National Cooperative Highway Research Program

NCHRP Synthesis 202

Severity Indices for Roadside Features

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Synthesis of Highway Practice 202

Severity Indices for Roadside Features

DANIEL S. TURNER
University of Alabama
and
JEROME W. HALL
University of New Mexico

Topic Panel

WAYNE F. COBINE, *Oregon Department of Transportation*
CHARLES E. DARE, *University of Missouri-Rolla*
JAMES H. HATTON, JR., *Federal Highway Administration*
MARK A. MAREK, *Texas State Department of Transportation*
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JOHN G. VINER, *Federal Highway Administration*
J. RICHARD YOUNG, JR., *Mississippi State Highway Department*

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to highway administrators, safety officials, design engineers, traffic engineers, and analysts who are concerned with improving highway safety. Severity indices, which serve as indicators of the expected injury consequences of a crash, are an integral part of the analysis of proposed roadside safety improvements. Severity indices that have been developed by many states and research agencies are described, as are the issues associated with developing the values, and applying and evaluating the indices.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

The history of severity indices, the issues associated with estimating accident severity and associated costs, and the range of indices that have been developed are described. This publication of the Transportation Research Board also discusses the relationship of accident severity indices with the American Association of State Highway Officials (AASHTO) Roadside Design Guide and the Federal Highway Administration (FHWA) ROADSIDE computer program. While research since the 1960s has sought to quantify severity indices for a range of object types and impact conditions, there remains a wide variation in the values from which analysts may choose when performing cost effectiveness evaluations.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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SEVERITY INDICES FOR ROADSIDE FEATURES

SUMMARY

Over the past 30 years, significant progress has been made in reducing the number of highway fatalities that occur in run-off-the-road (ROR) accidents. Improvements are most evident on interstate freeways, where obstacle-free roadsides and the judicious use of barrier systems provide a restrained motorist in an errant vehicle with a good chance of surviving an excursion onto the roadside. Similar treatments have been effective on arterial, collector, and even local roads, but the expense of implementing corrective action has limited the extent of improvements to these roads.

As part of the economic evaluation of alternative roadside safety improvements, the analyst must compare the incremental benefits resulting from a treatment with the additional costs required to build and maintain it. In these cases, the expected benefits arise from a reduction in the frequency and/or severity of collisions with roadside obstacles. A critical element in the projection of benefits is the severity of those crashes that are expected to occur with and without a particular treatment. These benefits are currently estimated in a multistep process that relies in part on severity indices.

This synthesis traces the historical development of severity indices and notes elements of consistency and disparity in the results of different studies. Alternative definitions were suggested, but most early researchers defined severity indices on a scale of 0 to 1: for specific objects, the severity index represented the proportion of reported accidents that resulted in a fatality or injury. Although there were points of agreement, results from studies often differed, possibly due to variations in object design and placement, impact speed, vehicle characteristics, and similar factors.

By the mid 1970s, a refined procedure and an enlarged scale of 0 (no damage) to 10 (fatality) were used to describe severity. Some indices were based more on professional judgment and expert opinion than on the results of accident studies; these indices were inherently difficult or impossible to validate using traditional methods. During the past 15 years, serious efforts have been made to develop justifiable severity indices using innovative techniques, including analyses of large accident databases, in-depth studies of particular objects, evaluation of vehicle damage, application of accident cost models, and the results of crash testing. In most cases, these studies have increased the level of understanding of severity indices, although the variations in values recommended by different studies have not been eliminated.

The development of severity indices continues today with a number of ongoing initiatives that may help clarify some of the long-standing concerns. One promising study seeks to use comprehensive roadway and accident databases to examine potential methods for establishing severity indices; this study recognizes that advances in vehicle safety, especially airbags, will have a major role in reducing crash severity. Another study is seeking to improve the understanding of the relationships between highway design features

and safety. Several studies are looking at computer-based methods, both in using national accident databases and in improving the computer tools currently used to evaluate roadside safety.

During compilation of this synthesis, an effort was made to identify the state of the practice in the use of severity indices for roadside safety studies. A questionnaire survey distributed to state highway and transportation departments identified several areas where these agencies are experiencing difficulty in evaluating alternative roadside safety improvements. It is clear from the responses that the understanding and use of severity indices currently recommended by the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) is a major concern. Because models for evaluating roadside safety depend on several assumptions regarding vehicle encroachments, the results are especially sensitive to even small changes in the assumed values for severity indices. Survey respondents had mixed feelings about the method of expressing these indices; some requested specific values for an expanded list of objects, whereas others sought a range of values that would accommodate the analyst's judgment. Most respondents make use of the AASHTO guidelines, although some indicated that application of these guidelines has occasionally led to nonintuitive or expensive forms of remedial action. Despite some shortcomings, the AASHTO procedures, together with supplemental information developed by FHWA, represent the best guidance available today; they generally should be used as a starting point for the beginning user. A couple of agencies have gone further and developed their own guidelines for determining problem locations and for selecting treatments.

The findings of this synthesis project offer several important opportunities for additional research. Many users of current roadside safety evaluation methods lack confidence in the results of their analyses; an effort is needed to correct any deficiencies and bolster the confidence of the users. The inventory of objects and conditions included in a list of severity indices should be expanded and annotated to facilitate proper analysis, especially by those analysts with limited engineering experience. The software commonly employed to simplify the analyses should be made more user-friendly; modifications should also limit the opportunity for serious errors due to the unwary acceptance of default values within the program. Levels of understanding of the roadside cost-effectiveness methodology vary considerably with the training and experience of the analyst; consequently, there is a real need for expanded training in this area, especially for young engineers.

A major effort is needed to significantly improve the quality and accuracy of severity indices. The endeavor must be comprehensive in terms of the obstacles and conditions addressed, and must recognize the dynamic aspects of both vehicle and roadway technologies that will continue to influence crash severity. The optimal method for undertaking this type of study is not certain. A meaningful study based on accident and roadway data would require extensive, high-quality databases. Alternative study procedures employing some of the innovative techniques used on a smaller scale in several recent studies might provide a better opportunity for resolving the severity index dilemma.

CHAPTER ONE

INTRODUCTION AND BACKGROUND

OVERVIEW OF ROADSIDE SAFETY

Concerted efforts by those involved with the human, vehicular, and roadway aspects of traffic safety have dramatically reduced the hazard of driving on the nation's streets and highways. Nationwide highway fatalities, for example, which consistently exceeded 50,000 per year during the late 1960s, decreased to less than 40,000 during 1992. This reduction in fatalities occurred during a period of substantial growth in the amount of vehicular travel, and as a result, the traffic fatality rate in the United States decreased from 8.8 fatalities per 100 million vehicle-kilometers (100 mvkm) of travel (5.5 per 100 million vehicle-miles [100 mvm]) in 1966 to 2.9 fatalities per 100 mvkm (1.8 per 100 mvm) in 1992. Though the current highway fatality toll is still substantial, there is no doubt that improvements over the last two decades have saved thousands of lives.

Interstate freeways, which promote highway safety by separating traffic from both intersecting and opposing flows, currently have average fatality rates of less than 1.4 fatalities per 100 mvkm (0.9 per 100 mvm). The design and operational features of freeways reduce the potential for serious, multiple-vehicle crashes; approximately 60 percent of freeway fatalities result from vehicles straying onto the roadside and either impacting a fixed object or overturning. Because of the greater opportunity for other crash types, the comparable value for these single-vehicle run-off-the-road (ROR) crashes on arterials is only 34 percent.

The introduction of additional interstate mileage over the past 25 years has been accompanied by an interesting shift in the distribution of all fatal collision types. In the latter half of the 1960s, single-vehicle ROR crashes accounted for approximately 33 percent of the highway fatalities. Despite a strong emphasis on improving roadside safety and the aforementioned decrease in fatality rates, these crashes currently account for nearly 39 percent of the highway fatalities (*1*). Expressed in a different manner, overall highway safety in the United States has shown a dramatic improvement, but fatal crashes involving multiple vehicles and pedestrians have been reduced to a greater extent than single-vehicle ROR crashes.

Roadside Objects

The foregoing statistics may be discouraging to those who have made a sincere effort to improve roadside safety. Many in the highway engineering community responded to the challenge posed by Representative John A. Blatnik in 1968 (*2*):

> It is the height of cynicism to contend that the drivers should never have left the road or that many of them must have been drunk, or that somehow the driver was at fault. Why or how he left the road is not the issue. Whether he left because he was drunk, or stealing a kiss, or because he suffered a bee sting, dozed, had a blowout, was sideswiped, or was forced off is irrelevant to road builders. What is relevant is that those who are responsible for road construction recognize that the roadside is as vital to the safe operation of a vehicle as the pavement itself, and that the duty to make the roadside safe is a very real one.

Representative Blatnik's comments were prompted by testimony from engineers of the 1960s, many of whom felt that their job was to design roadways, rather than to provide safe roadsides for errant drivers. At the urging of Congress and various highway safety organizations, the U.S. Department of Transportation (US DOT) and the American Association of State Highway Officials (AASHO) took leadership positions in promoting roadside safety. One of the initial AASHO publications in this field, referred to as the "Yellow Book," served as a wake-up call to numerous highway engineers at the state and local level (*3*).

The Federal Highway Administration's (FHWA's) handbook on highway safety devoted extensive coverage to clear roadside recovery areas, the design and placement of objects, and the use of traffic barriers (*4*). During this same period, FHWA initiated several major research projects on roadsides, barriers, and attenuators (*5*), and individual state highway agencies undertook countless small studies. (The glossary at the end of this document provides a description of technical terms that may be unfamiliar to the reader.)

Development of Design Guidelines

As a result of these and other efforts, a basic understanding evolved concerning the nature of roadside hazards and the primary methods for their remediation (remove, relocate, redesign, shield, or warn). Crash testing and the development of standards for acceptable levels of occupant deceleration led to design guidelines for essential fixed objects that would serve their intended purpose without needlessly injuring the occupants of impacting vehicles.

In related developments, researchers tested and refined the designs of roadside and median barriers to help maximize their performance in safely redirecting impacting vehicles while causing minimal injury to occupants. Crash cushions, an essential element in the design of safer roadsides, were also improved. The American Association of State Highway and Transportation Officials' (AASHTO's) 1977 *Guide for Selecting, Locating, and Designing Traffic Barriers* (commonly known as the Barrier Guide) presented comprehensive information on both the warranting criteria and the design and usage of roadside and median barriers and crash cushions (*6*). Meaningful research and development over the past 16 years has accomplished the following:

- Made incremental improvements in barrier design (e.g., to better accommodate both lightweight vehicles and large trucks, and to refine end treatments)
- Improved the engineer's understanding of those roadside

characteristics that contribute to the severity of single-vehicle ROR crashes
- Highlighted the importance of roadway geometrics in the occurrence of these crashes.

Compared with his/her counterpart from a generation ago, today's highway designer has a fuller appreciation of the importance of safe roadside design and a more detailed set of warrants for the application of remedial treatments (*7*). The reduction in highway fatalities and the dramatic decline in the travel-based rate of highway fatalities demonstrate that roadsides pose far less of a hazard today than they did in the 1960s. On the other hand, the fact that single-vehicle ROR crashes now account for a greater proportion of the highway fatalities than they did a generation ago suggests that progress in this particular area may not have kept pace with the overall advances in highway safety.

A cynic might explain this lag by noting that provision of a 9-meter (30-foot) clear roadside, which was first recommended in the mid 1960s and has since been implemented on many major roadways, simply makes it more likely that a driver who has encroached onto the roadsides of today's rural highways will travel 12 meters (40 feet) or more before hitting a fixed object. A competing explanation is that roadside encroachment frequency is a function of roadway alignment (especially horizontal curvature), and that it is much more expensive to straighten adverse alignment than it is to remove/relocate/redesign or shield fixed objects along a tangent roadway. The most compelling explanation recognizes that the potential exists for single-vehicle ROR crashes along both sides of virtually all 6.4 million kilometers (4 million miles) of streets and highways in the United States; with various resource constraints it has simply not been possible to retrofit safety treatments to this extensive mileage during the past 25 years.

