Improving the Highway Safety Process: An Update and Enhancement to the Oregon DOT's Crash Reduction Factors List

Christopher M. Monsere, Robert L. Bertini, David de la Houssaye and Peter Bosa

ABSTRACT

Appropriate selection of cost-effective countermeasures for highway safety improvement projects requires an estimate of the safety effects of alternative designs. The Oregon Department of Transportation (ODOT), like many agencies, makes these estimates using crash reduction factors (CRFs). Since the development of ODOT's original database in the early 1990s, there have been significant methodological improvements in the evaluation of engineering countermeasures that have resulted in a wealth of new published research. This project, when complete, will provide a comprehensive update to ODOT's CRFs database. The CRFs are being updated via a thorough review and quality assessment of recent literature with input from an expert advisory group. Results will be incorporated into ODOT's safety project analysis tools and disseminated through ODOT's regional offices and other local agencies using an interactive web page. The CRF website will allow users to interactively search for effective countermeasures for a based on key parameters, as well as providing direct access to the literature review database. This paper provides a summary of national and international concurrent and complementary research, discusses the methodology used to review CRFs, and outlines development of an interactive web page.

INTRODUCTION

Developing a transportation system that balances safety, mobility and efficiency is a primary objective of most transportation agencies. Most will identify safety as a top priority or goal. In spite of these objectives, there are still an unacceptably high number of traffic-related fatalities and injuries on United States highways—upwards of 42,000 fatalities and almost 3 million injuries per year (NHTSA, 2003). Nearly every state has a highway safety improvement program, many of which were implemented with Federal guidance following the passage of the Highway Safety Act of 1966. Typical state approaches to highway safety improvement include the following steps (Davis, 2000):

1. Identification of hazardous roadway locations using crash records;
2. Detailed engineering studies of selected hazardous locations to identify roadway design problems;
3. Identification of potential countermeasures;
4. Assessment of the costs and benefits of potential countermeasures;
5. Implementation of countermeasures with the highest net benefits; and
6. Assessment of countermeasure effectiveness following implementation.

Identification and implementation of countermeasures are keys to safety improvement planning. The estimated economic benefits clearly depend on expected crash reductions from each countermeasure, yet these projections are considered the least certain element of the safety improvement planning process (Pfefer, 1999). These projections are called crash reduction factors (CRFs) and are estimates of the expected reduction in different crash types following the implementation of a particular countermeasure. Alternatively, some literature and some states may discuss CRFs as accident reduction factors (ARF) or accident or crash modification factors (AMF/CMF).

CRFs are used by many states, including Oregon, as a tool to evaluate the cost-benefit relationships between various roadway improvements and their effectiveness in reducing crashes and/or reducing the severity of those crashes. Although a need was recognized for a comprehensive national list of crash reduction factors 30 years ago (Strathman et al., 2001), responsibility for their development has, until very recently, remained with individual states. Most states have compiled their lists from the literature coupled with evaluations of their own projects. Few states have had the resources, expertise or a sufficient number of applications to conduct statistically valid studies. As such, considerable variation exists among states in the types of countermeasures used and the quality and sources of research used (Strathman et al., 2001).

Fortunately, countermeasures for highway safety improvements and research into their effectiveness have become a major focus in transportation research and planning in recent years. This research has been moving to a national level, which is a very positive development. The American Association of State Highway and Transportation Officials (AASHTO) Strategic Highway Safety Plan (SHSP) and the Federal Highway Administration's adoption of the "Vital Few" approach, along with work toward developing a Highway Safety Manual have provided the necessary motivation.

ODOT has used their current list of countermeasures since the early 1990's and has embarked upon a project to update and enhance the Oregon CRF database. The following sections present a summary of previous and continuing research in the area, describe research objectives and methodology, and present a description and example of how the CRF database will operate.

