG)

Safety Performance Functions (SPFs)

$N_{spf\ int} = N_{bimv} + N_{bisv}$

Multiple-Vehicle Collisions

$N_{bimv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-10)

$= \exp(-10.99 + 1.07 \times \ln(31{,}000) + 0.23 \times \ln(24{,}000))$

$= \mathbf{10.973}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$N_{brsv} = \exp(a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min}))$ (coefficients from Table 12-12)

$= \exp(-10.21 + 0.68 \times \ln(31{,}000) + 0.27 \times \ln(24{,}000))$

$= \mathbf{0.635}\ \boldsymbol{crashes/year}$

⁂ $N_{spf\ int} = N_{bimv} + N_{bisv}$

$= 10.973 + 0.635 = \mathbf{11.607}\ \boldsymbol{crashes/year}$

For pedestrians, general level of pedestrian activity is assumed to be medium-low; thus, from Table 12-15, PedVol (pedestrians/day) = 240 and maximum number of lanes crossed, n_{lanesx}, = 5

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

(coefficients from Table 12-14)

$$= \exp\left(-9.53 + 0.40 \times \ln(31{,}000 + 24{,}000) + 0.26 \times \ln\left(\frac{24{,}000}{31{,}000}\right) + 0.45 \times \ln(240) + 0.04 \times 7\right)$$

= 0.083 crashes/year

Crash Modification Factors (CMFs)

General

Intersection Left-Turn Lanes: number of approaches with left-turn lanes = 4; thus, from Table 12-24, $CMF_{1i} = \mathbf{0.660}$

Intersection Left-Turn Signal Phasing: number of approaches with protected signal phasing = 4; thus, from Table 12-25, $CMF_{2i} = (0.94)^4 = \mathbf{0.781}$

Intersection Right-Turn Lanes: number of approaches with right-turn lanes = 4; thus, from Table 12-26, $CMF_{3i} = \mathbf{0.850}$

Right-Turn-on-Red: right-turn-on-red allowed; thus, $CMF_{4i} = \mathbf{1.000}$

Lighting: lighting present (yes); thus,

$CMF_{5i} = 1.0 - 0.38 \times p_{ni}$ (coefficients from Table 12-27)

$= 1.0 - 0.38\ (0.235)$

= **0.911**

Red-Light Cameras: no red-light cameras (none); thus, $CMF_{6i} = \mathbf{1.000}$

⁂ $CMF_{combined} = CMF_{1i} \times CMF_{2i} \times CMF_{3i} \times CMF_{4i} \times CMF_{5i} \times CMF_{6i}$

$= 0.660 \times 0.781 \times 0.850 \times 1.000 \times 0.911 \times 1.000$

$= \mathbf{0.399}$

Pedestrian

Bus Stop: number of bus stops within 1,000 ft = 0; thus, from Table 12-28, $CMF_{1p} = \mathbf{1.000}$

Schools: number of schools within 1,000 ft = 0; thus, from Table 12-29, $CMF_{2p} = \mathbf{1.000}$

Alcohol Sales Establishments: number of alcohol sales establishments within 1,000 ft = 0; thus, from Table 12-30, $CMF_{3p} = \mathbf{1.000}$

Predicted Crashes ($N_{predicted}$)

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

$N_{predicted\ bi} = N_{spf} \times CMF_{combined}$

$= 11.607 \times 0.399$

$= \mathbf{4.630\ crashes/year}$

$N_{pedi} = N_{pedbase} \times CMF_{ip}$

$= 0.083 \times (1.000 \times 1.000 \times 1.000)$

$= \mathbf{0.083\ crashes/year}$

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

$= 4.630 \times 0.015$ (with f_{biker} coefficient from Table 12-17)

$= \mathbf{0.069\ crashes/year}$

⁂ $N_{predicted\ int} = C_r \times (N_{pred\ bi} + N_{pedi} + N_{bikei})$

$= 1.00 \times (4.630 + 0.083 + 0.069)$ (where calibration factor, C_r, = 1.00)

$= \mathbf{4.783}\ \boldsymbol{crashes/year}$

Also (needed for $N_{expected}$ calculations):

$N_{predicted\ bimv} = N_{bimv} \times CMF_{combined}$

$= 10.973 \times 0.399$

$= \mathbf{4.377}\ \boldsymbol{crashes/year}$

$N_{predicted\ bisv} = N_{bisv} \times CMF_{combined}$

$= 0.635 \times 0.399$

$= \mathbf{0.253}\ \boldsymbol{crashes/year}$

<u>Expected Crashes ($N_{expected}$)</u>

$N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$N_{exp} = wN_{predicted} + (1 - w)N_{observed}$

where $w = \frac{1}{1 + k \times \sum_{\substack{all\\study\\years}} N_{pred}}$

Multiple-Vehicle Collisions

$w_{bimv} = \frac{1}{1 + (0.39)(4.377)} = 0.369$ (with k coefficient from Table 12-10)

$N_{\exp bimv} = (0.369)(4.377) + (1 - 0.369)(1.0)$ (with 1.0 crashes/year observed)

$= \mathbf{2.247}\ \boldsymbol{crashes/year}$

Single-Vehicle Crashes

$w_{bisv} = \frac{1}{1 + (0.36)(0.253)} = 0.916$ (with k coefficient from Table 12-12)

$N_{\exp bisv} = (0.916)(0.253) + (1 - 0.916)(0.5)$ (with 0.5 crashes/year observed)

$= \mathbf{0.274}\ \boldsymbol{crashes/year}$

⁂ $N_{expected\ total} = N_{\exp bimv} + N_{\exp bisv}$

$= 2.247 + 0.274$

$= \mathbf{2.521}\ \boldsymbol{crashes/year}$

C.5 Case Study: Site Crash Characteristics

Following are the crash characteristics for the case study site. Data were obtained from SDDOT then summarized.

C.5.1 Annual Crashes

Annual crashes for the site are relatively sparse, apparently increasing during the more recent years most likely due to an increase in traffic levels, as shown in Figure C.6.

2004 - 2018
Annual Crashes
by Portion of the Site

Year	All	Intersection	Segments
2004	1	1	
2005	4	2	2
2006	3	2	1
2007	2	1	1
2008	5	3	2
2009	9	7	2
2010	3	3	
2011	2	2	
2012	3	2	1
2013	6	5	1
2014	11	10	1
2015	6	4	2
2016	6	6	
2017	13	9	4
2018	8	5	3
	82	62	20

Figure C.6 Annual Crashes

C.5.2 Accident Severity

Along with the relatively few crashes, the accident severity was reasonably low as would be expected generally within an urban environment, as shown in Figure C.7. This is applicable across all years.

2004 - 2018
Accident Severity
by Portion of the Site

Accident Severity	All	Intersection	Segments
Fatal injury	1		1
Incapacitating	3	1	2
Non-incapacitating	8	6	2
Possible	14	11	3
No injury	54	44	10
Wild animal hit	2		2

Figure C.7 Accident Severity

C.5.3 Month

Related to these, no month had a particularly high crash frequency though January and April were higher than the other months, as shown in Figure C.8. This is applicable across all years.

2004 - 2018
Monthly Crashes
by Portion of the Site

Month	All	Intersection	Segments
January	12	11	1
February	9	7	2
March	6	4	2
April	11	7	4
May	2	2	
June	6	6	
July	5	5	
August	5	3	2
September	7	4	3
October	8	6	2
November	7	4	3
December	4	3	1

Figure C.8 Monthly Crashes

C.5.4 First Harmful Event

Again, not surprisingly given the urban environment, the overwhelming first harmful event for crashes within the site is between two motor vehicles in transport, as shown in Figure C.9. Crash history shows one (1) pedestrian hit crash and six (6) crashes involving fixed objects (e.g., posts, light posts, trees). This is applicable across all years.

2004 - 2018
First Harmful Event
by Portion of the Site

First Harmful Event	All	Intersection	Segments
Overturn/rollover	3	2	1
Pedestrian	1	1	
Animal - wild	3		3
Motor vehicle in transport	67	54	13
Other movable object	1	1	
Highway traffic signpost/sign	2	1	1
Light/luminaire support	3	2	1
Tree/shrubbery	1		1
Snowbank	1	1	

Figure C.9 First Harmful Event

C.5.5 Manner of Crash/Collision Impact

Related to this, many of the multi-vehicle crashes involved rear-end or angle crashes, the latter particularly at the intersection of 69th St and Cliff Ave, as shown in Figure C.10. Again, this is not surprising given the urban environment and the nature of intersection movements and conflicts. This is applicable across all years.

2004 - 2018
Manner of Crash/Collision Impact
by Portion of the Site

Manner of Crash/Collision Impact	All	Intersection	Segments
No collision between 2 MV in transport	13	8	5
Rear-end (front to rear)	28	18	10
Head-on (front to front)	1		1
Angle	33	31	2
Sideswipe, same direction	4	4	
Sideswipe, opposite direction	1	1	
Wild animal hit - damage only	2		2

Figure C.10 Manner of Crash/Collision Impact

C.5.6 Light Conditions

Additionally, most crashes occurred during daylight conditions, which is not surprising given normal daily traffic distribution, as shown in Figure C.11. Most of the non-daylight crashes occurred in portions where the roadway was lighted which, again, is not surprising given the urban environment and the site characteristics. This is applicable across all years.

2004 - 2018
Light Conditions
by Portion of the Site

Light Condition	All	Intersection	Segments
Daylight	53	38	15
Dark - roadway not lighted	4	1	3
Dark - lighted roadway	20	18	2
Dark - unknown roadway lighting	1	1	
Dawn	3	3	
Dusk	1	1	

Figure C.11 Light Conditions

C.5.7 Summary

In summary, overall, the crash occurrence at the site is relatively sparse with, in general, nothing surprising about the crash characteristics given the urban environment and the site characteristics. There is nothing apparent that would require adjustment to the Highway Safety Manual (HSM) procedure as applied to the site.

APPENDIX D: BENEFITS ESTIMATION SPREADSHEET (BES)

D.1 Background

State and local governments use access management to improve traffic flow, preserve roadway capacity, and ensure safe operation of motorized, pedestrian, and bicycle traffic on rural and urban streets and highways. Improved operational efficiency leads to lower transportation costs, increased energy efficiency, and reduced highway emissions. Safe and efficient operation of the roadway also contributes to the short- and long-term economic vitality of the businesses and communities served.

Methods to manage access, which may include limiting or reducing the number and location of access points, installing medians to eliminate or reduce left turns, providing alternative access via other roadways, or other techniques carry financial costs. In addition to direct costs of constructing the treatment, compensation to landowners for lost property or access may be required. Determining whether to apply a treatment depends on a comparison of those costs to the public benefit it will generate.

Estimating the current and future public benefit of a proposed access management treatment is not simple. The benefit may depend upon land use and zoning, traffic volumes and characteristics, highway or street function and attributes, and the number and location of adjacent access points. The Access Management Manual and the Highway Safety Manual (HSM) present general principles for describing or estimating the value of safety and operational improvements, but complete, specific, and locally calibrated methods are not presented. The South Dakota Department of Transportation (SDDOT) has developed a rudimentary tool based on the HSM for estimating safety benefits from certain access management improvements, and the City of Sioux Falls has correlated crash frequencies to access density on urban arterials, but no comprehensive method or tool exists to estimate the total financial value of the public benefit expected from a proposed access management treatment. Without a sound estimate of public benefit, deciding whether the treatment is worth the investment is difficult.

To address this problem, a spreadsheet software tool has been developed to facilitate analysis of the financial benefits of proposed access management treatments. The spreadsheet software tool has two main elements: a benefits estimation spreadsheet (BES) and an accompanying HSM implementation spreadsheet (HSMIS) for estimation of potential safety impacts. The following is a description of the BES, including a brief description, discussion of general spreadsheet entry steps, and an example of data entry to results.

D.2 Brief Description of Spreadsheet

The BES, as shown in Figure D.1, has several distinct parts.

