Safety Effects of Access Management Techniques: State of Knowledge and Recent Research

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ABSTRACT/ INTRODUCTION

The recently released Highway Safety Manual (HSM) (*1*) set a new, and high standard for assessing and assimilating knowledge on the safety implications of roadway design decisions. Critical reviews were conducted before applying rigorous assessment criteria and inclusion/exclusion rules before presenting this knowledge in the HSM. Several of the resulting crash modification factors pertained directly or indirectly the safety effects of access management techniques. However, access management is not addressed specifically in the HSM, so there is a dearth of information on how access management can be accomplished to minimize adverse safety impacts. However, the US Federal Highway Administration (FHWA) has initiated a research project to improve the state of knowledge on this subject, in effect to fill this gap in the HSM. There are two fundamental aspects to this new research. The first addresses the crash modification implications for access management decisions, while the second addresses how that knowledge could be applied in practice using multiple regression crash prediction models or, similar to the HSM predictive methodology, using base models and crash modification factors. The paper is, in effect, a report on progress made in this major research effort. The first part of the paper is, in effect, a status report on the current FHWA project. The second part is an investigation on how the HSM can be used as a limited tool for the safety assessment of some aspects of access management.

UPDATE ON CURRENT FHWA PROJECT

The objective of the research is to develop relationships between safety and access management policies and practices. The end vision is a software tool that estimates the safety performance of a corridor based on inputs related to the roadway, access management strategies, and the surrounding land use. While it would be desirable to include all aspects of access management in this evaluation, it is not a feasible or practical approach largely due to the limitations in data availability and the need to resolve substantial challenges in modeling the data. As such, it was necessary to develop an evaluation framework to identify a more focused approach.

The first step was a cursory literature review to identify lessons that can be learned from related investigations by other researchers and from pertinent research summaries. Table 1 presents a summary of information from key sources that were identified for this review in consultation with FHWA. Also provided is a confidence level rating, on a scale from 1 to 3, for the information in each source that pertains to a specific access management feature. This rating is largely subjective but does assign high confidence to those before after studies that appear to properly use state-of-the-art evaluation techniques (e.g., the empirical Bayes method), or to cross-sectional studies that consider interactions and correlations among are access management features, and which are based on solid techniques (e.g., negative binomial generalized linear modeling).

Based on the studies identified and summarized as part of the literature review, the project team established a list of potential access management strategies to be included in the analysis. The preliminary list was presented to a focus group and revised based on comments received. The final list of access management strategies was presented in an evaluation framework, which included a two-tiered prioritization for the research. The two-tiered prioritization identifies the relative importance of access management strategies, based on comments from the focus group, and the need to include the strategies in a safety evaluation tool. The prioritized list is shown in Table 2.

The research team also identified and reviewed several modeling techniques that have been employed by others to develop relationships between access management and safety. Based on the literature review and the state-of-the-practice for modeling the safety effects of access management strategies, two alternative modeling structures are being pursued, both based on the negative binomial generalized linear modeling approach. The following are the two potential model structures for this research:

Table 1.1: Knowledge Sources for Table 1.2

Source	Reference
1	Bonneson, J.A., and P.T. McCoy, NCHRP Report 395: Capacity and Operational Effects of Midblock Left-Turn Lanes, Transportation Research Board, National Research Council, Washington, D.C., 1997.
2	Gluck, J.S., H.S. Levinson, and V. Stover, NCHRP Report 420: Impact of Access Management Techniques, Transportation Research Board, National Research Council, Washington D.C., 1999.
3	Huang, H.F., J.R. Stewart, and C.V. Zegeer, HSIS Summary Report: Evaluation of Lane Reduction "Road Diet" Measures and Their Effects on Crashes and Injuries, Federal Highway Administration, FHWA -HRT-04-082.
4	Potts, I.B., et. al., NCHRP Report 524: Safety of U-Turns at Unsignalized Median Openings, Transportation Research Board, National Research Council, Washington D.C., 2004.
5	Lu., J. and K. Williams, Safety Evaluation of Right Turns Followed by U-Turns as an Alternative to Direct Left Turns, for Florida DOT, Center for Urban Transportation Research, University of South Florida, 2001.
6	Potts, I., et. al., NCHRP Project 3-72: Lane Widths, Channelized Right Turns, and Right-Turn Deceleration Lanes in Urban and Suburban Areas; http://design.transportation.org/Documents/Potts-NCHRPProject3-72.pdf (Active)
7	Schultz, G.G., K.T. Braley, and T. Boschert, Correlating Access Management with Crash Rate, Severity, and Collision Type, Transportation Research Board, 87th Annual Meeting, Washington, DC, January 13-17, 2008.
8	Jagannathan, R., Gimbel, M., Bared, J., Hughes, W., Persaud, B., and Lyon, C., "Safety Comparison of New Jersey Jughandles and Conventional Intersections, TRB Annual Meeting CDROM (2006).
9	Rakha, H., A.M. Flintsch, M. Arafeh, A.G. Abdel-Salam, D. Dua, and M. Abbas, Access Control Design on Highway Interchanges: Final Contract Report VTRC 08-CR7, Virginia Transportation Research Council, 2008.
10	Brown, H.C., S. Labi, A. P. Tarko, and J.D. Fricker, A Tool for Evaluating Access Control on High-Speed Urban Arterials – Part 1. Joint Transportation Research Program, Purdue University and Indiana DOT, 1998.
11	Phillips, S.L., J.E. Hummer, and R.S. Foyle, Effects of Increased U-Turns at Intersections on Divided Facilities and Median Divided versus 5-Lane Undivided Benefits, North Carolina State University, August 2004.
12	Huffman, C., and J. Poplin, The Relationship between Intersection Density and Vehicular Crash Rate on the Kansas State Highway System, Kansas DOT and Kansas University, 2002.
13	Gluck, J.S., and H.S. Levinson, The Relationship between Access Density and Accident Rates: Comparisons of NCHRP Report 420 and Minnesota Data, NCHRP Research Results Digest #247, May 2000.
14	Eisele, W.L., and W.E. Frawley, Estimating the Safety and Operational Impact of Raised Medians and Driveway Density: Experiences from Texas and Oklahoma Case Studies, Transportation Research Record 1931, 2005.
15	Harkey, D.L., R. Srinivasan, C. Zegeer, B. Persaud, C. Lyon, K. Eccles, F. Council, and H. McGee, Crash Reduction Factors for Traffic Engineering and Intelligent Transportation System (ITS) Improvements: State of Knowledge Report, Research Results Digest, Vol. 299, Transportation Research Board, November 2005
16	Zhou, H., K.M. Williams, and W. Farah, A Methodology to Evaluate the Effects of Access Control near Freeway Interchange Areas, Transportation Research Board, 87th Annual Meeting, 2008.
17	Miller, J.S., L.A. Hoel, S. Kim, and K.P. Drummond, Transferability of Models that Estimate Crashes as a Function of Access Management, Transportation Research Record 1746, 2001.
18	Liu, P., J. Lu, H. Chen, and G. Sokolow, Impacts of Separation Distances between Driveway Exits and Downstream U-Turn Locations on the Safety Performance of Right-Turns followed by U-Turns, Transportation Research Board, 87th Annual Meeting, January 2009.

1. Baseline safety performance functions with adjustments using crash modification factors.
The final evaluation tool would operate as a two-step process similar to the method in the Highway Safety Manual.
a. Apply a crash prediction model to estimate the crash frequency for a baseline condition. Separate models would be developed for the nine land use/area types, representing common baseline conditions (e.g., urban 4-lane arterial).
b. Apply crash modification factors (CMFs) to adjust the base model to reflect planned or existing access management strategies. CMFs would be identified or developed for common access management strategies (e.g., left- and right-turn lanes, signal spacing, and driveway density).