SUMMARY OF SIMILAR EFFORTS

Currently, there are many relevant safety-related research efforts underway at the state, national and international levels. One key project to evaluate countermeasures is currently sponsored by the National Cooperative Highway Research Program (NCHRP). The goal of NCHRP Project 17-25, "Crash Reduction Factors for Traffic Engineering and ITS Improvements" is to "develop reliable CRFs for traffic engineering, operations, and ITS improvements." Five criteria are given for "reliable" CRFs (NCHRP, 2005):

- The CRFs are methodologically and statistically valid;
- The applicability of the CRF is known and documented;
- The CRFs reflect improvements or combinations of improvements that are of interest to DOT's;
- The CRFs should represent the different crash categories that reflect the impact of the improvement; and
- The CRFs reflect variability, which should be statistically documented.

The NCHRP project is more extensive than the Oregon update and includes comprehensive state surveys and interviews.

The Highway Safety Manual (HSM) will incorporate safety performance into the elements involved in highway planning, design, maintenance, construction and operation decisions of state roads and highways. The HSM will be a comprehensive source for safety knowledge much like the Highway Capacity Manual (HCM) is for traffic operations. It is being developed by the Task Force for the Development of the HSM, a committee of the Transportation Research Board. NCHRP 17-25 is coordinating closely with the HSM.

Another effort, Safety Analyst, is a software package under development by the Federal Highway Administration (FHWA) in partnership with thirteen state Departments of Transportation. The vision is to "provide state-of-the-art analytical tools for use in the decision-making process to identify and manage a system-wide program of site-specific improvements to enhance highway safety by cost-effective means." (Safety Analyst, 2005). The tool will provide a method for network screening, countermeasure selection, and cost-benefit analysis.

Several states have compiled lists of countermeasures and their effectiveness, but each state has followed a different design and used differing research standards in their reports. Among the states whose reports are available are South Dakota, Ohio, Kentucky, and North Carolina. Pedsafe, an online searchable database available at *http://www.walkinginfo.org/pedsafe*, is a very thorough and well-categorized information source for pedestrian and bicycle countermeasures.

Finally, there are numerous print-based guidebooks and manuals available that are a "toolbox" for practitioners, particularly those attempting to incorporate low-cost safety improvements into their projects. The NCHRP has produced a series of guides for highway and road design as part of the AASHTO initiative to implement the SHSP, listing countermeasures by crash type and evaluating each based on the extent of their application and studies of effectiveness. These 13 guides are available on-line from the NCHRP/AASHTO website as Report 500 (see *http://safety.transportation.org*). The Institute of Transportation Engineers (ITE) has also released a listing of various countermeasures and their effectiveness in table format. The "ITE Toolbox of Countermeasures" list includes cost categories, and indicates which countermeasures are applicable for different crash types (ITE, 2004).

The need for reliable CRFs has clearly been recognized. There is also research evaluating individual strategies and the literature is expanding rapidly. This project has drawn on many of these reports to develop a list of crash reduction factors, and will use them selectively for data on crash reduction percentages. The NCHRP guides appear to be the best recently completed comprehensive source, referencing most of the studies available from and providing evaluations of research quality.

PROJECT OBJECTIVES

In spite of the above efforts, ODOT identified a need to create a database of CRFs and countermeasure options that could be considered for use on ODOT projects. ODOT's existing list contains approximately 70 total countermeasures, divided into categories that often do not clearly relate to particular situations or crash types. These countermeasures are currently used in Oregon's Countermeasure Analysis Tool (an internal web-based tool used to perform benefit-cost analyses of safety projects). The current list lacks documentation for the engineer to make judgments about the applicability of the particular countermeasure and the descriptions do not always make clear the methods, resources or statistical reliability of analyses used to develop the CRF.

A need was recognized to compile and present countermeasures in a way that would make it far simpler for ODOT engineers and planners to search for applicable countermeasures for a given situation, and to have a greater degree of confidence in the CRF described. This project has improved the categorization scheme of these countermeasures for easier lookup, and provides easy access to a summary of the existing research and effectiveness of each countermeasure where credible research is available. This encourages the engineer and planner to "drill down" to the original research sources of each CRF. Most crash reduction factor lists do not reflect the specific applicability of CRF research or the reliability of the study methods. This information will be included in the final CRF database. Finally, another goal is to clearly document the methodology and sources to enable easy updating of the database in the future. Much new research is being performed; the advantage of a well-designed database is that this new research can be easily incorporated as it is published.

