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CRASH REDUCTION FACTORS FOR TRAFFIC ENGINEERING AND INTELLIGENT TRANSPORTATION SYSTEM (ITS) IMPROVEMENTS: STATE-OF-KNOWLEDGE REPORT

This digest is an interim deliverable from NCHRP Project 17-25, “Crash Reduction Factors for Traffic Engineering and ITS Improvements,” which is being carried out under a contract with The University of North Carolina Highway Safety Research Center (HSRC) under the direction of David L. Harkey (Principal Investigator). Other members of the research team that contributed to this digest include Dr. Raghavan Srinivasan and Charles Zegeer of HSRC; Dr. Bhagwant Persaud and Craig Lyon of Ryerson University; and Kimberly Eccles, Dr. Forrest Council, and Dr. Hugh McGee of BMI-SG. This digest summarizes the current status of crash reduction factors for a variety of treatments, provides a summary of the “best available” crash reduction factors, and discusses the relationship between this study and other ongoing research studies that are either documenting or developing additional factors.

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INTRODUCTION

Crash or accident reduction factors (CRFs or ARFs) provide a quick way of estimating crash reductions associated with highway safety improvements and are used by many states and local jurisdictions in program planning to decide whether to implement a specific treatment and/or to quickly determine the costs and benefits of selected alternatives. This digest provides a summary of the “best available” crash reduction factors for a variety of safety treatments. Related to CRFs are accident or crash modification factors (AMFs or CMFs). CRFs are the quantitative results from research studies, indicating the percentage reduction in crashes that can be expected after implementing a treatment or program. AMFs are derived from crash reduction factors and are used in predictive methodologies to estimate the reduction in crashes that can be expected for a specific treatment or installation. AMFs are often expressed in the form of (1–CRF); thus a CRF of 15% would be represented as an AMF equal to 0.85. **The remainder of this digest will use the terminology AMF as a means of being consistent with other ongoing NCHRP research in this arena.**

AMFs are currently used in tools such as the Interactive Highway Safety Design Model (IHSDM) and SafetyAnalyst, which have been developed by the FHWA *(1, 2)*. Within IHSDM, AMFs are used to predict future safety for different alternative roadway designs or rehabilitation designs. In SafetyAnalyst, AMFs are applied to estimate the safety effectiveness measures within the economic appraisal tool. AMFs will also be a key component of the Highway Safety Manual now being produced

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by a TRB Task Force and NCHRP *(3)*. Finally, better AMFs will allow AASHTO and NCHRP to update guides already developed or those to be developed in the future that will assist states and local users with the implementation of AASHTO's *Strategic Highway Safety Plan.*

States and municipalities must have accurate AMFs in order to achieve the greatest return on their investment when choosing among alternative treatments. The availability of more reliable AMFs may also be used in the development of broad-based policy decisions related to project planning and design. Given the importance of AMFs in the decision-making processes of states and municipalities, it is critical to address the impediments that prevent more extensive use of AMFs. These impediments include the following:

- **Origins/Transferability.** The origins of AMFs are not always clear to the end user. Some states have developed AMFs using their own crash data. Other states have simply adopted AMFs that were developed in other states. The extent to which AMFs are valid when transferred to places beyond the development domain (e.g., from one state to another), where roadway, traffic, weather, driver characteristics, accident investigation practices, and other relevant characteristics are different, is unknown.
- **Methodological Issues.** Many existing AMFs are derived from before–after analysis of actual countermeasure implementation. Indeed, such before–after studies, as opposed to cross-sectional/regression-type analysis, will produce the best AMF estimates, but only if conducted properly. Unfortunately, many current studies reflect changes in crash experience resulting from improvements at sites that had experienced unusually high accident rates in the before-treatment period. The selection bias inherent in this approach often results in significantly exaggerated AMF estimates due to the phenomenon of regression to the mean. The following methodological problems are also often found:
  - ○ Failure to properly separate out the safety effects of other changes (e.g., traffic volumes, the impacts of other treatments implemented at the same time, crash reporting differences between jurisdictions or across time, underlying crash trends across time).
  - ○ Sample sizes that are too small. Large numbers of sites with the same combination of applied countermeasures are needed for a valid analysis. For some treatments and the subsequent type of crash reduction expected, hundreds or thousands of locations may be necessary along with many years of crash data (e.g., pedestrian treatments and crashes are a good example of this problem).
  - ○ Use of comparison groups that are unsuitable for a variety of reasons.
  - ○ Incorrect interpretation of the accuracy of estimates or presenting results without statements of accuracy.
- **Variability.** The value of an AMF may depend on a variety of factors such as traffic volumes, crash experience, and site characteristics. Thus, research that results in a single AMF value may be of limited applicability. Accident modification functions rather than factors may be more appropriate.
- **Crash Migration and Spillover Effects.** After countermeasures have been implemented in a particular location, crashes may migrate to adjacent locations. For example, the conversion of a two-way stop control to a multiway stop control at an intersection may lead to an increase in crashes due to driver confusion at surrounding intersections that continue to be two-way stop controlled. Likewise, the prohibition of left turns at an intersection may lead to an increase in left-turn crashes at upstream and downstream intersections. Existing AMFs rarely account for this phenomenon. For AMFs to be useful, they have to account for these effects or at a minimum recognize their existence.
- **Lack of Information on Effectiveness.** AMFs have not been developed for many ITS improvements or other operational strategies. For example, on many freeways, safety service patrols have become more common as a way of reducing the impact of incidents and reducing secondary crashes. However, no AMFs exist for this countermeasure. Other ITS countermeasures of high interest for which no reliable AMFs exist include pedestrian safety treatments (e.g., in-pavement lighting and countdown signals) and dynamic or changeable message signs (including those related to variable speed limits).

- **Combinations of Treatments.** Most AMFs are designed for individual treatments. However, multiple treatments are typically made when a facility is being rebuilt. Although states use different formulas for combining individual AMFs when considering multiple treatments, there is very little sound research on the multitude of actual combinations of treatments currently in use. Thus, it is unknown whether current predictions based on combining individual AMFs accurately capture the true combined effect.
- **Publication/Citation Issues.** A less-cited issue that is prevalent in much of the research is related to the quality of the material that is available and often used in the development of AMFs. Specific problems include these issues:
    - Publication bias (i.e., the tendency to only publish studies that produced favorable results for the treatment being evaluated).
    - Selective citing of results (i.e., the tendency to ignore negative aspects of results such as declining effects over time or unintended consequences that would lead to increases in some crash types). In some cases, a sponsoring organization may not want negative results published if they invested significant funds in a countermeasure program.

In summary, although several AMFs already exist, the issues just described affect the quality of those factors now being used in many states and local jurisdictions and impede their more extensive use. The objective of this ongoing NCHRP project is to improve the quality of existing AMFs and to develop additional AMFs (or perhaps functions) where there are currently voids. The first phase of this research study included a critical review of the literature to document the best available AMFs and a survey of state DOTs to determine the applicability of existing AMFs and priorities for new or improved AMFs. Included in this digest are (1) an AMF Knowledge Matrix that provides a status report on the quality of AMFs for a large number of treatments, (2) summaries of the AMFs that are deemed to be credible at this time, and (3) a discussion of other ongoing research efforts also aimed at improving AMFs.