Figure D.1 Benefits Estimation Spreadsheet (BES) Operational Tabs

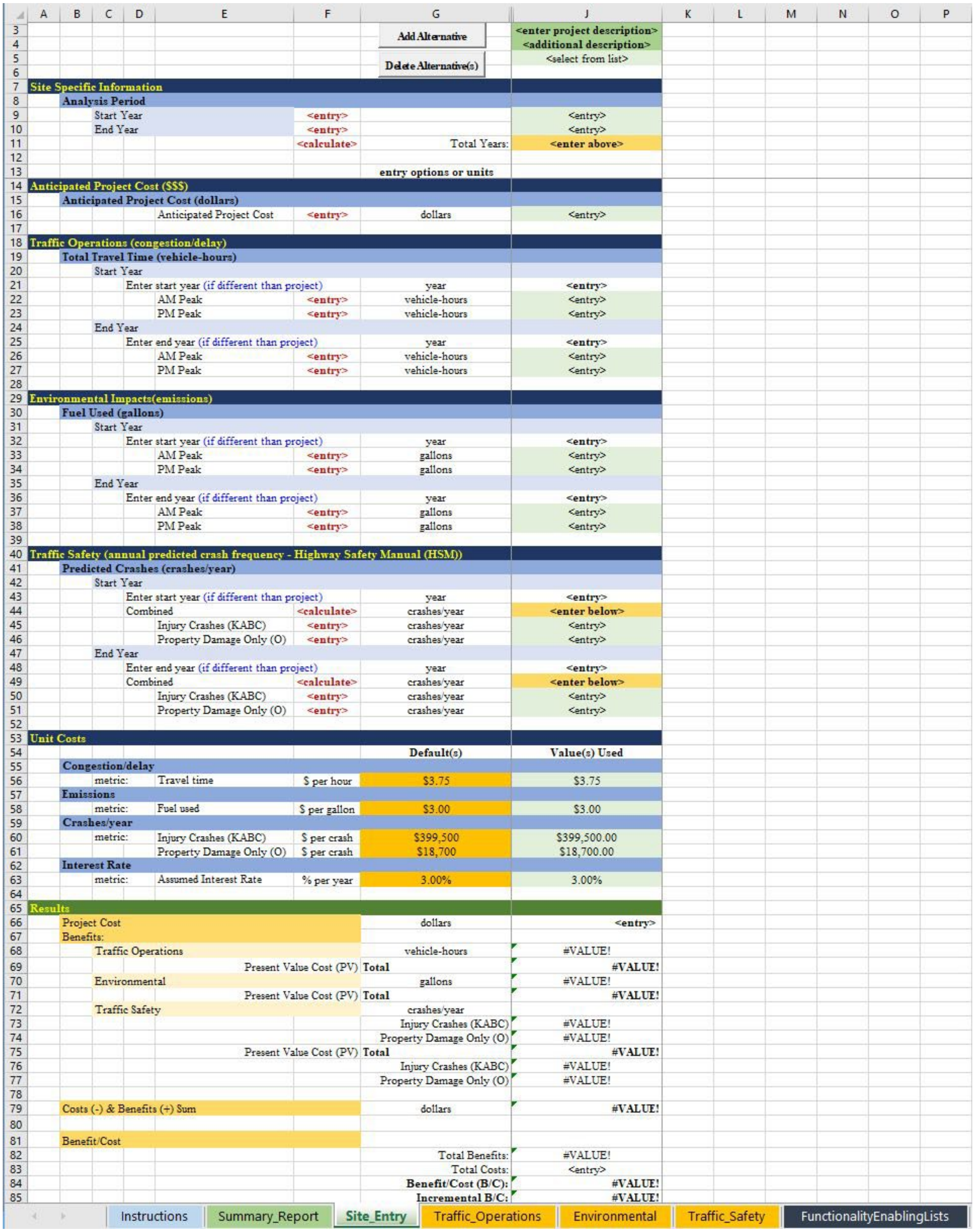
- The “Instructions” tab, shown in light blue, contains summary instructions for spreadsheet operation, with reference to these instructions for more detail.
- The “SummaryReport” tab, shown in light green, contains a summary of the results for each alternative and provides a printable version.
- The “Site_Entry” tab, shown in dark green, contains the primary worksheet for user interaction. Within this tab, users will enter values for each alternative, generally beginning with a “no-build” or “existing” option and progressing through each alternative option. These values include

alternative descriptions, analysis period start and end years, anticipated project costs, and values obtained from alternate software (e.g., Synchro/SimTraffic and the HSMIS) for traffic operations, environmental impacts, and traffic safety). At the bottom of the "Site_Entry" worksheet, results from analyses are also shown.

- The "Traffic Operations" tab, "Environmental" tab, and "Traffic_Safety" tab, shown in orange, contain worksheets that perform linear interpolation calculations and net benefit calculations. These sheets require no user interaction. These worksheets all use the entered data from the "Site_Entry" tab to interpolate values from the Start Year until the End Year for calculation of estimated benefits, returning the pertinent results to the Site_Entry tab. Both the "Traffic Operations" tab and "Environmental" tab worksheets use AM Peak and PM Peak entered values, whereas the "Traffic Safety" tab worksheet uses the crashes/year.
- The "FunctionalityEnablingLists" tab, shown in dark blue, contains a worksheet for the operational pick list for "no-build" or "build" used in the "Site_Entry" worksheet tab and requires no user interaction.

Regarding the "Site_Entry" tab, as shown in Figure D.2, there are distinct sections related to the analytical aspects of access management: Anticipated Project Cost ($$$), Traffic Operations (congestion/delay), Environmental Impacts (emissions), and Traffic Safety (annual predicted crash frequency). Prior to these sections, there is a section for brief alternative identification (Site Specific Information) and analysis period. Finally, following the analytical aspects, is a section for updating Unit Costs to reflect current valuations and a Results section.

The following discussion of data entry steps will refer to Figure D.2, as well as cropped sub-sections of Figure D.2, to describe the steps a user would use for data entry of a project with a base "no-build" (or existing alternative) as well as one or more additional alternatives.



		F	G	J
3			Add Alternative	<enter project description>
4				<additional description>
5			Delete Alternative(s)	<select from list>
6				
7	**Site Specific Information**			
8	**Analysis Period**			
9	Start Year	<entry>		<entry>
10	End Year	<entry>		<entry>
11		<calculate>	Total Years:	<enter above>
12				
13			entry options or units	
14	**Anticipated Project Cost ($$$)**			
15	**Anticipated Project Cost (dollars)**			
16	Anticipated Project Cost	<entry>	dollars	<entry>
17				
18	**Traffic Operations (congestion/delay)**			
19	**Total Travel Time (vehicle-hours)**			
20	Start Year			
21	Enter start year (if different than project)		year	<entry>
22	AM Peak	<entry>	vehicle-hours	<entry>
23	PM Peak	<entry>	vehicle-hours	<entry>
24	End Year			
25	Enter end year (if different than project)		year	<entry>
26	AM Peak	<entry>	vehicle-hours	<entry>
27	PM Peak	<entry>	vehicle-hours	<entry>
28				
29	**Environmental Impacts(emissions)**			
30	**Fuel Used (gallons)**			
31	Start Year			
32	Enter start year (if different than project)		year	<entry>
33	AM Peak	<entry>	gallons	<entry>
34	PM Peak	<entry>	gallons	<entry>
35	End Year			
36	Enter end year (if different than project)		year	<entry>
37	AM Peak	<entry>	gallons	<entry>
38	PM Peak	<entry>	gallons	<entry>
39				
40	**Traffic Safety (annual predicted crash frequency - Highway Safety Manual (HSM))**			
41	**Predicted Crashes (crashes/year)**			
42	Start Year			
43	Enter start year (if different than project)		year	<entry>
44	Combined	<calculate>	crashes/year	<enter below>
45	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
46	Property Damage Only (O)	<entry>	crashes/year	<entry>
47	End Year			
48	Enter end year (if different than project)		year	<entry>
49	Combined	<calculate>	crashes/year	<enter below>
50	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
51	Property Damage Only (O)	<entry>	crashes/year	<entry>
52				
53	**Unit Costs**			
54			**Default(s)**	**Value(s) Used**
55	**Congestion/delay**			
56	metric: Travel time	$ per hour	$3.75	$3.75
57	**Emissions**			
58	metric: Fuel used	$ per gallon	$3.00	$3.00
59	**Crashes/year**			
60	metric: Injury Crashes (KABC)	$ per crash	$399,500	$399,500.00
61	Property Damage Only (O)	$ per crash	$18,700	$18,700.00
62	**Interest Rate**			
63	metric: Assumed Interest Rate	% per year	3.00%	3.00%
64				
65	**Results**			
66	Project Cost		dollars	<entry>
67	Benefits:			
68	Traffic Operations		vehicle-hours	#VALUE!
69		Present Value Cost (PV)	**Total**	#VALUE!
70	Environmental		gallons	#VALUE!
71		Present Value Cost (PV)	**Total**	#VALUE!
72	Traffic Safety		crashes/year	
73			Injury Crashes (KABC)	#VALUE!
74			Property Damage Only (O)	#VALUE!
75		Present Value Cost (PV)	**Total**	#VALUE!
76			Injury Crashes (KABC)	#VALUE!
77			Property Damage Only (O)	#VALUE!
78				
79	Costs (-) & Benefits (+) Sum		dollars	#VALUE!
80				
81	Benefit/Cost			
82			Total Benefits:	#VALUE!
83			Total Costs:	<entry>
84			**Benefit/Cost (B/C):**	#VALUE!
85			**Incremental B/C:**	#VALUE!

Instructions | Summary_Report | Site_Entry | Traffic_Operations | Environmental | Traffic_Safety | FunctionalityEnablingLists

Figure D.2 Site_Entry Tab from Benefits Estimation Spreadsheet (BES)

D.3 Entry Steps

For data entry into the BES there are eight distinct steps, as shown in Figure D.3. These steps are associated directly with sections of the BES and each will be explained in the following sections. For the discussion, the steps will be described using column J, which is the column displayed at the right in Figure D.2, but these steps apply to any additional columns that would be generated for additional site alternatives per Figure D.3.

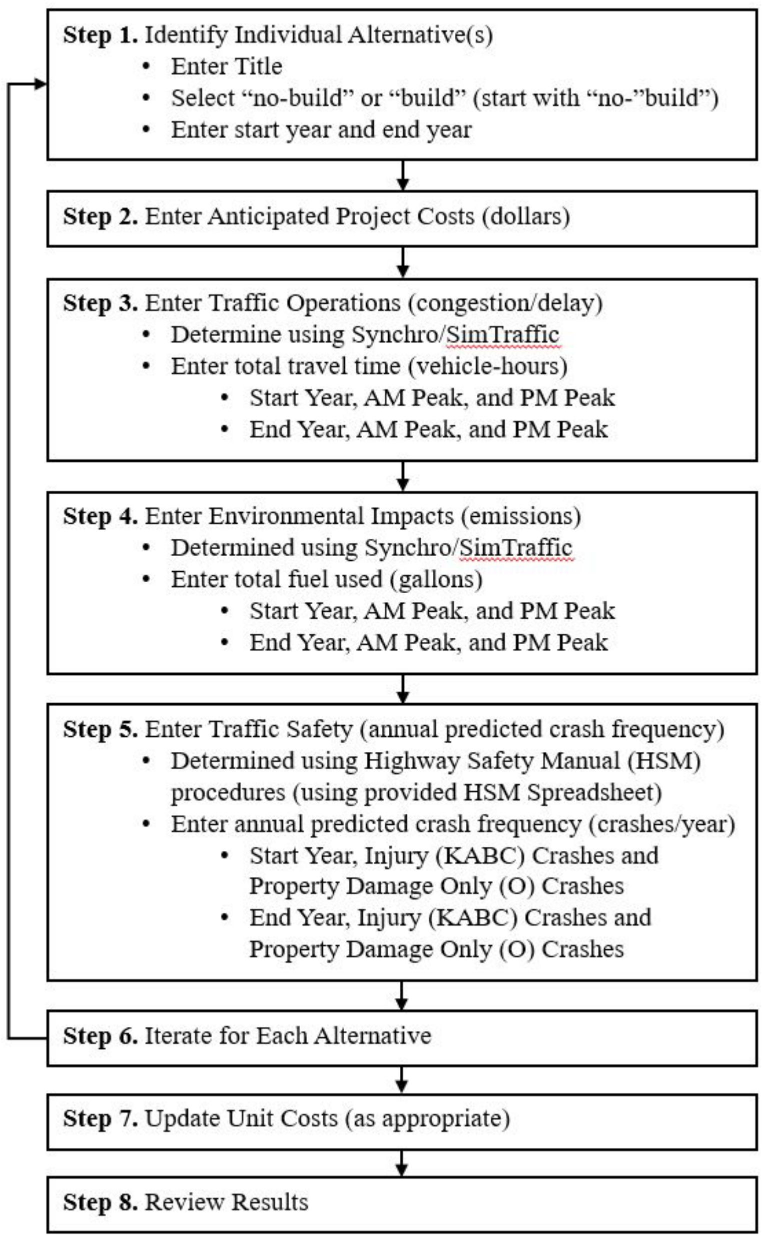


Figure D.3 BES Entry Steps Flowchart

D.3.1 Step 1 – Identify Individual Alternatives

For step 1, there should always be a “no-build” (or existing alternative) to begin with that captures site characteristics as exist prior to any construction and this “no-build” option should be entered in column J as shown in Figure D.4. Additionally, there should be one or more “build” alternatives with each “build”

	A	B	C	D	E	F	G	J
3							Add Alternative	<enter project description>
4								<additional description>
5							Delete Alternative(s)	<select from list>
6								
7	Site Specific Information							
8		Analysis Period						
9			Start Year			<entry>		<entry>
10			End Year			<entry>		<entry>
11						<calculate>	Total Years:	<enter above>
12								

Figure D.4 Entry of Individual Alternatives (BES)

alternative contained within an additional column (e.g., column K, L, M, etc.) and these alternatives ordered by increasing project cost from left to right to facilitate the incremental benefit/cost calculations. Within the data entry process, these alternatives can either be treated singly or all alternatives can be identified and columns for each generated at this point by clicking the “Add Alternative” button. Either way, once an alternative has been initiated, enter a project description in cell J3 and any additional description in cell J4, identify the site as the “no-build” or a “build” option by selecting from the pick list that will appear if cell J5 is clicked (which is the first “<select from list>” option). Again, column J is for the “no-build” option with subsequent columns for alternative “build” options that will be compared against the “no-build” option. Once the “no-build” or “build” option has been identified, proceed by entering the “Start Year” and “End Year” of the analysis period in cells J9 and J10, respectively. Once these are entered, the Total Years will appear in cell J11. Again, all the prior discussion applies to subsequently generated columns.

