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16. Abstract

Highway safety is an ongoing concern to the Texas Department of Transportation (TxDOT). As part of its proactive commitment to improving highway safety, TxDOT is moving toward including quantitative safety analyses earlier in the project development process. The objectives of this research project are: (1) the development of safety design guidelines and evaluation tools to be used by TxDOT designers, and (2) the production of a plan for the incorporation of these guidelines and tools in the planning and design stages of the project development process.

This report describes the role and application of accident modification factors (AMFs) in the highway geometric design process. The potential applications of AMFs are identified and procedures for using AMFs are outlined. AMFs that can be used in design applications are also identified. Those AMFs that are needed to evaluate key highway design elements are identified. Recommendations are made regarding future research needed to enhance the use of AMFs in the design process.

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ROLE AND APPLICATION OF ACCIDENT MODIFICATION FACTORS IN THE HIGHWAY DESIGN PROCESS

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NOTICE

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CHAPTER 1. INTRODUCTION

OVERVIEW

This report describes the role and application of accident modification factors (AMFs) in the highway design process. The objectives of this document are: (1) to identify potential applications of AMFs in the highway design process and (2) to describe issues related to these applications. With regard to the first objective, guidelines for the application of AMFs are outlined herein. These guidelines are focused on the use of AMFs during the preliminary design stage of the design process; however, they could be used during other stages.

Initially, the role of AMFs in safety evaluation is described and the methods used in their development are discussed. Then, potential applications of AMFs in the design process are identified and procedures for using AMFs are outlined. Next, AMFs that could be used in design applications are identified. Then, issues associated with the development and application of AMFs are described. Finally, recommendations are made regarding future research needed to enhance the role and application of AMFs in the design process.

BACKGROUND

This section reviews the development and application of factors that describe the relationship between a change in geometry, traffic control device, signalization, or clear zone and the change in crash frequency associated with the roadway. Initially, some definitions are offered to facilitate the discussion of safety and geometric design. Then, the historic role of crash reduction factors (CRFs) in safety improvement evaluation is reviewed. Finally, the more recent role of AMFs is described and compared to that of CRFs.

Definitions

This section defines several terms related to the use of AMFs and CRFs. The definitions offered are consistent with their use in the safety-related literature; however, they may be enhanced for consistency with TxDOT design practice and the objectives of this research project.

Safety (or "substantive safety") is the expected crash frequency and severity associated with a facility for a given set of design components, traffic control devices, and exposure conditions (e.g., traffic volume, segment length). Given that crashes are random events and that conditions can change over time, the safety of a specific type of facility is best conceptualized as the average of the crash frequencies reported for a large group of facilities with similar features and conditions. Thus, the term "expected" is defined as an average of many years of crash data *if* traffic volume, driver behavior, geometry, and traffic control devices could be held fixed during these years.

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Safety prediction model (or simply "model") is an equation, or set of equations that can be used to estimate the safety of a typical facility. The model includes factors related to crash risk and exposure. A figure or table is sometimes used to portray the relationship (instead of an equation). A model can be derived to include one or more AMFs. Models intended for practical application have one or more empirically based factors that require calibration to local conditions to ensure accurate predictions.

Accident modification factor is a constant or equation that represents the change in safety following a change in the design or operation of a facility. A figure or table is sometimes used to portray the relationship (instead of an equation). An AMF can be computed as the ratio $N_w/N_{w/o}$, where N_w represents the expected number of crashes experienced by a highway facility *with* one or more specified design components and $N_{w/o}$ represents the expected number of crashes experienced by the same facility *without* the specified components. AMFs are often used as multiplicative factors to adjust the estimate obtained from a safety prediction model (i.e., the safety of the "typical" facility) to a value that reflects the safety of a specific facility.

AMFs typically range in value from 0.5 to 2.0, with a value of 1.0 representing no effect on safety by the addition (or change to) the specified component. AMFs less than 1.0 indicate that the specified component is associated with fewer crashes.

To illustrate the concept of AMF, consider a road segment that has an expected crash frequency of 3.0 crashes/yr. A change is made to the road cross section and, after a period of time, a follow-up evaluation indicates that the change resulted in an expected crash frequency of 4.0 crashes/yr. The AMF for this change is 1.3 (= 4.0/3.0).

As a second illustration of the AMF concept, consider that a safety prediction model is used to estimate the expected crash frequency of a typical two-lane highway with a specified annual average daily traffic volume (AADT) and length. The model was developed to reflect the following as "typical:" 12-ft lanes, 6-ft shoulders, no grade, no horizontal curves, 10-ft horizontal clearance, 1V:4H side slope, and no vertical grades. This model estimates an expected crash frequency of 5.0 crashes/yr for the "typical" road segment. It is desired to estimate the crash frequency of a specific road segment for which all geometric elements are "typical" except that the clear zone is 20 ft wide. An AMF for horizontal clearance has a value of 0.93 at a clearance distance of 20 ft. Thus, the expected crash frequency for the specific road segment is estimated as 4.6 crashes/yr (= 5.0 × 0.93).

Crash reduction factor is a constant that represents the portion of crashes reduced as a result of a safety improvement (e.g., add a left-turn bay) at a specific location or along a specific road segment. CRFs typically range in value from 0.10 to 0.90. Larger CRFs in this range indicate a more significant reduction in crashes due to the improvement. To illustrate, consider a road segment that has an expected crash frequency of 3.0 crashes/yr. An improvement is made to the road's cross section and, after a period of time passes, a follow-up evaluation indicates that the change resulted

in an expected crash frequency of 2.0 crashes/yr. The CRF for this improvement is 0.33 (= [3.0 − 2.0]/3.0) representing a 33-percent reduction in crashes.

Crash Reduction Factors

CRFs were first developed for the Federal Hazard Elimination Program (HES) (*1, 2*). In this early application, CRFs were used to estimate the safety effects of improvements in: (1) the geometry of a specific highway segment or intersection, (2) the traffic control devices used on the segment or at the intersection, (3) the signalization used at the intersection, or (4) the roadside clear zone or safety appurtenances. As reported by Shen et al. (*3*), about 80 percent of state departments of transportation (DOTs) in the U.S. use CRFs to help identify safety improvements for locations with above-average crash patterns.

Development of Crash Reduction Factors

As noted in the previous section, the CRF is defined as:

$$CRF = 1 - \frac{N_w}{N_{w/o}}$$

(1)

where:
CRF = crash reduction factor associated with a specific improvement;
N_w = expected number of crashes with the improvement, crashes/yr; and
$N_{w/o}$ = expected number of crashes without the improvement, crashes/yr.

As suggested by the variable definition in Equation 1, the term "improvement" (or "countermeasure") is frequently used to describe the change in geometry, traffic control device, signalization, or clear zone. These terms imply the anticipation of a reduction in crashes following the change. When Equation 1 is used to quantify the CRF for a specific improvement, the expected number of crashes with the improvement N_w is typically estimated as the "number of reported crashes *after* the improvement X_a."

There are several statistical methodologies available for using before-after crash data to quantify the CRF for a specific improvement. The most direct method is based on the use of Equation 1 where the expected number of crashes without the improvement $N_{w/o}$ is estimated as the "number of reported crashes *before* the improvement X_b." This method is often referred to as the "simple before-after study."

Research (*4, 5*) has shown that the use of the "simple before-after study" method to develop CRFs often leads to biased values that overstate the true effectiveness of an improvement. In fact, Shen et al. (*3*) noted that many of the CRFs in current use are of suspect accuracy due to the apparent use of this method in their development. The bias is due to several factors that are unaccounted for in the simple before-after study. These factors are summarized in the following paragraphs. It

should be noted that more sophisticated statistical methods that overcome these sources of bias are described in a subsequent section of this report.

Possible Sources of Bias in the Development of CRFs. Many DOTs are using techniques to develop their CRFs that do not account for several factors that can influence the estimate of the expected number of crashes without the improvement $N_{w/o}$. These factors include:

- Regression-to-the-Mean: locations selected for improvement inherently have a high crash frequency, a portion of which are solely due to random variation in annual crashes. Crashes in subsequent years will decline independently of any improvements made. However, simple before-after studies will incorrectly associate this reduction with the improvement and, thereby, overestimate the true long-term crash reduction potential of the countermeasure.