AMF KNOWLEDGE MATRIX

To determine the knowledge gaps in AMF quality, the initial tasks in the project were (1) to document the state of the practice for the development, application, and validity of existing AMFs and (2) to determine user priorities for improved AMFs. An extensive critical review of the literature and a survey of state DOTs were conducted to ascertain this information for 100 treatments, including both traditional and ITS countermeasures. Table 1 presents the results and divides the treatments into three categories: intersections, roadway segments, and miscellaneous. (The integration of the ITS treatments into the three categories differs from the presentation in the project interim report. [*4*]) The research team also reviewed the literature pertaining to combinations of treatments (e.g., installation of a left-turn signal phase in conjunction with a left-turn lane). No credible AMFs were found with respect to any of the combinations reviewed and, therefore, are not included in the matrix. The following information is provided for each treatment in the matrix and is described in subsequent sections:

- User priority level.
- Level of predictive certainty.
- Ongoing/future work.

User Priority Level

As part of the state DOT survey, respondents were asked to rate the importance of having an AMF for each of the 100 intersection, roadway segment, and miscellaneous treatments. Each respondent provided a rating of high, medium, or low for each treatment. The results were used to establish an overall level of importance for each treatment. The rows that are shaded within the matrix indicate the top 25 treatments as rated by the state DOT respondents. The rank-order of these top 25 treatments is shown in the column labeled "User Priority Level." Also shown in this column, with an asterisk, are the eight treatments that were later given priority by the NCHRP project panel.

Level of Predictive Certainty

A level of predictive certainty (LOPC) was assigned to each AMF on the basis of the critical reviews conducted. This rating indicates the confidence level one should have in the AMF for that treatment. The critical factor in determining the LOPC was the rigor of the methodology used in the study in which the AMF was developed. The qualitative

(text continued on page 8)

TABLE 1 AMF Knowledge Matrix

Intersection Treatments

Treatment	User Priority Level	Level of Predictive Certainty					Ongoing/ Future Work
		High	Medium-High	Medium-Low	Low	Non-Existent	
Install a roundabout	19	✓ *(5)*					✓*(6)*
Reduce or eliminate intersection skew				✓ *(7)*			
Correct sight distance				✓ *(7)*			✓ *(8, 9)*
Install offset T's						✓	
Install turn lane or bypass lane at T-intersection				✓ *(10, 11)*			
Add exclusive left-turn lane	1	✓ *(12)*					✓ *(8, 9)*
Install double left-turn lane (change from single)						✓	
Create positive offset for opposing left-turn lanes						✓	✓ *(13)*
Add exclusive right-turn lane	4	✓ *(12)*					✓ *(8, 9)*
Add channelization for right-turns	11					✓	✓ *(14, 15)*[1]
Install median acceleration lane						✓	
Add raised/painted median islands				✓ *(12, 16)*			✓ *(17)*
Install a traffic signal	2*	✓ *(18)*[2]					
Remove a traffic signal	*	✓ *(19)*[3]					✓[4]
Add a left-turn phase (protected or protected/ permissive)	8			✓ *(12, 20)*			✓
Modify signal change interval			✓ *(22)*				
Add all-red phase						✓	
Change cycle length						✓	
Change from incandescent to LED signals						✓	
Add signal heads				✓ *(23)*			
Increase signal head size				✓ *(24)*			
Add backplates						✓	
Install red-light hold systems							✓ *(28)*[5]
Install dynamic advance-warning flashers "Red Signal Ahead"	17*				✓ *(29)*		
Install overhead flashing beacon						✓	
Convert to all-way stop			✓ *(30)*				
Remove all-way stop						✓	

Convert stop-control to yield-control			✓ *(31)*				
Install red-light cameras		✓ *(25,26)*					✓ *(27)*
Prohibit left turns						✓	
Install rumble strips on approach to intersection						✓	✓ *(32)*
Install intersection lighting	13				✓ *(33, 34*, 35)		✓ *(36)*
Close driveways near intersections	22					✓	
Install marked crosswalk				✓ *(37)*[6]			✓ *(17)*
Add pedestrian signals or pedestrian phase						✓ *(38, 39)*	✓ *(15, 17)*
Install curb extensions (bulbouts)						✓	✓ *(17)*
Install raised crosswalks						✓	
Install raised/tabled intersection						✓	
Reduce turn radius (shorten pedestrian crossing)						✓	
Remove parking near intersection						✓ *(40)*	
Roadway Segment Treatments							
Add a travel lane	8				✓ *(41)*		✓ *(8, 9)*
Convert two-lane road to multilane road							
Reduce number of lanes (road diet)				✓ *(21, 42)*[7]			
Narrow lane widths to add lanes			✓ *(43)*[8]				✓ *(8, 9)*
Narrow urban lanes to install turn lane						✓	
Add passing lanes (two-lane roads)			✓ *(7)*				✓ *(44)*
Add two-way left-turn lane (TWLTL)			✓ *(7)*[9]				
Replace a TWLTL with median/left-turn bays						✓	
Widen median					✓ *(83, 84)*		✓[10]
Install raised median	20					✓	✓ *(8, 9, 45)*
Increase lane width	21		✓ *(7, 70)*[11]				✓ *(8, 9)*
Change shoulder width and/or type	15		✓ *(7)*[9]				✓ *(8, 9)*
Flatten horizontal curve	12		✓ *(7, 46)*[12]				✓ *(8, 9)*
Improve curve superelevation	18		✓ *(7)*[10]				
Reduce grade					✓*(7)*		
Flatten vertical curve						✓	✓ *(8, 9)*
Add static curve warning signs and/or pavement markings						✓	✓ *(49)*
Add dynamic curve warning sign						✓	
Add shoulder rumble strips	5		✓ *(47)*[13]				✓ *(49, 50)*

(continued on next page)

TABLE 1 (Continued)

Roadway Segment Treatments

Treatment	User Priority Level	Level of Predictive Certainty					Ongoing/ Future Work
		High	Medium-High	Medium-Low	Low	Non-Existent	
Add edgeline rumble strips	14					✓[14]	✓ *(50)*
Add centerline rumble strips (two-lane roads)	10		✓ *(51)*				✓ *(49, 50)*
Remove roadside obstacle	3			✓ *(7)*			✓ *(52, 53)*
Flatten sideslope	22				✓ *(54)*		✓ *(52)*
Install/upgrade guardrail	22*		✓ *(55)*				
Install median barriers	6			✓ *(55)*			✓ *(56)*[15]
Relocate utility poles				✓ *(57)*			
Use shoulder on freeways/expressways for bus lane						✓	
Remove parking						✓	
Eliminate left-turns at driveways	16					✓	
Add delineation						✓	✓ *(58)*
Install roadway segment lighting	23*			✓ *(59)*			
Use dynamic message sign						✓	
Use variable speed limit							✓ *(60)*
Use automated speed enforcement	*					✓	
Install reversible roadways/lane control						✓	
Reduce speed limit				✓ *(55)*			✓ *(61, 62, 63)*
Use differential speed limit						✓	✓ *(64)*
Add sidewalk/walkway	*					✓	
Stripe bicycle lane						✓	
Add midblock pedestrian signal						✓	
Install raised crosswalks (non-intersection)						✓	
Install mid-block pedestrian crossing	*					✓	✓ *(17)*
Miscellaneous Treatments							
Lengthen acceleration lane						✓	
Consolidate driveways				✓ *(7)*[16]			
Add traffic calming						✓	

Provide signal coordination	7				✓ *(65)*	
Increase pavement friction				✓ *(66)*		✓[17]
Provide pedestrian refuge			✓ *(67, 68)*			✓ *(17)*
Install raised medians at crosswalk		✓*(37)*				
Install pedestrian countdown signals						✓ *(17)*
Install crosswalk in-pavement lighting						✓ *(17, 69)*
Install automatic pedestrian detectors						✓ *(17)*
Fog/wind/weather detection and warning systems					✓	
Install ramp metering					✓	
Use safety service patrols					✓	
Implement 511/traveler information					✓	
Implement integrated public safety/transportation communications					✓	
Use drone radars					✓	
Install truck rollover warning system					✓	
Install truck height warning					✓	

Notes:
Shaded rows indicate the top 25 treatments as rated by the state DOT respondents.
Asterisks indicate the eight treatments given priority by the NCHRP Project 17-25 panel.
Numbers in parentheses are the references for the best available AMF(s) or the ongoing/planned research effort(s).