D.3.2 Step 2 – Enter Anticipated Project Costs

For step 2, enter the anticipated project cost within Cell J16 as shown in Figure D.5 which, for the “no-build” option, should be $0. For other alternatives, the value entered should be greater than $0 and, as before, placed in the column appropriate to the site alternative on row 16. Alternatives are ordered by increasing project cost from left to right to facilitate the incremental benefit/cost calculations.

	A	B	C	D	E	F	G	J
13							entry options or units	
14	Anticipated Project Cost ($$$)							
15		Anticipated Project Cost (dollars)						
16					Anticipated Project Cost	<entry>	dollars	<entry>
17								

Figure D.5 Entry of Anticipated Project Costs (BES)

D.3.3 Step 3 – Enter Traffic Operations (congestion/delay)

For step 3, the values are obtained from an operational analysis, obtained via Synchro/SimTraffic, to determine Travel Time, in vehicle-hours. From Synchro/SimTraffic, values should be obtained for each period as indicated in Figure D.6 and obtained from Synchro/SimTraffic output as shown in Figure D.7. These periods include both AM and PM peak timeframes for both the Start Year and the End Year as shown by cells J22 and J23 for the Start Year and cells J26 and J27 for the End Year. As shown in Figure D.7, output from Synchro/SimTraffic provides both the travel time value required for Step 3, as indicated by the A annotation, as well as the fuel used value required for Step 4, as indicated by the B annotation. These numbers are obtained from PDF output files from Synchro/SimTraffic. For each alternative, four separate output files should be available with the data as shown in Figure D.7. Enter each travel time value appropriately into the AM and PM Peak data entry positions as shown in Figure D.6. Again, all the prior discussion applies to subsequently generated columns.

18	**Traffic Operations (congestion/delay)**			
19	**Total Travel Time (vehicle-hours)**			
20	Start Year			
21	Enter start year (if different than project)		year	**<entry>**
22	AM Peak	<entry>	vehicle-hours	<entry>
23	PM Peak	<entry>	vehicle-hours	<entry>
24	End Year			
25	Enter end year (if different than project)		year	**<entry>**
26	AM Peak	<entry>	vehicle-hours	<entry>
27	PM Peak	<entry>	vehicle-hours	<entry>
28				

Figure D.6 Entry of Traffic Operations (congestion/delay) (BES)

Start Time		6:50
End Time		8:00
Total Time (min)		70
Time Recorded (min)		60
# of Intervals		2
# of Recorded Intervals		1
Vehs Entered		2817
Vehs Exited		2852
Starting Vehs		148
Ending Vehs		113
Travel Distance (mi)		3506
Travel Time (hr)	A	138.7
Total Delay (hr)		36.5
Total Stops		3330
Fuel Used (gal)	B	114.3

Figure D.7 Synchro/SimTraffic Output

D.3.4 Step 4 – Enter Environmental Impacts (emissions)

For step 4, the values are obtained from an operational analysis, obtained via Synchro/SimTraffic, to determine Fuel Used, in gallons. From Synchro/SimTraffic, values should be obtained for each period as indicated in Figure D.8. These periods include both AM and PM peak timeframes for both the Start Year and the End Year as shown by cells J33 and J34 for the Start Year and cells J37 and J38 for the End Year.

29	**Environmental Impacts(emissions)**			
30	**Fuel Used (gallons)**			
31	Start Year			
32	Enter start year (if different than project)		year	**<entry>**
33	AM Peak	<entry>	gallons	<entry>
34	PM Peak	<entry>	gallons	<entry>
35	End Year			
36	Enter end year (if different than project)		year	**<entry>**
37	AM Peak	<entry>	gallons	<entry>
38	PM Peak	<entry>	gallons	<entry>
39				

Figure D.8 Entry of Environmental Impacts (BES)

The fuel used value required for Step 4 is indicated by the B annotation in Figure D.7. For each alternative, four separate Synchro/SimTraffic output files should be available with the data as shown in

Figure D.7. Enter each fuel used value appropriately into the AM and PM Peak data entry positions as shown in Figure D.8. Again, all the prior discussion applies to subsequently generated columns related to each site alternative.

D.3.5 Step 5 – Enter Traffic Safety (annual predicted crash frequency)

For step 5, the values are obtained from a safety analysis based on HSM procedures, nominally obtained via the accompanying HSMIS, to determine Predicted Crashes, in crashes/year. Using HSMIS, values should be obtained for each period and crash severity category as indicated in Figure D.9. The periods include both

40	Traffic Safety (annual predicted crash frequency - Highway Safety Manual (HSM))			
41	Predicted Crashes (crashes/year)			
42	Start Year			
43	Enter start year (if different than project)		year	<entry>
44	Combined	<calculate>	crashes/year	<enter below>
45	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
46	Property Damage Only (O)	<entry>	crashes/year	<entry>
47	End Year			
48	Enter end year (if different than project)		year	<entry>
49	Combined	<calculate>	crashes/year	<enter below>
50	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
51	Property Damage Only (O)	<entry>	crashes/year	<entry>

Figure D.9 Entry of Traffic Safety (BES)

the Start Year and the End Year with the crash severity categories of Injury Crashes (KABC) and Property Damage Only (O) as shown by cells J45 and J46 for the Start Year and cells J50 and J51 for the End Year. For these values, other HSM procedures (e.g., manually) will also provide the required output; however, as shown in Figure D.10, HSMIS output provides the values for Injury Crashes (KABC) and

Summary values:		
Sums:		
0.00	N_{SPF}	0.00
0.00	$N_{predicted}$	0.000
0.00	Injury (KABC)	0.000
0.00	Property Damage Only (O)	0.000
0.00	$N_{observed}$	0.00
0.00	$N_{expected}$	0.000

Figure D.10 Highway Safety Manual Implementation Spreadsheet (HSMIS) Output

Property Damage Only (O). The values transferred from the HSMIS to the BES are those indicated in Figure D.10 by the red outlined cells to the left of the Injury (KABC) and Property Damage Only (O) titles. These red outlined cells provide a total for both KABC and O predicted crashes for all portions of an alternative. For each alternative, two separate HSMIS analyses should be generated, one for the Start Year and one for the End Year. Enter each crashes/year value in data entry positions as shown in Figure D.9. Again, all the prior discussion applies to subsequently generated columns related to each site alternative.

D.3.6 Step 6 – Iterate for Each Alternative

For step 6, given a "no-build" option entered in column J as shown in Figure D.4, additional "build" alternatives are added as needed with steps 2 through 5 processed for each. As stated previously, these alternatives can either be treated singly or all alternatives can be identified and columns for each generated by clicking the "Add Alternative" button. The operations triggered by clicking this button add a column to each of the tabs, including the green Site_Entry tab as well as the orange "Traffic Operations" tab, "Environmental" tab, and "Traffic_Safety" tabs, which perform calculations.

D.3.7 Step 7 – Update for Each Alternative

For step 7, default unit costs are provided as shown in Figure D.11, but these may be modified based on current data. For the unit costs involved, both congestion/delay and crashes/year costs are unlikely to

53	Unit Costs					
54					Default(s)	Value(s) Used
55	Congestion/delay					
56		metric:	Travel time	$ per hour	$3.75	$3.75
57	Emissions					
58		metric:	Fuel used	$ per gallon	$3.00	$3.00
59	Crashes/year					
60		metric:	Injury Crashes (KABC)	$ per crash	$399,500	$399,500.00
61			Property Damage Only (O)	$ per crash	$18,700	$18,700.00
62	Interest Rate					
63		metric:	Assumed Interest Rate	% per year	3.00%	3.00%

Figure D.11 Updating Unit Costs (BES)

change often. However, the price per gallon of fuel can fluctuate often. Though true, SDDOT may decide a general price per gallon to be used during a particular period (e.g., fiscal year). Depending on SDDOT policy, either use the default values or modify as needed.

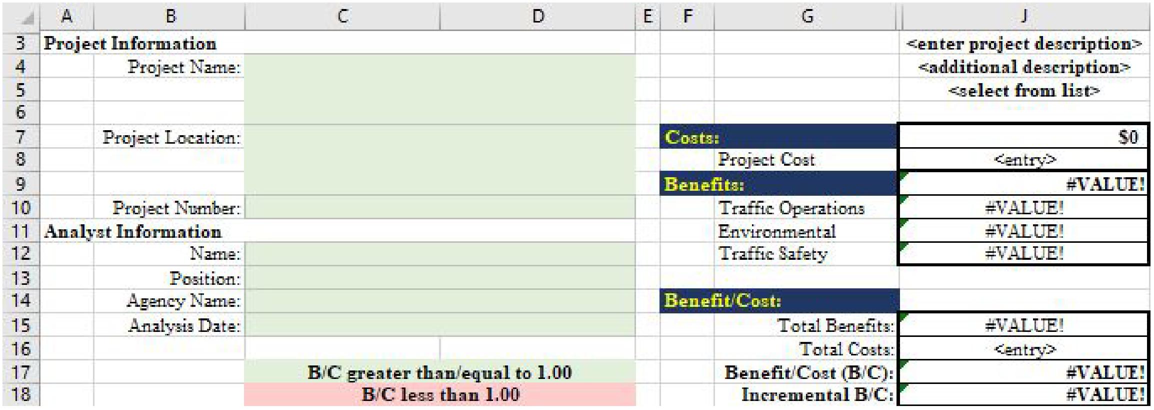
D.3.8 Step 8 – Review Results

Finally, for step 8, results are presented in the Results section of the Site_Entry tab, as shown in Figure D.12, as well as within the Summary_Report tab, as shown in Figure D.13. Dollar value estimates, based on net present values, and differences in metrics for each analytical aspect are presented. The differences in metrics are relative to the "no-build" option; thus, for the "no-build" option column there will be no values but for the "build" alternatives values will indicate increases or decreases compared against the "no-build" option. The results are shown in the Site_Entry tab, shown in Figure D.12, for analysts to view results as entry occurs. However, as shown in Figure D.13, the results within the Summary_Report tab

65	Results				
66	Project Cost			dollars	<entry>
67	Benefits:				
68		Traffic Operations		vehicle-hours	#VALUE!
69			Present Value Cost (PV)	Total	#VALUE!
70		Environmental		gallons	#VALUE!
71			Present Value Cost (PV)	Total	#VALUE!
72		Traffic Safety		crashes/year	
73				Injury Crashes (KABC)	#VALUE!
74				Property Damage Only (O)	#VALUE!
75			Present Value Cost (PV)	Total	#VALUE!
76				Injury Crashes (KABC)	#VALUE!
77				Property Damage Only (O)	#VALUE!
78					
79	Costs (-) & Benefits (+) Sum			dollars	#VALUE!
80					
81	Benefit/Cost				
82				Total Benefits:	#VALUE!
83				Total Costs:	<entry>
84				Benefit/Cost (B/C):	#VALUE!
85				Incremental B/C:	#VALUE!

Figure D.12 Reviewing Results (BES) – Site_Entry Tab

provide a more concise and printable version of the results and printing using standard Excel functions is facilitated. The print options have been setup to facilitate three (3) alternatives per page, retaining the left descriptive columns on each page. Users are free to adjust the print settings by adjusting the settings within Excel; however, more than three (3) alternatives per page results in rather small text.



	A	B	C	D	E	F	G	J
3	**Project Information**							**<enter project description>**
4		Project Name:						**<additional description>**
5								**<select from list>**
6								
7		Project Location:				**Costs:**		**$0**
8							Project Cost	<entry>
9						**Benefits:**		**#VALUE!**
10		Project Number:					Traffic Operations	#VALUE!
11	**Analyst Information**						Environmental	#VALUE!
12		Name:					Traffic Safety	#VALUE!
13		Position:						
14		Agency Name:				**Benefit/Cost:**		
15		Analysis Date:					Total Benefits:	#VALUE!
16							Total Costs:	<entry>
17			**B/C greater than/equal to 1.00**				**Benefit/Cost (B/C):**	**#VALUE!**
18			**B/C less than 1.00**				**Incremental B/C:**	**#VALUE!**

Figure D.13 Reviewing Results (BES) – Summary_Report Tab

The above are the basic steps to using the BES. The following section will implement these steps using an example with a “no-build” and one “build” alternative.