METHODOLOGY

Database Design

The new CRF database includes a complete listing of crash reduction factors, beginning with ODOT's original list and incorporates lists from other states and from the literature including (Pline, 1992), (Agent, 1996), (Ogden, 1996), (Tople, 1998), (SEMCOG, 1998), (Robertson, 2000), (Huang et al., 2001), (Ohio DOT, 2003), (ITE, 2004a), (NCHRP, 2003a-h) and (ITE, 2004b). This resulted in a list of approximately 200 countermeasures currently that was reduced to a smaller subset based on research findings and expert panel input.

These countermeasures were first categorized into an urban or rural separation, although many are applicable to both cases. A second categorization classified each countermeasure according to its applicability to intersections, roadway segments, or pedestrian crashes. A third categorization was based on countermeasure type, broken down into:

- Design improvement;
- Markings or signs;
- Operations/Intelligent Transportation Systems;
- Pedestrian;
- Railroad crossing;
- Roadside improvement; and
- Traffic calming.

Further categories include crash types and specific causal factors, such as weather, speed, and visibility. Crash type categories include angle, head-on, sideswipe-meeting, sideswipe-overtaking, ran off roadway, parking maneuver, rear-end, turning movements, pedestrian or bicycle, driveway related, and railroad crossing. Many countermeasures fall into multiple categories; this will be incorporated into the search engine so that all countermeasures applicable to given search criteria will be shown. The intent and design of the database is to provide very direct countermeasure descriptions rather than a very detailed list. For example, one CRF researched is curve flattening, where a major study shows very different results depending on the percentage reduction performed. A 30-degree curve flattened to 5 degrees results in a reduction of total crashes of about 80%, whereas the same curve flattened to 25 degrees results in about a 16% reduction in total crashes (NCHRP, 2003d). The study gives a variety of curve radii and the corresponding CRF for different changes, but the database will need to be limited to only a few examples.

Research Evaluation

It is well documented in the literature that many past safety analysis were of poor quality because their methodology did not account for some rather common problems with crash data or trends. Shen and Gan (2003) and Hauer (2005) discuss several recognized problems, including:

- Regression to the mean: a phenomenon where a countermeasure is assumed to be implemented during a period of unusually high crash rates, thus the crash rates in the after period could be assumed to be lower even without the countermeasure as they approach the historical mean for the location.
- Crash migration: a controversial phenomenon, where a treatment in one area results in higher crash rates at another area. For example, when a curve is flattened as in the above example, crashes on that particular curve might be reduced while a resulting increase in speed (caused by the flatter curve) might increase crashes on the next curve.
- Maturation: the prospect that a before and after study might fail to recognize pre-existing trends in crashes at that location. Other factors could be causing a year to year reduction in crashes, such as weather, traffic flow, crash reporting practices, etc. Changes in these factors could result in a downward (or upward) trend in crashes before the countermeasure, which could be expected to continue without the improvement
- External causal factors: separated into two main groups: those that can be “recognized, measured and understood such as traffic volume growth,” and less recognizable factors such as weather, economic conditions, etc. While the first group can be compensated for in a before-after study, those in the second group could contribute to any observed effect of a treatment, potentially changing between the before and after time periods and affecting the results of the study.

As part of the critical review, research on each countermeasure and resulting CRFs will be evaluated on a 1 to 5 scale (5 representing highest quality) for quality and thoroughness. This will be based on the type of study (see below), the extent of the research, and the quality of the citations. If the source or study quality is not verifiable, the study will receive a score of 1. These scores will be weighted and a composite CRF will be determined and expressed, in most cases, as a range.

A brief summary of the types of studies to be found in the literature are described in the following subsections. The most common study type is the simple before and after comparison, called the naïve before and after study by Hauer (1997). Increasingly common and more reliable, other methods of study include the before and after with comparison group method and the before and after study with Empirical Bayes (EB) method. These study designs are considered somewhat more effective in accounting for some of the above issues.

Simple Before and After Study

In this analysis, accident data is taken after the implementation of the countermeasure and compared to crash data before its implementation. Typically, a two to three year period both before and after the countermeasure is used to compare crash rates. In most cases, the site is chosen for its crash performance in the past and regression-to-the-mean is likely to be present. Adjustments for volume, weather, and other factors are usually not taken into account. These studies are considered the least reliable of the study types but will be rated based on evidence provided by the researchers to address the above limitations. Studies using this method were ranked of 1-3 depending on study methodology.