- Crash Migration: a transfer of crashes resulting from an improvement rather than a reduction. Simple before-after studies will associate the reduction with the improvement and, thereby, overestimate the true crash reduction potential of the countermeasure. For example, the addition of a traffic signal will reduce right-angle crashes but may increase rear-end crashes. The flattening of a curve may reduce crashes but may increase them at the downstream curve.

- Maturation: a reduction in crashes that is partially due to changes in factors that are not considered in the before-after study. Such factors may include: weather, major reconstruction leading to significant traffic diversion, economy, and crash reporting threshold. For example, if the area-wide economy declines during the "after" period resulting in lower speeds and less travel, it may result in fewer crashes being reported at the treated location. Simple before-after studies will associate the reduction with the improvement and, thereby, overestimate the true crash reduction potential of the countermeasure.

- Exposure: a reduction in crashes that is due to a reduction in exposure to the crash. Exposure is a measure of crash "opportunity" and is not a cause of crashes. Typical exposure measures include: traffic volume, road length, and percentage of heavy vehicles. Simple before-after studies will associate the reduction in exposure with the improvement and, thereby, overestimate the true crash reduction potential of the countermeasure.

Lack of Sensitivity to Crash Type and Severity. Shen et al. (*3*) noted that only about 50 percent of the DOTs have developed CRFs that are sensitive to crash type (e.g., rear-end, head-on, etc.) and crash severity (fatal, incapacitating injury, etc.). The CRFs reported by the DOTs that do provide this sensitivity reveal that most countermeasures do not have a uniform influence across all crashes and severity levels. For example, the addition of a traffic signal may significantly reduce right-angle crashes (e.g., $CRF_{ra} = 0.65$) but only slightly reduce rear-end crashes (e.g., $CRF_{re} = 0.20$).

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Application of Crash Reduction Factors

After the CRFs have been developed, they can be used to assess the safety benefit of alternative improvements. This section describes their basic method of application. Initially, it describes the evaluation of a single improvement (or countermeasure). Then, it describes a technique for evaluating several improvements, when all improvements are to be combined into one project.

Safety Effect of One Countermeasure. The safety benefit derived by implementation of an improvement is quantified in terms of the crashes it eliminates (or prevents). This benefit can be estimated using the following equation:

$$\Delta N = -N_{w/o} \; CRF \qquad\qquad (2)$$

where:

$\Delta N =$ reduction in crashes due to implementation of a safety improvement (i.e., countermeasure) $(= N_w - N_{w/o})$.

A reduction in crashes is mathematically represented as a negative quantity in Equation 2.

When using Equation 2 to compute safety benefit, the expected number of crashes without the improvement $N_{w/o}$ is typically estimated as the number of reported crashes X at the subject location. However, it is generally recognized that X is not a reliable estimate of the long-term average crash frequency at the location (*4*). In fact, if the location was identified because it is a "high-crash location," then X would almost certainly overestimate the expected crash frequency at the location and the reduction ΔN (obtained by using X in Equation 2) would also be overestimated. Techniques for obtaining unbiased estimates of $N_{w/o}$ and ΔN are described in a subsequent section.

For improvements that last multiple years, Equation 2 would be applied for each year of the improvement's design life. The estimate $N_{w/o}$ would be increased each year in direct proportion to the annual increase in AADT. The crash reduction computed for each year would then be summed to yield the total reduction in crashes.

Safety Effect of Multiple Countermeasures. Multiple countermeasures are often implemented at the same location. In a recent survey of DOTs, Shen et al. (*3*) found that very few CRFs have been quantified for combinations of countermeasures. As a substitute, an equation is typically used by the DOTs to predict the combined effect of the individual countermeasures. The form of this equation is:

$$CRF_c = 1 - (1 - CRF_1) \times (1 - CRF_2) \times (1 - CRF_3) \times ... \times (1 - CRF_n) \qquad (3)$$

where:

$CRF_c =$ combined CRF for all n countermeasures.

The formulation of Equation 3 implies that a change in any one factor has an effect on the magnitude of all other applicable adjustment factors. This formulation indirectly accounts for the interaction among adjustment factors by moderating the impact of multiple reduction factors. However, to date, there has been no research reported that verifies the accuracy of Equation 3.

To compute the safety benefit ΔN associated with multiple countermeasures, Equation 3 would first be used to estimate CRF_c. Then, this value would then be used in Equation 2 to compute the reduction in crashes attributed to the countermeasures.

Current Research to Address CRF Issues

The issues identified by Shen et al. (*3*) are undergoing a detailed and comprehensive examination in a current research project sponsored by the National Cooperative Highway Research Program (NCHRP). Specifically, NCHRP has commissioned Project 17-25 (*Crash Reduction Factors for Traffic Engineering and ITS Improvements*) to investigate these and other issues. The objective of this project is to develop reliable CRFs for traffic engineering, operations, and intelligent transportation system (ITS) improvements. This project is slated for completion in July 2005.

Accident Modification Factors

In recent years, the concept of CRF has been extended to the more general concept of AMF. This extension reflects the recognition that a change in geometry, traffic control device, signalization, or clear zone could result in either an increase or a decrease in crashes. The term "reduction," used with CRF, is limiting because it does not recognize the possibility that crashes can increase following a change in roadway design or operation. The extension to AMF also facilitates a broader application of the CRF concept in the context of its use with safety prediction models. In this context, AMFs are used with a safety prediction model to: (1) estimate the expected crash frequency for a specific location, or (2) estimate the effect of a change in conditions on safety.

The relationship between the AMF and CRF is defined as:

$$AMF = 1 - CRF \tag{4}$$

When combinations of AMFs are used, Equations 3 and 4 are typically combined to yield the following equation for computing the effect of multiple changes in geometry, traffic control device, signalization, or clear zone:

$$AMF_c = AMF_1 \times AMF_2 \times AMF_3 \times ... \times AMF_n \tag{5}$$

where:
AMF_c = combined AMF for all n changes.

As noted in the discussion associated with Equations 1 and 2, an accurate estimate of the expected number of crashes without the improvement $N_{w/o}$ is needed to develop unbiased CRFs and to accurately estimate the reduction in crashes due to the implementation of a safety improvement ΔN. This need is extended to the development of AMFs and the estimation of a change in crashes (increase or reduction) due to a change in conditions. However, the variables N_w and $N_{w/o}$ are hereafter redefined slightly, relative to their first use in Equation 1. Specifically, the term "change" is hereafter substituted for the word "improvement." This modification is intended to reflect the broader range of application with AMFs than with CRFs.

Two methods are described in this section for estimating $N_{w/o}$. The first method presented is easier to apply because it does not require crash data for the subject location. The second method presented does require crash data for the location but yields a more accurate estimate of $N_{w/o}$.

Expected Crash Frequency without Knowledge of Crash History. Harwood et al. (*6*) recommend the combined use of AMFs and a "base" safety prediction model to estimate $N_{w/o}$. The base model predicts the crash experience for a location of typical geometric design, traffic control device usage, and roadside design components. Many atypical discreet factors (e.g., driveways, passing lanes, etc.) would not be represented in the base model. Rather, their safety effect would be accounted for by using the appropriate AMF (e.g., $AMF_{driveway}$, $AMF_{passing\,lane}$) with the base model. Similarly, design elements that have a continuous relationship are represented in the base model at typical values (e.g., no grade, 12-ft lane width). Conditions that are atypical at a particular location are incorporated using the appropriate AMF (e.g., AMF_{grade}, $AMF_{lane\,width}$). In this manner, AMFs are used to adjust the base model prediction to reflect conditions at the subject location. The form of this relationship is:

$$N_p = N_{base}\ AMF_{c,p} \tag{6}$$

where:

$N_p =$ expected number of crashes at subject location, crashes/yr;
$N_{base} =$ expected number of crashes for base (i.e., typical) conditions, crashes/yr; and
$AMF_{c,p} =$ combination of AMFs that describe atypical conditions at the subject location.

