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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.

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 ($= 5.0 \times 0.93$).

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:

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

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., $CRF_{re} = 0.20$).

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:

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

where:

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

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:

$$CRF_c = 1 - (1 - CRF_1) \times (1 - CRF_2) \times (1 - CRF_3) \times \dots \times (1 - CRF_n) \quad (3)$$

where:

CRF_c = combined CRF for all n countermeasures.