NEED FOR ROADSIDE SAFETY COST MODELS

Highway engineers need a tool to make the most effective use of their limited funds for improving roadside safety. Specifically, they need to estimate the costs of alternative engineering treatments for improving roadside safety, and they need to compare these costs to the projected safety consequences of the road users. Highway agencies should have comparatively little difficulty in calculating treatment costs. Though the expected cost of ROR crashes along a section of road is somewhat more elusive, it can (in theory) be expressed as the product of the following:

- The likelihood that a vehicle traversing a particular section of road will encroach on the roadside; this probability is a function of roadway design characteristics, including horizontal curvature, gradient, lane width, presence of a shoulder, and similar parameters
- The likelihood that a vehicle encroaching onto the roadside will strike an object; this probability is a function of object size and placement, together with the roadside slopes
- The average cost of a vehicular impact with the particular object; this cost may be estimated on the basis of the "typical" severity of an impact with this type of object. Severity for a particular object depends on several factors, including object size/rigidity, impact speed and angle, vehicle type, and occupant restraint.

This process, as it might be employed by a roadside safety analyst, is developed in the *Roadside Design Guide* (*7*). A simplified version of this process is shown in Figure 1. The iterative analysis process evaluates various proposed treatments that might enhance roadside safety. In the initial step, an encroachment model is used to estimate the probability that vehicles will stray onto the roadside. This subject was investigated in the mid 1960s, and the findings developed in that study have been used extensively (*8*); in fact, some have argued that they have been used too extensively, considering that the original data were developed for median encroachments. Certain treatments, particularly roadway realignment, have the potential to reduce the rate of encroachments. The annual number of encroachments is the product of the encroachment rate, the daily traffic volume, and the section length.

The second step in the analysis uses an accident model to predict the number of annual accidents that will result from the encroachments. The conditional probability that an encroaching vehicle will actually strike an object can be estimated as a function of the size and lateral placement of the object and the design speed of the road. As suggested by the flow chart, the design of proposed treatments can affect the accident probability. For existing conditions, the combined results of the first two steps should be close to the actual number of annual accidents at the location. If the predicted and observed accident frequencies do not agree, the discrepancy may be due to the quality and completeness of accident reporting, or the validity of the encroachment and accident models.

The *Roadside Design Guide* recommends that alternative treatments be compared on the basis of their road-user benefits and their implementation costs. Benefits of roadside safety treatments arise from a reduction in accident frequency and/or a decrease in crash severity. The accident cost model in the third phase of roadside safety analysis uses information on the expected severity of crashes for various proposed treatments. Crash severity obviously depends on numerous vehicle, roadway, and occupant parameters; without knowing all of these factors, it is impossible to consistently predict the severity of individual crashes. With certain assumptions, however, it is possible to estimate the average severity of roadside obstacle crashes.

A severity index, which reflects the average severity for a particular set of conditions, provides an indicator of the relative likelihood that a collision will result in a fatality, differing levels of injury, or property damage. In current practice, severity indices are described on a scale of 0 (no significant property damage) to 10 (certain to be fatal). The *Roadside Design Guide* suggests severity indices for several roadside obstacles as a function of design speed. The analyst selects a severity index that most closely corresponds to the actual condition being evaluated. The cost model then uses the definition of the severity index scale, together with generally accepted costs for crashes of varying severity levels, to estimate the financial consequences of an average crash into an object. Since a small change in the severity index can double the average accident cost, it is clear that the results of roadside safety analysis are highly dependent on reliable crash severity information.

Estimation of the costs of constructing and maintaining a proposed treatment (as required in the fourth step of the analysis), and using the principles of engineering economy to convert these to annual costs, are relatively straightforward tasks. In the final step, the expected safety benefits are compared with the implementation costs to determine if a proposed treatment is worthwhile. Based on the results of this economic comparison, the analyst may

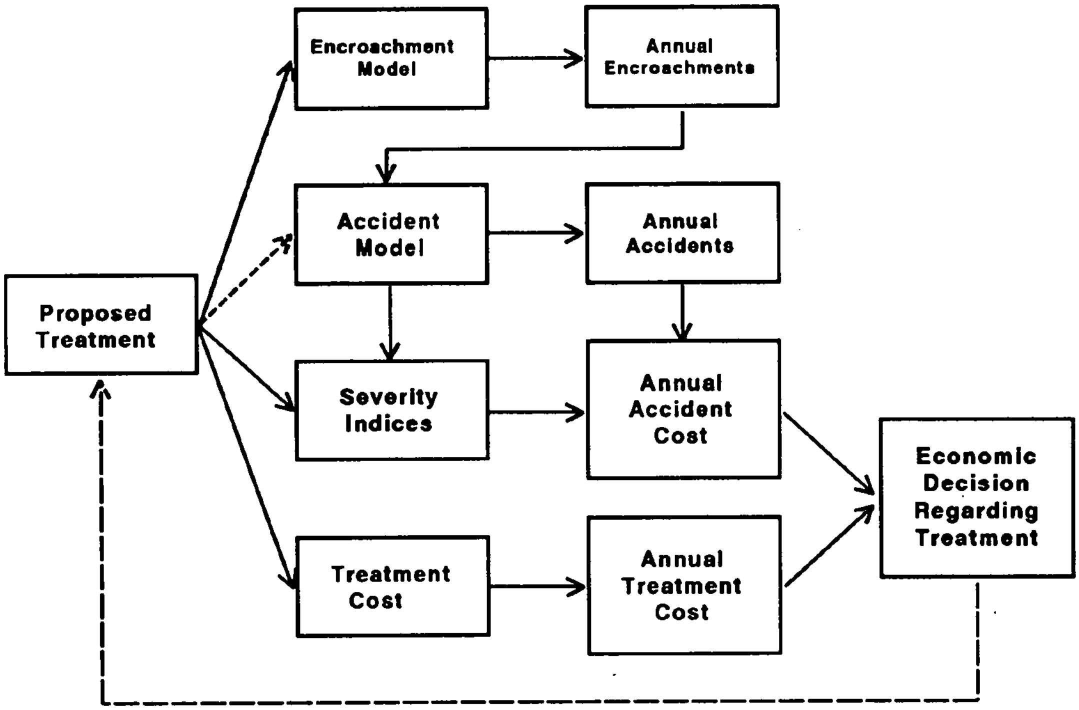

FIGURE 1 Roadside safety analysis process.

accept the proposed treatment, test other alternatives, or conclude that there is no economically justifiable treatment at the location.

Difficulty in Estimating Accident Severity and Cost

The most significant problem facing the analyst who seeks to estimate ROR accident costs for a section of road is determining realistic cost/severity consequences of impacts with various roadside objects. Authoritative sources provide estimates of crash severity (*6,7*); however, these sources also offer disclaimers, noting that the actual severity of an impact with a particular object is highly variable. The average severity consequences of crashes depend on a multitude of factors that may not be readily apparent.

The projected cost of single-vehicle ROR accidents along a section of highway is highly sensitive to the assumed severity of impacts with both the existing objects along the roadside and the conditions that would exist if these objects were removed, relocated, redesigned, or shielded. In recognition of the uncertainty of existing crash severity data for fixed objects and the importance of accurate information in the analysis of alternative roadside safety improvement programs, this synthesis project was undertaken to assess the techniques currently used by state highway agencies to develop and incorporate severity index information in their analyses of roadsides.

STUDY APPROACH

A literature review was initiated with the assistance of the Transportation Research Board's (TRB's) Transportation Research Information Service (see Chapter 2 for results of this review). To supplement the literature review, telephone interviews were conducted with individuals from the AASHTO Task Force for Roadside Safety, members of the panel for this synthesis project, authors of articles reviewed during this study, and FHWA engineers; knowledge, opinions, and inferences from these interviews are incorporated in Chapter 2. The survey of state highway and traffic engineers was developed by the authors, reviewed by the synthesis project panel, and distributed by the National Cooperative Highway Research Program (NCHRP); the survey procedure and results are described in Chapter 3.

This project located numerous compilations of severity indices produced by different research projects. The scope and size of the databases used to develop these indices, the analysis methods, and even the severity index definitions were not consistent from one study to the next. Nevertheless, the set of compilations provides a useful indicator of the type and range of available information (selected tabulations are included in Appendix A). Before using values from any of these tables, the reader is advised to review the associated technical reference cited and discussed in Chapter 2 to ensure an appreciation of the purpose, scope, and limitations of the original study. In addition, the current status of severity indices, as discussed in Chapter 4, should be considered when assessing the validity of the older severity indices given in Appendix A.

CHAPTER TWO

OVERVIEW OF SEVERITY INDICES

HISTORICAL DEVELOPMENT OF SEVERITY INDICES

A comprehensive literature review was conducted to identify those severity indices that are widely accepted as accurate and representative, and to identify objects and situations for which indices have not yet been designated. Instead of accomplishing this objective, the review revealed that severity indices are still incompletely developed; no consensus has yet been reached as to the most appropriate values for many of the most commonly struck roadside objects. The review indicated that conflicting values and philosophies have emerged, that variability and incompleteness of accident data have limited many previous studies, and that much work remains to be done to provide universally accepted values.

This chapter outlines the historical development of severity indices. Prominent research efforts are presented chronologically to document major improvements. Several sets of severity indices developed over the past 30 years are provided in Appendix A to illustrate the slow progress in development efforts.

"Objective Criteria for Guardrail Installation," *Highway Research Record 174* (*9*)

The most significant early research dealing with roadside accident severity indices appears to have been conducted by Glennon and Tamburri, as reported in Highway Research Record (HRR) 174. The researchers developed severity indices for embankments and fixed objects in California using the following formula:

$$\text{Severity Index} = \frac{25 \times (\text{fatal accidents}) + 6 \times (\text{injury accidents}) + \text{PDO accidents}}{\text{total accidents}} \qquad (1)$$

The Glennon and Tamburri study was noteworthy because of its quantitative use of accident data to develop guardrail warrants. In addition, this study resulted in the development of a data file of embankment accidents. These embankment data continued in use for the next 30 years and are mentioned in subsequent discussions within this chapter.

The researchers obtained accident reports for 1,368 embankment collisions that occurred during 1963. The reports were screened and field visits were made to remove those collisions involving fixed objects or bodies of water. The remaining 999 accidents were then categorized by embankment height and slope. For each category, an average severity index was calculated. These index values are shown in Table 1. Regression equations were then developed to predict the severity index of any accident, given the embankment condition.

Accident data were subsequently gathered for 1963 and 1964 collisions involving guardrail placed at embankments. Using Equation (1), the severity index for guardrail was calculated as 4.6. The guardrail index could be compared to the index calculated for any combination of slope and embankment height to determine whether the barrier was warranted.

The researchers repeated their analysis for 3,194 accidents involving fixed objects on freeways. These data were used in Equation (1) to find severity indices for 11 types of fixed objects. The most severe type of collision, with a severity index of 8.3, involved abutments and piers. The least severe collisions involved timber signposts, with a severity index of 2.1. Table A-1 in Appendix A contains a list of severity indices for the remaining objects studied by Glennon and Tamburri.

NCHRP Report 148: Roadside Safety Improvement Programs on Freeways: A Cost-Effectiveness Priority Approach (*10*)

As Glennon indicated in 1974 in NCHRP Report 148, a "severity index is a numerical weighting scheme that ranks roadside obstacles by degree of accident consequence" (*10*). He noted that severity indices should be used only for comparative purposes, "for instance, comparison of the accident consequences of protective guardrail with those of bridge abutments."

Glennon described seven categories that might be useful in ranking accident severity, depending on the specific objectives of an evaluation program (e.g., reduction of injury and fatal accidents, fatalities, or accident costs). Potential severity index definitions were as follows:

1) Average property damage cost per accident
2) Average direct cost per accident (includes property damage, hospitalization, insurance premiums, funeral expenses, etc.)
3) Average total cost per accident (in addition to direct cost, this includes loss of future earnings and values for human suffering)
4) Average number of fatalities per accident
5) Average number of fatal and nonfatal injuries per accident
6) Proportion of total accidents that are fatal accidents
7) Proportion of total accidents that are fatal and nonfatal injury accidents.