2. Crash prediction models that incorporate all variables in the model.
a. Specify all variables in a single model to estimate the number of expected crashes for a corridor.
b. Crash prediction models would be developed to include all relevant variables such as area type, land use, number of lanes, median type, traffic volume, speed limit, and segment length. The model would also incorporate access management strategies (e.g., presence of turn lanes, driveway density, signal spacing, corner clearance, and non-traditional left-turn treatments).

TABLE 1.2 Summary of Knowledge from Various Sources on the Safety Effects of Access Management Techniques

Note: Confidence Ratings: 1 = low, 2 = medium, 3 = high, X = not applicable.

Source #	Left-Turn Lanes	Right-Turn Lanes	Driveway Spacing	Corner Clearance	Signal Spacing	Install Non-Traversable Median	Install TWLTL	Cross-Road Spacing from Inter-change	Alternative Left-Turn Treatment	Provides Model(s)	Comments
1	2					2	2		2	3	
2	X		2	X	1	1	1			1	Provides crash models based on unsignalized access spacing, median type, and signal spacing.
3							3			3	From 4 lanes to two lanes plus a TWLTL.
4						1			2	1	
5									1	1	
6		2								1	
7			1		1	1.5	1.5		1	1	Includes stepwise LRM based on noted techniques.
8									1	1	
9								1.5		1	Data are limited to 1 state (VA). This is very specific to spacing from interchange to first road.
10			3		3	3	3			3	Provides crash models for Total, PDO, and Fatal/Injuries.
11			1.5			1	1				
12			1							1	Investigates relationship between crash rate and access density.

Source #	Left-Turn Lanes	Right-Turn Lanes	Driveway Spacing	Corner Clearance	Signal Spacing	Install Non-Traversable Median	Install TWLTL	Cross-Road Spacing from Inter-change	Alternative Left-Turn Treatment	Provides Model(s)	Comments
13			1.5		1	1	1			1.5	Based on crash rates, so can be improved to better model traffic volumes.
14			1			1	1			1	Primarily focuses on LRM to compare relationship between access density & crash rate. Effects of median type (median and TWLTL) are not directly considered in the model.
15	X	X			X		3				Provides CMFs for noted techniques. One CMF from NCHRP17-25 (add TWLTL to 2-lane road) is rated. Others, based on literature assessment, are not.
16								1		1	Specific application. Models did not account for traffic volume.
17			2		2	1	1			2	Compares accuracy of crash models (from other literature sources) against historical data sets (10 years of data on 3 corridors in VA).
18									2	2	Data are limited to 1 state (FL).

TABLE 2. Prioritization of Access Management Policies and Techniques

Access Management Policy/Strategy	Applicable Principles	Priority
Establish unsignalized access spacing (consider commercial and residential separately, consider driveways and intersections separately, and consider full movement and limited movement separately or as ratio)	Limit the number of conflict points. Separate conflict areas.	1
Establish signal spacing criteria (consider full movement and limited movement separately or as ratio)	Locate signals to favor through movements. Limit the number of conflict points. Separate conflict areas.	1
Establish spacing criteria for interchange cross roads	Limit the number of conflict points. Separate conflict areas.	1
Establish spacing criteria for median openings/crossovers	Limit the number of conflict points. Separate conflict areas.	1
Establish corner clearance criteria	Preserve the functional area of intersections. Separate conflict areas.	1
Provide median and accommodate left-turns and u-turns	Limit the number of conflict points. Separate conflict areas. Manage left-turn movements.	1
Provide left-turn lane	Remove turning vehicles from through-traffic lanes.	1
Non-traditional accommodation of left-turns (e.g., Michigan u-turn, superstreet, New Jersey jug-handle)*	Manage left-turn movements. Limit the number of conflict points.	1
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.	1
Provide two-way left-turn lane	Remove turning vehicles from through-traffic lanes.	2
Provide right-turn lane	Remove turning vehicles from through-traffic lanes.	2
Provide frontage/backage road	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	2
Internal cross-connectivity	Limit the number of conflict points. Remove turning vehicles from through-traffic lanes.	2

*Note: This is a subset of "provide a median" since they are applicable only on a divided facility to help answer the question of how should the left-turn movement be accommodated.