D.4 Add Alternative and Delete Alternative(s) Buttons

To facilitate BES use with regard to adding or deleting alternatives, two buttons exist.

D.4.1 Add Alternative Button

Clicking the Add Alternative button will add an additional column throughout the spreadsheet, i.e., to the Site_Entry worksheet as well as the Summary_Report, Traffic_Operations, Environmental, and Traffic_Safety worksheets. Additionally, the operations triggered by this button create a new column and copy and paste the default column values into the new column within each of these worksheets. Thus, simply copying and pasting an existing column to a new column within the Site_Entry tab will not carry through the functionality within the other worksheets needed for calculations. A user would need to copy and paste a new column into each of the other sheets to accomplish this but using the button to generate these columns is far simpler.

D.4.2 Delete Alternative(s) Button

Clicking the Delete Alternative(s) button will delete a column (or columns) throughout the spreadsheet, i.e., to the Site_Entry worksheet as well as corresponding columns within the Summary_Report, Traffic_Operations, Environmental, and Traffic_Safety worksheets. Thus, simply deleting an existing column (or columns) within the Site_Entry tab will not carry through within the other worksheets. A user would need to delete the same column (or columns) from each of the other sheets to accomplish this but using the button to delete these columns is far simpler.

The column (or columns) deleted are those with cells selected, whether the entire column (by clicking on the column letter at the top) or any cell within that column. With cells selected, clicking the Delete Alternative(s) button will delete all columns with a selected cell from each of the tabs mentioned previously.

D.5 Example – 69th St and Cliff Ave, Sioux Falls, SD

Using the eight data entry steps for the BES, as shown in Figure D.3 previously, an example using the case study for the 69th St and Cliff Ave area in Sioux Falls, SD, is discussed. The case study area includes the intersection itself as well as along the approaches in four directions and considered only the "no-build" and a single "build" option. The example will discuss the data entry using data obtained from Synchro/SimTraffic as well as the HSMIS with images displaying the entered data accompanied by an explanation of data origination.

D.5.1 Step 1 – Identify Individual Alternatives (example)

For step 1, both the "no-build" (or existing alternative) and a single "build" alternative were considered. Thus, within the BES, the Add Alternative button was used to add a single column (column K) for the "build" alternative, with the already existing column (column J) reserved for the "no-build" option. These two alternatives are shown in Figure D.14. Following the addition of the column, descriptive information

	A	B	C	D	E	F	G	J	K
3							Add Alternative	69th St and Cliff Ave	69th St and Cliff Ave
4								Sioux Falls, SD	Sioux Falls, SD
5							Delete Alternative(s)	no-build	build
6									
7	Site Specific Information								
8		Analysis Period							
9			Start Year			<entry>		2008	2008
10			End Year			<entry>		2028	2028
11						<calculate>	Total Years:	21	21
12									

Figure D.14 Entry of Individual Alternatives (BES) (example)

was entered into the first two rows (rows 3 and 4) as well as designation of "no-build" and "build" using the pull-down list presented on the third row (row 5). Next, the Start Year (2008) and End Year (2028) for the Analysis Period was entered with the Total Years calculated after those values were entered.

D.5.2 Step 2 – Enter Anticipated Project Costs (example)

For step 2, shown in Figure D.15, as the first column (column J) is the "no-build" option, $0 was entered. For the second column (column K) that represents the "build" option, $2,500,000 was entered. This value was obtained as an estimate from Shannon Ausen with the City of Sioux Falls.

13						entry options or units		
14	Anticipated Project Cost ($$$)							
15		Anticipated Project Cost (dollars)						
16				Anticipated Project Cost	<entry>	dollars	$0	$2,500,000
17								

Figure D.15 Entry of Anticipated Project Costs (BES) (example)

For steps 3 and 4, which involve entry of the traffic operations (congestion/delay) and environmental impacts (emissions) estimation data, the primary source of data is Synchro/SimTraffic output. To obtain this data, a previous Synchro/SimTraffic model was constructed and run for an operational analysis of the site. From this analysis and using traffic volume data for both an existing time period and a future time period, AM and PM Peak output were obtained for both the "no-build" and "build" cases. This Synchro/SimTraffic modelling resulted in four output PDF files for the "no-build" alternative and four output PDF files for the "build" alternative, including:

- No-build
  - current volume, AM peak
  - current volume, PM peak
  - future volume, AM peak

- future volume, PM peak
- Build
  - current volume, AM peak
  - current volume, PM peak
  - future volume, AM peak
  - future volume, PM peak

A snippet of the results for these separate Synchro/SimTraffic models are shown in Figures D.16-D.23. Figures D.16 and D.17 relate to the no-build alternative using current volumes for the AM and PM peak.

Start Time	6:50
End Time	8:00
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	2817
Vehs Exited	2852
Starting Vehs	148
Ending Vehs	113
Travel Distance (mi)	3506
Travel Time (hr)	138.7
Total Delay (hr)	36.5
Total Stops	3330
Fuel Used (gal)	114.3

Figure D.16 No-build, current volume, AM (example)

Start Time	4:20
End Time	5:30
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	2896
Vehs Exited	2921
Starting Vehs	151
Ending Vehs	126
Travel Distance (mi)	4015
Travel Time (hr)	149.0
Total Delay (hr)	33.3
Total Stops	3181
Fuel Used (gal)	129.4

Figure D.17 No-build, current volume, PM (example)

Figures D.18 and D.19 relate to the no-build alternative using future volumes for the AM and PM peak.

Start Time	6:50
End Time	8:00
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	5064
Vehs Exited	4604
Starting Vehs	552
Ending Vehs	1012
Travel Distance (mi)	5554
Travel Time (hr)	2020.0
Total Delay (hr)	1864.8
Total Stops	8573
Fuel Used (gal)	587.3

Figure D.18 No-build, future volume, AM (example)

Start Time	4:20
End Time	5:30
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	5559
Vehs Exited	5149
Starting Vehs	600
Ending Vehs	1010
Travel Distance (mi)	5853
Travel Time (hr)	1969.4
Total Delay (hr)	1804.7
Total Stops	8543
Fuel Used (gal)	585.2

Figure D.19 No-build, future volume, PM (example)

Figures D.20 and D.21 relate to the build alternative using current volumes for the AM and PM peak.

Start Time	4:20
End Time	5:30
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	2838
Vehs Exited	2824
Starting Vehs	136
Ending Vehs	150
Travel Distance (mi)	3923
Travel Time (hr)	139.6
Total Delay (hr)	25.9
Total Stops	2567
Fuel Used (gal)	126.8

Figure D.20 Build, current volume, AM (example)

Start Time	6:50
End Time	8:00
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	2904
Vehs Exited	2903
Starting Vehs	128
Ending Vehs	129
Travel Distance (mi)	3627
Travel Time (hr)	131.3
Total Delay (hr)	25.0
Total Stops	2840
Fuel Used (gal)	118.8

Figure D.21 Build, current volume, PM (example)

Figures D.22 and D.23 relate to the build alternative using future volumes for the AM and PM peak.

The values in Figures D.16 through D.23 are used for Steps 3 and 4.

Start Time	6:50
End Time	8:00
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	8322
Vehs Exited	7875
Starting Vehs	522
Ending Vehs	969
Travel Distance (mi)	7724
Travel Time (hr)	1377.8
Total Delay (hr)	1150.4
Total Stops	17711
Fuel Used (gal)	532.4

Figure D.22 Build, future volume, AM (example)

Start Time	4:20
End Time	5:30
Total Time (min)	70
Time Recorded (min)	60
# of Intervals	2
# of Recorded Intervals	1
Vehs Entered	8408
Vehs Exited	8067
Starting Vehs	545
Ending Vehs	886
Travel Distance (mi)	7658
Travel Time (hr)	1466.3
Total Delay (hr)	1240.5
Total Stops	17847
Fuel Used (gal)	550.5

Figure D.23 Build, future volume, PM (example)

D.5.3 Step 3 – Enter Traffic Operations (congestion/delay) (example)

For step 3, the values of traffic operations (congestion/delay) are the travel times (i.e., "Travel Time (hr)") from Figures D.16 through D.23. As shown in Figure D.24, the values for the "no-build," start year for AM Peak and PM Peak are 138.7 and 149.0, respectively, which come from the output shown in Figures D.16 and D.17. The values for the "no-build," end year for AM Peak and PM Peak are 2,020.0 and 1,969.4, respectively, which come from the output shown in Figures D.18 and D.19. The values for the "build," start year for AM Peak and PM Peak are 131.3 and 139.6, respectively, which come from the output shown in Figures D.20 and D.21. The values for the "build," end year for AM

Peak and PM Peak are 1,377.8 and 1,466.3, respectively, which come from the output shown in Figures D.22 and D.23.

18	**Traffic Operations (congestion/delay)**				
19	**Total Travel Time (vehicle-hours)**				
20	Start Year				
21	Enter start year (if different than project)		year	**2008**	**2008**
22	AM Peak	<entry>	vehicle-hours	**138.7**	**131.3**
23	PM Peak	<entry>	vehicle-hours	**149.0**	**139.6**
24	End Year				
25	Enter end year (if different than project)		year	**2028**	**2028**
26	AM Peak	<entry>	vehicle-hours	**2,020.0**	**1,377.8**
27	PM Peak	<entry>	vehicle-hours	**1,969.4**	**1,466.3**
28					

Figure D.24 Entry of Traffic Operations (congestion/delay) (BES) (example)

D.5.4 Step 4 – Enter Environmental Impacts (emissions) (example)

Similarly for step 4, the values of environmental impacts (emissions) are the fuel used (i.e., "Fuel Used [gal]") from Figures D.16 through D.23. As shown in Figure D.25, the values for the "no-build," start year for AM Peak and PM Peak are 114.3 and 129.4, respectively, which come from the output shown in Figures D.16 and D.17. The values for the "no-build," end year for AM Peak and PM Peak are 587.3 and 585.2, respectively, which come from the output shown in Figures D.18 and D.19. The values for the "build," start year for AM Peak and PM Peak are 118.8 and 126.8, respectively, which come from the output shown in Figures D.20 and D.21. The values for the "build," end year for AM Peak and PM Peak are 532.4 and 550.5, respectively, which come from the output shown in Figures D.22 and D.23.

29	**Environmental Impacts(emissions)**				
30	**Fuel Used (gallons)**				
31	Start Year				
32	Enter start year (if different than project)		year	**2008**	**2008**
33	AM Peak	<entry>	gallons	**114.3**	**118.8**
34	PM Peak	<entry>	gallons	**129.4**	**126.8**
35	End Year				
36	Enter end year (if different than project)		year	**2028**	**2028**
37	AM Peak	<entry>	gallons	**587.3**	**532.4**
38	PM Peak	<entry>	gallons	**585.2**	**550.5**
39					

Figure D.25 Entry of Environmental Impacts (BES) (example)

D.5.5 Step 5 – Enter Traffic Safety (annual predicted crash frequency) (example)

For step 5, the values were obtained from a safety analysis based on HSM procedures using the accompanying HSMIS to determine Predicted Crashes, in crashes/year. From the HSMIS, both the Injury Crashes (KABC) and Property Damage Only (O) crashes/year can be obtained for both the Start Year and the End Year. Figures D.26 through D.29 show the HSMIS output for each of these alternative (i.e., "no-build" and "build") as well as the start and end years for each. The values to acquire are the KABC and O values to the far left under the "Sums:" column beneath the "Summary values" header with the red borders. The values in this column sum the individual sub-portions of the project (e.g., for this example, the intersection as well as each individual approach), which are displayed in the columns to the right.