[1] NCHRP Project 3-72 originally included channelized right-turn lanes in the study scope. The panel decided after the interim report to pursue lane widths and right-turn deceleration lanes, but not channelized right-turn lanes because of budgetary constraints.
[2] AMF was developed from urban intersection data set; no AMF exists for rural intersections.
[3] AMF is for one-way streets in an urban environment.
[4] A new empirical Bayes before–after study is being conducted as part of NCHRP Project 17-25.
[5] Yellow-light hold study
[6] For unsignalized intersections only; no AMF for signalized intersections.
[7] Recently, two studies conducted using different methodologies have arrived at different conclusions regarding the magnitude of the safety effect. A reanalysis effort is being conducted as part of NCHRP Project 17-25 to explain why these differences exist and derive a better estimate of the safety effect.
[8] Freeways only, no AMFs for other road types.
[9] Information available for two-lane roads only.
[10] A reanalysis effort of the data from "Association of Median Width and Highway Accident Rates" (84) is being considered within NCHRP Project 17-25.
[11] AMFs available for rural two-lane and multilane roads; no AMF available for urban/suburban arterials.
[12] AMF available for rural two-lane roads; no AMF available for rural multilane or urban/suburban arterials.
[13] AMF available for freeways only; no AMF available for other road classes.
[14] There has been some work on profiled pavement markings that have some similarities to edgeline rumble strips. (71)
[15] The research team is aware of a TRB paper under review which should increase the knowledge level significantly.
[16] AMF available for rural two-lane roads only; no AMF available for rural multilane roads or urban/suburban arterials.
[17] A new empirical Bayes before–after study is being conducted as part of NCHRP Project 17-25.

definitions used in establishing the LOPC were as follows:

- **High.** The AMF was developed in a rigorous before–after study that incorporated the current *best* study design and statistical analysis methods. At this time, the empirical Bayes (EB) methodology described by Hauer represents the best available approach. (*85*)
- **Medium-High.** The AMF was developed in a before–after study that incorporated sound (but not the current state-of-the-art) statistical methods and/or may have been reviewed and vetted by an expert panel of researchers. This level may include AMFs that were produced by an expert research panel from the combination of findings from different (less controlled) before–after and cross-sectional studies. Because the expert panel's judgment concerning the certainty level of the AMF is reflected in the LOPC, some of these AMFs did not always merit a medium-high rating. This level also includes AMFs that were developed in a rigorous meta-analysis by a recognized meta-analysis expert. (Meta-analysis is the combination of the results of various studies using techniques that allow the expert to overcome some of the shortcomings of the original research.) Not all meta-analysis results warranted a medium-high LOPC (see discussion below).
- **Medium-Low.** The AMF was developed from a cross-sectional analysis (controlling for other factors statistically) or from less-than-rigorous before–after studies, but are still judged to be of value. An example would be a before–after study in which regression-to-the-mean was not viewed as a major potential bias because high-crash locations were not studied.
- **Low.** The AMF was developed in a simple before–after study without control for biases or from cross-sectional studies in which modeling techniques were questionable.
- **Nonexistent.** No studies were found that included AMFs.

It is also important to understand that within each level of predictive certainty, there can be a wide range of accuracy or confidence. For example, some AMFs have been developed for which the expert panel was able to utilize the results of at least one key study that was considered critical and very well done. However, in other cases, the expert panel may not have been able to identify any critical studies and had to rely on their collective knowledge, experience, and judgment. Obviously, the AMFs developed without results from any critically valid studies have a lower level of predictive certainty than the ones developed with at least one such study.

As noted previously, AMFs produced from a rigorous meta-analysis may be considered to have a LOPC of medium-high. Many of the meta-analyses that have been conducted include studies from multiple countries as well as studies that are several decades old. There are enough differences among the application of treatments in North America, Europe, and Australia to warrant caution in combining the results of these studies. Likewise, there have been enough changes in drivers and vehicles to warrant caution in the inclusion of studies that are more than 25 years old. Thus, the following criteria were used in assessing whether an AMF from a meta-analysis was deemed to be of medium-high quality:

- A minimum of three North American studies (post-1980) had to be included in the analysis, and the percentage of North American studies had to be at least 20%. There was an exception to this threshold if the treatment was believed to produce different operational characteristics in the United States compared to other countries. For example, shoulders in many European countries are designed and used for passing maneuvers, which is completely different from their function in the United States. In those cases, the percentage of studies from the United States needed to be substantially greater than 20%.
- The treatment in the meta-analysis had to be clearly defined to ensure the results were applicable to the treatment of interest, including specifics on applicability to various classes of roadways. For example, if the treatment of interest was speed-limit reduction on two-lane rural roads, then a meta-analysis in which the only U.S. studies were related to Interstates was not considered.
- The results had to be statistically significant (i.e., the 95% confidence interval could not include 0). The intent here was to avoid including any AMF for which the sign may change (i.e., the lower end of the confidence interval results in a crash decrease while the upper end results in a crash increase).

Ongoing/Future Work

The existence of ongoing or planned research that might improve the AMF was determined by a review of several research-in-progress databases, discussions with other highway safety researchers, and conversations with research sponsors such as FHWA and the Insurance Institute for Highway Safety (IIHS). The studies listed are those that have the greatest potential for producing AMFs for specific treatments. Results from these studies should be reviewed in the future to determine if the level of predictive certainty for an AMF has been improved.

CREDIBLE ACCIDENT MODIFICATION FACTORS

The initial list of countermeasures included in the surveys sent to the state DOTs combined with the countermeasures added by the survey respondents exceeded 100 specific treatments or programs. A literature search was conducted for each of these treatments to find the best AMF for each one. Out of the 100 treatments included in Table 1, 20 are considered to be credible and have a level of predictive certainty of either high or medium-high. These 20 treatments are shown in Table 2. For each of these treatments, a summary of the research study from which the AMF was developed is presented in Table 3. Each summary includes the AMF(s), the level of predictive certainty, the study methodology, a description of the sites used in the study, and supplemental comments and footnotes to describe the study results and applicability.