Base safety prediction models have been developed by Harwood et al. (*6*) and others (*4, 7*). These models can be used for various highway segments and intersection facilities. Most segment models are calibrated for a specific functional class. Most intersection models are calibrated for a specific type of intersection control (e.g., signalized, two-way stop control, etc.) and number of approach legs. The model structure used most often for highway segments is:

$$N_{base} = a\ AADT^b\ L\ e^{(c\ +\ d\times other\ factors)} \tag{7}$$

where:

$AADT =$ annual average daily traffic volume, veh/d;

$L =$ roadway length, mi; and

$a, b, c, d =$ calibration coefficients.

A similar model structure is used for intersections.

When Equations 6 and 7 are used to develop a CRF or AMF or to estimate the effect of a change in safety ΔN, the variable values used in them should reflect existing conditions at the subject location. In this manner, the value obtained from Equation 6 would represent $N_{w/o}$ (i.e., $N_{w/o} = N_p$). In fact, Equations 6 and 7 are sufficiently general that they can be used to estimate the expected crash frequency for any combination of conditions (existing or proposed). This flexibility is illustrated in subsequent sections of this report.

The base safety prediction model shown in Equation 7 is illustrative of typical base models (*4, 6, 7*) for roadway segments. The volume and length variables are common to most models. The calibration coefficients are used to scale the model for specific roadway classifications, facility types, and conditions. The "other factors" term represents any additional geometric variables that improve model accuracy.

Expected Crash Frequency with Knowledge of Crash History. If the crash history of the subject location is available, the empirical Bayes method can be used to estimate the expected number of crashes at the subject location. This estimate would be more accurate than that obtained from Equation 6 due to the inclusion of the subject location's crash history in the calculation. It is based on a weighted average of the value from Equation 6 and the reported crash count X for the subject location. This estimate can be computed using the following equation:

$$N_{p|x} = N_p w + \frac{X}{Y}(1 - w) \tag{8}$$

with,

$$w = \left(1 + \frac{K N_p Y}{L}\right)^{-1} \tag{9}$$

where:

$N_{p|x} =$ expected number of crashes at subject location given that X were reported, crashes/yr;

$N_p =$ expected number of crashes at subject location (from Equation 6), crashes/yr;

$X =$ number of crashes reported at the subject location, crashes;

$Y =$ number of years during which X crashes were reported, yr;

$w =$ weight given to N_p; and

$K =$ dispersion parameter.

The dispersion parameter used in Equation 9 is an empirical constant that represents the amount of variability in the crash data used for model calibration. This value is obtained from the regression analysis used to calibrate the base safety prediction model. A unique value exists for each model and database.

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When Equations 6 through 9 are used to develop a CRF or AMF or to estimate the effect of a change in safety ΔN, the variable values used in Equations 6 and 7 should reflect existing conditions at the subject location. In this manner, the value obtained from Equation 6 would represent $N_{w/o}$ (i.e., $N_{w/o} = N_{p|x}$).

Development of Accident Modification Factors

AMFs have been developed using one of three techniques. The first technique is based on an observational before-after study of locations where a specific change was implemented. The second technique is based on a cross-sectional study of locations with and without the component (e.g., raised-curb median). The third technique is based on the use of a panel of highway safety experts to judge the most likely effect of a change in condition. Each technique is summarized in this section.

Before-After Study. Three different methods have been used to develop AMFs using the observational before-after study. Each of these methods is summarized in this section. For all three methods, the expected number of crashes with the change N_w is estimated as the "number of reported crashes *after* the change X_a" (i.e., $N_w = X_a$).

Simple Before-After Study. The simple before-after study method quantifies the change in crashes at a specific location where only one change is made to the geometry, traffic control device, signalization, or clear zone. With this study, the expected number of crashes without the change $N_{w/o}$ is estimated as the "number of reported crashes *before* the change X_b" (i.e., $N_{w/o} = X_b$). The equation below is used to compute the AMF associated with the change:

$$AMF = \frac{N_w}{N_{w/o}} = \frac{X_a}{X_b} \qquad (10)$$

As noted previously, research (*4*, *5*) has shown that the use of AMFs obtained from this method are often biased and tend to overstate the true effectiveness of a change.

Before-After Study with Comparison Group. A second method used to develop AMFs extends the "simple before-after study" by including one or more comparison locations. This method is more reliable that the "simple before-after study" because it can account for maturation and exposure. However, it does not account for the effect of regression-to-the-mean or migration. The statistical analysis techniques often used with this method are described by Griffin and Flowers (*5*).

Before-After Study Using Empirical Bayes Adjustment. A third method used to estimate an AMF also extends the "simple before-after study" by using a safety prediction model to estimate the expected crash frequency of a location both with and without the change. The key to this method is the estimate of the expected number of crashes that would have occurred without the change $N_{w/o|x}$, given that X crashes were reported. This estimate can be computed using Equation 11.

$$N_{w/o|x} = N_{p|x} \frac{N_{w|o,A}}{N_{w/o}}$$

(11)

where:

$N_{w/o|x}$ = expected number of crashes without the change, given that X crashes were reported, crashes/yr; and

$N_{w/o, A}$ = expected number of crashes without the change based on the conditions (e.g., traffic volumes) present in the "after" period, crashes/yr.

To develop an AMF with this method, the value of $N_{p|x}$ is first obtained from Equation 8. Then, the value of $N_{w/o}$ is obtained from Equation 6 (i.e., $N_{w/o} = N_p$). Next, the value of $N_{w/o, A}$ is also obtained from Equation 6; however, it is estimated using conditions (e.g., traffic volumes) present during the "after" period. Then, $N_{w/o|x}$ is computed using Equation 11. Finally, $N_{w/o|x}$ is substituted for $N_{w/o}$ in the following equation to obtain an unbiased estimate of the AMF associated with the changed condition.

$$AMF = \frac{N_w}{N_{w/o}} = \frac{X_a}{N_{w/o|x}}$$

(12)

Cross-Sectional Study. An AMF can also be estimated using a cross-sectional (or panel-data) study. For this study, the expected crash frequency of a group of locations having a specific component of interest is compared to the expected crash frequency of a group of locations with similar characteristics, but which do not have the component. The expected crash frequency of the former group is represented as N_w and that of the latter group as $N_{w/o}$. Any differences in crash frequency between the two groups is attributed to the change in conditions. The ratio of the estimates is the AMF (i.e., $AMF = N_w / N_{w/o}$).

Statistical techniques can also be used to calibrate a safety prediction model using the combined database (i.e., data from locations with and without the component). With this alternative, a variable in the model is used to represent the effect of the factors of interest (e.g, grade, speed, lane width, etc.). The resulting calibrated model can then be used to estimate both N_w and $N_{w/o}$. As before, the ratio of these two values is used to compute the desired AMF.

Expert Panel. Although the use of expert panels is not a quantitative, statistically based method of predicting AMFs, this approach has been used by Harwood et al. (6) to estimate AMFs for rural highways. This method requires an initial critical review of the literature describing the safety effect of a specific geometric element, traffic control device, signal operation, or clear zone component. Then, the findings from this review are digested by a panel of highway safety and highway design experts, and then used to estimate the expected safety effect of a specific design component by consensus of opinion. A disadvantage of this approach is that it is not based wholly

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on a quantitative analysis of data from specific sites. Hence, a bias may be introduced by the experiences and preferences of the panel members.

Application of Accident Modification Factors

Once a set of AMFs are developed by an agency, they can be used to estimate the effect of a change in geometry, traffic control device, signalization, or clear zone on safety. This section describes the basic method of applying AMFs in the design process. Initially, it describes the evaluation of a single change. Then, it describes a technique for evaluating several changes when they are to be combined into one project. The application method is more formally described and illustrated in a subsequent section of this report.