Glennon envisioned that severity indices would be computed from historical accident data; the precision of an index would, therefore, depend on the accuracy and availability of accident records for each obstacle type.

Another consideration that can influence the choice of a severity index is the rarity of fatal accidents. To achieve statistical reliability for the proportion of fatal accidents, larger quantities of accident data would be needed than are generally available for the entire range of roadside hazards. Consequently, Glennon cautioned that "weighting scheme measures (Nos. 1, 2, 3, 4, and 6) that give

TABLE 1
1963 CALIFORNIA EMBANKMENT SEVERITY INDICES (9)

EMBANKMENT CATEGORY		NUMBER OF ACCIDENTS				SEVERITY INDEX
Embankment Height (ft)	Embankment Slope	Fatal	Injury	Property Damage	Total	
1-5	5:1	0	2	9	11	1.91
	4:1	0	2	7	9	2.11
	3:1	0	4	6	10	3.00
	2:1	0	22	20	42	3.62
	1.5:1	0	10	7	17	3.94
	1:1	0	1	3	4	2.25
6-10	5:1	0	2	2	4	3.50
	4:1	1	4	3	8	6.50
	3:1	0	5	5	10	3.50
	2:1	1	34	31	66	3.94
	1.5:1	2	42	27	71	4.63
	1:1	1	19	5	25	5.76
11-20	4:11	1	1	3	5	6.80
	3:1	0	6	3	9	4.33
	2:1	5	75	44	124	4.98
	1.5:1	3	73	41	117	4.73
	1:1	1	14	9	24	4.88
21-30	4:1	0	1	1	2	3.50
	3:1	0	0	2	2	1.00
	2:1	1	33	22	56	4.38
	1.5:1	8	42	28	78	6.17
	1:1	1	21	5	27	5.78
31-40	2:1	1	22	5	28	5.80
	1.5:1	1	20	8	29	5.65
	1:1	1	5	4	10	5.90
41-50	2:1	0	3	3	6	3.50
	1.5:1	2	13	7	27	6.12
	1:1	0	10	1	11	5.55
51-70	2:1	0	8	4	12	4.33
	1.5:1	3	25	6	34	6.80
	1:1	2	3	2	7	10.00
71-100	2:1	1	6	3	10	6.40
	1.5:1	0	20	3	23	5.37
	1:1	1	4	2	7	7.28
101-150	2:1	0	1	1	2	3.50
	1.5:1	0	16	3	19	5.22
	1:1	1	7	1	9	7.68
151-200	2:1	0	2	0	2	6.00
	1.5:1	1	7	3	11	6.36
	1:1	3	8	0	11	11.20
201-500	1.5:1	1	6	1	8	7.75
	1:1	5	7	0	12	13.90

Note: 1 ft = 0.3048 m

greater weight to fatal accidents than injury accidents will not necessarily be more successful" in achieving the program objective, even if that objective is to reduce fatalities.

Glennon recommended using the severity index number 7, above, defined as the proportion of fatal and nonfatal injury accidents associated with each obstacle. This method was endorsed for the following reasons:

- It is easily calculated and is uncomplicated by extraneous calculations that require *estimates* of cost or *assumptions* on abstract values. [Glennon's italics]
- It has less error sensitivity to average passenger occupancies than measures that employ numbers of injuries and/or fatalities.
- It does not pretend that accident reporting levels are accurate or consistent, nor is it as sensitive as other measures to differences in reporting levels.
- It is expressed in decimal fractions ranging from 0.000 to 1.000, a convenient basis for analysis.
- It gives numbers that appear to be ranked rationally according to the severity of the roadside obstacle. For example, the severity indices for bridge abutments, guardrails, and breakaway luminaries are 0.66, 0.39, and 0.22, respectively.
- It gives a cost-effectiveness ratio that is dimensionally understandable (i.e., the cost to reduce one injury [fatal or nonfatal] accident).

NCHRP Report 148 includes tables of single-vehicle accident severity indices for 11 types of roadside obstacles along freeways. Crash data from five states during 1967–68 were used to calculate these indices. Thus, the severity indices reflect the consequences of impacts with guardrail, abutment, and other objects that were designed nearly 30 years ago. Calculated severity indices for certain objects were quite consistent among the states (utility poles ranged from 0.53 to 0.56), whereas values for other objects varied considerably among the states (trees ranged from 0.43 to 0.64).

Next, Glennon generalized the severity values, placing each of the 11 roadside obstacles into one of 6 broad categories of accident severity. He designated a severity index range and an assigned severity value for each general category. By matching the category for a given obstacle with the assigned severity value, a table of severity indices was prepared for this synthesis (see Table A-2).

Effectiveness of Roadside Safety Improvements: Volume I, A Methodology for Determining the Safety Effectiveness of Improvements on All Classes of Highways (11)

Glennon and Wilton refined the work presented in NCHRP Report 148 and published the results in a 1974 FHWA report. They developed revised severity indices for 14 roadside obstacles from responses to questionnaires sent to 34 cities and 13 state highway agencies. Recommended values, categorized by facility (freeway, highway, or urban street), are shown in Table A-3.

The researchers acknowledged that the severity index values presented in these companion reports (*10,11*) were somewhat limited by small sample sizes and by a failure to distinguish between various obstacle designs. However, as an additional validation of their choice of severity index definition, they noted that "severity indices appear to increase from urban streets to rural surface highways to freeways."

A contemporary study conducted four years later in Maryland by Hall and Mulinazz used the same severity index definition to evaluate 20,000 single-vehicle fixed object accidents on state and U.S. highways during 1970–75 (*12*). The overall severity index for these crashes was 0.44, with severity indices for objects ranging from less than 0.3 (for signposts) to over 0.52 (for poles, trees, and light supports). The researchers noted problems with unreported accidents and differences in object design. In the latter case, they indicated that the calculated severity index of 0.40 for guardrail reflected an average for impacts with W-beam, single- and multiple-wire cable, each in conjunction with varying mounting heights and blunt, flared, or buried terminals. Because of this averaging, the severity indices reported in the Hall and Mulinazzi study do not exhibit the degree of variability resulting from the finer object stratification employed by Glennon (*10,11*).

The difference between the Glennon-Wilton and Hall-Mulinazzi studies illustrates one of the problems with severity index research. Usually, average values are calculated and the degree of averaging affects the results. Differences in speed, approach angle, object construction, object size, vehicle type, vehicle safety characteristics, and other factors are neglected when average values are employed in the analysis. This research would be much more accurate if detailed data were used to determine the severity index for each variation of each collision, but current data are insufficient to support this level of calculation.

Cost-Effectiveness Program for Roadside Improvements on Texas Highways—Volume 2: Computer Program Documentation Manual (13)

Weaver, Post, and French of the Texas Transportation Institute (TTI) published the results of an extensive study of fixed objects and sideslopes in 1975 as the initial step of a roadside safety program for the Texas state highway agency. A survey document was widely distributed to collect input on the probability of injury or death from accidents in certain roadside circumstances. Responses from the 98 questions in this Delphi-type study were used to estimate the average severity of accidents involving the various objects. The scale utilized by the TTI researchers ranged from 0 to 10; a description of their severity index definition is provided in the next section of this synthesis in conjunction with the discussion of the AASHTO Barrier Guide.

The TTI research team constructed a cost-effectiveness methodology to evaluate roadside objects for possible treatment. This procedure was computer based so that it could simultaneously compare and prioritize objects throughout the state. Data collection forms were designed, highway employees were trained, and an exhaustive program was conducted to inventory roadside objects. This process was an integral component of the roadside safety treatment program in Texas (*14,15*).

For W-section guardrail, Weaver reported severity indices ranging from 3.6 to 5.7 (for standard post spacing) and from 3.9 to 5.9 (for nonstandard post spacing). As shown in Table A-4, severity indices for the other roadside objects were cited as specific values, rather than as ranges.

Glennon's severity indices, on a scale of 0 to 1, cannot be directly compared to Weaver's severity indices, which are on a scale of 0 to 10. Glennon's values cannot be multiplied by 10 to convert them to Weaver's scale. One reason for this is that the object definitions were not always identical. A second reason is

TABLE 2
COMPARISON OF GLENNON AND WEAVER SEVERITY INDEX VALUES

Glennon's Object	SI_G	Weaver's Object	SI_W
Guardrails		W-Section Guardrail	
Short (<30 m)		Standard post spacing	3.6-5.7
Safety end-treatment	0.35	Nonstandard post spacing	3.9-5.9
No safety end-treatment	0.45		
Long (>30 m)			
Safety end-treatment	0.30		
No safety end-treatment	0.35		
Bridge Abutments and Piers	0.60	Bridge Abutments	
		Vertical face	9.3
		Sloped face	2.5
Bridge Rail—smooth	0.35	Bridge Rail—rigid but smooth	3.3
Retaining Walls and Fences	0.35	Retaining Walls—face	3.3

Note: SI_G is Glennon's severity index; SI_W is Weaver's severity index.

that the designated severity values were not distributed similarly across the two scales, i.e., Glennon's largest value was 0.60 even though his scale reached to 1.00. Weaver's largest value was 9.3 on a scale of 10.0.

The categories tabulated in the respective reports differ significantly. The four most comparable listings and their severity indices on rural surfaced highways are presented in Table 2. For guardrails, bridge rails, and retaining walls, Weaver's severity indices are an order of magnitude greater than Glennon's. This relationship appears to fail, however, for the most rigid object (bridge abutments).

Guide for Selecting, Locating, and Designing Traffic Barriers (6)

The Weaver report was used as the basis for defining the severity index system in this 1977 AASHTO publication, commonly referred to as the Barrier Guide. The Barrier Guide includes a table from the Weaver report (see Table 3), which defines the severity index on a 0 to 10 scale. An impact with a fixed object that would definitely result in property damage only (PDO) was assigned a severity index of 0. At the other extreme, an impact that was virtually certain to result in a fatality was given a severity index of 10. Of course, most fixed objects have intermediate consequences in terms of crash severity.

The Barrier Guide includes an extensive set of severity index values (see Table A-4), listing 15 roadside objects, further quantifying them by detailed descriptions and, in the case of longitudinal barriers, by end treatments. As seen earlier, some of the values assigned by Weaver correspond closely to severity indices developed by Glennon (*11*), while others differed greatly. Utility poles, for example, are rated as 7.1 in the Barrier Guide, and as 0.55, 0.45, or 0.40 by Glennon (for freeways, rural highways, or urban streets, respectively).

The tabulated values are presented as guidelines that could be used "in the absence of more definitive data." However, the Barrier Guide urges analysts to use discretion in assigning severity indices, and to exhaust "all available objective data" before resorting to judgment. In the ideal situation, the analyst would categorize all recent fixed object crash data by roadway type, speed limit, operating speed, object type, and occupant injury, then determine the appropriate severity indices from the locally developed data. As a practical matter, the necessary data are often not readily available. For example, data based on actual reported accidents tend to be biased toward the more severe and costly crashes since minor collisions are seriously underreported.

Synthesis of Safety Research Related to Traffic Control and Roadway Elements (16)

The discussion of severity indices for roadside objects in Chapter 3 of this 1982 FHWA report was restricted to the 1975 study by Weaver, et al. (*13*). The restriction is significant because the comprehensive FHWA synthesis was intended to represent the state of the art. This synthesis noted that values developed in the Weaver report were not based on a detailed accident analysis, but were "relative subjective measures of an obstacle's potential to produce a given outcome on the vehicle and/or occupant when a collision occurs."