RELATED RESEARCH

As noted previously, this research project is being undertaken to document the state of the practice in AMF development, determine the next set of AMFs that need to be developed, and then develop as many of those AMFs as the project budget will allow. Since this project began, additional research efforts have been started that are directly related to the objectives

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TABLE 2 Treatments with AMFs that have a Level of Predictive Certainty of High or Medium-High

Treatment	Level of Predictive Certainty
Intersection Treatments	
Install a roundabout	High
Add exclusive left-turn lane	High
Add exclusive right-turn lane	High
Install a traffic signal	High
Remove a traffic signal	High
Modify signal change interval	Medium-High
Convert to all-way stop control	Medium-High
Convert stop-control to yield-control	Medium-High
Install red-light cameras	High
Roadway Segment Treatments	
Narrow lane widths to add lanes	Medium-High
Add passing lanes (two-lane roads)	Medium-High
Add two-way left-turn lane (TWLTL)	Medium-High
Increase lane width	Medium-High
Change shoulder width and/or type	Medium-High
Flatten horizontal curve	Medium-High
Improve curve superelevation	Medium-High
Add shoulder rumble strips	Medium-High
Add centerline rumble strips	Medium-High
Install/upgrade guardrail	Medium-High
Miscellaneous Treatments	
Install raised medians at crosswalks	Medium-High

TABLE 3 Summaries of Research Studies That Developed AMFs

TREATMENT: Install Roundabout — **AMF Level of Predictive Certainty: High**

METHODOLOGY: Empirical Bayes Before-After

REFERENCE: Persaud, Retting, Garder, and Lord - 2001 (*5*)

STUDY SITES:

- Treatment sites included 23 intersections that were converted between 1992 and 1997 to roundabouts (19 were previously controlled by stop signs, and 4 were controlled by signals) from the states of Colorado, Florida, Kansas, Maine, Maryland, and Vermont.
- The roundabouts were in rural, suburban, and urban environments.
- Single-lane and multilane roundabouts were included; traffic volumes at the treatment sites in the after condition ranged from 4,600 vpd to 31,500 vpd.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Lane - Environment	No. of Improved Sites	AMF
Single Lane - Urban (prior control - stop sign)	8	
All Crashes		0.28
Injury Crashes		0.12
Single Lane - Rural (prior control - stop sign)	5	
All Crashes		0.42
Injury Crashes		0.18
Multilane - Urban (prior control - stop sign)	6	
All Crashes		0.95
Injury Crashes		—
Single/Multilane - Urban (prior control - signal)	4	
All Crashes		0.65
Injury Crashes		0.26
All Conversions	23	
All Crashes		0.60
Injury Crashes		0.20

COMMENTS:

- The authors were not able to determine the safety effects for pedestrians and bicyclists, but refer the reader to the positive results that have been found in Scandinavian evaluations.[A]
- No evidence was found to indicate roundabouts result in more difficulties for older drivers.
- Results from NCHRP Project 3-65, Applying Roundabouts in the United States, include a more extensive analysis of crashes at roundabouts in the United States but were not available for release at the time of this publication. The AMFs from that effort should be used in place of those presented here when they become available.

FOOTNOTES:

[A] Ulf and Jörgen - 1999 (*72*)

TABLE 3 (Continued)

TREATMENT: Add Exclusive Left-Turn Lane

AMF Level of Predictive Certainty: High

METHODOLOGY: Empirical Bayes Before-After[A]

REFERENCE: Harwood, Bauer, Potts, Torbic, Richard, Kohlman-Rabbani, Hauer, & Elefteriadou - 2002 (*12*)

STUDY SITES:

- Included rural and urban sites located in eight states – Illinois, Iowa, Louisiana, Minnesota, Nebraska, North Carolina, Oregon, and Virginia
- 199 treatment sites where a left-turn lane (LTL) was added, as well as 300 similar intersections that were not improved during the study period and used for comparison and reference sites.
- All improvements were made during the years 1989 through 1998. Mean duration of before and after periods were 6.7 years and 3.9 years, respectively.

COMMENTS:

- Stop-controlled locations had stop signs on the minor road approaches.
- Mean total entering ADT for rural stop-controlled, rural signalized, urban stop-controlled, and urban signalized improved sites were 9,700 vpd, 17,800 vpd, 15,500 vpd, and 26,800 vpd, respectively.
- All tests of statistical significance in this report were performed at the 5% significance level (95% confidence level). Only statistically significant results are shown.
- AMF (both approaches) = AMF (one approach) x AMF (one approach)

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

		AMF	
Total Intersection Accidents (all severity levels, all accident types)	**No. of Improved Sites**	**One Approach**	**Both Approaches**
Rural Stop-Controlled Intersection (4-legs)	25	0.72	0.52
Rural Stop-Controlled Intersection (3-legs)	36	0.56	—
Rural Signalized Intersection (4-legs)		0.82[D]	0.67[D]
Rural Signalized Intersection (3-legs)		0.85[D]	—
Urban Stop-Controlled Intersection (4-legs)	9	0.73[C]	0.53[C]
Urban Stop-Controlled Intersection (3-legs)	8	0.67	—
Urban Signalized Intersection (4-legs)	39	0.90	0.81
Urban Signalized Intersection (3-legs)		0.93[D]	—
Fatal and Injury Intersection Accidents (all accident types)			
Rural Stop-Controlled Intersection (4-legs)	24	0.65	0.42
Rural Stop-Controlled Intersection (3-legs)	11	0.45[C]	—
Urban Stop-Controlled Intersection (4-legs)	9	0.71[C]	0.50[C]
Urban Signalized Intersection (4-legs)	39	0.91	0.83
Project-Related Accidents (all severity levels)[B]			
Rural Stop-Controlled Intersection (4-legs)	23	0.63	0.40
Rural Stop-Controlled Intersection (3-legs)	35	0.38[C]	—
Urban Stop-Controlled Intersection (4-legs)	7	0.74	0.55
Urban Signalized Intersection (4-legs)	35	0.87[E]	0.76[E]

FOOTNOTES:

[A] The study applied two alternative evaluation approaches (B/A with yoked comparisons and B/A with a comparison group) and recommended that the EB evaluation results be used if statistically significant. If not, it was recommended that statistically significant comparison group results be used, followed by statistically significant yoked comparison results. The authors note that results from either comparison method may be "overly optimistic."

[B] Project-Related Accidents - All accidents involving one or more vehicles that had made, were making, or intended to make the specific left-turn maneuver(s) for which the left-turn lane(s) being evaluated were installed.

[C] AMF based on comparison group evaluation.

[D] Recommended AMF based on analysis-driven expert panel results from Harwood, Council, Hauer, Hughes, and Vogt - 2000 (7).

[E] AMF based on yoked comparison evaluation.

TABLE 3 (Continued)

TREATMENT: Add Exclusive Right-Turn Lane

AMF Level of Predictive Certainty: High

METHODOLOGY: Empirical Bayes Before-After[A]

REFERENCE: Harwood, Bauer, Potts, Torbic, Richard, Kohlman-Rabbani, Hauer, & Elefteriadou - 2002 (*12*)

STUDY SITES:

- Included rural and urban sites located in eight states – Illinois, Iowa, Louisiana, Minnesota, Nebraska, North Carolina, Oregon, and Virginia.
- 108 treatment sites where a right-turn lane (RTL) was added, as well as 300 similar intersections that were not improved during the study period and used for comparison and reference sites.
- All improvements were made during the years 1989 through 1998. Mean duration of before and after periods were 6.7 years and 3.9 years, respectively.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Total Intersection Accidents (all severity levels, all accident types)	No. of Improved Sites	AMF One Approach	AMF Both Approaches
Rural Stop-Controlled Intersection (4-legs)	28	0.86	0.74
Urban Signalized Intersection (4-legs)	18	0.96	0.92

Authors recommend that the AMFs for rural stop-controlled intersections be applied to urban stop-controlled intersections, and that the AMFs for urban signalized intersections be applied to rural signalized intersections.