Additional modeling techniques are being considered. While more complicated than traditional generalized linear modeling (GLM) techniques, Full Bayes or neural network modeling may offer benefits for evaluating access management strategies in urban areas where intersections and access points may be close together, giving rise to spatial correlation among sites. Of particular relevance is the ability of the advanced techniques to calibrate complex model forms. Specifically, models can be calibrated with a mixture of multiplicative terms such as those accommodated through a linear link in a traditional GLM, and additive terms for point hazards such as driveways and median openings.

Models are being explored for the nine scenarios identified in Table 3. The results of the modeling will be used in the final substantive project task to develop functional specifications for a safety evaluation tool to allow users to investigate the safety implications of access management policies and techniques. It is envisioned that an Excel-based platform (or other widely available platform) will eventually be used. The functional specifications will include decision trees, identifying required and optional inputs, as well as default values, to investigate the various scenarios included in this study (i.e., types of access management policies/strategies for different area type and land use scenarios). Figure 1 illustrates a potential framework for a corridor-level analysis tool.

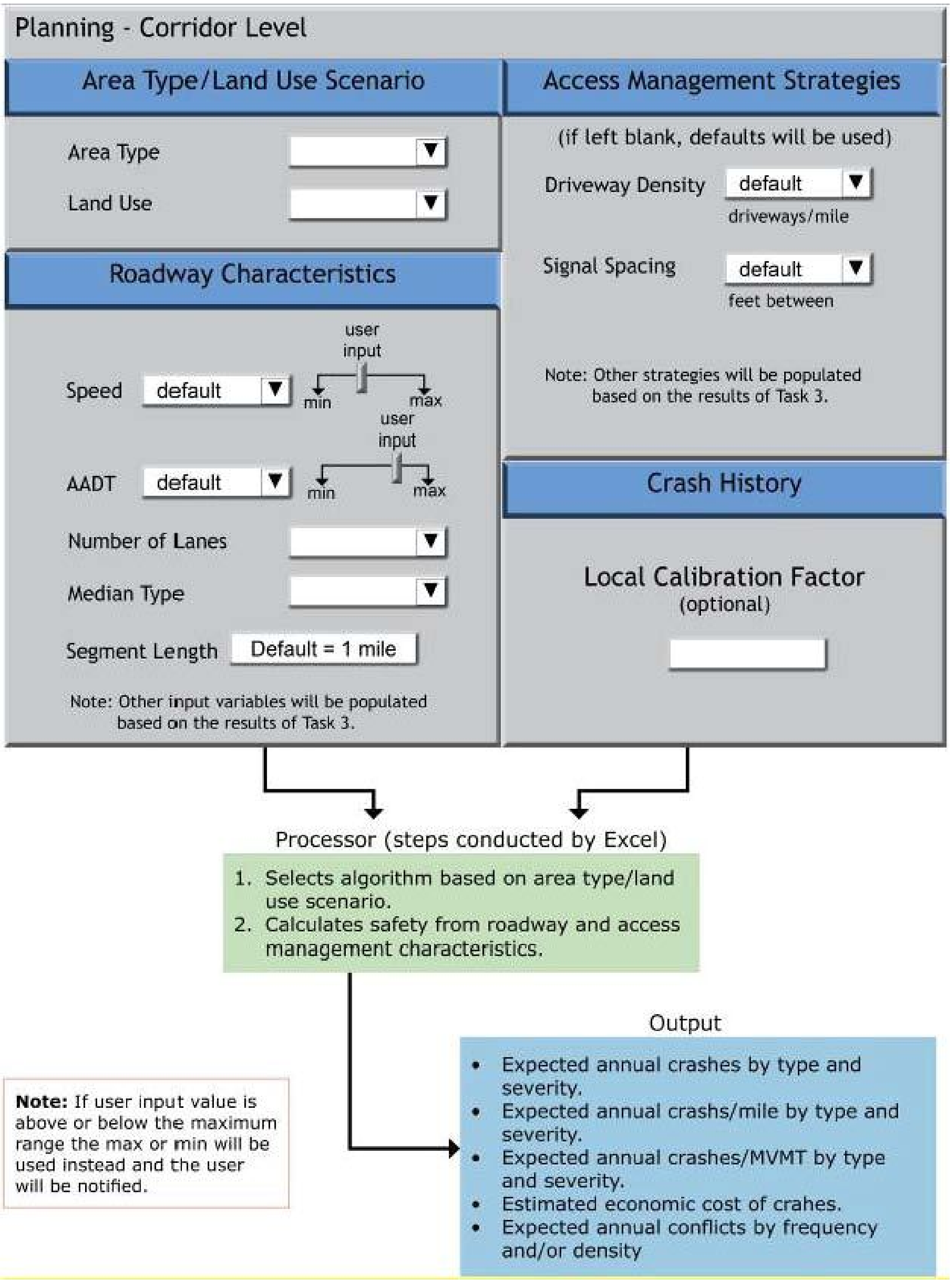

Figure 1 Framework for a Potential Safety Evaluation Tool

TABLE 3. Primary Area Types and Land Use Scenarios

Area Type	Land Use
Urban: Large urban cities with population of at least 250,000.	Residential Commercial Mixed Use
Suburban: Smaller cities next to the large urban city selected for this study with population of 50,000 to 250,000.	Residential Commercial Mixed Use
Urbanizing: Independent cities away from large urban cities with build up plans to reach or exceed population of 250,000; or townships close to the large urban city selected for this study with build up plans to become a suburban city.	Residential Commercial Mixed Use

EXPLORATORY DATA ANALYSIS

Data for the modeling are being assembled in three jurisdictions in three different States. So far, exploratory analysis of one data set has brought to light some issues that will need to be addressed. These include:

- Whether the modeling should be done at the corridor level or at the level of the individual elements (i.e., segments and intersections. Since access management strategies are often done at a corridor level, and since some individual element models are available in sources such as the Highway Safety Manual, it seems desirable to attempt the development of corridor level models. Preliminary data analysis revealed that it is a challenge to define corridors that are essentially uniform in access management features. However, there is sufficient variation in these features among corridors, and the crash counts are large enough, that models can be feasibly developed.
- Initial results suggest that there are substantial challenges to be met in the modeling effort because of the correlation in the independent variables. Table 4, which presents a correlation matrix for several of these variables, provides evidence of this challenge. If interactions cannot be modeled in the classical way because of insufficient sample size, consideration will be given to pooling data from the three jurisdictions with an indicator variable (in effect a separate multiplier) for each jurisdiction. The same indicator variable approach and pooling of data may be necessary to address the nine scenarios in Table 3.
- The inclusion of strongly correlated variables in a model will, in general, underestimate the safety benefits of an access management strategies associated with these variables. This underestimation can be such that a variable could have an illogical sign. This problem can be avoided by excluding a variable that may be strongly correlated with another one that is included in the model. This will limit the practicality of the tool since the practitioner may be interested in assessing the safety impacts associated with an omitted variable. A reasonable compromise between statistical efficiency and practicality may be to estimate a series of "second best" models with alternate sets of variables.

ASSESSMENT OF THE INFORMATION IN THE HIGHWAY SAFETY MANUAL RELATED TO THE SAFETY OF ACCESS MANAGEMENT TECHNIQUES

The section details an investigation on how the HSM can be used as a limited tool for the safety assessment of some aspects of access management. Information in the HSM related to access management and safety is contained in two parts -- Part C: Predictive Method and Part D: Crash Modification Factors.

Part D actually has a section (13.14) "Crash Effects of Roadway Access Management" that provides crash modification factors for "modifying access point density". "Reducing number of median crossings and intersections" is also identified as an access management treatment but the HSM indicates that no CMF is available. Elsewhere in Chapter 13, there are CMFs for "Provide a raised median". In general, all CMFs presented are based on cross-sectional models rather than from the preferred before-after studies.