Cost-Effectiveness of Countermeasures for Utility Pole Accidents (17)

This 1983 report by Zegeer and Parker presented the results of an FHWA-funded study that is based on data collection and analysis of 9,583 utility pole accidents along 4,000 kilometers (2,500

TABLE 3
WEAVER/AASHTO BARRIER GUIDE SEVERITY INDEX DEFINITION (*6*)

SEVERITY INDEX	% PDO[a] ACCIDENTS	% INJURY ACCIDENTS	% FATAL ACCIDENTS
0	100	0	0
1	85	15	0
2	70	30	0
3	55	45	0
4	40	59	1
5	30	65	5
6	20	68	12
7	10	60	30
8	0	40	60
9	0	21	79
10	0	5	95

[a]Property Damage Only

miles) of urban and rural roads in four states. Using the proportion of fatal plus injury accidents as an indicator, the researchers attempted to identify and quantify the factors affecting utility pole accident severity (*17,18*). For the entire sample of utility pole crashes, 1.0 percent resulted in a fatality and an additional 46.3 percent resulted in nonfatal injuries. The resulting severity index was 0.473, quite similar to the 0.45 reported by Glennon (*11*), but substantially different than the value of 7.1 given in the AASHTO Barrier Guide (*6*).

The relatively large database employed by Zegeer and Parker adds credibility to their severity estimate; this does not mean, however, that the results were identical in each of the four states studied. The amount of variability is reflected by the percentage of injury accidents, which ranged from 38.0 percent in one state to 52.5 percent in another. These results illustrate the inherent problem of using data from a small sample of states to generate average national values. There are, indeed, substantial differences from state to state.

Horizontal curvature and pole type were found to be significant contributors to accident severity. Interestingly, speed limit had no significant effect on severity for the utility pole accidents examined in this study. This could be because the speed limit is often much different from the operating speed of a vehicle. The law enforcement official investigating a utility pole accident has direct knowledge of the speed limit but no direct knowledge of the actual (operating) speed of a vehicle that strikes a pole. The speed limit is usually recorded on the accident report form. The operating speed is a more desirable piece of data, but if recorded, it is no more than an estimate by the investigating officer.

The results of the Zegeer and Parker investigation of utility poles, and comparisons with the results of other studies, highlight the difficulty in determining a single severity index that would adequately represent all utility poles. A stratification of severity indices to reflect varying distances from the road, varying roadway alignment, varying impact speeds, and various utility pole designs might be required to produce more realistic values. This compilation of data would obviously demand a very large database, careful preparation and screening of the data, and a thorough statistical analysis to identify the true relationship between these factors and the severity indices for utility poles (or any other roadside obstacle).

Cost-Effectiveness Techniques for Highway Safety: Resource Allocation—Final Report (*19*)

In the 1980s, McFarland and Rollins conducted research at TTI to investigate cost-effectiveness techniques for highway safety. The results were published in a 1985 FHWA report. In one portion of their study they used a sample of 136,000 roadside accidents that occurred in Texas during 1978 and 1979 to examine the correlation of Weaver's severity indices with accident data (*20*). The researchers assigned costs to each accident on the basis of fatalities and various injury classifications. They then grouped accident records by the type of fixed object struck and calculated average accident costs for each object. The researchers further classified their results by rural and urban roadways.

To convert accident costs into severity indices, the researchers developed their own relationship between crash cost and severity index. They initially selected three fixed objects (underpass, culvert, and curb) that could be clearly identified on police accident reports and that have available and credible AASHTO Barrier Guide severity index values. By using the derived accident costs and the Barrier Guide severity indices for these three objects, the researchers formed the major portion of a curve describing fixed object accident cost versus crash severity. The remainder of the curve was obtained through logic and comparison of severities for various types of collisions. The researchers used the resulting curve to assign severity index values to the remainder of their fixed objects based on accident costs. Table A-5 displays the severity indices produced by this method.

The TTI researchers found that their average accident costs were lower than those given by AASHTO because the "actual percentages of all accidents that are fatal or injury accidents tend to be considerably lower than those in the AASHTO Barrier Guide" (*19*). This was an important observation. Over time, it became apparent that Weaver's indices were too high for many objects. Weaver's results were developed through an iterative, subjective process, and it appears that the responses were skewed by recollections of dramatic high-severity impacts with certain rigid objects and by omission of low-severity, unreported accidents.

McFarland and Rollins compared the severity indices from their study with those developed by Weaver (*13*). They noted several disparities and proposed modifications to the Barrier Guide's severity indices for selected types of roadside obstacles. For example, the Barrier Guide's severity index value of 7.1 for impacts with utility poles appeared to be too high, since the TTI values were 3.2 and 4.8 for urban and rural areas, respectively. On the other hand, AASHTO's severity index for trees (3.0) is considerably lower than the values developed by the TTI research for impacts in urban (7.6) and rural (8.0) areas.

For rigid sign posts, the severity index values of McFarland and Rollins agree with those in the AASHTO Barrier Guide. They assigned a severity index of 0.0 for accidents involving breakaway sign supports, under the assumption that there were many unreported crashes where vehicles drove away from impacts with these objects. (In retrospect, this might not have been a valid assumption.) Likewise, traffic signal poles were assumed to be breakaway and reported impacts with crash cushions had very low severity; both were assigned severity indices of 0.0. The revised values from this analysis are given in Table A-6.

Based on accident analyses, McFarland and Rollins recommended additional adjustment factors to reflect differences in road types and in the lateral placement of fixed objects relative to the road, contending that such corrections help account for the observed variability in crash severities.

"Severity Measures for Roadside Objects and Features," *Transportation Research Record 1074* (*21*)

In a study of fixed object crashes in New Mexico from 1980 to 1982, Brogan and Hall calculated severity indices for fixed object types on two classifications of rural highways — interstate and other federal-aid. Culverts, embankments, bridges, and trees had the highest severity indices, but the results differed by roadway system. This simple form of tabulating severity indices can be misleading. For example, trees, with a severity index of 0.50, were the highest severity fixed object on New Mexico's rural interstate highways, but they accounted for only 2 percent of the fixed object collisions on this system. On other federal-aid highways, trees accounted for 12 percent of the single-vehicle fixed object accidents, while the severity index was 0.44. Toward the other extreme, fences accounted for over 20 percent of the crashes on both roadway systems, but their severity index was only 0.32.

The researchers used unit cost data (for fatal, injury, and PDO accidents) from the National Highway Traffic Safety Administration (NHTSA), together with the distribution of crashes by severity, to calculate average costs for impacts with the 11 fixed object types. Average costs, which can be disproportionately affected by high-cost fatal crashes, ranged from $2,000 to $20,000. Accident costs by fixed object type, as estimated in this manner, exhibited significantly more variation than the corresponding severity indices.

The work by Brogan and Hall illustrates two points vital to the understanding and use of severity indices. First, the magnitude of the index value for any object does not indicate its total potential to cause harm at a specific site. The severity value must be used in conjunction with some measure of exposure (number of vehicles passing the site, distance from edge of pavement, etc.) to yield the potential for harm. Second, severity indices may differ by type of roadway system due to differences in design standards and operating speeds. These differences are often lost when average severity indices are calculated after combining accidents on all classes of roads for a particular jurisdiction.

Severity Measures for Roadside Objects and Features (*22*)

This FHWA report documents a 1985 research project conducted at TTI. In this study, Mak identified and collected secondary information — including accident data, full-scale crash testing results, and computer simulation studies — from several sources. The resulting comprehensive database was subsequently used to develop and evaluate cost-effective methods for measuring the severity of roadside accidents.

Severity Indices from Accident Data

One part of Mak's multiphase study used several years of Texas accident data to develop severity indices, generating the following measures of severity:

- Percent of incapacitating and fatal accidents
- Relative severity index (RSI)
- Average cost ($) per accident.

In defining the RSI, sites were categorized by highway, vehicle, and area types. The RSI for an object was then calculated as follows:

$$\text{RSI} = 10 \times \log_e \left[\frac{\begin{array}{c}\%\text{ fatal \& incapacitating injury}\\ \text{accidents at target site}\end{array}}{\begin{array}{c}\%\text{ fatal \& incapacitating injury}\\ \text{accidents at all sites}\end{array}} \right] \qquad (2)$$

Mak studied 14 different objects for 37 combinations of severity measure, area, vehicle type, and roadway type. For example, one analysis examined fixed object accidents involving commercial vehicles on urban interstate highways. Mak presented the results in an extensive series of figures and tables. Figure 2 is typical of those produced by this phase of Mak's study. The figure is not general; it was prepared for one unique category of collisions — commercial vehicles on rural Texas roads. Both the mean and standard deviation are shown for each object. This level of detail is useful in evaluating individual objects in specific circumstances. It is also necessary when using more sophisticated statistical procedures, like those discussed later in this synthesis.

Another example of this stage of Mak's research is reproduced as Table A-7. As shown in this table, there is no direct correlation

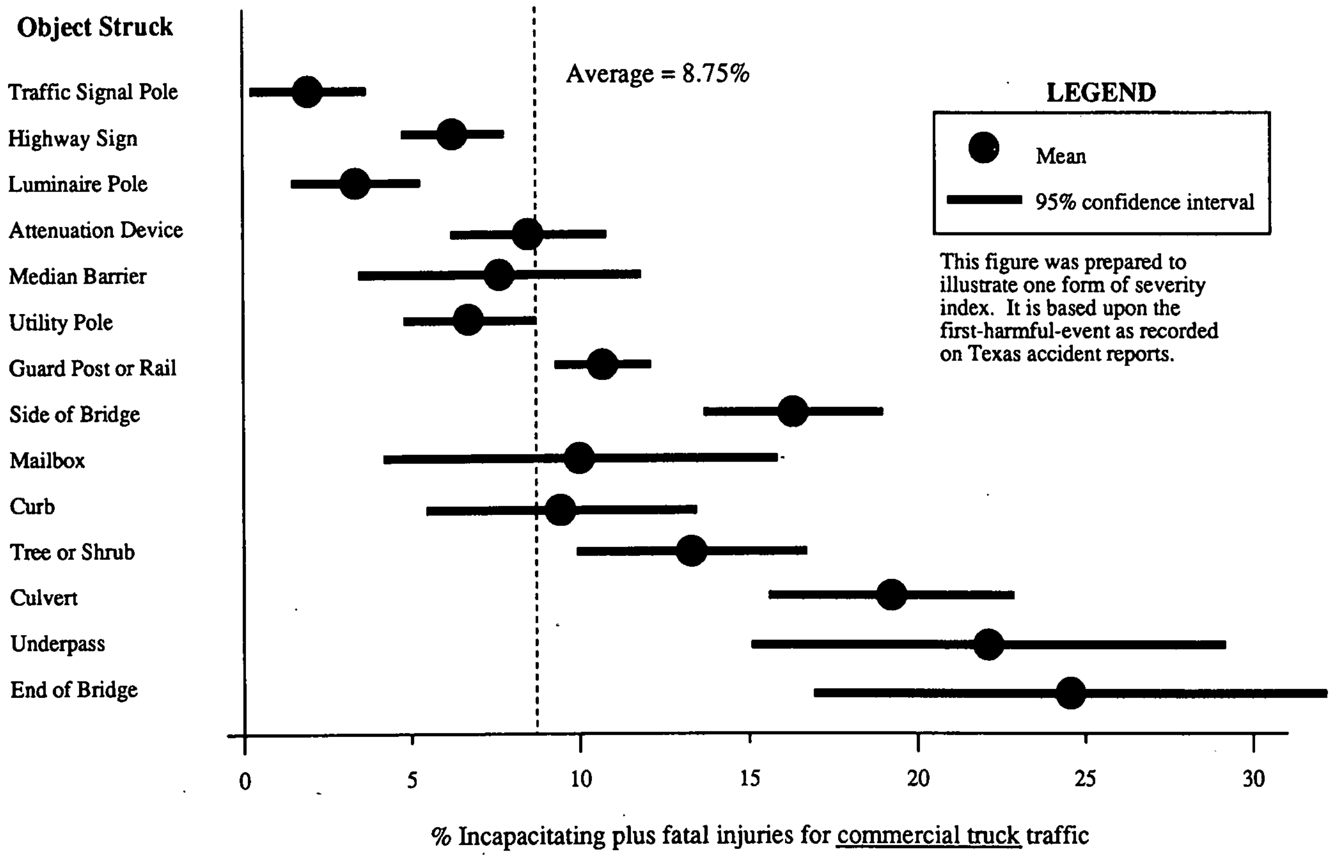

FIGURE 2 One example of Mak's severity measures for 14 Texas roadside objects (*18*).

among the three types of severity measures. Because of the definition of RSI, the rankings of objects in the first two columns are identical; however, the rankings differ in the Average Cost Per Accident column. Furthermore, the severity measures in the first two columns have distinctly different scales; consequently, they yield varying proportional differences between pairs of objects.