Comparison Group

A before and after with comparison group study employs a group of control sites without treatment to compare with the treated site. These control sites must be similar in terms of geography and traffic volume characteristics. The method improves on the simple before and after model by predicting expected crashes at the treated site. However, the results are only as good as the quality of the relationship between the control sites and the treated site. Studies using this method were ranked of 2-4 depending on study methodology.

Cross Sectional Studies

In these studies, multivariable regression models are constructed to estimate the effect of various roadway design features on crash performance. They have the methodological advantage of being able to avoid many of the problems with regression-to-the mean but have the additional problem of sorting out the influence of each variable in the analysis. For example, many roadway attributes are correlated (a roadway with high design standards is also likely to have paved shoulders) and these interactions need to be properly designed and controlled. Most safety researchers recommend interpreting the results of these models with care. Studies using this method were ranked of 2-4 depending on study methodology.

Empirical Bayes

The Empirical Bayes (EB) method, considered the most accurate and robust, attempts to statistically predict the number of crashes at a given location during the after period had no treatment been done. The EB method is best described by Hauer (1997). The methodology uses historical crash data for a treated site in combination with estimated safety performance functions to predict crashes at the treated site without application of any countermeasure. With proper application, the method can account for many of the crash data problems and trends. At the present time, studies that use this methodology are considered state-of- the-art. Studies using this method were ranked of 3-5 depending on study methodology.

Countermeasure Synthesis

The final database provides a brief summary of research for each countermeasure and some reflection of the validity of each study. Where reliable research is available, the database includes an average percentage reduction in crashes for each countermeasure. Some of these numbers in the literature refer to all crashes, others to a particular crash type. Some differentiate between fatal, injury and property damage crashes, although this differentiation has been rare in the literature. The database includes specific information on the applicable crash type for each percentage reduction given in the literature and shows a range of values from different studies where available.

PRELIMINARY RESULTS

To date, a listing of countermeasures has been compiled and categorized. Many of the countermeasures fall into multiple categories, and apply to multiple crash types. As the research has progressed, the categories and database have been modified to include additional information about each countermeasure to enable effective and comprehensive lookup abilities. In the near future, the CRF review, website and database should be completed and searchable online.

The online CRF database will be provided through an interactive website. The interface is designed for both new and advanced users. An icon-intensive "walk-through" design will guide users through a pre-determined listing of attribute categories. First, users will be asked to choose whether they are concerned with an area located within an urban, rural, or both (urban and rural) setting. Next, the user will be asked to choose among the three crash types: intersection, roadway, or pedestrian. Similar screens guide the user through a selection of countermeasure type, crash type, and causal factors. Since the number and type of options available to the user at each screen are determined by the previous selection, the user eventually ends up with an output of countermeasures for use in a very specific situation. This approach is an effective means of quickly identifying a short-list of possible countermeasures of interest to the user. The icons will provide an easy to follow symbology of all countermeasure category elements, which eliminates confusion generated by the definition terms.

An additional advanced query page will enable broad queries of the database. For example, one could perform a query for all countermeasures applicable to an urban environment regardless of other characteristics. Users of the website may choose to use this more robust advanced query page to access the CRF database. From this text-based screen, the user is asked to identify all elements of every countermeasure category that are of interest. Any, all, or none of the elements may be selected from each category, which provides maximum user control over the query process. Figure 1 shows a sample query from the interactive page.

Each search method—icon-driven or advanced query—will produce a list of effective countermeasures suitable to the search criteria. The user can then select *Summary Pages* for each of the listed countermeasures. Figure 2 is an example of a summary page. The summary page lists the specific countermeasure, a picture, corresponding crash reduction factors, applicable use criteria, brief discussion of the countermeasure, and references used to determine the countermeasure's CRFs.