Safety Effect of One Change without Knowledge of Crash History. A variation of Equation 2 can also be used to estimate the effect of a change on safety. Initially, the expected number of crashes for the base condition is computed using Equation 7. Then, the set of AMFs needed to tailor the base crash frequency to that of the existing location are combined using Equation 5. Next, the expected number of crashes at the subject location N_p is obtained from Equation 6. It serves as an estimate of $N_{w/o}$ (i.e., $N_{w/o} = N_p$). Then, an AMF representing the specified change in condition is identified as is its counterpart in the set of AMFs previously used to compute N_p. Finally, the following equation is used to estimate the expected change in crashes due to the change in condition:

$$\Delta N = N_{w/o} \left(\frac{AMF_w}{AMF_{w/o}} - 1 \right)$$

(13)

where:

ΔN = change in crashes due to a change in condition ($= N_w - N_{w/o}$), crashes/yr;

$N_{w/o}$ = expected number of crashes without the change ($= N_p$), crashes/yr;

$AMF_{w/o}$ = AMF of design component to be changed but reflecting *existing* conditions; and

AMF_w = AMF of design component to be changed, reflecting the changes.

A positive value of ΔN denotes an increase in crash frequency.

For changes that last multiple years, Equation 6 would be reapplied for each year of the change's design life. Specifically, the AADT for each year of the design life would be estimated and used in Equation 6 to compute $N_{w/o}$ for that year. Then, the change in crashes for each year would be computed using Equation 13 with the yearly estimates of $N_{w/o}$. The AMF variables (i.e., $AMF_{c,p}$ and AMF) are constant for each year. The change in crashes for each year is summed for all years to yield the total change in crash frequency.

Safety Effect of One Change with Knowledge of Crash History. This section describes a method for estimating the effect of a change in conditions on safety when the crash history is

known. This method improves the accuracy of the estimate obtained from Equation 13 by combining the reported crash count at a specific location with the expected crash frequency obtained from Equation 6. The combined quantity represents the expected crash frequency without the change, given that X crashes were reported $N_{w/o|x}$.

Initially, the expected number of crashes for the base condition is computed using Equation 7. Then, the set of AMFs needed to tailor the base crash frequency to that of the existing location are combined using Equation 5. Next, the expected number of crashes at the subject location N_p is obtained from Equation 6. Then, N_p is used in Equation 8 with the reported crash count X to estimate $N_{p|x}$. It serves as an estimate of $N_{w/o|x}$ (i.e., $N_{w/o|x} = N_{p|x}$). Then, an AMF representing the specified change in condition is identified as is its counterpart in the set of AMFs previously used to compute N_p. Finally, $N_{w/o|x}$ is substituted into the following equation and used to compute the impact of the change in terms of the crashes it eliminates (or causes):

$$\Delta N = N_{w/o|x} \left(\frac{AMF_w}{AMF_{w/o}} - 1 \right)$$
(14)

For changes that last multiple years, Equation 6 would be reapplied for each year of the change's design life. Specifically, the AADT for each year of the design life would be estimated and used in Equation 6 to compute $N_{w/o}$ for that year. Next, the value of $N_{w/o,i}$ obtained for year i is used with the following equation to compute the corresponding $N_{w/o|x,i}$ for the same year:

$$N_{w/o|x,i} = N_{p|x} \frac{N_{w|o,i}}{N_{w/o,1}}$$
(15)

where:

$N_{w/o,i}$ = expected number of crashes without the change based on the conditions (e.g., traffic volumes) present in year i ($i = 1, 2, ..., n$), crashes/yr.

In Equation 15, $N_{p|x}$ and $N_{w/o,1}$ are constant for each year. The value $N_{w/o,1}$ is obtained from Equation 6 using conditions present in the first year (i.e., $N_{w/o,1} = N_p$). It is substituted for N_p in Equation 8 along with the reported crash count X to estimate $N_{p|x}$.

Once the yearly values of $N_{w/o|x,i}$ are computed, they are used with Equation 14 to estimate the change in crashes that occur for each year i. The AMF variables (i.e., $AMF_{c,p}$ and AMF) are constant for each year. The change in crashes for each year is summed for all years to yield the total change in crash frequency.

Safety Effect of Multiple Changes without Knowledge of Crash History. Multiple changes are often considered for the same location. If an AMF is not available for the combination being considered, Equation 5 can be used to estimate the combined effect of the individual changes.

The following steps are used to compute the change in safety that is associated with multiple design changes.

Initially, the expected number of crashes for the base condition is computed using Equation 7. Then, the set of AMFs needed to tailor the base crash frequency to that of the existing location are combined using Equation 5. Next, the expected number of crashes at the subject location N_p is obtained from Equation 6. It serves as an estimate of $N_{w/o}$ (i.e., $N_{w/o} = N_p$). Then, the AMFs representing the specified change in conditions are identified as are their counterparts in the set of AMFs previously used to compute N_p. There should be a one-to-one match between the two sets of AMFs used, in terms of the design components that each AMF addresses.

The AMFs corresponding to the specified design components to be changed but reflecting the *existing* conditions are defined as $AMF_{c, w/o}$. Those AMFs corresponding to the components to be changed and reflecting these changes are defined as $AMF_{c, w}$. Equation 13 is used with these estimates to obtain the change in crashes.

Safety Effect of Multiple Changes with Knowledge of Crash History. The effect of multiple changes in conditions can also be evaluated when crash history is available. In this instance, the same procedure as that described for "one change with knowledge of crash history" is used. However, the procedure described in the previous section for estimating $AMF_{c, w/o}$ and $AMF_{c, w}$ is used.

Accident Modification Functions

Many AMFs developed in recent years have adopted an equation form to reflect a sensitivity to one or more variables (*6*). Figure 1 illustrates the relationship used to determine the AMFs for lane and shoulder width. As the trends in the figure indicate, the AMF for both widths vary with AADT. Similar relationships are reported by Harwood et al. (*6*) for the AMFs associated with curve radius, superelevation rate, driveway density, roadside hazard rating, and intersection skew angle.
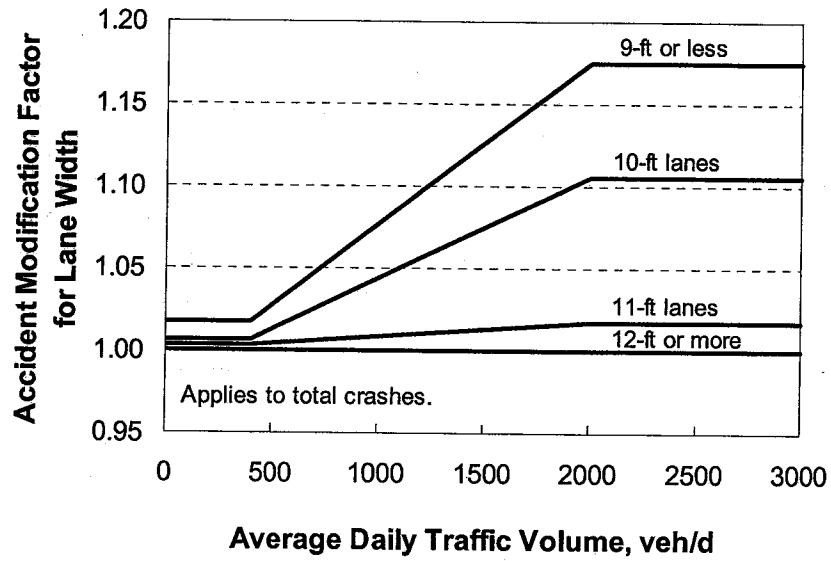
a. Lane Width AMF.
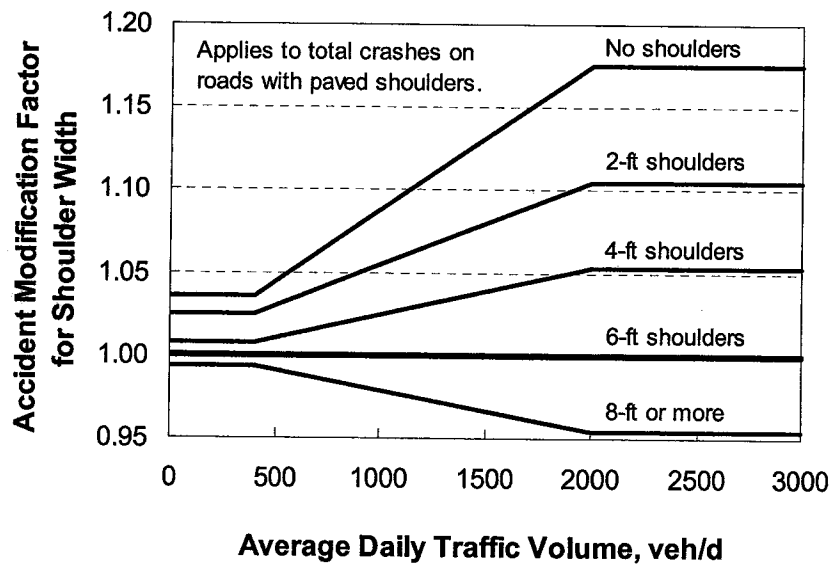
b. Shoulder Width AMF.