Mak's research produced an extensive set of data summaries. Due to temporal and financial constraints, the project was unable to conduct a concurrent analysis of the information; as a result, this task did not produce comprehensive conclusions.

Severity Indices From Vehicle Damage Reports

A second segment of this project sought to estimate accident severity as a function of vehicle damage ratings (using the Traffic Accident Data Project [TAD] alpha code). Researchers used codes for various locations on damaged vehicles to predict the probability of driver injury. Three different injury levels were used with 34 combinations of area and highway types. Tabular results, together with graphs of the probability of injury, were presented in the project report. As with the previous task, researchers generated a great deal of information, but without subsequent detailed analysis.

Use of NASS Data

Mak's report also documented the difficulties with using the National Accident Sampling System (NASS) data files for severity index calculations. For example, NASS data may not be compatible from year to year because of changes, additions, and deletions to data items. In addition, the fixed object sample size is comparatively small, the documentation is less than desirable, and there is a distinct lack of detail. Nevertheless, the researchers used NASS data to examine eight fixed objects for various combinations of area, highway, and vehicle types. The following severity measures were employed in this evaluation:

1) Percent of incapacitating and fatal injury accidents
2) Relative Severity Index based on 1) above
3) Percent of severe-to-fatal (AIS 3) injury accidents
4) Relative Severity Index based on 3) above
5) Average cost per accident.

First-Harmful Event Versus Most-Harmful Event

Mak's initial severity estimates were based on the first-harmful event (FHE) in the accident sequence. The analysis was repeated for the most-harmful event (MHE) in the sequence, generating a total of 42 tables. The researchers found that severity indices derived from the FHE were different from those derived from the MHE; later research by others supports this conclusion. Table A-8, which is typical of those produced by this portion of the study, demonstrates that the five different severity measures developed by Mak for the NASS FHE data do not necessarily agree in rank or magnitude for the eight collision types.

Logistic Regression Approach

In yet another portion of Mak's study, researchers used in-depth accident data in conjunction with logistic regression to predict probability of injury. This effort relied on a rather small database, which had been collected for a different purpose. Perhaps for these reasons, the resulting models were not particularly good predictors of severity. However, the findings suggest that this technique might be successful under other circumstances.

Other Approaches by Mak

Other activities in Mak's project led to the compilation of a database on full-scale crash test results, summaries of computer simulation programs and studies, and an evaluation of existing roadside objects to identify areas where the accuracy or specificity of severity measures required improvement. Finally, the investigators recommended research plans to address data needs and gaps in the knowledge for specific types of fixed obstacles.

Summary of Mak's Study

Mak's research was a comprehensive data-gathering exercise that produced a wealth of information about possible techniques for estimating the severity of collisions with various roadside objects. This research demonstrated the viability of several techniques for establishing severity indices. However, the example severity measures were not uniform or consistent and occasionally yielded conflicting evidence about the potential severity of collisions with different objects.

Mak's project highlighted many opportunities for future research efforts to improve severity indices; unfortunately, the results did not lead in a single direction. In fact, the extensive accumulation of information may have raised more questions than it answered.

TRB Special Report 214: Designing Safer Roads, Practices for Resurfacing, Restoration and Rehabilitation (23)

At the request of Congress, TRB's Special Projects Division undertook an investigation of the relationship between safety and roadway design practices for resurfacing, restoration, and rehabilitation. The research, which was limited to nonfreeway federal-aid highways, relied exclusively on secondary data and a panel of experts in the various disciplines needed to develop, apply, and assess the effectiveness of geometric design standards. The results were published in TRB Special Report 214.

This TRB report addressed several of the basic problems with highway safety studies. For example, it stated that shortcomings in research methods and reporting of results had hindered the development of reliable relationships between design and safety. It also indicated that the results of cost-effectiveness analyses can be very sensitive to imputed accident costs and several other factors, partly because the establishment of the severity of the average collision is such a critical component in accident costs. A small change in severity can cause an extreme change in the economic cost of an accident. The project panel noted disagreement among knowledgeable safety officials regarding the appropriate costs to associate with a fatality or an injury, and reviewed the difficulty in applying the results of cost-effectiveness analyses. This remains a point of contention among safety officials.

An entire appendix of TRB Special Report 214 analyzes the degree of hazard posed by specific obstacles and the probability that a collision with a certain obstacle would result in an injury or fatality. The report advocates a roadside encroachment model as the most suitable method to examine safety effects of specific roadside features. While developing this model, the committee reviewed prior research, noting that the development of such models was not possible until the mid 1960s when field data became available from the work of Hutchinson (*8*). Ensuing models continued to rely in large part on Hutchinson's original encroachment data, which were collected from the median along a low-volume freeway site with generally straight alignment. TRB Special Report 214 concludes that these data were inappropriate for general use, and consequently does not recommend previously-derived models for use in analyzing the safety effects of roadside hazards on two-lane highways.

The panel for this TRB study developed an independent modeling approach using accident data rather than encroachment data. Although many researchers use the terms interchangeably, others (including the panel) make a distinction between an accident and a collision. The panel defined a collision as an impact with a roadside obstacle, whereas an accident is a collision that makes the impacting vehicle immobile. In other words, the number of collisions exceeds the number of accidents. The panel predicted accident frequencies as a function of the conditional probability of an accident given that a collision occurred. This probability was based on the regression-based estimates from Zegeer and Parker (*17*); in the case of utility poles, for example, the estimate was 0.9 accidents per collision. The model was extended, using recommendations from Glennon and Wilton (*11*) on the fraction of accidents that result in a fatality or injury. The combination of factors served as a guide for use in a roadside safety model.

Joint factors based on these two sources (*11,17*) are shown in Table A-9. These factors provide estimates of the number of accidents per collision and the number of casualty accidents per accident for several types of objects and roadside situations. Since these results permit comparisons among various roadside conditions to identify those with the greatest potential injury, they constitute a form of severity index.

TRB Special Report 214 recommends caution in applying the values for number of accidents per collision, noting that estimating the percentage of vehicles that drive away from a collision is inherently difficult. Values clearly vary with object rigidity and can also differ based on study methods and definitions. In contrast to the foregoing value for utility poles, for example, Mak and Mason (*24*) estimate that only two-thirds of the collisions with utility poles are reported. Values shown in Table A-9 for other objects may likewise overstate the percentage of collisions that are accidents.

Safety Effects of Cross-Section Design for Two-Lane Roads, Volume I (25)

This 1987 report by Zegeer, et al. presented results of a study funded by FHWA and TRB. In one portion of the project, researchers analyzed data from 25,000 accidents in three states to assess crash severity for various obstacle types. Fourteen ROR, fixed-

TABLE 4
SEVERITY INDEX VALUES CALCULATED USING THE 1987 WASHINGTON STATE SEVERITY INFORMATION (*25*)

Object	Glennon (*10*)	Washington SI[a]	Washington SIs[b]	Kentucky (*26*)
Tree	0.33-0.70	0.56	2.61	3.52
Culvert/Headwall		0.66	2.78	3.38
Embankment				
Earth	0.22-0.70	0.55	2.46	3.14
Rock		0.50	2.32	3.14
Bridge				2.95
Bridge End	0.70	0.58	2.77	
Bridge Column	0.70	0.60	2.87	
Bridge Rail	0.43-0.70	0.43	2.16	
Utility/Light Pole	0.53	0.49	2.31	2.68
Breakaway	0.22			
Guardrail	0.33-0.53	0.43	2.17	2.67
Median Barrier				2.59
Crash Cushion				2.56
Curbing	0.43			2.16
Fence		0.42	2.14	1.96
Sign	0.22-0.70	0.41	2.12	1.91
Fire Hydrant		0.31	1.81	1.70
Building/Wall		0.00		1.56
Barrier Wall		0.42	2.07	
Mailbox		0.40	2.00	

[a] Severity index calculated using Glennon procedure (*10*) with Washington data (*25*).
[b] Severity index calculated using Kentucky procedure (*26*) with Washington data (*25*).

object accident types were examined, but as indicated in Table A-10, only Washington was able to provide information for each object type. Objects with the highest combined percentages of fatal and injury accidents included culverts, bridge columns, trees, and embankments. Data in Table A-10 suggest an imperfect relationship between the percentages of fatal crashes and injury crashes for a particular object type. This may be a reflection of state-to-state differences in accident data, or it may be due to limitations in the amount of data available for any particular type of object.

The data in Table A-10 may be used to develop severity indices for different objects. Procedures used by Glennon (*10*) and the Kentucky Transportation Center (KTC) (*26*) were applied to these data to yield two sets of severity indices. The comparisons, shown in Table 4, indicate a reasonable similarity between the sets of severity indices. Although there is some variation in the numerical values for certain objects, the objects fall in the same general decreasing order of severity index for both scales.

This Zegeer study reinforces the findings of earlier studies regarding the difficulties of using accident data to calculate severity indices. Different calculation techniques may return different severity index values. Also, extremely large data sets are necessary to overcome state-to-state variability, yet national data may not fit individual regions or states. Severity indices calculated for one state may not fit another data set from that state, much less another state.

AASHTO *Roadside Design Guide* (*7*)

Some of the difficulties associated with assigning a severity index value to a roadside object were summarized in 1989 when AASHTO published the *Roadside Design Guide*:

- Impacts into the side, corners, or face of a hazard may differ in severity.
- Higher impact speeds result in more severe collisions.
- The severity index will vary with other factors, such as the type of vehicle involved.

Accordingly, the severity index values (still on a scale of 0 to 10) suggested in the *Roadside Design Guide* are tabulated by impact location and by design speed (see Table A-11). However, with respect to the third point, the document notes that "the actual values used can vary depending on particular circumstances and the judgement of the [ROADSIDE cost-effectiveness] program user." (This statement is supported by controlled crash tests at

TABLE 5
AASHTO *ROADSIDE DESIGN GUIDE* SEVERITY INDEX DEFINITION (*7*)

SEVERITY INDEX	PDO ($500)	PDO ($2500)	SLIGHT INJURY	MODERATE INJURY	SEVERE INJURY	FATAL INJURY
0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.5	100.0	0.0	0.0	0.0	0.0	0.0
1.0	66.7	23.7	7.3	2.3	0.0	0.0
2.0	0.0	71.0	22.0	7.0	0.0	0.0
3.0	0.0	43.0	34.0	21.0	1.0	1.0
4.0	0.0	30.0	30.0	32.0	5.0	3.0
5.0	0.0	15.0	22.0	45.0	10.0	8.0
6.0	0.0	7.0	16.0	39.0	20.0	18.0
7.0	0.0	2.0	10.0	28.0	30.0	30.0
8.0	0.0	0.0	4.0	19.0	27.0	50.0
9.0	0.0	0.0	0.0	7.0	18.0	75.0
10.0	0.0	0.0	0.0	0.0	0.0	100.0

Note: PDO is Property Damage Only

TTI, which have yielded varying results.) Furthermore, values are given only for very broad categories of objects: longitudinal barrier, rigid object, breakaway hardware, foreslopes, backslopes, crash cushions, and culverts.

An example cited earlier in this chapter compared the utility pole severity indices from the 1977 AASHTO Barrier Guide to those developed by Glennon. In the *Roadside Design Guide*, such an object would be classified as a "rigid object" with a severity index ranging from 4.0 to 6.7 (for speeds of 70 to 110 km/h [40 to 70 mph], respectively), or as "breakaway hardware" with a severity index ranging from 2.1 to 2.4. The comparable value from the Barrier Guide was 7.1 and from Glennon was 0.40 to 0.55.