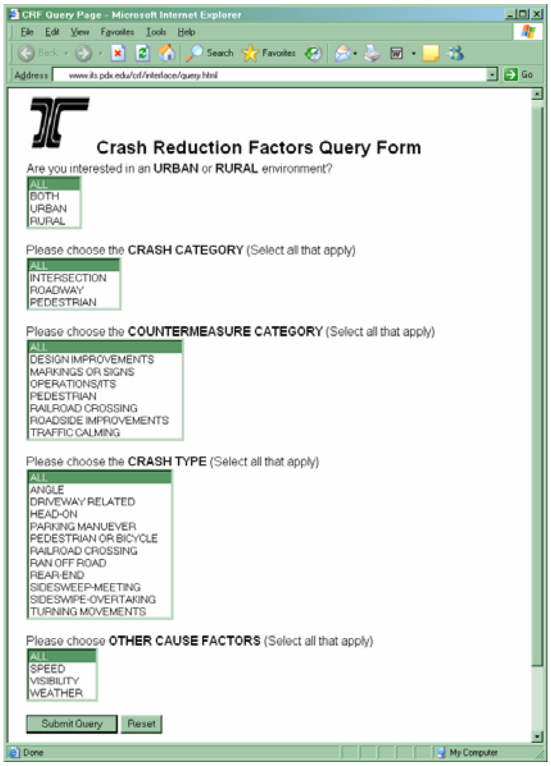

Figure 1. Sample Query Form

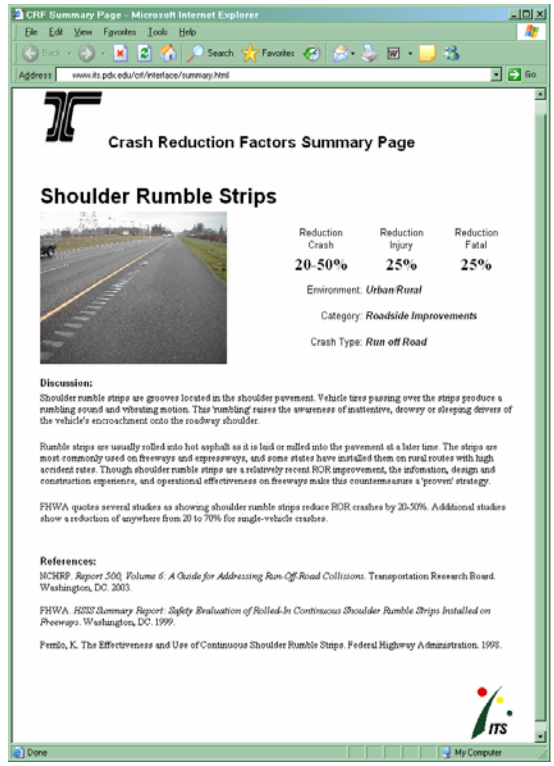

Figure 2. Sample CRF Summary

CONCLUSIONS

This project aims to compile the best available data for a comprehensive list of countermeasures and their respective crash reduction factors for ODOT to use in their transportation safety planning and engineering. The final database product will provide ODOT and local Oregon agencies with an easily searchable reference base for looking up the available data on a wide range of countermeasures. The new flexible database design will include a notation for the reliability of the research and will be as specific as possible regarding crash reduction factors and the crash types to which they apply. Actual results from applying these countermeasures should be expected to vary according to specific circumstances of their application. Any intersection or roadway segment will have different characteristics, and the results of any countermeasure can be expected to vary. Often, countermeasures are used in combination, making precise study of any one countermeasure more difficult. It is important to note that most CRF data should be used only as a guide; professional judgment in particular situations must continue to play a major role in decisions. No list of countermeasures, no matter how carefully researched, can accurately predict impact on every unique traffic situation. The usefulness of such a list is limited to expected benefit-cost analysis, as well as providing ideas for countermeasures to be applied under specific circumstances.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support and extend special thanks to the Oregon Department of Transportation, particularly the members of the project Technical Advisory Committee. We also acknowledge the support of Barnie Jones and Rob Edgar of ODOT Research. We acknowledge the support of our research team members including Carolyn Bonner (now with Ferguson and Associates), Beth Wemple at Kittelson and Associates, Inc., John McGill at Synectics Transportation Consultants, Inc., Dr. Kate Hunter-Zaworski and Matt Little of Oregon State University. The contents of this report reflect the views and opinions of the authors, who are responsible for the facts and the accuracy of the data presented here.

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