Figure 1. Accident Modification Functions for Lane and Shoulder Width.

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CHAPTER 2. AMF APPLICATIONS AND ISSUES

CRFs have historically been used in the hazard elimination program to evaluate potential safety improvements for streets and highways. As such, most of the CRFs that are available focus on the effect of a change in traffic control device, signalization, pavement surface condition, and roadside safety treatment. Few CRFs have addressed highway geometric design components. For this reason, CRFs have not been widely used during the design process. This section examines the role and application of AMFs in the highway design process. It also addresses the issues associated with their use and identifies the additional AMFs that need to be developed through research.

APPLICATION OF AMFs IN THE HIGHWAY DESIGN PROCESS

This section identifies three potential applications of AMFs in the highway design process. Initially, these applications are identified in terms of the part of the design process within which they may serve a useful purpose. Then, a procedure for their use is described and followed by an example application.

Potential Design Applications of AMFs

Three potential design applications of AMFs are described in this section. Two of the applications relate to the direct evaluation of safety as part of the preliminary design stage and the design exception process. The third application relates to the evaluation of design consistency during the preliminary design stage.

Safety Evaluation - Preliminary Design Stage

The major design features of the roadway are usually defined during the preliminary design stage. During this stage, alternative locations and features are considered and the most promising ones are evaluated in greater detail. This stage of the design process was described previously by Bonneson et al. (8).

Some evaluation tools are used in the preliminary design stage to assess the operational performance, environmental impact, right-of-way requirement, and construction cost of various design alternatives. Safety evaluation tools are being developed to facilitate the assessment of the safety. The objective of the assessment is to ensure that the design offers a reasonable balance between cost and effectiveness. Collectively, these tools can be used together to quantify the cost and effectiveness of each alternative.

The following tools are being developed nationally to facilitate the quantitative evaluation of safety benefit during the design process:

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- *Highway Safety Manual (9)*
- *Interactive Highway Safety Design Model (10)*
- *Safety Analyst (11)*

AMFs are used in each of these tools to facilitate the evaluation of design alternatives.

Safety Evaluation - Design Exception Process

In some circumstances, it may not be practical or reasonable to require a design to satisfy each and every design criterion. In some situations, it may be extremely expensive to adhere to a specific criterion. In other instances, adherence may impose a significant hardship on adjacent land owners or local residents. The process of evaluating a request for deviation from agency-adopted design criteria and making a decision to grant or deny the request is known as the "design exception process." The objective of this evaluation is to ensure that the safety and operational efficiency of the facility are kept in balance with other design-related impacts (e.g., aesthetics, environment) and are reflective of the funds available for construction. The design exception process is usually handled on a case-by-case basis. This process varies greatly from state to state, where each DOT has their own organizational structure, review, documentation, and approval processes (12).

A procedure for processing design exception requests has been established by TxDOT. It states that a Roadway Design Exception Committee will review all design exception requests related to a deviation or variance from specific controlling criteria described in the *Roadway Design Manual* (13). An exception must be processed for any design element that does not meet these "controlling" criteria. The controlling criteria requiring a design exception are listed in Table 1.

Table 1. Controlling Criteria Requiring Design Exception.

New Location and Reconstruction Projects (4R)	Resurfacing, Restoration, and Rehabilitation Projects (3R)
Design Speed Lane Width Shoulder Width Bridge Width* Structural Capacity* Horizontal Alignment Vertical Alignment Grades Stopping Sight Distance Cross Slope Superelevation Vertical Clearance	Deficient Bridge Rails (high volume roadways) Design Speed (high volume roadways) Horizontal Alignment (high volume roadways) Vertical Alignment (high volume roadways) Superelevation (high volume roadways) Grades (high volume roadways) Lane Width Shoulder Width Bridge Width* Structural Capacity*
* Reviewed by the Bridge Design Exception Committee	

Safety evaluation tools can be used to assist in the evaluation of design exceptions. These tools could be used to quantify the change in crash frequency that would likely occur if the design

exception was, and was not, granted. From this analysis, one of the following conclusions might be reached in support of the request:

- There is likely to be fewer total crashes and no increase in the portion of severe (i.e., injury or fatal) crashes.
- There is likely to be no change in total crashes and no increase in the portion of severe crashes.
- There is likely to be an increase in total crashes but the increase will be offset by a reduction in the number of fatal and injury crashes.

Information used to reach one of the aforementioned conclusions could be obtained using Equation 13 or 14 to compute the change in crashes for the case where the design exception request is granted and again for the case where it is not granted. Of the two equations, Equation 14 is likely to yield the more accurate estimate of ΔN because it includes information about a large sample of similar locations as well as the reported crash count X. As noted previously, the use of AMFs with only the reported crash count may overstate the change in crashes because of regression-to-the-mean.

Design Consistency Evaluation - Preliminary Design Stage

Design consistency is the conformance of a highway's geometric and operational features with driver expectancy (*14*). Geometric features that are unexpected or atypical (relative to previously encountered features) may increase the risk of driver error, which may decrease the safety of the highway segment, intersection, or interchange. As noted by Alexander and Lunenfeld (*15*), driver expectancy is an important component of the driving task and can significantly affect the risk of a crash. Thus, by improving design consistency, it is anticipated that a facility will operate with fewer failures (e.g., driver errors) and related crashes.

Research on the topic of design consistency has taken the form of design consistency checklists, speed change evaluations, and driver workload considerations. Less attention has been paid to the quantification of the safety benefits of design consistency. However, recent research projects have developed tools to measure design consistency (*14*) and its relationship to safety (*16*).

Wooldridge et al. (*14*) recommend the use of AMFs to identify when a change in a specific design component is sufficiently significant as to be deemed "inconsistent with driver expectancy." In this application, they recommend using the change in AMF associated with successive road segments as a means of identifying inconsistencies. They specified threshold values of AMF change for this purpose. It should be noted that this application does not require the use of a base safety prediction model or the reported crash count.

Development and Application of Evaluation Procedures

This section describes the potential application of AMFs within the highway design process. These applications include:

- safety evaluation of design alternatives,
- safety evaluation of design exceptions, and
- design consistency evaluation.

The evaluation of design safety consists of the prediction of crash frequency associated with one or more alternative design components (e.g., horizontal curve) and the sizes of the various elements of which they are comprised (e.g., radius, superelevation rate). This evaluation would likely occur during the preliminary design stage of the design process. Information from this evaluation would be used in the selection of the preferred design component.

The evaluation of design exceptions consists of predicting the effect of a design exception on crash frequency. In this application, one or more AMFs would be used to quantify the safety implications of a proposed deviation from a design control value.

The evaluation of design consistency consists of quantitatively assessing the degree of conformance between driver expectancy and a highway's geometric features, operational features, or both. Significant changes in design character (e.g., cross section) among adjacent road segments that are unexpected can lead to increased driver workload and a reduction in the level of safety. Information from this evaluation would be used to either maintain consistency in roadway design or facilitate the introduction of changes in design character at a rate that does not compromise safety.

Safety Evaluation of Design Alternatives

For the evaluation of design safety, AMFs are used to compare the safety effects of different highway design components. For instance, a designer may be interested in choosing between two alternative horizontal curve radii. The goal is to quantify the crash frequency for the geometric design alternatives and use this information as part of comprehensive analysis of the benefits and costs of each design alternative. A procedure for achieving this goal is described in the next section. Thereafter, it is illustrated in an example application.

Procedure. The procedure for estimating the safety effects of changes in geometric design components consists of two elements: base safety prediction models and AMFs. In this procedure, Equation 7 is first used to estimate the expected number of crashes for base conditions N_{base}. Then, AMFs are used in Equation 6 to adjust the value obtained from the base model such that the result is an estimate of the expected crash frequency associated with the existing or initial design $N_{w/o}$. Next, a design change is specified and the corresponding AMF is identified. Finally, the change in safety ΔN is quantified using Equation 13.