		<enter project portion description>	<enter project portion description>	<enter project portion description>	<enter project portion description>	<enter project portion description>
	Facility Category:	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial
	if RTLTW:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if RML:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if USA:	2-lane, Undivided Arterial	3-lane, Arterial with center TWLTL	4-lane, Undivided Arterial	4-lane, Divided Arterial	4-legged, Signalized Intersection
	entry options or units					
Summary values:						
Sums:						
2.61	N_{SPF}	0.32	0.45	0.02	0.11	1.71
1.86	$N_{predicted}$	**0.338**	**0.513**	**0.019**	**0.126**	**0.868**
0.55	Injury (KABC)	**0.086**	**0.135**	**0.005**	**0.037**	**0.288**
1.31	Property Damage Only (O)	**0.252**	**0.378**	**0.014**	**0.090**	**0.580**
2.50	$N_{observed}$	0.75	0.25	0.00	0.00	1.50
1.88	$N_{expected}$	0.371	0.467	0.019	0.116	0.904

Figure D.26 HSMIS Output – No-Build, Start Year (HSMIS) (example)

		South Segment (2028) - no-build	North Segment (2028) - no-build	East Segment (2028) - no-build	West Segment (2028) - no-build	69th and Cliff (2028) - no-build
	Facility Category:	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial
	if RTLTW:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if RML:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if USA:	2-lane, Undivided Arterial	3-lane, Arterial with center TWLTL	4-lane, Undivided Arterial	4-lane, Divided Arterial	4-legged, Signalized Intersection
	entry options or units					
Summary values:						
Sums:						
18.49	N_{SPF}	3.04	1.77	1.34	0.74	11.61
13.36	$N_{predicted}$	**3.201**	**2.005**	**1.499**	**0.834**	**5.817**
3.94	Injury (KABC)	**0.813**	**0.527**	**0.421**	**0.244**	**1.931**
9.42	Property Damage Only (O)	**2.388**	**1.478**	**1.078**	**0.591**	**3.886**
2.50	$N_{observed}$	0.75	0.25	0.00	0.00	1.50
7.08	$N_{expected}$	1.835	1.169	0.838	0.490	2.745

Figure D.27 HSMIS Output – No-Build, End Year (HSMIS) (example)

		North Segment (2007) - build	East Segment (2007) - build	South Segment (2007) - build	West Segment (2007) - build	69th and Cliff (2007) - build
	Facility Category:	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial
	if RTLTW:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if RML:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if USA:	4-lane, Divided Arterial	4-lane, Divided Arterial	4-lane, Divided Arterial	4-lane, Divided Arterial	4-legged, Signalized Intersection
	entry options or units					
Summary values:						
Sums:						
2.40	N_{SPF}	0.32	0.03	0.22	0.11	1.71
1.39	$N_{predicted}$	**0.308**	**0.027**	**0.221**	**0.103**	**0.729**
0.43	Injury (KABC)	**0.090**	**0.008**	**0.064**	**0.030**	**0.242**
0.95	Property Damage Only (O)	**0.218**	**0.019**	**0.156**	**0.073**	**0.487**
2.50	$N_{observed}$	0.25	0.00	0.75	0.00	1.50
1.47	$N_{expected}$	0.304	0.026	0.277	0.095	0.765

Figure D.28 HSMIS Output – Build, Start Year (HSMIS) (example)

		North Segment (2028) - build	East Segment (2028) - build	South Segment (2028) - build	West Segment (2028) - build	69th and Cliff (2028) - build
	Facility Category:	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial
	if RTLTW:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if RML:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if USA:	4-lane, Divided Arterial	4-lane, Divided Arterial	4-lane, Divided Arterial	4-lane, Divided Arterial	4-legged, Signalized Intersection
	entry options or units					
Summary values:						
Sums:						
16.04	N_{SPF}	1.14	0.84	1.72	0.74	11.61
9.03	$N_{predicted}$	**1.096**	**0.783**	**1.692**	**0.679**	**4.783**
2.83	Injury (KABC)	**0.320**	**0.229**	**0.494**	**0.198**	**1.588**
6.20	Property Damage Only (O)	**0.776**	**0.555**	**1.198**	**0.480**	**3.195**
2.50	$N_{observed}$	0.25	0.00	0.75	0.00	1.50
5.25	$N_{expected}$	0.702	0.481	1.113	0.427	2.521

Figure D.29 HSMIS Output – Build, End Year (HSMIS) (example)

Within the BES, as shown in Figure D.30, the values from the HSMIS output were entered into the start year and end year entries for both the "no-build" and "build" alternatives. The "no-build," start year entries of 0.55 for KABC and 1.31 for O were obtained from the output shown in Figure D.26 with the sum of 1.86 in the BES matching the $N_{predicted}$ in the HSMIS. The "no-build," end year entries of 3.94 for KABC and 9.42 for O were obtained from the output shown in Figure D.27 with the sum of

40	**Traffic Safety (annual predicted crash frequency - Highway Safety Manual (HSM))**			
41	**Predicted Crashes (crashes/year)**			
42	Start Year			
43	Enter start year (if different than project)	year	**2008**	**2008**
44	Combined <calculate>	crashes/year	**1.86**	**1.38**
45	Injury Crashes (KABC) <entry>	crashes/year	0.550	0.430
46	Property Damage Only (O) <entry>	crashes/year	1.310	0.950
47	End Year			
48	Enter end year (if different than project)	year	**2028**	**2028**
49	Combined <calculate>	crashes/year	**13.36**	**9.03**
50	Injury Crashes (KABC) <entry>	crashes/year	3.940	2.830
51	Property Damage Only (O) <entry>	crashes/year	9.420	6.200
52				

Figure D.30 Entry of Traffic Safety (BES) (example)

13.36 in the BES matching the $N_{predicted}$ in the HSMIS. The “build,” start year entries of 0.43 for KABC and 0.95 for O were obtained from the output shown in Figure D.28 with the sum of 1.38 in the BES matching the $N_{predicted}$ in the HSMIS. The “build,” end year entries of 2.83 for KABC and 6.20 for O were obtained from the output shown in Figure D.29 with the sum of 9.03 in the BES matching the $N_{predicted}$ in the HSMIS.

D.5.6 Step 6 – Iterate for Each Alternative (example)

Step 6 was essentially accomplished by generating the columns for all alternatives (“no-build” and “build”) above and entering the data as each step was explained.

D.5.7 Step 7 – Update Unit Costs (example)

For step 7, default unit costs are provided as shown in Figure D.11, but for this example the fuel used costs were modified to reflect a change in price per gallon, shown in Figure D.31.

53	Unit Costs						
54					Default(s)	Value(s) Used	Value(s) Used
55	Congestion/delay						
56		metric:	Travel time	$ per hour	$3.75	$3.75	$3.75
57	Emissions						
58		metric:	Fuel used	$ per gallon	$3.00	$3.89	$3.89
59	Crashes/year						
60		metric:	Injury Crashes (KABC)	$ per crash	$399,500	$399,500.00	$399,500.00
61			Property Damage Only (O)	$ per crash	$18,700	$18,700.00	$18,700.00
62	Interest Rate						
63		metric:	Assumed Interest Rate	% per year	3.00%	3.00%	3.00%

Figure D.31 Updated Unit Costs (BES) (example)

D.5.8 Step 8 – Review Results (example)

Finally, for step 8, results are presented in the Results section of the Site_Entry tab shown in Figure D.32. Dollar value estimates and differences in metrics for each analytical aspect are presented with a final B/C provided. The differences in metrics are calculated against the “no-build” option; thus, for the “no-build” option column there will be no values but for the “build” alternatives values will be relative to the “no-build” option. Multiple options will be first compared against the “no-build” option using the B/C but also incrementally against each other using the incremental B/C.

65	Results					
66	Project Cost		dollars	no-build option	$	2,500,000
67	Benefits:					
68	Traffic Operations		vehicle-hours			-3,191,575.0
69		Present Value Cost (PV)	Total	no-build option	$	7,949,065
70	Environmental		gallons			-241,650.0
71		Present Value Cost (PV)	Total	no-build option	$	619,677
72	Traffic Safety		crashes/year			
73			Injury Crashes (KABC)			-13.4
74			Property Damage Only (O)			-39.0
75		Present Value Cost (PV)	Total	no-build option	$	4,113,206
76			Injury Crashes (KABC)			$3,619,867
77			Property Damage Only (O)			$493,339
78						
79	Costs (-) & Benefits (+) Sum		dollars	no-build option	$	10,181,948
80						
81	Benefit/Cost					
82			Total Benefits:	no-build option		$12,681,947.87
83			Total Costs:	no-build option		$2,500,000.00
84			Benefit/Cost (B/C):	no-build option		5.07
85			Incremental B/C:	no-build option		5.07

Figure D.32 Reviewing Results (BES) – Site_Entry Tab (example)

Finally, the results within the Summary_Report tab provide a more concise and printable version of the results, shown in Figure D.33. Within the Summary_Report tab, printing using standard Excel functions is facilitated. The print options have been setup to facilitate three (3) alternatives per page, retaining the left descriptive columns on each page. Users are free to adjust the print settings by adjusting the settings within Excel; however, more than three (3) alternatives per page results in rather small text.

	A	B	C	D	E	F	G	J	K
3	**Project Information**							**69th St and Cliff Ave**	**69th St and Cliff Ave**
4		Project Name:						**Sioux Falls SD**	**Sioux Falls SD**
5								**no-build**	**build**
6									
7		Project Location:				**Costs:**		**no-build option**	**$2,500,000**
8							Project Cost	no-build option	$2,500,000
9						**Benefits:**		**no-build option**	**$12,681,948**
10		Project Number:					Traffic Operations	no-build option	$7,949,065
11	**Analyst Information**						Environmental	no-build option	$619,677
12		Name:					Traffic Safety	no-build option	$4,113,206
13		Position:							
14		Agency Name:				**Benefit/Cost:**			
15		Analysis Date:					Total Benefits:	no-build option	$12,681,947.87
16							Total Costs:	no-build option	$2,500,000.00
17			**B/C greater than/equal to 1.00**				**Benefit/Cost (B/C):**	**no-build option**	**5.07**
18			**B/C less than 1.00**				**Incremental B/C:**	**no-build option**	**5.07**

Figure D.33 Reviewing Results (BES) – Summary_Report Tab (example)

APPENDIX E: HIGHWAY SAFETY MANUAL IMPLEMENTATION SPREADSHEET (HSMIS)

E.1 Background

State and local governments use access management to improve traffic flow, preserve roadway capacity, and ensure safe operation of motorized, pedestrian, and bicycle traffic on rural and urban streets and highways. Improved operational efficiency leads to lower transportation costs, increased energy efficiency, and reduced highway emissions. Safe and efficient operation of the roadway also contributes to the short- and long-term economic vitality of the businesses and communities served.

Methods to manage access, which may include limiting or reducing the number and location of access points, installing medians to eliminate or reduce left turns, providing alternative access via other roadways, or other techniques carry financial costs. In addition to direct costs of constructing the treatment, compensation to landowners for lost property or access may be required. Determining whether to apply a treatment depends on a comparison of those costs to the public benefit it will generate.

Estimating the current and future public benefit of a proposed access management treatment is not simple. The benefit may depend upon land use and zoning, traffic volumes and characteristics, highway or street function and attributes, and the number and location of adjacent access points. The Access Management Manual and the Highway Safety Manual (HSM) present general principles for describing or estimating the value of safety and operational improvements, but complete, specific, and locally calibrated methods are not presented. The South Dakota Department of Transportation (SDDOT) has developed a rudimentary tool based on the HSM for estimating safety benefits from certain access management improvements, and the City of Sioux Falls has correlated crash frequencies to access density on urban arterials, but no comprehensive method or tool exists to estimate the total financial value of the public benefit expected from a proposed access management treatment. Without a sound estimate of public benefit, deciding whether the treatment is worth the investment is difficult.

To address this problem, a spreadsheet software tool has been developed to facilitate analysis of the financial benefits of proposed access management treatments. The spreadsheet software tool has two main elements: a benefits estimation spreadsheet (BES) and an accompanying HSM implementation spreadsheet (HSMIS) for estimation of potential safety impacts. The following is a description of the HSMIS, including a brief description, discussion of general spreadsheet entry steps, and an example of data entry to results.

E.2 Brief Description of Spreadsheet

The HSMIS, as shown by the spreadsheet tabs in Figure E.1, has several distinct parts.

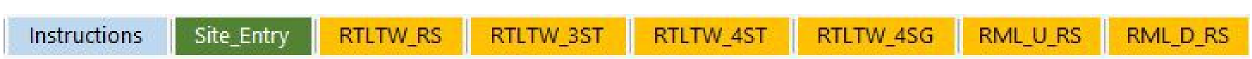


Figure E.1 HSM Implementation Spreadsheet (HSMIS) Operational Tabs

- The “Instructions” tab, shown in light blue, contains summary instructions for spreadsheet operation, with reference to these instructions for more detail.
- The “Site_Entry” tab, shown in dark green, contains the primary worksheet for user interaction. Within this tab, users will enter values for each alternative, generally beginning with a “no-build” or “existing” option and progressing through each alternative option. These

values include facility category and type and site characteristics such as volumes, lengths, observed crashes, and geometric and descriptive details relevant to safety impacts. At the top of the ”Site_Entry” worksheet, results from analyses are reported.

- The tabs shown in orange, only a portion of which are shown in Figure E.1, contain worksheets that perform HSM calculations for each project portion based on facility category and type. These worksheets all use the entered data from the “Site_Entry” tab to perform calculations and return results to the “Site_Entry” worksheet appropriately.
- The “FunctionalityEnablingLists” tab, shown in dark blue, contains a worksheet for the various operational pick lists used in the “Site_Entry” worksheet tab and requires no user interaction.

The following discussion of data entry steps will refer to cropped sub-sections of the “Site_Entry” worksheet, to describe the steps a user would use for data entry of a project with a base “no-build” (or existing alternative) as well as one or more additional alternatives.