As in the Barrier Guide, the *Roadside Design Guide*'s severity index is a relative ranking of the degree of damage and injury expected from collisions with various objects. However, the scale is revised to more finely quantify the probabilities of various levels of damage. Specifically, the former PDO category was subdivided into two levels, while nonfatal injuries were categorized as slight, moderate, and severe. The redefined relationship between severity index and the expanded damage scale is shown in Table 5.

In comparison with the definitions employed by AASHTO's 1977 Barrier Guide, the *Roadside Design Guide*'s use of six crash classifications gives the impression of a greater level of precision. As a practical matter, however, many users lack the expertise to discern fine differences between classifications, and many jurisdictions do not have accident data collection and analysis systems that can provide reliable information in the necessary level of detail.

"Guidelines for Installation of Guardrail," *Transportation Research Record 1302* (*27*)

Pigman and Agent at the KTC conducted a comprehensive study to establish cost-effective guidelines for installation of guardrail. The ensuing KTC report *Warrants and Guidelines for Installation of Guardrail* (*26*) and TRR 1302 outlined their efforts. The researchers modified the ROADSIDE computer program to use specific data, including severity indices, developed from Kentucky roadway and accident files. In essence, the researchers used ROADSIDE's cost-effectiveness methodology to identify combinations of roadside factors that warranted guardrail.

TABLE 6
KENTUCKY GUARDRAIL STUDY SEVERITY INDEX VALUES (*26*)

Speed Limit	Guardrail Severity Index	Fixed Object Severity Index
70 km/h (40 mph)	2.2	3.1
80 km/h (50 mph)	2.5	3.4
100 km/h (60 mph)	2.8	3.7

Severity indices were calculated for various roadside objects based on the injury levels shown on police accident reports. Injury and fatality accidents were converted to an equivalent number of PDO (EPDO) accidents. EPDO accidents were defined as the sum of the fatal plus incapacitating accidents (multiplied by a weighting factor of 9.5), the nonincapacitating injury or possible injury accidents (multiplied by 3.5), and the PDOs. Pigman and Agent defined the severity index as the number of EPDO accidents divided by the actual number of accidents; possible values for this index thus ranged from 1 to 9.5. As shown in Table 6, this technique produced logical results for guardrail for 70, 80, and 100 km/h (40, 50, and 60 mph). When considered across all speed and volume ranges, the average severity index for guardrail was 2.67.

Researchers repeated the foregoing analysis for other object types. Average severity indices over all speed ranges for individual objects are presented in Table A-12. Consistent with the earlier studies, researchers found the highest severity objects to be trees, culverts, and embankments.

At the time it was conducted, the KTC project was notable because of the rigor with which a state transportation agency pursued its own severity indices, cost-effectiveness findings, and other data for the purpose of formulating guardrail criteria. The KTC researchers used the best available methodology and data to develop reasonable criteria that were appropriate to their conditions. The severity indices developed in this study, although unique to the conditions in Kentucky, represented the best approach for the safety task at hand. It should be noted, however, that changes in the assumptions made by the researchers would have affected the results. For example, the weighting factors of 9.5, 3.5, and 1 for the three categories of crash severity could be debated. Likewise, the grouping of injury levels, a necessary accommodation to data availability and reliability, influenced the results.

As part of their study, Pigman and Agent sought to develop severity indices for various combinations of embankment height and slope. Unfortunately, Kentucky roadside data were not suitable for performing this analysis. Instead, the researchers utilized data from the Glennon and Tamburri (*9*) study of California embankment crashes. The KTC procedure discussed previously was applied to the California accidents, although data limitations precluded the calculation of severity indices as a function of speed limit. Pigman and Agent acknowledged that vehicular changes over the past 30 years, including modifications to weight, wheelbase, handling characteristics, and safety features, limit the validity of their embankment severity indices.

As shown in Table A-12, severity indices increase with both steeper slopes and higher embankments. In comparison with the average guardrail severity index of 2.67, crashes into embankment slopes of 3:1 have lower average severities. Pigman and Agent concluded that it was better not to use guardrail on embankments of 3:1 or flatter.

Guidelines for Guardrail on Low-Volume Roads (28)

Using procedures similar to those in the Kentucky study, Arnold at the Virginia Transportation Research Council (TRC) developed and published guardrail warrants for the Virginia DOT (VDOT). The California accident data set was again used for determining embankment severity indices. The VDOT severity weighting formula (fatal = 12, injury = 3, PDO = 1) was used to find an average severity index for each combination of slope and height. Subsequently, researchers employed multiple regression analysis to predict severity index as a function of height and slope.

The same type of analysis was applied to Virginia guardrail accidents to find an average severity index. Researchers then used the embankment and guardrail severity indices in the ROADSIDE computer program to investigate various combinations of height and sideslope. Guardrail warrants were developed from the output.

Researchers used an alternate analysis, similar to the McFarland and Rollins study (*19*), for fixed objects. They then determined the numbers of PDO, injury, and fatal accidents for each type of object, and converted these numbers to average costs per accident. The cost versus severity index curve in the *Roadside Design Guide* was then used to estimate the severity index of all fixed objects examined; Arnold found that structures had the highest value. The severity indices for structures and guardrail were adopted for input to the ROADSIDE computer program during the calculation of guardrail warrants for fixed objects.

TABLE 7
VIRGINIA GUARDRAIL STUDY SEVERITY INDEX VALUES (*28*)

Severity Index	Object or Condition
2.06 to 3.16	Height = 0.3 m to 30.5 m (1 ft. to 100 ft.), Slope = 1.5:1 to 2.5:1
1.97	Guardrail for embankments
3.73	Structures (most severe of fixed objects)
3.18	Guardrail for fixed objects

Table 7 summarizes the findings of the Arnold study. Because he employed separate but logical analysis techniques, two very different severity indices were determined for guardrail—one for slopes and the other for fixed objects. The results reemphasize the potential problems of mixing severity index data developed with different analysis methods or with different data sets.

Guidelines for Guardrail Installation on Embankments and at Bridge Ends: Low Volume Roads in Missouri (29)

Dare investigated guidelines for guardrail at embankments and at bridges on low volume roads in Missouri. He used the ROADSIDE computer program in a manner similar to the Kentucky and Virginia studies. Traffic volumes of up to 10,000 vehicles per day, embankment heights of up to 31 meters (100 feet), and speeds of 70, 80, and 100 km/h (40, 50, and 60 mph, respectively) were considered. Dare also incorporated life-cycle costs, including barrier installation and repair, extra earthwork, and accident costs.

Severity indices for this study were adapted from *Supplemental Information for Use with the ROADSIDE Computer Program* (*30*), which is discussed in the next section of this synthesis, using the following assumptions:

- Cross slopes of 2:1 and 3:1—using the supplement's suggested index values, with linear increases as embankment height increased from 1.2 m (4.0 ft.) to 6.0 m (20.0 ft.), but with a constant value for embankments higher than 6.0 m (20.0 ft.) (as noted previously, a linear increase in the severity index does not imply a linear increase in cost since expense increases dramatically at higher severity levels)
- Guardrail on embankments—selecting values from the middle of the range in the supplemental tables to represent average conditions over the life of the installation
- Bridge parapets—substituting severity indices for smooth vertical rock cut since no direct listing for this item appeared in the supplemental tables
- Side of hazard—using permanent stream/pond with water depth of three or more feet
- Guardrail at bridge ends—using midrange values from the supplemental table

The analysis results were presented as a series of tables and design figures, indicating where guardrail was and was not warranted. In addition, Dare concluded that future improvements in input parameters for the ROADSIDE program could affect his warrants. He stated that improvements were "especially important with respect to severity indices, which are still evolving. The severity indices will undoubtedly have to be adjusted in the future to reflect improved crash-worthiness of the vehicle fleet and improved performance of roadside safety devices." Dare recognized that small changes to severity index values could have pronounced effects on accident costs, that the accuracy of the best current index values had not been verified, and that changes could be expected for future severity indices.

Analysts must be aware that future changes, such as increased use of airbags, will substantially alter injury characteristics and thus modify severity indices, especially for frontal collisions. As this occurs, research like that of Dare should probably be revisited.

Supplemental Information for Use with the ROADSIDE Computer Program (30)

In response to "numerous requests by both FHWA and state personnel for more detailed severity indices," FHWA published this document in August 1991. Although it was intended to present the state of the art in accident severity, users were cautioned to consider it "a guide to approximate severity indices rather than a series of exact figures." As in the *Roadside Design Guide*, the severity index values presented in this supplement are relative rankings based on "anticipated performance and intuitive judgement." It is worth noting that there was no direct use of accident data in preparation of the supplemental values.

In an attempt to more precisely reflect differences in object types, design characteristics, and placement, the severity index tables in the supplement list six categories of objects. Furthermore, a range of values is presented, along with instructions for selecting an appropriate value within the stated range. For example, rather than simply choosing a value of 4.7 for a rigid object at 80 km/h (50 mph) from the *Roadside Design Guide*, a user could further quantify the object as a tree with diameter less than 100 mm (4 inches), and select a value between 0.6 and 3.2 (depending on whether it is located on an uphill backslope or on a nonrecoverable foreslope). The supplemental severity indices, without the extensive explanatory notes, are shown in Table A-13.

Presenting severity index ranges, rather than discrete values, may encourage the user to select a value that reflects other relevant conditions. For instance, if an analyst is evaluating a barrier along a roadway with a high percentage of large trucks, the selection of a value toward the upper end of the range would incorporate the fact that the barrier is less effective for trucks than for cars. On the other hand, a cynic might suggest that such broad ranges of severity indices could allow a user to justify any answer desired for other reasons.A number of professionals have expressed concern that this is a frequent occurrence.

With respect to the utility pole example developed earlier, the supplement's range of values within each speed category reflects the type of roadside slope and object design. In this case, the values range from 2.6 to 5.0 (with an average of 3.8) at 70 km/h (40 mph) to 4.4 to 8.6 (with an average of 6.5) at 110 km/h (70 mph).

The supplement document noted that its severity index values do not reflect impacts at (simplistically) the roadway's design speed but rather at an average estimated impact speed:

> This means that for most features there will be many low severity accidents included; vehicles that are nearly stopped before reaching the feature or striking it in such a way that occupants are not seriously injured. That is why the numbers are generally lower than the values in the 1977 Barrier Guide which represented the severity of crashes at 60 mph (100 km/h) (*30*).

Severity indices in the supplemental report were developed as *relative* values, providing a basis for an economic analysis of proposed improvements. The report stressed that its indices were not based on actual accident data: "accident reports seldom contain all the information needed to identify the object or obstacle struck in detail. Even more importantly, accident records do not cover even the majority of accidents" since minor, low-speed collisions are rarely reported.

The selection of a severity index has a significant effect on cost-effectiveness analysis. The example problem from Appendix A of the *Roadside Design Guide* was reworked, using the modified severity index values presented in this report. For each of the three improvement options, the benefit-cost ratio was lower using the new severity index values; in the most dramatic change, the benefit-cost ratio of one alternative decreased from 3.1 to 0.6. Consequently, the report recommends that analysts evaluate a potential improvement over a range of appropriate severity index values.

Traffic Barriers and Control Treatments for Restricted Work Zones (31,32)

Ross and others at TTI developed several sets of severity indices for use with barrier and control treatments in restricted work zones. The researchers used a benefit-cost methodology to develop selection guidelines appropriate for barrier end treatments. For longitudinal barriers, impact severity (in ft lbs) was estimated based on the kinetic energy of the impacting vehicle. Upper limits were placed on impact conditions; above these limits, the vehicle was assumed to penetrate the barrier. Using the same 0 to 10 severity index scale as is in the *Roadside Design Guide*, researchers assigned a severity index of 7.5 to a penetration-type accident; this value was thought to be conservative.