If the project is associated with an existing alignment, the reported crash count X can be used to improve the accuracy of the estimated expected crash frequency associated with the existing or initial design. In this variation of the estimation procedure, Equation 8 is used to estimate the expected crash frequency given that X crashes were reported $N_{p|x}$. This value is then equated to $N_{w/o|x}$ and used with Equation 14 to estimate the change in safety due to the change in conditions ΔN.

Example Application. In this example application of the design safety evaluation, a 3-mile two-lane rural highway segment linking two major intersections is being reconstructed. This segment contains one tangent section without any vertical curves. Existing lane widths are 11 ft with no shoulder. Current traffic volume is estimated at 5000 veh/d. All other conditions are the same for both the existing condition and the design alternative.

Step 1: Estimate Expected Number of Crashes for Base Conditions. The safety prediction model included in the prototype chapter for rural two-lane highways of the forthcoming *Highway Safety Manual* (*9*) can be obtained from Equation 7 by substituting the following values for the calibration coefficients: $a = 0.0002244$, $b = 1.0$, $c = 0.0$, and $d = 0.0$. Using this model, the expected number of crashes for the base condition is estimated as:

$$
\begin{aligned}
N_{base} &= 0.0002244 \times AADT \times L \\
&= 0.0002244 \times 5000 \times 3 \\
&= 3.37 \; crashes/yr
\end{aligned}
\tag{16}
$$

This equation predicts crash frequency for a road segment having a specified set of typical design element dimensions. The dimensions that underlie Equation 16 include 12-ft lanes and 6-ft shoulder widths (*9*).

Step 2: Adjust Base Conditions to Reflect Existing or Initial Design. Using AMFs available from Figure 1, the value from Equation 16 is adjusted to reflect existing conditions (i.e., 11-ft lanes, and no shoulder). These AMFs are $AMF_{lane\_width} = 1.02$ and $AMF_{shoulder\_width} = 1.18$. The result of this computation is:

$$
\begin{aligned}
N_{w/o} &= (AMF_{lane\_width} \times AMF_{shoulder\_width}) \times 3.37 \\
&= (1.02 \times 1.18) \times 3.37 \\
&= 4.06 \; crashes/yr
\end{aligned}
\tag{17}
$$

Step 3: Specify a Design Change and Identify the Appropriate AMFs. The designer has identified a design alternative as having 12-ft lanes with 8-ft paved shoulders. From Figure 1, AMFs are identified for the changes in lane and shoulder width as $AMF_{lane\_width} = 1.00$ and $AMF_{shoulder\_width} = 0.95$.

Step 4: Compute Safety Change. The change in safety as a result of the alternative lane and shoulder widths can be estimated as:

$$\Delta N = 4.06 \left(\frac{1.00 \times 0.95}{1.02 \times 1.18} - 1 \right)$$
$$= -0.86 \ crashes/yr$$

(18)

The alternative is estimated to reduce crash frequency on the segment by 0.86 crashes/yr. From a safety perspective, this alternative is attractive. However, this estimate represents only one piece of information about the alternative; the decision to accept or reject this alternative should be made in the larger context of its overall impact on operation, safety, right-of-way, and construction cost.

Safety Evaluation of Design Exceptions

Design exceptions often represent one of two scenarios. The first scenario occurs when an existing highway is considered for reconstruction and one or more of its design components do not meet current design criteria. An exception might be needed if there are significant adverse impacts associated with bringing the roadway into compliance with current criteria. For example, a highway was in compliance with the criteria "of the day" when it was originally designed with 11-ft lanes and 2-ft shoulders. However, it is now being considered for reconstruction and the current criterion requires provision of 12-ft lanes and 8-ft shoulders. If the right-of-way impacts associated with widening the roadway are significant, a design exception may be requested to allow continued use of the existing cross section.

The second scenario occurs when a roadway component that is compliant with current criteria is being reconstructed and a proposed new value for its dimension does not meet the minimum threshold for a controlling criterion. In this scenario, the change is in a direction of "compliant" with the current controlling criterion to "not compliant." For example, a multilane highway has four 12-ft lanes and 8-ft shoulders that are compliant with current criteria. It is now being considered for reconstruction that would include the provision of a center turn lane; however, right-of-way constraints preclude any widening of the roadway. A design exception may be requested to allow the use of five 10-ft lanes and 7-ft shoulders.

AMFs are less likely to be available for the second scenario because agencies rarely implement changes in this manner (in which case they are difficult to study). Such AMFs are referred to herein as "non-compliant AMFs." More generally, AMFs are developed using crash data for design features that are brought into compliance with a design criterion. These AMFs are referred to herein as "compliant AMFs." In some instances, it is possible to mathematically estimate a non-compliant AMF using a compliant AMF (e.g., by taking its reciprocal). However, the use of converted AMFs to evaluate a design exception (in the context of the second scenario) would represent an significant extrapolation and would be of suspect accuracy.

Procedure. The procedure for estimating the safety effect of a design exception is similar to that used to evaluate design alternatives; however the use of the existing crash counts is recommended because of the improved accuracy that they provide. In this procedure, Equation 7 is first used to estimate the expected number of crashes for base conditions N_{base}. Then, AMFs are used in Equation 6 to adjust the value obtained from the base model such that the result is an estimate of the expected crash frequency associated with the existing design $N_{w/o}$. Next, the existing crash count X is used with $N_{w/o}$ in Equation 8 to estimate the expected number of crashes at the subject location, given that X were reported $N_{p|x}$. It serves as an estimate of $N_{w/o|x}$ (i.e., $N_{w/o|x} = N_{p|x}$). Then, a design change is specified and the corresponding AMF is identified. Finally, the change in safety ΔN is quantified using Equation 14.

Example Application. In this example application of the design safety evaluation, a 3-mile two-lane rural highway segment linking two major intersections is being reconstructed. Existing lane widths are 11 ft with no shoulders. The traffic volume is estimated at 5,000 veh/d. The controlling criteria for this project requires 12-ft lanes and 8-ft shoulders. However, existing land development is intensive and acquisition of the needed additional right-of-way would be significant. Existing crash history indicates the occurrence of nine crashes in the previous three years along the segment.

Step 1: Estimate Expected Number of Crashes for Base Conditions. The safety prediction model included in the prototype chapter for rural two-lane highways of the forthcoming *Highway Safety Manual* (*9*) can be obtained from Equation 7 by substituting the following values for the calibration coefficients: $a = 0.0002244$, $b = 1.0$, $c = 0.0$, and $d = 0.0$. Using this model, the expected number of crashes for the base condition is estimated as:

$$
\begin{aligned}
N_{base} &= 0.0002244 \times ADT \times L \\
&= 0.0002244 \times 5000 \times 3 \\
&= 3.37 \; crashes/yr
\end{aligned}
\tag{19}
$$

This equation predicts crash frequency for a road segment having a specified set of typical design element dimensions. The dimensions that underlie Equation 19 include 12-ft lanes and 6-ft shoulder widths (*9*).

Step 2: Adjust Base Conditions to Reflect Existing Design. Using AMFs available from Figure 1, the value from Equation 16 is adjusted to reflect existing conditions (i.e., 11-ft lanes, and no shoulder). These AMFs are $AMF_{lane\_width} = 1.02$ and $AMF_{shoulder\_width} = 1.18$. The result of this computation is:

$$
\begin{aligned}
N_{w/o} &= (AMF_{lane\_width} \times AMF_{shoulder\_width}) \times 3.37 \\
&= (1.02 \times 1.18) \times 3.37 \\
&= 4.06 \; crashes/yr
\end{aligned}
\tag{20}
$$

Table 2. Summary of AMFs for Quantifying Design Inconsistencies.