Fatal and Injury Intersection Accidents (all accident types)			
Rural Stop-Controlled Intersection (4-legs)	29	0.77[B]	0.59[B]
Urban Signalized Intersection (4-legs)	17	0.91	0.83

COMMENTS:

- Stop-controlled locations had stop signs on the minor road approaches.
- Mean total entering ADT for rural stop-controlled, rural signalized, urban stop-controlled, and urban signalized improved sites were 9,700 vpd, 17,800 vpd, 15,500 vpd, and 26,800 vpd, respectively.
- All tests of statistical significance in this report were performed at the 5% significance level (95% confidence level). Only statistically significant results are shown.
- AMF (both approaches) = AMF (one approach) x AMF (one approach).
- There were no significant results, and thus no AMFs produced, for project-related accidents, which were defined as all accidents involving one or more vehicles that had made, were making, or intended to make the specific right-turn maneuver(s) for which the right-turn lane(s) being evaluated were installed.
- There were no significant results, and thus no AMFs produced, for three-leg intersections (urban or rural, signalized or stop-controlled).

FOOTNOTES:

[A] The study applied two alternative evaluation approaches (B/A with yoked comparisons and B/A with a comparison group) and recommended that the EB evaluation results be used if statistically significant. If not, it was recommended that statistically significant comparison group results be used, followed by statistically signficant yoked comparison results. The authors note that results from either comparison method may be "overly optimistic."

[B] AMF based on comparison group evaluation.

TABLE 3 (Continued)

TREATMENT: Install a Traffic Signal **AMF Level of Predictive Certainty: High**

METHODOLOGY: Empirical Bayes Before-After

REFERENCE: McGee, Taori, & Persaud - 2003 (*18*)

STUDY SITES:

- Included sites located in five states – California, Florida, Maryland, Virginia, Wisconsin – and Toronto.
- Three-leg intersection data included 22 treatment sites (converted from stop to signal control) and 118 reference group sites (99 stop-control and 19 signalized intersections).
- Four-leg intersection data included 100 treatment sites (converted from stop to signal control) and 295 reference group sites (96 stop-control and 199 signalized intersections).
- An additional reference group was developed from the HSIS California urban data and included 1,418 stop-control and 799 signalized intersections.[A]
- Minor street traffic volumes for the treatment sites ranged from 911 to 3,952 vpd; major street volumes ranged from 11,739 to 24,584 vpd.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Intersections	No. of Improved Sites	AMF
3-Leg Intersections	22	
All Crashes		0.86
Right-Angle Crashes		0.66
Rear-End Crashes		1.50
4-Leg Intersections	100	
All Crashes		0.77
Right-Angle Crashes		0.33
Rear-End Crashes		1.38

COMMENTS:

- AMFs are for crashes involving fatalities and injuries only; property-damage-only (PDOs) were excluded from the analysis.
- AMFs were developed using data from urban intersections. The authors do not recommend that these results be applied to rural intersections.
- The study notes that the results could be adapted (i.e., reversed) to assess the safety of removing a traffic signal. The authors of the study do not have as much confidence in using the results in this way.

FOOTNOTES:

[A] The Highway Safety Information System (HSIS) is a multistate safety database that contains accident, roadway inventory, and traffic volume data for a select group of states and is sponsored by the FHWA.

TABLE 3 (Continued)

TREATMENT: Remove a Traffic Signal — **AMF Level of Predictive Certainty: High**

METHODOLOGY: Empirical Bayes Before-After

REFERENCE: Persaud, Hauer, Retting, Vallurupalli, and Mucsi - 1997 (*19*)

STUDY SITES:
- 199 treatment sites and 71 comparison sites in Philadelphia
- Treatment sites were unwarranted signals and mostly changed from signal control to all-way stop control between 1979 and 1988.
- All intersections were at one-way streets in non-arterial streets in an urban environment.
- Crash data were acquired for the years 1978 through 1992.
- Traffic volumes were often estimated from upstream and downstream AADTs due to the sparse volume data available.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Type of Collision (all severities)	No. of Improved Sites	AMF
All Crashes	199	0.76
Right-Angle and Turning Crashes		0.76
Rear-End Crashes		0.71
Pedestrian Crashes		0.82
Fixed-Object Crashes		0.69[A]
Light Condition (all severities)	199	
Day		0.78
Night		0.70
Injury Severity (all collision types)	199	
Severe		0.47
Minor		0.76

COMMENTS:
- The authors note the inability to account for year-to-year variation in traffic volumes, but nonetheless express confidence in the results.
- It is important to note that this study was for one-way streets in an urban environment. There are no comparable studies for two-way streets or for intersections in rural environments.

FOOTNOTES:

[A] The AMF for fixed-object crashes was based on the classical estimate (i.e., expected number of crashes in the after period is based on count of crashes in before period as opposed to the EB estimate of before period crashes).

TABLE 3 (Continued)

TREATMENT: Modify Signal Change Interval — **AMF Level of Predictive Certainty: Medium-High**

METHODOLOGY: Before-After with Control Group

REFERENCE: Retting, Chapline, and Williams - 2002 (*22*)

STUDY SITES:

- Included crash data from 40 treatment intersections and 56 control intersections in Nassau County and Suffolk County, New York.
- All intersections were standard 4-leg junctions.
- The treatment sites were randomly selected for the signal timing change, eliminating the site-selection bias.
- Six years of crash data were used in the analysis (October 1991 - October 1997), with 3 years each in the before and after periods.
- Analysis included only "reportable" crashes, which require an injury or a minimum of $1000 in property damage in New York.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Accident Type (all severities)	No. of Treated Sites	AMF
All Crashes	40	0.92
Multiple-Vehicle Crashes		0.95[A]
Rear-End Crashes		1.12[A]
Right-Angle Crashes		0.96[A]
Pedestrian/Bicyclist Crashes		0.63
Accident Type (injury crashes only)		
All Crashes	40	0.88
Multiple-Vehicle Crashes		0.91
Rear-End Crashes		1.08[A]
Right-Angle Crashes		1.06[A]
Pedestrian/Bicyclist Crashes		0.63

COMMENTS:

- AMF is based on the odds ratio.
- Both the yellow change interval and the red clearance interval were adjusted at the treatment sites to conform to the Institute of Transportation Engineers *Proposed Recommended Practice for Determining Vehicle Change Intervals* (1985). In some cases, this meant an increase in the interval, while in others, the interval was decreased.
- Yellow change intervals at the treatment sites ranged from 3 to 4 seconds in the before period and 2.6 to 5.4 seconds in the after period. Red clearance intervals ranged from 2 to 3 seconds in the before period and 1.1 to 6.5 seconds in the after period.
- Authors acknowledge that the results do not account for variables such as geometry, traffic volume and other signal parameters such as cycle length and number of phases.

FOOTNOTES:

[A] Results were not significant at a 90% confidence level (P > 0.10).

TABLE 3 (Continued)

TREATMENT: Convert to All-Way Stop Control — **AMF Level of Predictive Certainty: Medium-High**

METHODOLOGY: Before-After Analysis w/Likelihood Functions

REFERENCE: Lovell and Hauer - 1986 (*30*)

STUDY SITES:

- Included data from three urban regions (San Francisco, Philadelphia, and Toronto) and one rural region (Michigan).
- The number of treatment sites in which an intersection was converted to all-way stop control in each region is as follows:
  - San Francisco: 49 sites (from two-way stop control)
  - Philadelphia: 222 sites (one-way streets; prior traffic control not stated)
  - Michigan: 10 sites (from two-way stop control)
  - Toronto: 79 sites (from two-way stop control)

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Type of Collision (all severities)	No. of Improved Sites	AMF
All Crashes	360[A]	0.53
Right-Angle Crashes		0.28
Rear-End Crashes		0.87
Left-Turn Crashes		0.80
Pedestrian Crashes		0.61
Crash Severity (all collision types)		
All Crashes	360[A]	0.53
Injury Crashes		0.29

COMMENTS:

- Analysis included the reanalysis of data sets from San Francisco, Philadelphia, and Michigan to correct for regression-to-the-mean bias and a new analysis of data from Toronto. Likelihood functions were used to combine the results from the various cities.
- The AMF for All Crashes (all collision types and all severities) was vetted by an expert panel and included as the recommended AMF for this treatment within FHWA's Interactive Highway Safety Design Model — IHSDM (Harwood, Council, Hauer, Hughes, and Vogt - 2000 [*7*]).