E.3 Entry Steps

For data entry into the HSMIS there are five distinct steps, as shown in Figure E.2. These steps are associated directly with sections of the HSMIS and each will be

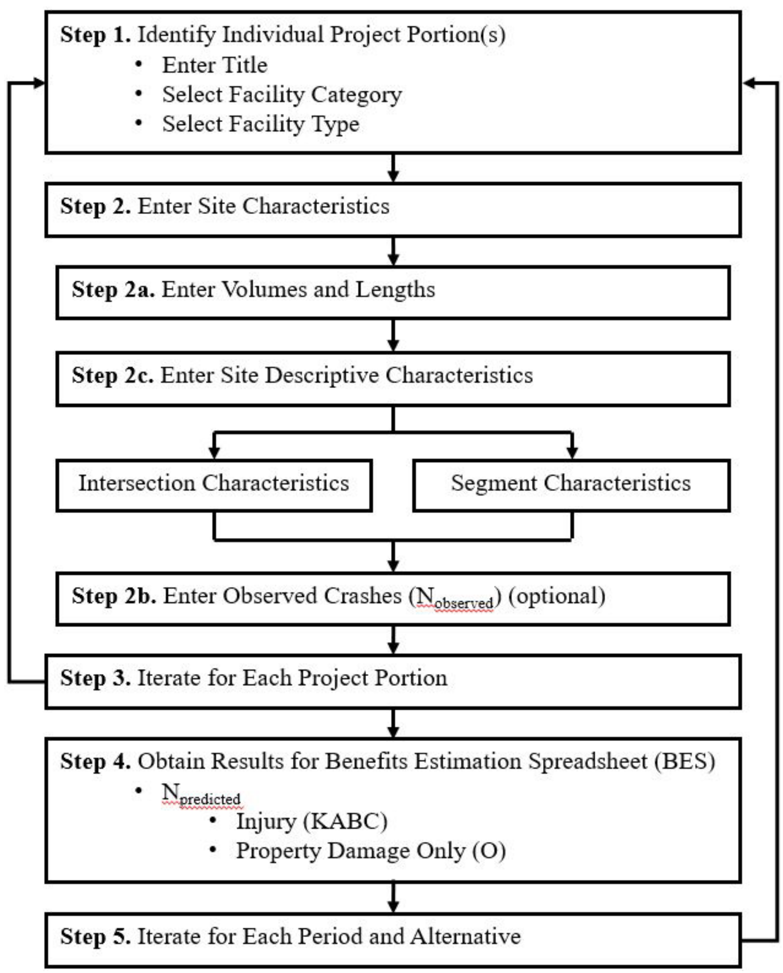


Figure E.2 HSMIS Entry Steps Flowchart explained in the following sections. For the discussion, the steps will be described using column J, but these steps apply to any additional columns generated for additional individual project portions per Figure E.2.

E.3.1 Step 1 – Identify Individual Project Portion(s)

For step 1, the first action should be saving the base HSMIS file to another name, most likely saving the file in a folder specific to the project being analyzed. The saved file should be specific to an individual site alternative and period (i.e., Start Year, End Year). Within this file, the Site_Entry worksheet will be used to enter site facility category, type, and characteristics for one or more project portions. Project portions refer to individual sub-portions of an overall project. For example, for an intersection site which also extends along four approaches, there will be an intersection sub-portion as well as four segment (approach) sub-portions. Fortunately, generally the file generated for the Start Year, once all the facility category, type, and characteristics have been entered, can be saved as the End Year file with appropriate modifications made to the End Year file.

Once the Start Year file has been saved, proceed by entering the data into column J as shown in Figure E.3. For the process, these project portions can either be treated singly or all portions can be identified

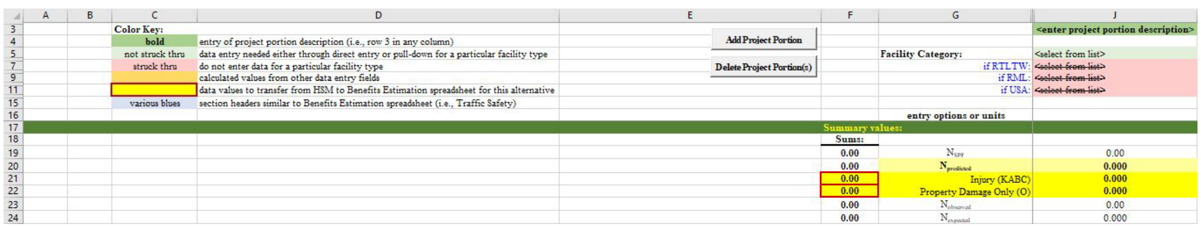


Figure E.3 Entry of Individual Project Portions (HSMIS)

and columns for each generated at this point by clicking the "Add Alternative" button. Either way, once a portion has been initiated, enter a project portion description in cell J3. After that, select the facility category from the list provided in cell J5. Once the facility category has been selected, the related facility type selection cell will become light green. Select the facility type from the list provided in the relevant cell (cells J7, J9, or J11). The selection of facility category and type directly impacts the remainder of the entry values, causing the cells relevant to the selected facility category and type to become light green and no longer struck through.

The Summary Values portion displays the results once site characteristics data have been entered. The values to transfer to the BES are contained in cells F21 and F22 with the red borders to the left of the Injury (KABC) and Property Damage Only (O) headers.

A color key has been provided in the upper left, shown in Figure E.3, to assist HCMIS users.

E.3.2 Step 2 – Enter Site Characteristics

For step 2, three sub-steps are involved, including entry of volume and length, optional entry of observed crashes, and entry of site descriptive characteristics, which will either be entry of intersection characteristics or segment characteristics based on the facility type selected previously during step 1. Again, as noted within the step 1 discussion, only the cells which are light green and no longer struck through require entry. Beyond that, entry of observed crashes is optional.

E.3.2.1 Step 2a – Enter Volumes and Lengths

For step 2a, enter the values as appropriate, as shown in Figure E.4. For intersections, a major and

Volume/Length					
	$AADT_{major}$		<entry>	veh/day	<entry>
	$AADT_{minor}$		<entry>	veh/day	<entry>
	Length		<entry>	miles	<entry>
	Pedestrians	Pedestrian Volume (all legs combined)	NA	pedestrians/day	<entry>
		General Level of Pedestrian Activity	None	High, Medium-high, Medium, Medium-low, Low	<select from list>
		maximum number of lanes crossed considering refuge islands	NA	number of lanes	<entry>

Figure E.4 Entry of Volumes, Lengths, and Pedestrian Values (HSMIS)

minor road AADT (annualized average daily traffic or volume) is entered. For segments, only the major AADT is entered but also a length (in miles). The pedestrian values are related to specific facility categories and types.

For those cells that contain “<entry>”, enter the value. For those cells that contain “<select from list>”, click in the cell and a pull-down tab will appear. Then click the pull-down tab and select from the list. Alternatively, direct typing of the value can be done but the choices are confined to those indicated in the related column G cell for “<select from list>” cells.

E.3.2.2 Step 2b – Enter Site Descriptive Characteristics

For Step 2b, entered site descriptive characteristics depend on the facility category and type indicated in step 1. The facility type will either be intersection or segment and, thus, those cells that become light green and no longer struck through require entry, as noted by the color key. However, based on facility category, not all cells within either the intersection or segment characteristics portions will require entry.

For intersection characteristics, as shown in Figure E.5, many of the entry fields should be reasonably

Intersection Characteristics					
	Intersection Skew Angle		0		<entry>
	Intersection left-turn lanes		None	None/Yes	<select from list>
		# of Approaches with Left-Turn Lanes	0		<entry>
	Intersection right-turn lanes		None	None/Yes	<select from list>
		# of Approaches with Right-Turn Lanes	0		<entry>
	Intersection left-turn lanes on uncontrolled major approaches		0	0, 1	<select from list>
	Number of uncontrolled major approaches with left-turn lanes		0	0, 1, 2	<select from list>
	Number of approaches with left-turn lanes		0	0, 1, 2, 3, 4	<select from list>
	Intersection Left-Turn Signal Phasing		Permissive	Permissive, Protected/permissive, Permissive/protected, Protected	<select from list>
	Number of Approaches with Left-Turn Signal Phasing		0	0, 1, 2, 3, 4	<select from list>
	Intersection right-turn lanes on uncontrolled major approaches		0	0, 1	<select from list>
	Number of uncontrolled major approaches with right-turn lanes		0	0, 1, 2	<select from list>
	Number of approaches with right-turn lanes		0	0, 1, 2, 3, 4	<select from list>
	Right-Turn-On-Red		Allowed	Allowed/Prohibited	<select from list>
	Number of Approaches with Prohibited Right-Turn-On-Red	n_{prohib}	0	0, 1, 2, 3, 4	<select from list>
	Lighting		None	None/Yes	<select from list>
	Red-Light Cameras		None	None/Yes	None
	Number of Bus Stops within 1,000 ft of the Intersection		0	0, 1, 2, 3	0
	Presence of Schools within 1,000 ft of the Intersection		None	None/Present	None
	Number of Alcohol Sales Establishments within 1,000 ft of the Intersection		0	0, 1, 2, 3, 4, 5, 6, 7, 8, 9	0

Figure E.5 Entry of Intersection Site Characteristics (HSMIS)

familiar and identifiable. Per prior comment, for those cells that contain “<entry>”, enter the value. For those cells that contain “<enter here or below>”, either enter the values in the disaggregate below (e.g., the FI and PDO) and the total will sum in the “<enter here or below>” cell or enter the total in the “<enter here or below>” cell directly. Some cells have been assigned default values as, normally, the entries for these cells would not deviate from the default. These include the presence of Red-Light Cameras, Number of Bus Stops within 1,000 ft of the Intersection, the Presence of Schools within 1,000 ft of the Intersection, and the Number of Alcohol Sales Establishments within 1,000 ft of the Intersection.

For segment characteristics, as shown in Figure E.6, many of the entry fields should be reasonably familiar and identifiable. Per prior comment, for those cells that contain “<entry>”, enter the value. For those cells that contain “<enter here or below>”, either enter the values in the disaggregate below (e.g., the FI and PDO) and the total will sum in the “<enter here or below>” cell or enter the total in the "<enter here or below>" cell directly. Automated Speed Enforcement has been assigned a default value as South Dakota has no automated speed enforcement.

For clarification regarding entry values for both intersection and segment entries, refer to HSM chapters 10 (rural, two-lane, two-way), 11 (rural, multi-lane), and 12 (urban and suburban arterials).

Segment Characteristics				
Posted Speed Limit (mph)		30	mph	<select from list>
Lane Width (LW)		12	feet	<select from list>
Shoulder Width (SW)		6	feet	<select from list>
Right Shoulder Width (SW)		8	feet	<select from list>
Shoulder Type/Right Shoulder Type		Paved	Paved/Gravel	<select from list>
Sideslope		1:7		<select from list>
Median Width		30		<entry>
Median Traversable?		Yes	Yes/No	<select from list>
Undivided or TWLTL?		Yes	Yes/No	<select from list>
Median Traversable?		Yes	Yes/No	<select from list>
Roadside Hazard Rating (RHR)		3		<select from list>
On-Street Parking		None	None/Yes	<select from list>
Curb Length with On-Street Parking (both sides combined)		0	miles	<entry>
Type of Parking		None	None/Parallel/Angle	<select from list>
Type of Land Use	Residential = Residential/Other, Commercial = Commercial or Industrial/Institutional	NA	Residential/Commercial	<select from list>
Roadside Fixed Objects		None	None/Yes	<select from list>
Fixed-Object Density	D_{fo}	0	fixed objects/mile	<entry>
Fixed-Object Offset	O_{fo}	0	feet	<entry>
Driveway Density (DD)		5	driveways/mile	<entry>
Number of Driveways by Driveway Type:	major commercial	<entry>	number	<entry>
	minor commercial	<entry>	number	<entry>
	major industrial/institutional	<entry>	number	<entry>
	minor industrial/institutional	<entry>	number	<entry>
	major residential	<entry>	number	<entry>
	minor residential	<entry>	number	<entry>
	other	<entry>	number	<entry>
Horizontal Curvature		None	None/Yes	<select from list>
	Length of Curve (L_c)	<entry>	(miles)	<entry>
	Radius of Curve	<entry>	(feet)	<entry>
	Spiral Presence	0	1 = yes, 0 = no, 0.5 = at one end	<select from list>
	Spiral Value	<calculate>		<select from list above>
	Actual Superelevation	0	decimal	<entry>
	AASHTO Superelevation	0	decimal	<entry>
Vertical Curvature		None	None/Yes	<select from list>
Centerline Rumble Strips		None	None/Yes	<select from list>
Passing Lanes		None	None/Conventional/Four-Lane	<select from list>
Two-Way Left-Turn Lanes (TWLTLs)		None	None/Yes	<select from list>
Lighting		None	None/Yes	<select from list>
Automated Speed Enforcement		None	None/Yes	None
Grade Level		0	number	<select from list>

Figure E.6 Entry of Segment Site Characteristics (HSMIS)

E.3.2.3 Step 2c – Enter Observed Crashes ($N_{observed}$) (optional)

Step 2c is optional and only required for determination of $N_{expected}$, which is an HSM combination of $N_{predicted}$ and $N_{observed}$ based on reliability of the base Safety Performance Function (SPF) model related to a specific facility category and type. For access management benefit estimation purposes, $N_{predicted}$ will be utilized. However, at times, $N_{expected}$ might prove interesting, perhaps within or beyond the purview of access management.