Design Component	Applicable AMF Variable	Critical Values by Warning Level	
		Level 2	Level 1
Reduction in lane width	$AMF\%$	5.0 %	10 %
Reduction in shoulder width	$AMF\%$	5.0 %	10 %
Driveway density	ΔAMF	0.05	0.10

For changes in driveway density, Wooldridge et al. (*14*) suggest the use of the following equation to estimate the impact on design consistency:

$$\Delta AMF = AMF_{Segment\,2} - AMF_{Segment\,1} \tag{25}$$

The critical values associated with this equation are listed in the last row of Table 2. Inconsistencies are noted to exist only when driveway density increases between adjacent highway segments.

It should be noted that this procedure has not been validated through practical application. As such, it should be considered experimental and any results from its use carefully examined. The main point of the discussion in this section is that some researchers believe AMFs may be useful in evaluating design consistency. However, additional work is needed to: (1) refine the evaluation procedure so that it can be used with a wider range of design components, and (2) confirm the validity of the critical AMF warning levels.

Example Application. In this example application of the design consistency evaluation procedure, a 3-mile two-lane rural highway segment linking two major intersections is being reconstructed. The segment AADT is 5000 veh/d. For the first 1.5 miles, the segment has lane widths of 12 ft and shoulder widths of 8 ft. For the last 1.5 miles, the shoulder width is reduced to 4 ft. The traffic volume is estimated at 5000 veh/d.

The evaluation of design consistency for the subject highway is based on a comparison of the two AMFs for shoulder width. Based on Figure 1, the AMF for the shoulder width on the first segment $AMF_{segment\,1}$ is 0.95. The AMF for the shoulder width on the second segment $AMF_{segment\,2}$ is 1.05. Equation 24 is used to estimate the effect of this change on design consistency as:

$$AMF\% = 100\left(\frac{1.05}{0.95} - 1\right) \tag{26}$$
$$= 11\%$$

The reduction in shoulder width results in an 11-percent change in AMF. This value exceeds the critical value of 10 percent identified in Table 2 indicating a Level 1 violation of design consistency. Guidance by Wooldridge et al. (*14*) is that strong consideration should be given to increasing the shoulder width to 8 ft throughout the segment.

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It was found that maintaining the existing (narrow) lanes and shoulders may result in there being one more severe crash in a four-year period.

From a safety perspective, requiring compliance with current criteria is attractive. However, this estimate represents only one piece of information about the effect of a design exception; the decision to accept or reject the request should be made in the larger context of its overall impact on operations, safety, right-of-way, and construction cost. For example, if the extra lane and shoulder width require a reduction in clear zone width, then crashes may actually increase if the request for exception is denied and the clear zone is reduced. The procedure described herein can be used to evaluate this combination of conditions, if needed.

It should be noted that Steps 4 and 5 could be repeated for other lane or shoulder widths and the incremental effect of this width evaluated in more detail. It is possible that the consideration of all impacts may lead to the conclusion that an exception that allows for a 6-ft shoulder width may offer the best combination of conditions.

Design Consistency Evaluation

As described previously, geometric features that violate driver expectancy may increase the risk of driver error and decrease the safety of the roadway. Recent research on this topic has focused on quantifying the safety effects of design inconsistencies for various geometric elements. In fact, Wooldridge et al. (*14*) proposed the use of changes in AMF, speed, and lane position to identify design inconsistencies for successive rural two-lane highway segments. The following geometric design elements were included in their analysis: lane width, shoulder width, lane drop, driveway addition, and length of passing lanes.

Procedure. For reductions in lane width and shoulder width, Wooldridge et al. (*14*) suggest the use of the following equation to estimate the impact on design consistency:

$$AMF\% = 100\left(\frac{AMF_{Segment\,2}}{AMF_{Segment\,1}} - 1\right) \tag{24}$$

In this equation, Segments 1 and 2 are numbered in the direction of travel.

Wooldridge et al. suggest that a design inconsistency exists if the *AMF%* exceeds specified critical value. The first two rows in Table 2 summarize the critical values proposed by Wooldridge et al. (*14*) for lane width and shoulder width. These values correspond to a two-level warning system. Level 1 denotes a condition for which mitigation is strongly encouraged. Level 2 denotes a condition deserving of an advisory warning and a suggested need for improvement. It should be noted that inconsistencies are stated to exist only when the lane width or shoulder width is reduced.

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Step 3: Estimate the Expected Number of Crashes Given that X were Reported. Equation 8 is used to refine the estimate of expected crash frequency based on the estimate from Equation 20 and the reported crash count. First, the weight w is computed from Equation 9 as:

$$w = \left(1 + \frac{K N_p Y}{L} \right)^{-1}$$

$$= \left(1 + \frac{0.24 \times 4.06 \times 3}{3.0} \right)^{-1} \tag{21}$$

$$= 0.51$$

The value of K (i.e., 0.24) used in this equation is provided in Exhibit 15 of the draft Chapter 8 of *Highway Safety Manual (9)*. The weight w is then used in Equation 8 to estimate $N_{w/o|x}$ as:

$$N_{w/o|x} = N_{w/o} w + \frac{X}{Y} (1 - w)$$

$$= 4.06 (0.51) + \frac{9}{3} (1 - 0.51) \tag{22}$$

$$= 3.54 \; crashes/yr$$

The fact that 3.54 is less than 4.06 is an indication that the subject highway segment is safer than similar segments with similar volume and geometry. It should also be noted that nine crashes in three years represents an average of 3.0 crashes/yr yet Equation 22 indicates that this average underestimates the true, long-run average of 3.54 crashes/yr.

Step 4: Specify the Design Change and Identify the Appropriate AMF. The design change to be evaluated is that needed to bring the segment into compliance with the controlling criteria. In this example, the design change is the use of 12-ft lanes and 8-ft shoulders, as required by the existing design criteria. From Figure 1, AMFs are identified for the changes in lane and shoulder width as $AMF_{lane\_width} = 1.00$ and $AMF_{shoulder\_width} = 0.95$.

Step 5: Compute Safety Change. The change in safety as a result of compliance with the controlling shoulder width criterion is:

$$\Delta N = 3.54 \left(\frac{1.00 \times 0.95}{1.02 \times 1.18} - 1 \right)$$

$$= -0.75 \; crashes/yr \tag{23}$$

From this computation, it appears that compliance with the shoulder width criteria is estimated to reduce crash frequency on the segment by 0.75 crashes/yr (i.e., three crashes in four years). Alternatively, granting the request may result in there being three more crashes in a four-year period than if it were denied. The analysis above was repeated using only severe crash frequency.

AVAILABLE AMFs

This section lists the geometric design components and features for which AMFs are available from the literature and applicable to highway geometric design. The objective of this section is to identify the AMFs that are currently available and for which there is sufficient documentation available on their development to ascertain their having reasonable accuracy. Specific AMF constants and functions are not presented in this section as they are not needed to achieve the stated objective.

Tables 3 and 4 list the AMFs available in the literature. Table 3 addresses AMFs for highway segments. Table 4 addresses AMFs for intersections. Reference numbers are used in each table to denote AMF availability and to provide an indication as to where the AMF can be found. CRFs for many of the components and features listed in the tables are also available and, using Equation 4, can be converted to AMF constants. The numerous indications of "n.a." are an indication that the safety impacts of many design components have yet to be accurately quantified.

Table 3. Sources of Design-Related AMFs for Road Segments.

Type	Design Category	Design Feature	Design Component	AMF Source Reference Number		
				Freeway	Rural Highway[1]	Urban Street
Road segments	Geometric design	Consistency	--	n.a.	14	--
		Horizontal alignment	Curve	18	9, 17 ‡	n.a.
			Spiral	n.a.	9	--
		Vertical alignment	Curve	17	17	--
			Tangent	n.a.	9	--
		Cross section	Traffic lane	n.a.	9 ‡	n.a.
			Shoulder	n.a.	9 ‡	--
			Median	n.a.	9 ‡	‡
			Passing lane (2-lane hwy.)	--	9	--
			On-street parking	--	--	18
		Accommodations for ped. and bike modes	Sidewalk	--	--	‡
			Midblock pedestrian crossing	--	--	18
	Roadside design	Cross section	Horiz. clearance to obstruction	17 ‡	9, 17 ‡	‡
			Side slope and ditch	n.a.	9	n.a.
	Access control	Access type	Driveway	--	9	n.a.