This comprehensive project also used crash test results and related analytical techniques to predict the severity of collisions and the accompanying occupant injuries. The key measures of risk were the impact velocity of the occupant striking the vehicle interior and ridedown acceleration subsequent to impact. The researchers undertook a complex process to relate these factors to crash test results and to occupant injuries. They initially matched the Maximum Abbreviated Injury Score (MAIS) to lateral occupant impact velocity through results given in the technical literature. A relationship was obtained even though there was considerable scatter in the data. The researchers then developed a relationship between MAIS and severity index by comparing injury descriptors at various MAIS and severity index levels. The relationship was converted to a model of severity index versus impact velocity.

Data were not available to develop a model relating ridedown acceleration and severity indices. The researchers used inferences in the technical literature to produce a conservative model of this relationship.

Once models had been developed for lateral impact and ride-

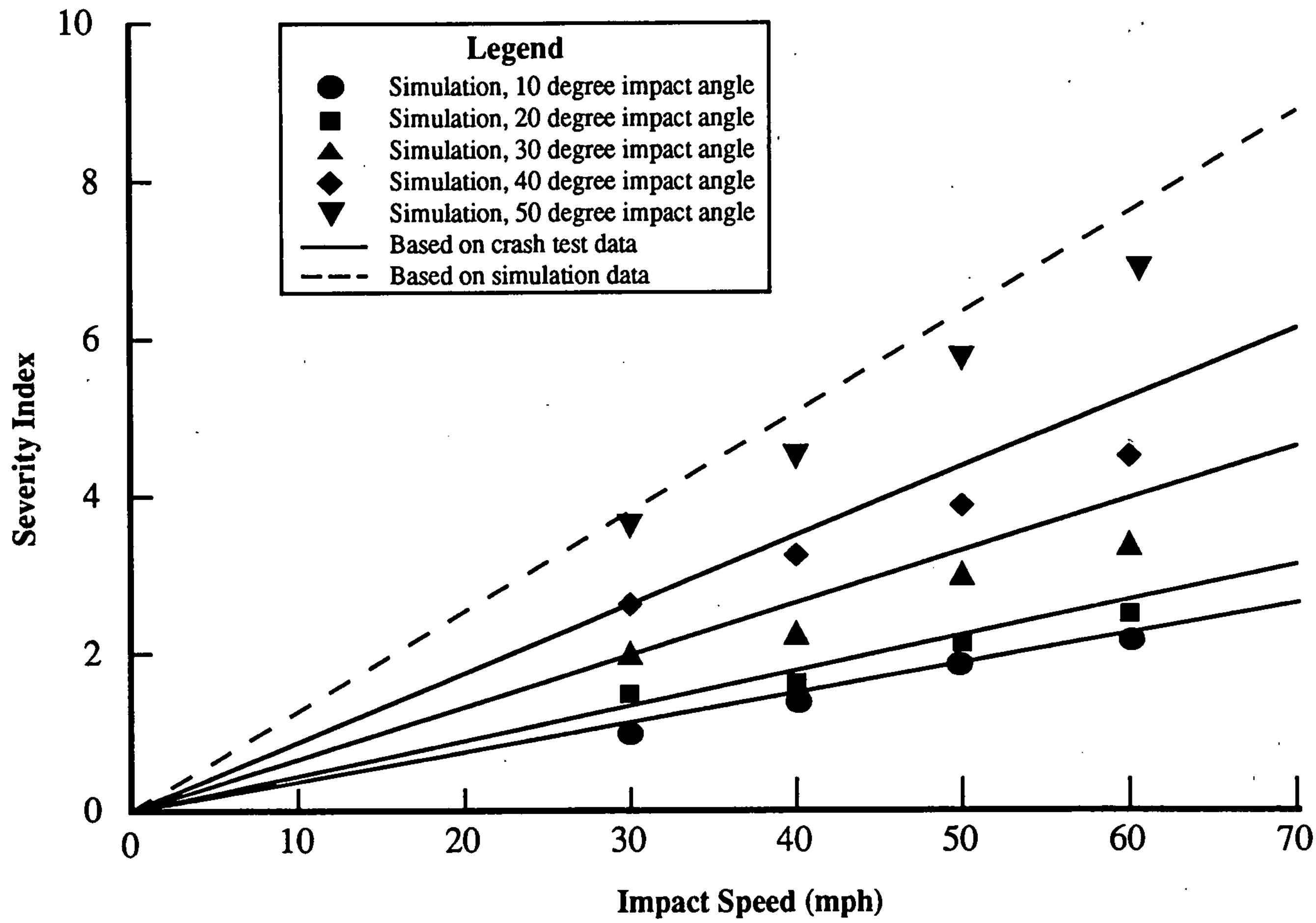

FIGURE 3 Ross' 1991 severity indices for concrete safety shape barrier. (Source: *Traffic Barriers and Control Treatments for Restricted Work Zones*) Note: 1.0 mph = 1.609 km/h

down effects, researchers used crash test results and computer simulations to develop severity index relationships for several barrier elements and barrier types (*32*). The project developed severity indices for concrete safety shape barriers (CSSB), the untreated end of CSSB, sloped-end treatment of CSSB, inertial crash cushions, and the GREAT™ barrier. For each of these features, the researchers found that the severity index depended on the speed, angle of impact, and mass of the impacting vehicle. Examples of the severity index relationships are shown in Figure 3 and in Tables A-14 and A-15.

In summary, Ross went to great lengths to develop severity indices for barriers, barrier end treatments, and crash cushions for use in roadway construction zones. The resulting severity indices were based on occupant injury, crash test results, computer simulation, and the best judgment of the researchers. The severity indices were rational in that higher speeds, larger impact angles, and heavier vehicles produced higher severity indices. In comparison with those indices developed through other types of research, these severity indices would be relatively difficult to validate.

At several points in this research, Ross and his colleagues made sweeping assumptions about certain key relationships. They used the best available data and their intuition to develop conservative estimates during these steps. The accuracies of these estimates and the overall effect on benefit-cost studies are unknown. However, it is safe to conclude that the resulting severity indices are as carefully and thoughtfully developed as current data and analytical tools permit.

"Low Service Level Guardrail Systems" (*33*)

Engineers have developed conventional guardrail systems that will contain a full-size, heavy sedan impacting the guardrail at a high speed and a large angle. Current designs are effective but can be expensive. Stephens conducted NCHRP Project 22-5 to investigate the potential for barriers on low-service-level roads and to prepare a user's guide for guardrail warrants on low-volume roads. His research was directed at identifying less expensive but effective barriers for these roads.

The user's guide developed by Stephens introduced the need for low-service-level guardrail systems, identified appropriate hardware, and outlined the warranting process for such guardrail. Example applications are given. Stephens used the ROADSIDE computer program to analyze area hazards and point hazards on low volume roads, producing a series of charts that described the application of guardrail as "suitable," "possible," or "not suitable" based on design conditions. Recommendations were developed from these charts.

While developing his charts, Stephens extracted severity indices from FHWA's *Supplemental Information for Use with the Roadside Computer Program* (*30*). He pointed out that the supplemental severity index values are useful while running the ROADSIDE program, but they can also be useful in performing an initial analysis and ranking of potential hazards. He indicated that when comparing options, with other things being equal, the feature or situation with the lowest severity index value would be the safest installation.

Benefit to Cost Analysis Program—Volume I, Reference Manual (*34*)

A recent NCHRP study on the evaluation of performance-level selection criteria for bridge railings included a detailed examination of the Benefit-Cost Analysis Program (BCAP) (*35*). This computer program was developed to facilitate the evaluation of alternative roadside safety improvements (*34*). As suggested by its name, BCAP compares an improvement's incremental benefits accruing to road users with the additional costs for construction and maintenance incurred by the highway agency (*36*). As a practical matter, the benefits of an improvement represent the reduction in expected accident costs, E(C), given by the following:

$$E(C) = \sum_{i=1}^{N} P(E) \times P(A|E) \times P(I_i|A) \times C(I_i) \tag{3}$$

where

$P(E)$ = Probability of an encroachment
$P(A|E)$ = Probability of an accident, given an encroachment
$P(I_i|A)$ = Probability of injury level i, given an accident
$C(I_i)$ = Cost associated with injury level i

For typical roadside objects, the severity of a collision, represented by $P(I_i|A)$, is a function of impact conditions, vehicle characteristics, and the nature of the object. In the particular case of bridge railings, the severity consequences are highly dependent on the postimpact trajectory of the vehicle striking the rail. Situations in which the vehicle is safely redirected onto the roadway have relatively low severities. At the other extreme, crashes involving penetration or rolling over the top of the bridge rail have high severities. The researchers on the NCHRP project analyzed 4,552 accidents involving Texas bridges for the period 1988–90 (*37*), and found that "the proportion of severe to fatal (% A+K) injury accidents increased from 8.4 percent for vehicles retained on the bridges to 21.4 percent for vehicles that went through the bridge railings to 39.6 percent for vehicles that went over the bridge railings." The study was unable to establish the reason(s) for the difference in severity between vaulting and penetration.

Algorithms within BCAP embody a number of assumptions regarding penetration force limits and vehicle rollover. The validity of these assumptions was questioned by the NCHRP researchers, especially since the results of model application differed substantially from real-world experience. They introduced corrections to BCAP to resolve the technical difficulties and coding errors. The purpose of these changes was to dramatically reduce the estimated percent of rail penetrations, while increasing the estimates of vehicles rolling over the rail. Even with these modifications to the program, the researchers expressed doubts about the validity of BCAP's accident prediction algorithms and accident severity evaluations. In response to these uncertainties, they required a benefit-cost ratio of 4.0 in the development of bridge railing performance level selection tables (*35*).

ONGOING RESEARCH EFFORTS

Severity indices are of great importance to the highway safety community because of their critical role in cost-effectiveness studies. This importance is partially reflected by the number and scope of ongoing research efforts. Several projects that may advance the understanding or reliability of severity indices are reviewed in this section.

"Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features"

Mak at TTI and Sicking at the University of Nebraska are currently conducting NCHRP Project 22-9 to develop improved microcomputer software for cost-effectiveness analysis procedures. The proposed software is intended for two primary uses:

- To access alternate roadside safety treatments for either point locations or sections of roadway
- To develop warrants and guidelines including those that consider performance levels of safety features.

"Development of Preliminary Severity Indices for Roadside Benefit Cost Models"

Council, at the University of North Carolina Highway Safety Research Center, is conducting a research project for the Centers for Disease Control with funding from FHWA. Council's investigation will use comprehensive roadway and accident data from North Carolina and Michigan to identify methods to develop severity indices for roadside features. An interesting aspect of the project is an effort to develop techniques to account for items like the effects of airbags and unreported accidents. Accident severity characteristics will change substantially as airbags become required; in fact, they will cause current severity indices to become obsolete. The heart of Council's work is intended to analyze such changes, to identify techniques to account for these changes, and to develop methods to produce severity index values that include consideration of the changes.

"Development of a Roadside Accident Data Collection and Analysis Plan"

Mak at TTI is conducting an FHWA project to develop techniques and plans for future accident research studies to improve benefit-cost models (such as the models being developed in NCHRP Project 22-9). Mak's proposed approach is to study the potential for development of severity indices through the collection of in-depth accident data.

Analysis of Federal Accident Databases

Carney is directing research at Vanderbilt University toward the use of comprehensive federal traffic accident data systems. Data from the Fatal Accident Reporting System (FARS) and NASS are being used for these efforts. Interesting findings have already surfaced during one FHWA-sponsored project (*38*), and researchers are conducting detailed analyses that could have pronounced influence on severity indices (*39,40*). For example, Troxel prepared a comprehensive and insightful summary of the historical development of severity indices (*41*), and has laid plans to investigate the following topics, some of which are extensions of previous work by Mak (*22*):

- Severity indices by linking accident data with vehicle crash test data
- Severity indices from a logistic-regression model of accident data
- Severity indices from regression of modified accident data
- Severity indices from regression of crash test data.