FOOTNOTES:

[A] Includes all sites from the four regions.

TABLE 3 (Continued)

TREATMENT: Convert Stop-Control to Yield-Control — **AMF Level of Predictive Certainty: Medium-High**

METHODOLOGY: Before-After with Control Group

REFERENCE: McGee and Blankenship - 1989 (*31*)

STUDY SITES:

- Treatment sites were converted from stop-control to yield control; comparison sites were stop-control intersections. The number of each type in each city was as follows:
  - Saginaw, MI (53 treatment sites; 42 control sites)
  - Pueblo, CO (69 treatment sites; 15 control sites)
  - Rapid City, SD (19 treatment sites, 8 control sites).
- The conversions took place between 1982 and 1987.
- The number of years of crash data included in each before and after period ranged from 1 to 2 years, depending on the city and year of conversion.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Total Accidents (all severities)	No. of Treated Sites	AMF
All Crashes	141[A]	2.37

COMMENTS:

- AMF computed from the cross product ratio (odds ratio) of the before and after crash frequencies at the treatment and control sites.
- No additional AMFs were provided. The authors do indicate that the proportion of fatal or injury accidents does not appear to increase with the conversion, nor is their a change in the distribution of collision types.
- The authors note the probability of an increase in crashes is greater with higher volumes, either major street volume, minor street volume, and/or the combination of the two volumes.

FOOTNOTES:

[A] Includes all sites from the three cities.

TABLE 3 (Continued)

TREATMENT: Install Red-Light Cameras | **AMF Level of Predictive Certainty: High**

METHODOLOGY: Empirical Bayes Before-After

REFERENCES: Persaud, Council, Lyon, Eccles, and Griffith - 2005 (*25*) and Council, Persaud, Lyon, Eccles, Griffith, Zaloshnja, and Miller - 2005 (*26*)

STUDY SITES:

- Included data from seven jurisdictions across the U.S. for 132 treatment intersections where red-light cameras had been installed.
- The reference group included similar signalized intersections in each jurisdiction that were not equipped with red-light cameras, which were used to develop SPFs and to investigate possible spillover effects.
- A second reference group of unsignalized intersections was used to account for time trends and to calibrate the SPFs.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Crash Severities	No. of Treated Sites	AMF
All Crash Severities	132	
Rear-End Crashes		1.15
Right-Angle Crashes		0.75
Injury Crashes Only	132	
Rear-End Crashes		1.24
Right-Angle Crashes		0.84

ECONOMIC ANALYSIS

Crash Severities	Percentage Change in Crash Cost
Total All-Severity Crashes	−8.9
Rear-End Crashes	8.5
Right-Angle Crashes	−27.7
Injury Crashes Only	
Total Crashes	−13.8
Rear-End Crashes	2.4
Right-Angle Crashes	−28.9

COMMENTS:

- Economic analysis was conducted to determine if the increase in rear-end crashes negated the decrease in right-angle collisions. Results showed there was a net economic benefit that ranged from $39,000 to $50,000 per year per site where red-light camera systems were installed.
- The economic analysis may be used to develop AMFs for total crashes, which account for the differences in injury severity that occur with different collision types. The AMF for all crash severities would be 0.91, while the AMF for injury crashes only would be 0.86.

TABLE 3 (Continued)

TREATMENT: Narrow Lane Widths to Add Lanes

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Empirical Bayes Before-After

REFERENCE: Bauer, Harwood, Hughes, and Richard - 2004 (*43*)

STUDY SITES:

- All treatment and reference sites were located on four freeways in Los Angeles and San Diego Counties, California.
- The treatments included two project types: (1) from four to five lanes and (2) from five to six lanes. The first type included 79 sites and 36.4 miles, while the second included 45 sites and 12.5 miles. All conversions were made in 1993.
- Crash data were acquired from the FHWA HSIS and included 2 years of before data and 7 years of after data.[A]
- Traffic volumes at the treatment sites ranged from 77,000 vpd to 128,000 vpd.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Conversions	No. of Treated Sites	AMF
4-Lane to 5-Lane Conversions	79	
All Crashes		1.11
Fatal, Injury, and PDO-Towaway Crashes		1.10
Fatal and Injury Crashes		1.11
5-Lane to 6-Lane Conversions	45	
All Crashes		1.03*
Fatal, Injury, and PDO-Towaway Crashes		1.04*
Fatal and Injury Crashes		1.07*

* Results for the 5-lane to 6-lane conversions were not statistically significant.

COMMENTS:

- The treatment described here is the addition of a travel lane to an urban freeway by decreasing existing lane widths through restriping, converting all or part of the shoulder to a travel lane, or by using both in combination. In most cases, the shoulder conversion was done to add an HOV lane. **Results are not applicable to other roadway types.**
- Other EB analyses conducted found:
  - – Increase in sideswipe collisions at 4- to 5-lane conversions and a decrease in such collisions at 5- to 6-lane conversions.
  - – Increase in crashes adjacent to on- or off-ramps for both types of conversions. Increase in crashes away from ramps for 4- to 5-lane conversions, but a decrease in crashes away from ramps for 5- to 6-lane conversions.
- The authors also examined accident migration patterns upstream and downstream of the conversions. The findings suggest that the conversion projects may result in fewer crashes upstream and an increased number of crashes downstream, which may reflect the fact that the operational bottleneck has been shifted.

FOOTNOTES:

[A] The Highway Safety Information System (HSIS) is a multistate safety database that contains accident, roadway inventory, and traffic volume data for a select group of states and is sponsored by the FHWA.

TABLE 3 (Continued)

TREATMENT: Add Passing Lanes (Two-Lane Roads)

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCE: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*)

COMMENTS:

- Expert panel considered these AMFs to be the best estimates for the installation of passing lanes on rural two-lane roadways. **Results are not applicable to other roadway types.**
- Expert panel notes that these AMFs are based on the assumption that the passing lanes are operationally warranted, and the length is appropriate for conditions.
- The AMFs apply to total accidents within the passing-lane section of the roadway and do not include upstream or downstream accidents.
- The AMF for short four-lane sections does not apply to extended lengths of four-lane highways.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Type of Passing Lane	AMF[A]
One-way (single direction of travel)	0.75
Two-way (short four-lane sections)	0.65

FOOTNOTES:

[A] Estimates are based on work by Harwood and St. John - 1984 (73) and Nettleblad - 1979 (*74*).

TREATMENT: Add Two-Way Left-Turn Lane (TWLTL)

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCE: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*)

COMMENTS:

- Expert panel considered this AMF function to be the best estimate for the installation of a TWLTL without data on left-turn volumes within the TWLTL.
- Expert recommends a minimum driveway density of 5 driveways/mile for the AMF to be applied; the AMF for any lesser density would be equal to 1.0.
- Estimate function for driveway-related accidents is based on work by Hauer, which included a critical review of 14 studies conducted between 1964 and 1997.[A] The AMF function shown here is more conservative than the Hauer AMF.
- Most of the studies reviewed by Hauer analyzed TWLTLs in urban and suburban areas. Hauer noted that the safety effects on rural roads should be at least as large as those on urban and suburban roads. Thus, the AMF shown here is applicable to rural and urban two-lane and multilane roads.