Notes:
1 - AMFs from References 9 and 14 apply only to two-lane rural highways.
‡ - This AMF is tentatively planned for development in NCHRP Project 17-25.
n.a. - AMF is not available.
"–" - not applicable.

Table 4. Sources of Design-Related AMFs for Intersections.

Type	Design Category	Design Feature	Design Component	Design Element by Area Type	
				Rural	Urban
Signalized intersections[1]	Geometric design	Horiz. alignment	Left-turn bay	9 ‡	‡
		Cross section	Right-turn bay	9	n.a.
			Island channelization	--	‡
			Alignment skew	9	n.a.
		Sight triangle	--	9	n.a.
Unsignalized intersections[1]	Geometric design	Horiz. alignment	Intersection legs (3 vs. 4)	9	n.a.
		Cross section	Left-turn bay	9 ‡	‡
			Right-turn bay	9	n.a.
			Island channelization	--	‡
			Alignment skew	9, 17	17
		Sight triangle	--	9	n.a.

Notes:

1 - Components also apply to frontage-road intersections at the interchange crossroad.

‡ - This AMF is tentatively planned for development in NCHRP Project 17-25.

n.a. - AMF is not available.

"–" - not applicable.

In a recent review of available CRFs, Shen et al. (*3*) found that some state DOTs have developed over 100 CRFs. These CRFs are not listed in Tables 3 and 4 because they lack documentation about their derivation and whether the four previously described sources of bias were removed from the underlying data. Frequently, the CRFs listed by Shen et al. for the same improvement category exhibit wide variability among the state DOT sources. This variability of CRFs among the states is evidence of possible bias in the factors.

ISSUES RELATED TO THE DEVELOPMENT AND APPLICATION OF AMFs

As noted in the previous section, numerous design-related AMFs need to be developed through research. In some instances, an existing CRF could be used in the design process; however, there is evidence that many CRFs have some bias, depending on the methods used for their development. Also, CRFs represent a subset of AMFs because they always address a crash *reduction* due to some type of improvement whereas AMFs are more versatile in that they address a change in crashes (increase or decrease) as a result of a change in design (which may not always be considered an improvement). This section discusses the issues associated with the development of AMFs for design-related applications.

Relationship between AMFs and Base Safety Prediction Model

As noted previously, AMFs are applied as a multiplicative factor to a base safety prediction model. The model calibration parameters represent a specified set of base conditions for a given highway or intersection. The AMF is used to adjust the base model to accurately represent

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conditions at a subject facility. The use of an AMF to evaluate the safety impact of a specific change from condition A to condition B is based on the assumption that condition B is *not* represented in the base model parameters. If this assumption cannot be confirmed by a review of the data and methods used to develop the CRF then it is possible that the data used to calibrate the base model reflect an unknown combination of both conditions. If some of the calibration data do include condition B, then it is likely that the expected crash frequency obtained from Equation 6 will be biased to be lower than the true value.

Role of Reported Crash Count

As indicated by the application procedures described in the previous section, the use of AMFs in the design process and in the design exception review process should be based on the use of a base safety prediction model. If reported crash counts are used directly as an estimate of the expected crash frequency of a facility (instead of Equation 6), then it is likely that this estimate will be biased to be larger than the true value.

If the facility being reconstructed has an available crash history, then this data can be used to improve the accuracy of the estimated expected crash frequency (using Equation 8). This use would require that the length of any new alignment not constitute more than 50 percent of the project length (*9*). This restriction is necessary because, when major changes in alignment take place, the reported crash data for the old alignment are not necessarily indicative of the crash experience that is likely to occur on the new alignment.

The use of reported crashes is particularly appropriate for the design exception review process. This use ensures that the safety implications of the design exception are estimated as accurately as possible, in recognition of the possible liability issues that underlie the approval of design exceptions.

In contrast to the aforementioned uses of AMFs in the design process and in the design exception review process, AMFs can be used without base predictive models for an evaluation of design consistency. Moreover, a crash count is not needed for this application.

Combination of Changes

Most AMFs were developed from observations of crash frequency changes following a single change in condition, with all other conditions unchanged. These AMFs are most applicable to facilities undergoing the same, one change (e.g., a lane widening project). They could also be justifiably combined (using Equation 5) and applied to facilities undergoing several unrelated changes (e.g., a lane widening project and the installation of new breakaway poles).

The estimate obtained from Equation 5 may not be accurate when the changes in design are related. Consider a project that involves lane and shoulder widening along with the addition of a climbing lane for the vertical grade section. These three changes are not independent because they

are likely to each reduce similar types of crashes on a common road segment. In this instance, the combined AMF (obtained from Equation 5) may overstate the true crash reduction potential of the three treatments. NCHRP Project 17-25 is expected to examine this issue in terms of the safety effects of simultaneous changes in geometric design components and/or traffic control devices.

Constant versus Function

Most AMFs are constants that are independent of traffic volume or other measures of crash exposure. A constant AMF implies that the portion of crashes reduced on a highway segment (or at an intersection) will be the same regardless of whether few or many vehicles travel through the facility. It is possible that the magnitude of the AMF may change for different levels of exposure. In fact, an effect of AADT has been documented in the AMFs for lane width and for shoulder width (see Figure 1) (9). There is a need to examine more closely the influence of different geometric design and traffic volume characteristics on some AMFs.

Crash Severity and Crash Type

The safety effects of changes in geometric design characteristics are likely to have a different affect on the severity of crashes (i.e., property-damage-only, injury, and fatal). For instance, converting fixed utility poles and sign supports to breakaway poles and supports should not change crash frequency but it should reduce the number of crashes leading to injury. A similar case for AMF sensitivity to crash type (e.g., rear end, right angle, fixed object) can also be made. Few AMFs have been developed that are specific to various levels of crash severity and crash type. NCHRP Project 17-25 is expected to examine these issues.

Crash Migration

Some AMFs predict the change in a specific type of crash, as a result of a change in geometry or traffic control device. For example, AMFs used for estimating the safety of different lane widths usually target run-off-the-road and head-on collisions (9). However, these changes could also effect crashes that are not of the intended type. Recent evaluations of camera enforcement effectiveness at signalized intersections have shown that enforcement cameras reduce right-angle crashes. However, these evaluations have also found that camera enforcement can increase rear-end collisions (18). This issue highlights the need for care in developing AMFs that target specific crash types.

CHAPTER 3. CONCLUSIONS

AMFs have a very definite and emerging role in the highway geometric design process. They can be used during various stages of highway design, the design exception evaluation process, and the design consistency review process. The procedures described in this report need to be refined and, possibly, automated using a spreadsheet to facilitate their use by TxDOT engineers.

Recent research has identified several issues that are likely to result in biased estimates of CRFs and AMFs if proper statistical techniques are not employed. There is compelling evidence that many of the CRFs developed for the HES program have some bias in them. This bias is due to many problems associated with before-after studies that were not well understood in previous years. New statistical techniques have been developed to mitigate this bias. These new techniques need to be used in the development of any new CRFs used by TxDOT.

To fully serve the highway design process, several additional AMFs are needed. As is evidenced in Tables 3 and 4, there are a relatively small number of design-related AMFs available at this time. There is also a need for AMFs for use in the design of pedestrian, bicycle, and transit facilities in the vicinity of streets and intersections. Similarly, agencies lack AMFs that reflect the geometric components of interchange ramps. Finally, AMFs applicable to ramp gore areas and ramp terminals at frontage roads are needed for Texas design applications. Specific AMFs in each of these categories are listed in Table 5. A review of the research in progress nationally indicates that the AMFs listed in this table are not being developed by other agencies. It is expected that some of these AMFs will be developed for TxDOT Project 0-4703.

Table 5. Summary of AMFs Needed.

Intersections	Interchange Ramps	Ramp Gores	Ramp Terminal at Frontage Road
• Channelized right-turn lane • Curb return radius & design • Driveway access density • Pedestrian crossing location • Bike lanes location & width • Approach lane width • Approach shoulder width	• Ramp configuration • Horizontal curve radius • Lane width • Shoulder width • Grade	• Gore configuration • Acceleration lane length • Deceleration lane length • Divergence angle • Entrance taper	• Terminal configuration • Ramp length • Divergence angle • Weaving section length

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