The Part C predictive methodology provides base crash prediction models and crash modification factors for making adjustments for non-base conditions. There are no specific crash modification factors for access management features. However, safety effects of such features could easily be inferred from the base models presented.

As will be seen later, there are potential inconsistencies in the information in the two HSM parts that need to be resolved before this information can be utilized in considering safety in devising access management strategies. Below is an assimilation and assessment of the information in the two parts of the HSM.

Table 4: Correlation Matrix for Selected Variables – North Carolina Dataset

Variable	Description	perclane3	percdiv	percvc	drwydens	unsigdens	sigdens	nomedop	Speed_ Limit	avgpcttrk	avgaadt
perclane3	Percentage of length with 5 or more lanes	1.000	0.135	0.080	-0.090	-0.149	0.476	-0.043	0.063	-0.037	0.282
percdiv	Percentage of length with curb or raised median		1.000	-0.055	-0.386	-0.411	-0.067	0.494	0.313	-0.011	0.071
percvc	Percentage of total length with visual clutter			1.000	0.269	-0.023	0.142	-0.032	-0.129	0.275	0.270
drwydens	Number of driveways/mile				1.000	0.475	-0.027	-0.065	-0.407	0.149	-0.013
unsigdens	Number of unsignalized intersections/mile					1.000	0.005	-0.258	-0.363	-0.099	-0.092
sigdens	Number of signalized intersections/mile						1.000	-0.233	-0.181	-0.135	0.194
nomedop	Number of median openings							1.000	0.331	0.168	0.162
Speed_Limit	Posted speed limit								1.000	0.249	0.196
avgpcttrk	Average percentage trucks in traffic									1.000	0.549
avgaadt	Average AADT										1.000
	Total Crashes/ mile/year	0.537	-0.061	0.364	0.135	0.022	0.576	-0.140	-0.003	0.129	0.515
	Rear-end Crashes/ mile/year	0.597	-0.067	0.311	0.148	0.004	0.636	-0.048	0.000	0.183	0.557
	Angle Crashes/ mile/year	0.362	-0.051	0.340	0.067	0.043	0.319	-0.176	-0.014	0.085	0.406
	Turning Crashes/ mile/year	0.328	-0.046	0.323	0.103	0.077	0.601	-0.186	-0.075	-0.081	0.210

Driveway Spacing – rural two-lane roads

The HSM Part D CMF from literature assimilation is given by:

CMF = {0.322 + DD x [0.05 - 0.005 x ln(AADT)]}/{0.322 + 5 x [0.05 - 0.005 ln(AADT)]}

The CMFs in Table 5 are implied from this Equation.

Table 5: CMFs implied from HSM Crash Modification Function for Driveway Density on rural two-lane roads

AADT	Reduce driveways from 40 to 30/mile	Reduce driveways from 20 to 10/mile
1000	0.836	0.755
5000	0.880	0.842
10000	0.918	0.902
15000	0.952	0.947

As can be deduced from the Equation and as seen in Table 5, the CMF increases with increasing AADT and with initial driveway density (for a given reduction in density). This contrasts with what can be inferred from the model for two-lane rural roads (2) that was used to develop the base model for the HSM. That model, and the report in which it is presented (2), indicates a CMF of 0.92 for reducing frequency by 10/mile, independent of AADT and before and after values for driveway density. While this is in the ballpark of the numbers in Table 5, its independence from AADT and initial driveway frequency is questionable. In short, for rural two-lane roads, more confidence should be placed on the HSM Part D CMFs than on those derived from the models used to develop the Part C predictive methodology.