ACCIDENT MODIFICATION FUNCTION

$$\mathrm{AMF} = 1 - 0.7 P_D P_{LT/D}$$

where:

P_D = driveway-related accidents as a proportion of total accidents

P_D estimated as:

$$\frac{0.0047\,DD + 0.0024\,DD^2}{1.199 + 0.0047\,DD + 0.0024\,DD^2}$$

where:

DD = driveway density (driveways per mile)

$P_{LT/D}$ = left-turn accident susceptible to correction by TWLTL as a proportion of driveway-related accidents

$P_{LT/D}$ = 0.5 (estimated by expert panel on the basis of work by Hauer)[A]

FOOTNOTES:

[A] Hauer - 2000 (*75*)

TABLE 3 (Continued)

TREATMENT: Increase Lane Width

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCES: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*) and Harwood, Rabbani, Richard, McGee, & Gittings - 2003 (*70*)

COMMENTS:

- The AMFs for ADTs greater than 2000 are largely based on work by Zegeer et al.; AMFs for ADTs less than 400 are based on work by Griffin and Mak. AMFs for ADTs between 400 and 2000 were based on expert panel judgment and an extensive critique of the literature by Hauer.[A]
- If lane widths differ for the two directions of travel, the AMF should be determined for each direction and then averaged to obtain an AMF for the roadway.
- The factors for rural multilane roads were developed by an expert panel. There is less confidence in the rural multilane AMF.
- **The AMFs developed do not apply to urban roadways.**

ACCIDENT MODIFICATION FUNCTION

Rural Two-Lane Roads

$$AMF = \left(AMF_{RA} - 1.0\right)P_{RA} + 1.0$$

where:

AMF = accident modification factor for total accidents

AMF_{RA} = accident modification factor for related accidents[B]

AMF_{RA} is calculated by dividing the AMF for the after-improvement condition by the AMF for the before condition - each can be selected from the following table:[C]

Lane Width	**Average Daily Traffic (ADT)** **≤ 400**	**400 to 2000**	**≥ 2000**
9 ft	1.05	$1.05+2.81\times10^{-4}$ (ADT-400)	1.50
10 ft	1.02	$1.02+1.75\times10^{-4}$ (ADT-400)	1.30
11 ft	1.01	$1.01+2.5\times10^{-4}$ (ADT-400)	1.05
12 ft	1.00	1.00	1.00

P_{RA} = proportion of total accidents constituted by related accidents

P_{RA} = 0.35 (estimated from distribution of accident types)

Rural Multilane Roads

$$AMF = f\left(AMF_{RA} - 1.0\right)P_{RA} + 1.0$$

where:

f = factor for roadway type

f = 0.75 for multilane undivided and 0.50 for divided

FOOTNOTES:

[A] Zegeer, Reinfurt, Hummer, Herf, and Hunter - 1988 (*76*); Griffin and Mak - 1987 (*77*); Hauer - 2000 (*78*).

[B] Related accidents include single-vehicle run-off-road, multiple-vehicle head-on, and opposing- and same-direction sideswipe accidents.

[C] Table developed in Harwood, Rabbani, Richard, McGee, and Gittings - 2003 (*70*).

TABLE 3 (Continued)

TREATMENT: Change Shoulder Width and/or Type

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCES: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*) and Harwood, Rabbani, Richard, McGee, & Gittings - 2003 (*70*)

COMMENTS:

- Shoulder width AMFs for ADTs greater than 2000 are largely based on work by Zegeer et al.; AMFs for ADTs less than 400 are based on low-volume roads work by Zegeer et al. AMFs for ADTs between 400 and 2000 were based on expert panel judgement and an extensive critique of the literature by Hauer.[A]
- Shoulder type AMFs are based on work by Miaou for differences in gravel and paved shoulders and Zegeer et al. for differences in turf and paved shoulders. Composite shoulders are 50% paved and 50% turf; the AMFs are averages for the two types.[A]
- If shoulder widths/types differ for the two directions of travel, the AMF should be determined for each direction and then averaged to obtain an AMF for the roadway.
- The AMFs developed do not apply to urban roadways.

ACCIDENT MODIFICATION FUNCTION

Rural Two-Lane Roads

$$AMF = \left(AMF_{WRA} AMF_{TRA} - 1.0\right) P_{RA} + 1.0$$

where:

AMF = accident modification factor for total accidents

AMF_{WRA} = accident modification factor for related accidents based on shoulder width[B]

AMF_{WRA} is calculated by dividing the AMF for the after-improvement condition by the AMF for the before condition - each can be selected from the following table:[C]

Shoulder Width	Average Daily Traffic (ADT)		
	≤ 400	400 to 2000	≥ 2000
0 ft	1.10	$1.1 + 2.5 \times 10^{-4}(ADT-400)$	1.50
2 ft	1.07	$1.07 + 1.43 \times 10^{-4}(ADT-400)$	1.30
4 ft	1.02	$1.02 + 8.125 \times 10^{-5}(ADT-400)$	1.15
6 ft	1.00	1.00	1.00
8 ft	0.98	$0.98 + 6.875 \times 10^{-5}(ADT-400)$	0.87

AMF_{TRA} = accident modification factor for related accidents based on shoulder type[B]

AMF_{TRA} is calculated by dividing the AMF for the after-improvement condition by the AMF for the before condition - each can be selected from the following table:

Shoulder Type	Shoulder Width (ft)							
	0	1	2	3	4	6	8	10
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11	1.14

P_{RA} = proportion of total accidents constituted by related accidents

P_{RA} = 0.35 (estimated from distribution of accident types)

FOOTNOTES:

[A] Zegeer, Reinfurt, Hummer, Herf, and Hunter - 1988 (*76*); Zegeer, Dean, and Mayes - 1981 (*79*); Miaou - 1996 (80); Hauer - 2000 (*81*).

[B] Related accidents include single-vehicle run-off-road and multiple-vehicle opposing- and same-direction sideswipe accidents.

[C] Table developed in Harwood, Rabbani, Richard, McGee, and Gittings - 2003 (*70*).

TABLE 3 (Continued)

TREATMENT: Flatten Horizontal Curve

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCE: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*)

COMMENTS:

- AMF applies to total accidents on the curved roadway segment.
- AMF was derived from the regression model developed by Zegeer et al.[A]
- **The AMF is applicable to rural two-lane roads only.**

ACCIDENT MODIFICATION FUNCTION

$$\mathrm{AMF} = \frac{1.55L_c + \dfrac{80.2}{R} - 0.012S}{1.55L_c}$$

where:

L_C = length of horizontal curve (miles); does not include spiral curve length

R = radius of curvature (ft)

S = 1 if spiral transition curve is present and 0 is no such transition exists

FOOTNOTES:

[A] Zegeer, Stewart, Council, Reinfurt, and Hamilton - 1992 (*82*)

TREATMENT: Improve Curve Superelevation

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Analysis-Driven Expert Panel

REFERENCE: Harwood, Council, Hauer, Hughes, & Vogt - 2000 (*7*)

COMMENTS:

- AMF applies to total accidents occurring on curved roadway segments.
- Expert panel noted there was no safety effect until the superelevation reached 0.01.
- AMF was derived from the results of Zegeer et al.[A]
- **The AMF is applicable to rural two-lane roads only.**

ACCIDENT MODIFICATION FUNCTION

Superelevation Deficiency (SD)	AMF
< 0.01	1.00
$0.01 < \mathrm{SD} < 0.02$	$1.00 + 6(\mathrm{SD} - 0.01)$
> 0.02	$1.06 + 3(\mathrm{SD} - 0.02)$