For Step 2c, prior determination of observed crashes should have occurred. Given the observed crashes, enter the values as indicated based on facility category and type as shown in Figure E.7.

Observed Crashes ($N_{observed}$)		<calculate>	crashes/year	<enter below>
Observed Crashes (entered)		<entry>	crashes/year	<entry>
Observed Crashes (summed from disaggregate below)		<calculate>	crashes/year	<enter below>
Multiple-Vehicle Non-Driveway Collisions	$N_{observed(total)}$	<calculate>	crashes/year	<enter here or below>
	$N_{observed(FI)}$	<entry>	crashes/year	<entry>
	$N_{observed(PDO)}$	<entry>	crashes/year	<entry>
Single-Vehicle Crashes	$N_{observed(total)}$	<calculate>	crashes/year	<enter here or below>
	$N_{observed(FI)}$	<entry>	crashes/year	<entry>
	$N_{observed(PDO)}$	<entry>	crashes/year	<entry>
Multiple-Vehicle Driveway-Related Collisions	$N_{observed(total)}$	<calculate>	crashes/year	<enter here or below>
	$N_{observed(FI)}$	<entry>	crashes/year	<entry>
	$N_{observed(PDO)}$	<entry>	crashes/year	<entry>
Multiple-Vehicle Non-Driveway Collisions - Collision Types to Include:	Rear-end collision	Yes	Yes/No	Yes
	Head-on collision	Yes	Yes/No	Yes
	Angle collision	Yes	Yes/No	Yes
	Sideswipe	Yes	Yes/No	Yes
	Sideswipe, same direction	Yes	Yes/No	Yes
	Sideswipe, opposite direction	Yes	Yes/No	Yes
	Other multiple-vehicle collisions	Yes	Yes/No	Yes
Single-Vehicle Crashes - Collision Types to Include:	Collision with parked vehicle	Yes	Yes/No	Yes
	Collision with animal	Yes	Yes/No	Yes
	Collision with fixed object	Yes	Yes/No	Yes
	Collision with other object	Yes	Yes/No	Yes
	Other single-vehicle collision	Yes	Yes/No	Yes
	Noncollision	Yes	Yes/No	Yes
Severity Type (1 = total, 2 = fatal and injury (all), 3 = fatal and injury (KAB))		1	1, 2, 3	1

Figure E.7 Entry of Observed Crashes (HSMIS)

The difference between the Observed Crashes (entered) and Observed Crashes (summed from disaggregate below) is that the former relates to rural, two-lane, two-way (RTLTW) and rural, multi-lane (RML) facility categories and the latter relates to urban and suburban arterial (USA) facility categories. For the latter, USA-related option, the value will automatically calculate from related values entered below.

For those cells that contain “<entry>”, enter the value. For those cells that contain “<enter here or below>”, either enter the values in the disaggregate below (e.g., the FI and PDO) and the total will sum in the “<enter here or below>” cell or enter the total in the “<enter here or below>” cell directly. The “Collision Types” selection rows that follow, as shown in Figure E.7, relate only to the USA facility categories. These are defaulted to “Yes” as these are the collision types to include and, generally, most analysts would include all collision types. The “Severity Types” selection row, as shown in Figure E.7, relates to the RML and USA facility categories. The severity type is defaulted to 1 (total) as, generally, most analysts would include all severities unless there were a reason not to.

Per prior comment, for those cells that contain “<select from list>”, click in the cell and a pull-down tab will appear. Then click the pull-down tab and select from the list. Alternatively, direct typing of the value can be done but the choices are confined to those indicated in the related column G cell for “<select from list>” cells.

E.3.3 Step 3 – Iterate for Each Project Portion

For step 3, given a project portion entered in column J as shown in Figure E.3, additional project portions are added as needed with step 2 processed for each. Again, project portions refer to individual sub-portions of an overall project. For example, an intersection site, which also extends along four approaches, would have an intersection sub-portion as well as four segment (approach) sub-portions. These project portions can either be treated singly or all alternatives can be identified and columns for each generated by clicking the “Add Alternative” button. As stated previously, these sub-portions can either be treated singly or all sub-portions can be identified and columns for each generated by clicking the “Add Alternative” button. The operations triggered by clicking this button add a column to each of the tabs, including the green Site_Entry tab as well as the orange tabs, which perform calculations specific to each Facility Category and Type designation.

E.3.4 Step 4 – Obtain Results for Benefits Estimation Spreadsheet (BES)

For step 4, results are presented in the Summary Values section, shown in Figure E.8. The primary

Summary values:		
Sums:		
0.00	N_{SPF}	0.00
0.00	$N_{predicted}$	0.000
0.00	Injury (KABC)	0.000
0.00	Property Damage Only (O)	0.000
0.00	$N_{observed}$	0.00
0.00	$N_{expected}$	0.000

Figure E.8 Reviewing Results (HSMIS)

values of interest are the $N_{predicted}$ values, specifically the Injury (KABC) and Property Damage Only (O) values which are entered into the BES, as shown in Figure E.9.

40	Traffic Safety (annual predicted crash frequency - Highway Safety Manual (HSM))			
41	Predicted Crashes (crashes/year)			
42	Start Year			
43	Enter start year (if different than project)		year	<entry>
44	Combined	<calculate>	crashes/year	<enter below>
45	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
46	Property Damage Only (O)	<entry>	crashes/year	<entry>
47	End Year			
48	Enter end year (if different than project)		year	<entry>
49	Combined	<calculate>	crashes/year	<enter below>
50	Injury Crashes (KABC)	<entry>	crashes/year	<entry>
51	Property Damage Only (O)	<entry>	crashes/year	<entry>

Figure E.9 Entry of Traffic Safety (BES)

The values entered into the BES from the HSMIS are obtained from column F in cells F21 and F22 with the red borders to the left of the Injury (KABC) and Property Damage Only (O) headers.

E.3.5 Step 5 – Iterate for Each Period and Alternative

For step 5, iterate through additional periods (e.g., Start Year and End Year) and alternatives to obtain the respective values from the HSMIS for the BES as needed. For each of these iterations, it is recommended that an individual spreadsheet file is saved. However, as noted, for individual alternatives the Start Year spreadsheet file can be used as a basis for the End Year spreadsheet, allowing modifications to be made rather than re-entry of all values.

E.4 Add Alternative and Delete Alternative(s) Buttons

To facilitate HCMIS use with regard to adding or deleting alternatives, two buttons exist.

E.4.1 Add Alternative Button

Clicking the Add Alternative button will add an additional column throughout the spreadsheet, i.e., to the Site_Entry worksheet as well as the orange tab worksheets. Additionally, the operations triggered by this button create a new column and copy and paste the default column values into the new column within each of these worksheets. Thus, simply copying and pasting an existing column to a new column within the Site_Entry tab will not carry through the functionality within the other worksheets needed for calculations. A user would need to copy and paste a new column into each of the other sheets to accomplish this but using the button to generate these columns is far simpler.

E.4.2 Delete Alternative(s) Button

Clicking the Delete Alternative(s) button will delete a column (or columns) throughout the spreadsheet, i.e., to the Site_Entry worksheet as well as corresponding columns within the orange tab worksheets. Thus, simply deleting an existing column (or columns) within the Site_Entry tab will not carry through within the other worksheets. A user would need to delete the same column (or columns) from each of the other sheets to accomplish this but using the button to delete these columns is far simpler.

The column (or columns) deleted are those with cells selected, whether the entire column (by clicking on the column letter at the top) or any cell within that column. With cells selected, clicking the Delete Alternative(s) button will delete all columns with a selected cell from each of the tabs mentioned previously.

E.5 Example – 69th St and Cliff Ave, Sioux Falls, SD

Using the 5 data entry steps for the HSMIS, as shown in Figure E.2 previously, an example using the case study for the 69th St and Cliff Ave area in Sioux Falls, SD, will be discussed. The case study area includes the intersection itself as well as along the approaches in four directions and considered only a "no-build" and a single "build" option. The example will discuss the data entry into the HSMIS for a portion of one of these options, showing both a segment and an intersection, with images displaying the entered data but explaining where these data originated. Following the data entry, results will be shown and discussed.

E.5.1 Step 1 – Identify Individual Project Portion(s) (example)

For step 1, the first action was to save the base HSMIS file to another name, in this case a name that reflects the "no-build" and "build" difference as well as the Start Year and End Year difference (e.g., HSMImplementation_20220303_example_no-build_2007"). For this example, there was an intersection and four approaches; thus, the Add Project Portion button was used to generate four additional columns to have five columns total, one for each approach and another for the intersection, as shown in Figure E.10. Within Figure E.10, note that each project portion has been assigned a title on the first row, e.g., "South Segment (2007) – no build." The title assigned should be descriptive to aid differentiation but, other than that, is inconsequential. Additionally, each project portion has been assigned a facility category and type by first selecting the facility category option

		South Segment (2007) - no-build	North Segment (2007) - no-build	East Segment (2007) - no-build	West Segment (2007) - no-build	69th and Cliff (2007) - no-build
	Facility Category:	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial	Urban and Suburban Arterial
	if RTLTW:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if RML:	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	if USA:	2-lane, Undivided Arterial	3-lane, Arterial with center TWLTL	4-lane, Undivided Arterial	4-lane, Divided Arterial	4-legged, Signalized Intersection
	entry options or units					
Summary values:						
Sums:						
2.61	N_{SPF}	0.32	0.45	0.02	0.11	1.71
1.86	$N_{predicted}$	0.338	0.513	0.019	0.126	0.868
0.55	Injury (KABC)	0.086	0.135	0.005	0.037	0.288
1.31	Property Damage Only (O)	0.252	0.378	0.014	0.090	0.580
2.50	$N_{observed}$	0.75	0.25	0.00	0.00	1.50
1.88	$N_{expected}$	0.371	0.467	0.019	0.116	0.904

Figure E.10 Entry of Individual Project Portions (HSMIS) (example)

within each row and selecting the appropriate facility category from the list. Once the Urban and Suburban Arterial facility category was selected, the "if USA:" row became light green and not struck through. Then the facility type matching each approach and the intersection type was selected from the facility type list.

The values within the Summary Values section have results because the data for this example has already been entered, as will be explained in the following. Please note that, for the following, the spreadsheet representation has been modified to show the entry values and associated row titles to compress the images to fit within the document formatting. Thus, there are five data entry columns: the first for the South approach, the second for the North approach, the third for the East approach, the fourth for the West approach, and the fifth for the Intersection itself.

E.5.2 Step 2 – Enter Site Characteristics (example)

For step 2, three sub-steps are involved, including entry of volume and length, entry of site descriptive characteristics which will either be entry of intersection characteristics or segment characteristics based on the facility type selected previously during step 1, and optional entry of observed crashes. Again, as noted within the step 1 discussion, only the cells which are light green and no longer struck through require entry. The values shown in the following have been determined through site review following the guidelines and discussion from the HSM.

E.5.2.1 Step 2a – Enter Volumes and Lengths (example)

For step 2a, enter the values as appropriate, as shown in Figure E.11. For intersections, a major and minor road AADT (annualized average daily traffic or volume) is entered. For segments, only the major AADT is entered but also a length (in miles). The pedestrian values are related to specific facility categories and types. For those cells that contain “<entry>”, enter the value. For those cells that contain “<select from list>”, click in the cell and a pull-down tab will appear. Then click the pull-down tab and select from the list.

			South	North	East	West	Intersection
Volume/Length							
$AADT_{major}$		~~<entry>~~	5,100	10,600	375	5,700	7,850
$AADT_{minor}$		~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	3,038
Length		~~<entry>~~	0.25	0.17	0.25	0.11	~~<entry>~~
Pedestrians	**Pedestrian Volume (all legs combined)**	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	NA
	General Level of Pedestrian Activity	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Low
	maximum number of lanes crossed considering refuge islands	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	3

Figure E.11 Entry of Volumes, Lengths, and Pedestrian Values (HSMIS) (example)

E.5.2.2 Step 2b – Enter Site Descriptive Characteristics (example)

For Step 2b, entered site descriptive characteristics depend on the facility category and type indicated in step 1. The facility type will either be intersection or segment and, thus, those cells that become light green and no longer struck through require entry. However, based on facility category, not all cells within either the intersection or segment characteristics portions will require entry.

For intersection characteristics, as shown in Figure E.12, many of the entry fields should be reasonably familiar and identifiable. For clarification, refer to HSM.