Driveway Spacing and Type -- Urban and Suburban Arterials

The HSM Part D CMFs from literature assimilation are as follows:

- Reduce driveways from 48 to 26-48 driveways/mile: CMF = 0.71
- Reduce driveways from 26-48 to 10-24 driveways/mile: CMF = 0.69
- Reduce driveways from 10-24 to less than 10 driveways/mile: CMF = 0.75

The CMFs inferred from HSM Part C predictive methodology models are shown in Table 6. That methodology provides separate models for multi-vehicle driveway and non-driveway crashes per mile, considering the AADT, the number and type of driveways and whether or not the arterial is divided. Thus, the inferred CMFs for changing driveway spacing also depend on these factors and so, in principle, are preferred to the Part D CMFs. (Both sets of CMFs are derived from cross-sectional studies, so the limitations in that methodology is not a consideration in expressing this preference.) The CMFs in Table 6 tend to be larger (i.e., the safety benefits of reducing driveway density are smaller) than those in Part C, so using the former would at worst err on the conservative side. In short, it is recommended that the CMFs from Part C be used, but within the range of the data used to estimate the models from which they may be inferred.

Table 6: Driveway Density CMFs inferred from the HSM Part C Models for Multi-vehicle Crashes on Urban Four lane Undivided (4U) and Divided (4D) Arterials

AADT	Reduce Driveways from 40 to 30/mile				Reduce Driveways from 20 to 10/mile			
	Major commercial		Major residential		Major commercial		Major residential	
	4U	4D	4U	4D	4U	4D	4U	4D
5000	0.817	0.886	0.853	0.922	0.712	0.895	0.791	0.937
10000	0.823	0.922	0.859	0.950	0.725	0.908	0.804	0.945
15000	0.826	0.927	0.863	0.954	0.733	0.914	0.812	0.949
20000	0.829	0.930	0.866	0.956	0.739	0.919	0.817	0.952
25000	0.830	0.933	0.868	0.958	0.743	0.922	0.821	0.954
30000	0.832	0.935	0.870	0.959	0.747	0.925	0.825	0.956
35000	0.833	0.936	0.872	0.961	0.750	0.927	0.827	0.957
40000	0.835	0.938	0.873	0.962	0.753	0.929	0.830	0.958

Non-traversable medians

The HSM Part D CMFs from literature assimilation are shown in Table 7.

Table 7: HSM Part D CMFs for Install Raised Median (Base condition: No median)

Setting	Crash Type	CMF
Urban two lane	Injury	0.61
Urban arterial multilane	Injury	0.78
	Non-injury	1.09
Rural multilane	Injury	0.88
	Non-injury	0.82

The CMFs inferred from HSM Part C predictive methodology models are shown in Table 8. That methodology, as noted above, provides separate models for multi-vehicle driveway and non-driveway crashes per mile, considering the AADT, the number and type of driveways, and whether or not the arterial has a median. Thus, the inferred CMFs for providing a median also depend on AADT and driveway spacing and type, and so, in principle, are preferred to the Part D CMFs.

Table 8: CMFs for Providing Median – based on the HSM Part C Models for Urban Four lane Undivided (4U) and Divided (4D) Arterials

AADT	Base model No driveways	Major Commercial		Major Residential	
		40/mile	20/mile	40/mile	20/mile
5000	0.635	0.456	0.635	0.623	0.847
10000	0.648	0.471	0.657	0.645	0.871
15000	0.656	0.481	0.671	0.659	0.884
20000	0.662	0.488	0.681	0.668	0.894
25000	0.666	0.494	0.689	0.676	0.901
30000	0.670	0.499	0.695	0.682	0.907
35000	0.673	0.503	0.701	0.687	0.911
40000	0.676	0.506	0.705	0.692	0.915

In short, it is recommended that the CMFs from Part C be used. However, caution in their use is advised and is especially important for minor categories (e.g., minor residential) and for low driveway densities (e.g., major residential with less than 10 driveways/mile, for which the CMF could actually be larger than 1. Thus, the range of calibration data, and the fact that the CMFs are being derived from cross-sectional data, must be considered in making such potentially illogical inferences.

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TEXT REFERENCES

1. American Association of State Highway and Transportation Officials. Highway Safety Manual. Washington D.C. 2010.

2. Vogt, A., and J.G. Bared. Accident Models for Two-Lane Rural Segments and Intersections. Transportation Research Record 1635. Washington, DC, 1998.