FOOTNOTES:

[A] Zegeer, Stewart, Council, Reinfurt, and Hamilton - 1992 (*82*)

TABLE 3 (Continued)

TREATMENT: Add Shoulder Rumble Strips — **AMF Level of Predictive Certainty: Medium-High**

METHODOLOGY: Before-After with Comparison Sites

REFERENCE: Griffith - 1999 (*47*)

STUDY SITES:
- Included 55 treatment sites and 55 matched comparison sites from rural and urban freeways in Illinois.
- The treatment sites covered 196 miles of rural freeway and 67 miles of urban freeway.
- The treatment sites were not selected on the basis of accident history; thus, there was no selection bias.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Freeways	No. of Improved Sites	IMF
All Freeways (Rural and Urban)	55	
All Single-Vehicle Run-Off-Road Crashes		0.82
Injury Single-Vehicle Run-Off-Road Crashes		0.87
Rural Freeways	29	
All Single-Vehicle Run-Off-Road Crashes		0.79
Injury Single-Vehicle Run-Off-Road Crashes		0.93

COMMENTS:
- Results for all freeways based on yoked comparison analysis; results for rural freeways based on comparison group method using 29 of the treatment sites. Results could not be developed for urban sites separately.
- An analysis of multivehicle accidents showed the rumble strips to have no effect on such accidents.
- **The AMF is not applicable to other road classes (two-lane or multilane).**

TABLE 3 (Continued)

TREATMENT: Add Centerline Rumble Strips — **AMF Level of Predictive Certainty: Medium-High**

METHODOLOGY: Empirical Bayes Before-After

REFERENCE: Persaud, Retting, & Lyon - 2003 (*51*)

STUDY SITES:

- Crash and traffic volume data were collected for 98 treatment sites, consisting of 210 miles, where centerline rumble strips had been installed on rural two-lane roads in the states of California, Colorado, Delaware, Maryland, Minnesota, Oregon, and Washington.
- The average length of the treatment sites was 2 miles, and the traffic volumes ranged from 5,000 to 22,000 vpd.
- The reference group of sites was developed from HSIS data for the states of California, Washington, and Minnesota.[A] Additional data were acquired from Colorado for SPF calibration for the Colorado sites.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Accident Type (all severities)	No. of Improved Sites	AMF
All Crashes	98	0.86
Frontal/Opposing-Direction Sideswipe Crashes		0.79
Accident Type (injury crashes)		
All Crashes	98	0.85
Frontal/Opposing-Direction Sideswipe Crashes		0.75

COMMENTS:

- The authors note that the results cover a wide range of geometric conditions, including curved and tangent sections and sections with and without grades.
- The results include all rumble strip designs (milled-in, rolled-in, formed, and raised thermo-plastic) and placements (continuous versus intermittent) that were present.
- **The AMF is not applicable to other road classes (multilane).**

FOOTNOTES:

[A] The Highway Safety Information System (HSIS) is a multistate safety database that contains accident, roadway inventory, and traffic volume data for a select group of states and is sponsored by the FHWA.

TABLE 3 (Continued)

TREATMENT: Install/Upgrade Guardrail

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Meta-analysis

REFERENCE: Elvik and Vaa - 2004 (*55*)

STUDY SITES:
- 20 studies were evaluated, including 12 U.S. studies (6 of which were conducted in 1982 or later)

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Run-Off-Road Accidents	AMF
Fatal Injury Crashes	0.56
All Injury Crashes	0.53

COMMENTS:
- The results apply to the installation of guardrail along an embankment. The studies were not differentiated by roadway class.
- The analysis also included an estimate for the change in accident rate, but the results were not significant.
- Results were also included for changing to softer guardrails. However, specifics on the type of change in hardware was not indicated, and not all results were significant. Therefore, they are not included here.

TREATMENT: Install Raised Medians at Crosswalks

AMF Level of Predictive Certainty: Medium-High

METHODOLOGY: Matched Comparison

REFERENCE: Zegeer, Stewart, Huang, and Lagerwey - 2001 (*37*)

STUDY SITES:
- 2000 sites were included in the study to evaluate the effect of marked vs. unmarked crosswalks (1000 matched pairs of each type).
- 260 of these sites were on multilane roads and had raised medians.
- On average, 5 years of crash data were collected for each site, as well as traffic data and pedestrian volume estimates.

CRASH TYPE STUDIED AND ESTIMATED EFFECTS

Total Pedestrian Accidents (all severities)	No. of Median Sites	AMF
Marked Crosswalks*	173	0.54
Unmarked Crosswalks*	173	0.61

* Applicable to urban and suburban multilane roads (up to 8 lanes) with traffic volumes greater than 15,000 vpd.

COMMENTS:
- The AMFs were computed from the pedestrian crash rates (ped crashes per million crossings) for sites with medians versus the sites without medians.

of this study. One of these studies is NCHRP Project 17-27, Parts I and II of the Highway Safety Manual (HSM). One of the objectives of that study is to develop the materials for the knowledge part of the manual, which will include information on the best available AMFs.

The research teams for NCHRP Projects 17-25 and 17-27 have been in close collaboration as the work on each project has progressed. The results included in this digest will also be included in the materials being developed by the 17-27 project team. The 17-27 team is also developing a quantitative methodology for assessing the credibility of AMFs as well as correcting for potential biases and other weaknesses. This methodology has been applied to a substantial number of AMFs included in an interim report for the project. If this methodology is deemed valid by the NCHRP Project Panel, the HSM Task Force, and the highway safety community at large, these supplemental AMFs produced in the 17-27 interim report will be included in the final report for NCHRP Project 17-25.

FHWA has undertaken a pooled fund study to evaluate the safety effect of a set of safety improvements. These improvements are mainly low-cost improvements that were identified in the NCHRP Report 500 Series, *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan.* The pooled fund study includes 24 states and has more than $4 million of funding. The participating states prioritized the improvements for evaluation. Currently, a contractor is developing study designs for the higher priority improvements and collecting information on the current or future implementation of those treatments. The intent of the pooled fund study is to conduct a scientifically rigorous evaluation, such as an empirical Bayes before–after study, for as many of these safety improvements as possible. This evaluation could include reactive studies of those measures that are already implemented or proactive studies of measures that will be implemented in the near future. A new NCHRP effort (Project 17-35, Evaluation of Low-Cost Safety Improvements) has been approved for funding for the next year and will be conducted in collaboration with this FHWA study.

Two additional NCHRP research projects that are being conducted in support of the Highway Safety Manual may also improve existing AMFs or produce additional AMFs. NCHRP Project 17-26, Methodology to Predict the Safety Performance of Urban and Suburban Arterials, will develop a methodology that predicts the safety performance of the various elements (e.g., lane width, shoulder width, use of curbs) considered in planning, design, and operation of non-limited–access urban and suburban arterials. NCHRP 17-29, Methodology to Predict the Safety Performance of Rural Multilane Highways, will be accomplishing the same goal for rural multilane roads.

The NCHRP 17-25 project team will continue to monitor all of these efforts with respect to AMF development. The final report for this project will include a comprehensive summary of the *best* AMFs that are available at that time and will present the factors and functions in a user-friendly format for practitioners. Any of these projects that continue beyond the end date of this project should be reviewed for new and/or improved AMFs. An ongoing effort to continually monitor the research, update AMFs, and disseminate the latest information through a web site or other means should also be established by an organization such as FHWA.

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