			South	North	East	West	Intersection
Intersection Characteristics							
Intersection Skew Angle		~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Intersection left-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	# of Approaches with Left-Turn Lanes	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Intersection right-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
	# of Approaches with Right-Turn Lanes	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Intersection left-turn lanes on uncontrolled major approaches		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Number of uncontrolled major approaches with left-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Number of approaches with left-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	4
Intersection Left-Turn Signal Phasing		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Protected/permissive
	Number of Approaches with Left-Turn Signal Phasing	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	4
Intersection right-turn lanes on uncontrolled major approaches		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Number of uncontrolled major approaches with right-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Number of approaches with right-turn lanes		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	4
Right-Turn-On-Red		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Allowed
	Number of Approaches with Prohibited Right-Turn-On-Red	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~0~~
Lighting		~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Yes
Red-Light Cameras		~~None~~	~~None~~	~~None~~	~~None~~	~~None~~	None
Bus Stops within 1,000 ft		~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	0
Schools within 1,000 ft		~~None~~	~~None~~	~~None~~	~~None~~	~~None~~	None
Alcohol Sales Establishments within 1,000 ft		~~0~~	~~0~~	~~0~~	~~0~~	~~0~~	0

Figure E.12 Entry of Intersection Site Characteristics (HSMIS) (example)

For segment characteristics, as shown in Figure E.13, many of the entry fields should be reasonably familiar and identifiable. For clarification, refer to HSM.

		South	North	East	West	Intersection
Segment Characteristics						
Posted Speed Limit (mph)	~~<select from list>~~	40	40	40	40	~~<select from list>~~
Lane Width (LW)	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Shoulder Width (SW)	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Right Shoulder Width (SW)	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Shoulder Type/Right Shoulder Type	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Sideslope	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Median Width	~~<entry>~~	~~0~~	12	~~0~~	18	~~<entry>~~
Median Traversable?	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Undivided or TWLTL?	~~<select from list>~~	~~Yes~~	Yes	~~Yes~~	No	~~<select from list>~~
Median Traversable?	~~<select from list>~~	~~Yes~~	Yes	~~Yes~~	No	~~<select from list>~~
Roadside Hazard Rating (RHR)	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
On-Street Parking	~~<select from list>~~	None	None	None	None	~~<select from list>~~
Curb Length with On-Street Parking (both sides combined)	~~<entry>~~	~~0~~	~~0~~	~~0~~	~~0~~	~~<entry>~~
Type of Parking	~~<select from list>~~	~~None~~	~~None~~	~~None~~	~~None~~	~~<select from list>~~
Type of Land Use	~~<select from list>~~	~~NA~~	~~NA~~	~~NA~~	~~NA~~	~~<select from list>~~
Roadside Fixed Objects	~~<select from list>~~	Yes	Yes	Yes	Yes	~~<select from list>~~
Fixed-Object Density	~~<entry>~~	40	40	40	40	~~<entry>~~
Fixed-Object Offset	~~<entry>~~	30	4	4	4	~~<entry>~~
Driveway Density (DD)	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Number of Driveways major commercial	~~<entry>~~	0	0	0	0	~~<entry>~~
by Driveway Type: minor commercial	~~<entry>~~	0	0	1	0	~~<entry>~~
major industrial/institutional	~~<entry>~~	1	0	0	0	~~<entry>~~
minor industrial/institutional	~~<entry>~~	1	0	1	0	~~<entry>~~
major residential	~~<entry>~~	1	1	0	1	~~<entry>~~
minor residential	~~<entry>~~	0	0	0	0	~~<entry>~~
other	~~<entry>~~	0	0	0	0	~~<entry>~~
Horizontal Curvature	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Length of Curve (L_c)	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Radius of Curve	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Spiral Presence	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Spiral Value	<select from list above>	<select above>	<select above>	<select above>	<select above>	<select above>
Actual Superelevation	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
AASHTO Superelevation	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Vertical Curvature	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Centerline Rumble Strips	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Passing Lanes	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Two-Way Left-Turn Lanes (TWLTLs)	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~
Lighting	~~<select from list>~~	None	Yes	Yes	Yes	~~<select from list>~~
Automated Speed Enforcement	~~None~~	None	None	None	None	~~None~~
Grade Level	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~

Figure E.13 Entry of Segment Site Characteristics (HSMIS) (example)

E.5.2.3 Step 2c – Enter Observed Crashes ($N_{observed}$) (optional) (example)

Step 2c is optional and only required for determination of $N_{expected}$, which is an HSM combination of $N_{predicted}$ and $N_{observed}$ based on reliability of the base SPF model related to a specific facility category and type.

For Step 2b, prior determination of observed crashes should have occurred. Given the observed crashes, enter the values as indicated based on facility category and type as shown in Figure E.14.

E.5.3 Step 3 – Iterate for Each Project Portion (example)

For step 3, the iteration for each project portion has been completed through the example above. However, the individual project portions could be done individually rather than as above. Additional project portions would be added as needed.

			South	North	East	West	Intersection
Observed Crashes ($N_{observed}$)		<enter below>	0.75	0.25	0.00	0.00	1.50
Observed Crashes (entered)		~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~	~~<entry>~~
Observed Crashes (summed from disaggregate below)		<enter below>	0.75	0.25	0.00	0.00	1.50
Multiple-Vehicle Non-Driveway Collisions	$N_{observed(total)}$	~~<enter here or below>~~	0.5	0.25	0	0	1
	$N_{observed(FI)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	<entry>
	$N_{observed(PDO)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	<entry>
Single-Vehicle Crashes	$N_{observed(total)}$	~~<enter here or below>~~	0.25	0	0	0	0.5
	$N_{observed(FI)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	<entry>
	$N_{observed(PDO)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	<entry>
Multiple-Vehicle Driveway-Related Collisions	$N_{observed(total)}$	~~<enter here or below>~~	0	0	0	0	~~<enter here or below>~~
	$N_{observed(FI)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	~~<entry>~~
	$N_{observed(PDO)}$	~~<entry>~~	<entry>	<entry>	<entry>	<entry>	~~<entry>~~
Multiple-Vehicle Non-Driveway Collisions - Collision Types to Include:	Rear-end collision	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Head-on collision	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Angle collision	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Sideswipe	~~Yes~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Yes
	Sideswipe, same direction	~~Yes~~	Yes	Yes	Yes	Yes	<select from list>
	Sideswipe, opposite direction	~~Yes~~	Yes	Yes	Yes	Yes	~~<select from list>~~
	Other multiple-vehicle collisions	~~Yes~~	Yes	Yes	Yes	Yes	Yes
Single-Vehicle Crashes - Collision Types to Include:	Collision with parked vehicle	~~Yes~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Yes
	Collision with animal	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Collision with fixed object	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Collision with other object	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Other single-vehicle collision	~~Yes~~	Yes	Yes	Yes	Yes	Yes
	Noncollision	~~Yes~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	~~<select from list>~~	Yes
Severity Type		~~1~~	1	1	1	1	1

Figure E.14 Entry of Observed Crashes (HSMIS) (example)

E.5.4 Step 4 – Obtain Results for Benefits Estimation Spreadsheet (BES) (example)

For step 4, results were previously displayed in Figure E.10. Result values are shown for each individual project portion, but a consolidated, summed result is presented to the left of the project portions, as shown in Figure E.15. The 0.55 crashes/year value for Injury (KABC) and the 1.31 crashes/ year value for Property Damage Only (O) are the values that are entered into the BES as shown in Figure E.16. As these values were for the "no-build," Start Year option, these are entered in rows 45 and 46 and the total generated by the BES, shown in Figure E.16, should match the $N_{predicted}$ value shown in Figure E.15.

Summary values:	
Sums:	
2.61	N_{SPF}
1.86	$N_{predicted}$
0.55	Injury (KABC)
1.31	Property Damage Only (O)
2.50	$N_{observed}$
1.88	$N_{expected}$

Figure E.15 Reviewing Results (HSMIS) (example)

40	Traffic Safety (annual predicted crash frequency - Highway Safety Manual (HSM))				
41	Predicted Crashes (crashes/year)				
42	Start Year				
43	Enter start year (if different than project)		year	2008	2008
44	Combined	<calculate>	crashes/year	1.86	1.38
45	Injury Crashes (KABC)	<entry>	crashes/year	0.550	0.430
46	Property Damage Only (O)	<entry>	crashes/year	1.310	0.950
47	End Year				
48	Enter end year (if different than project)		year	2028	2028
49	Combined	<calculate>	crashes/year	13.36	9.03
50	Injury Crashes (KABC)	<entry>	crashes/year	3.940	2.830
51	Property Damage Only (O)	<entry>	crashes/year	9.420	6.200
52					

Figure E.16 Entry of Traffic Safety (BES) (example)

E.5.5 Step 5 – Iterate for Each Period and Alternative (example)

For step 5, iterate through additional periods (e.g., Start Year and End Year) and alternatives to obtain the respective values from the HSMIS for the BES as needed. For each of these iterations, it is recommended that an individual spreadsheet file is saved. However, as noted, for individual alternatives the Start Year spreadsheet file can be used as a basis for the End Year spreadsheet, allowing modifications to be made rather than re-entry of all values.

For this example, as somewhat indicated by the BES entry data in Figure E.16, there were four separate spreadsheets: 1) no-build, start year; 2) no-build, end year; 3) build, start year; and 4) build, end year.

As noted previously, though each of these spreadsheets could be initialized from the default, generally it will be easier to complete one, save a copy, and complete data entry by modifying values. Care should be taken as choices of facility category and type may adjust which fields to enter.

APPENDIX F: MAINTENANCE DOCUMENTATION

F.1 Spreadsheet Tool Maintenance

For the BES and the HSMIS, general maintenance involves preserving the base versions of the spreadsheets. This can be accomplished through saving versions of each spreadsheet in a specific folder where no additional files are stored and only copying the files from this folder, never saving to the original files.

Additionally, as both spreadsheet tools are macro-enabled, users may need to indicate a trusted location for executing office documents. To do so, follow these steps:

- Open one of the spreadsheet tools (either BES or HSMIS)
- Click the **File** menu
  - Select **Options** (near the bottom left typically) – a dialog window will open
  - Select **Trust Center** (near the bottom left of the left pane of the dialog window)
  - Click the **Trust Center Settings**… button – another dialog window will open
  - Select **Trusted Locations** (near the upper left of the left pane of the dialog window)
  - Click the **Add new location** button – another dialog window will open
  - Click the **Browse** button – another dialog window will open
  - Browse to the folder within which you wish to run Macro Enabled Documents
  - Click OK
  - At this point, you can **optionally** check the "Subfolders of this location are also trusted" option
  - Click OK three (3) additional times
- Reload the spreadsheet tools and macros should be enabled

Maintenance specific to each spreadsheet tool is covered in the following sections.

F.2 Benefits Estimation Spreadsheet (BES)

For the BES, periodic updates should be administered to the Unit Costs section of the spreadsheet for costs related to congestion/delay (i.e., travel time), emissions (fuel used), crashes/year (i.e., both injury crashes and property damage only [PDO] crashes), and interest rate. The Unit Costs section is contained within the Site_Entry tab of the spreadsheet. These unit costs generally increase over time. SDDOT should review and adjust the values annually. Crash valuations are already updated annually and can be obtained from the safety office. Beyond this, the other tabs should not require adjustment or maintenance as long as they are not modified by a user.

F.3 Highway Safety Manual Implementation Spreadsheet (HSMIS)

For the HSMIS, standard maintenance should be minimal and be confined to that covered in the introductory section. However, if updates to either the Safety Performance Functions (SPFs), Crash Modification Factors (CMFs), or proportion of crashes by severity, i.e., injury (KABC) and property damage only (O), are desired, the maintenance will be more significant.

Updates to the SPFs could result from release of another version of the HSM with modified factors or by development of South Dakota-specific SPFs with modified factors. With either option, the appropriate base N_{SPF} equations within the orange tabs representing the 18 different facility category types would need to be updated. To find these, first identify the appropriate tab related to the facility category type. Next, under the SPF calculations section, the first row should be the N_{SPF}. To modify the equation, unhide columns H and I, modify the equation within the N_{SPF} cells in both columns H and J, then hide columns H and I again. Save the resulting spreadsheet with an updated date and redistribute to users.

Updates to the CMFs are both similar yet more involved to SPF updates. CMF operations are found under the CMF Calculations section of the orange tabs. Some CMF modifications may only involve updates to the corresponding values in column G, which define values based on volume ranges or other factors. Other CMFs may require changes to the equations in columns H and J. For these, the process of unhiding columns H and I, performing the changes in both columns H and J, then hiding columns H and I again is similar.

Additions to CMFs are even more significant as changes would be made to the orange tabs in a couple sections and, depending on the CMF, the Site_Entry tab would also require modification to collect the data needed for CMF operation. Within the orange tabs, the CMFs would need to be coded into the appropriate facility category type within the CMF Calculations section but also included in the multiplicative overall CMF equation just above the $N_{predicted}$ cell. On the Site_Entry tab, an entry requesting the requisite data would need to be added and, using conditional formatting and if-then-else statements, adjusted to appropriately indicate the need for data entry based on the facility category type selection. The research team is willing to collaborate with SDDOT personnel to further clarify the process. For these, the process of unhiding columns H and I, performing the changes in both columns H and J, then hiding columns H and I again is similar.

For updates to the proportion of crashes by severity, i.e., injury (KABC) and property damage only (O), the changes would be specific to each facility type category and are indicated in the KABC and O rows near the top of each orange tab. If the state determines South Dakota-specific values for each of these, the values are readily updateable by simply changing the proportion values in column G.