A comprehensive effort of this nature has the potential to greatly enhance knowledge of the relationship between severity indices and accident data. At the least, this effort should help determine which types of severity index research hold the greatest promise for future investigations.

Effect of Highway Standards on Safety

McGee, Hughes, and Lerch are conducting NCHRP Project 17-9, "Effect of Highway Standards on Safety." The objective of the research is to assess safety effects on highway design standards and to synthesize the results into a design guidance document that addresses safety needs.

As part of the project, the researchers reviewed methodologies that may be used to evaluate safety impacts of highway designs. They assessed the cost-effectiveness procedure described in the *Roadside Design Guide*. They reviewed the ROADSIDE computer program, identified data inputs, and discussed potential enhancements. The three primary enhancements suggested by the researchers were as follows (*42*):

- To improve user friendliness
- To improve the theory and empirical basis of the model
- To expand the model to analyze longer highway segments with varying roadside and median designs.

The researchers offered several constructive criticisms of the ROADSIDE program, which were categorized as encroachment estimation, impacts estimation, accident severity estimation, and economic estimation factors. The accident severity estimation criticism involved the fact that the designer must input many severity values to run the model. Severity indices are unavailable for many types of structures and embankments, thus forcing the analyst to generalize those indices under a simple heading such as rigid objects. McGee and his colleagues proposed a wider range of more-specific objects, and indicated that it would be "more appropriate for the designer to specify the object or objects, and then the program should 'look up' the severity indices" (*42*).

FHWA Internal Investigations

FHWA has long pursued improvements in severity indices, cost-effectiveness methodologies, modeling, and other tools to enhance roadside safety. Improvements sought for the Barrier Guide (*6*) eventually led to development of the *Roadside Design Guide* (*7*). FHWA invested a substantial effort to improve severity indices during the time between the two documents. As a result of user feedback, severity indices continued to evolve, leading to the 1991 *Supplemental Information for Use with the ROADSIDE Computer Program* (*30*).

In addition to pursuing its own research, FHWA has been very supportive of state initiatives. During telephone interviews conducted while developing this synthesis, the authors found that researchers in Kentucky, Missouri, Nebraska, and Virginia had received encouragement and technical assistance from FHWA while conducting research related to severity indices. Several of these projects (*26,28,29*) are documented in this synthesis. In one instance, FHWA engineers helped extrapolate severity indices to lower speed ranges than currently found in the *Roadside Design Guide*. In another, they helped researchers obtain more detailed severity indices than existed in published tabulations.

A brief sample of expanded severity indices, taken from internal working papers of the FHWA Office of Engineering, is included as Table A-16. These indices represent the collective opinions of experts, supplemented and verified with accident data to the extent possible.

Summary of Ongoing Research

Significant ongoing research efforts are pursuing separate routes toward using accident data and other methods to identify severity index relationships. This diversity underscores the fact that there is not yet a consensus on the best method, or even on the feasibility, of the concept of developing rational severity indices. These projects, along with continued internal efforts by FHWA, offer the promise of advancing the state of the art.

ACCIDENT DATA

As noted in TRB Special Report 214 (*23*), researchers have often experienced difficulties and frustrations in using traffic accident data in scientific studies. Several factors—including the quality of accident data, the difference in FHE and MHE, the cost values associated with accidents, and the regression-to-the-mean concept—seem especially pertinent to this synthesis and will therefore be briefly reviewed.

Accident Data Quality

Many current researchers feel strongly that accident data can limit the quality of severity indices. For example, there are substantial dangers in trying to mix and match severity indices developed from accident data in different states. Injuries and fatalities vary from state to state, as does the quality of accident data.

In a recently completed NCHRP synthesis on accident data quality (*43*), O'Day identified several problems associated with accident data reporting, quality, and use. Additionally, he addressed programs that could be used to enhance data quality. Several of these issues are relevant to existing severity indices and to future studies of this topic.

Most states use reporting thresholds; accidents that appear to do less than a certain amount of property damage (e.g., $500) are not investigated or reported. However, not all states have thresholds, and threshold values vary from state to state. As a result of thresholds, many minor accidents remain unreported. This omission complicates the determination of severity indices and causes severity indices based on traditional definitions to have inflated values.

Consistency of coverage is a second accident data problem. The number of accidents investigated (and to some degree, the data quality) is related to the amount of time available for accident investigation. For example, police may underreport accidents that occur on rainy or snowy days because they are saturated with calls. A corresponding difficulty is the consistency from location to location, especially with units of local government. In some cities, accident reporting is a low priority, and as a result, the number of reported accidents is well below the actual number of collisions.

Missing data hamper the use of some accident records. Investigating officers may neglect to record the information, or there may be a local practice of saving officers' time by not obtaining all the information for certain types of accidents. For example, some jurisdictions record restraint system usage only for injured persons. The failure to collect this information for persons who were saved from injury by wearing their seat belts hinders the use of these data in safety studies.

The availability of data needed for a specific type of study can also be a problem. For example, few accident record systems capture information about collisions that occur on embankments. If this information is desired, the analyst must usually travel to the field, determine the accident location, and secure measurements of embankment height and slope. A related example involves the injury scale. The most commonly used scale is that adopted by the American National Standards Institute (ANSI) D-16.1, which is defined as follows:

K = person with fatal injury
A = person with incapacitating injury
B = person with nonincapacitating evident injury
C = person with possible injury
0 = no injury

It is difficult for investigating officers to be consistent in applying these descriptions. A severely injured person may later die, or an apparently severe injury may turn out to be minor. The states report different average values for the various severities. O'Day found that "California reports only 4.8% incapacitating ("A") injuries while Illinois reports 23.83%." He also noted that Alabama reported 55 percent "A" injuries, although it used a somewhat different definition for this category of injuries. O'Day obviously used the extreme values from his survey to illustrate the range of reported severities. Most states fall closer together than California, Illinois, and Alabama. However, his point is clear—state to state differences can be significant.

Consistency of data elements can be a substantial problem, especially when using accident data from several jurisdictions. This problem may be noticeable when a researcher attempts to develop a large database by combining information from several states that have unequal reporting thresholds, different injury level descriptions, or even different levels of investigating officer training.

The level of detail in accident reporting provides another example. The collection of accident data is time-consuming and expensive. Data collection necessitates a trade-off between the amount of time and effort available to capture the data and the level of detail that is desired. Many safety analysts would prefer a more detailed scale of injuries than is currently used by most jurisdictions. It appears that progress on developing more credible severity indices is highly dependent on an improved injury level definition.

Data entry errors also confound accident studies. Errors may be introduced on the report form by the investigator or by entry of the data into a computer database. The most common error is in the description of the crash location. An Alabama study found that as many as 30 percent of the collisions in large urban areas had insurmountable difficulties in identification of the exact location. Equally serious locational problems have been reported on rural highway systems. Other data entry problems are more subtle or subjective in nature. For example, some law enforcement agencies may instruct their officers to always check something in every block of the accident report form. In the face of uncertainty, these officers tend to check the first entry for any block, thus introducing biased data into the accident record system.

In summary, O'Day's synthesis does a thorough job of identifying those factors that prevent more complete use of accident data. Several examples were mentioned to illustrate that there are real limits in the ultimate accuracy of any severity index based on reported accident data. Techniques must be developed and used to eliminate or compensate for accident data limitations and their effect on severity index precision.

First-Harmful Event Versus Most-Harmful Event

A significant problem in using accident data to generate severity index values involves identification of the object struck and its role in the accident. Most states capture the FHE of an accident sequence on the police accident report. The FHE might be thought of as the first damage occurring in any accident. Researchers have typically used the FHE to identify the fixed object involved in off-road accidents.

In a recent article, Viner discusses the difference between the FHE and the MHE in an accident sequence (*44*). The MHE is that single impact that causes the greatest trauma and damage in the sequence of events in each accident. The MHE is the appropriate identifier for development of severity indices. Unfortunately, few states collect MHE information; most record only the FHE on accident reports.

An example will illustrate the difference. Suppose vehicle A went out of control and sideswiped vehicle B. The damage was relatively minor and no injuries occurred in this collision. However, vehicle B deflected into a utility pole, killing the driver and seriously injuring an occupant. The FHE is the vehicle-vehicle collision for both vehicles. The MHE for vehicle A is the vehicle-vehicle collision, but the MHE for vehicle B is the pole collision. The FHE and MHE are identical for vehicle A but are completely different for vehicle B.

Viner analyzed the relationship between MHE and FHE for more than 14,000 off-road fatalities. For trees, the FHE turned out to be the MHE 85 percent of the time. In utility pole collisions, the FHE and MHE were identical 79 percent of the time. For other fixed objects and for embankments, the correlation between FHE and MHE was significantly weaker. For example, a vehicle striking a curb had the same FHE and MHE in only 23 percent of the accidents.

Turner found similar results in a field study of 538 off-road accidents in Huntsville, Alabama (*45*). The FHE "hit mailbox" was recorded for 85 collisions, 21 of which involved occupant injuries. Detailed reviews found that in 91 percent of the injury accidents, the MHE was actually a collision with a secondary object; in other words, the FHE and the MHE were the same for only 9 percent of these crashes.

A few simple but strong conclusions may be drawn. First, the FHE and MHE in off-road accidents are frequently different. Second, MHE data are desirable, but few states currently collect this information on their accident report forms. Third, severity indices developed using FHE data can differ significantly from those developed with MHE data. Most researchers have failed to identify whether they used FHE or MHE values in developing severity indices. This discrepancy may account for some of the past variations from study to study and from state to state. Future researchers should not attempt to develop severity indices unless MHE data are available.

Estimates of Accident Costs

The roadside safety cost-effectiveness methodology requires the analyst to estimate the financial values associated with future accidents at a given site. On the surface this sounds simple. Given the number of accidents at each severity level, an average cost per accident can be applied to yield total cost. In practice this concept is not so simple. There have been longstanding differences of opinion in the highway community about the appropriate costs for the various accident severities.

An early illustration is provided by the Glennon and Tamburri paper (*9*) discussed previously in this chapter. These researchers stated that economic values are the most convenient basis for evaluating the three classes of accident severity. However, they also noted that "many different philosophies have related the economic value of traffic accidents." After further investigation they concluded that "a consideration of human suffering and the loss of future earnings would increase the severity weights of fatal injury accidents considerably and would have a substantial influence on the severity indices, if indices were calculated from accident cost."

Many other examples can be cited from studies reviewed during this chapter. In 1987, TRB Special Report 214 (*23*) pointed out that several organizations had established cost values for the various levels of accident severities, but none of the estimates had gained universal acceptance. The authors further state that results of cost-effectiveness analyses could be very sensitive to imputed accident costs. Because of the controversial nature of accident costs, as well as their importance in the evaluation of treatments, a brief review of accident costs is included in the following paragraphs as background material.

Both direct and indirect costs are included when estimating the financial impact of an accident. One of the early definitions of direct cost that received wide acceptance was stated in HRR 12 (*46*): "Damage to property, ambulance use, hospital and treatment services, value of work time lost, legal and court fees, damage awards and settlements, and other miscellaneous items. . ." Different definitions have emerged since the Highway Research Board (HRB) paper was published, with many including costs due to loss of future earnings.

Direct accident costs are calculated through a detailed scrutiny and record keeping exercise involving the number of fatalities, injuries, and property damage per accident in a given jurisdiction. This calculation can involve exhaustive procedures to document the individual costs associated with each component of direct costs.

Indirect costs may encompass items like production and consumption losses for the affected person; losses to the home, family, and community of the injured person; cost for accident investigation; and costs of insurance administration (*19*). Many other categories of expenses could also be classified as indirect.

There are three commonly used methods for calculating indirect cost of a fatal accident (*20*). The first method incorporates the cost to others but not the cost of the value of the person's life to himself or herself. The National Safety Council (NSC) endorsed this method for many years, and released annual financial estimates for the various levels of accident severity. The second technique does not subtract consumption from future total production for the deceased. NHTSA was an early champion of this technique (*20*). The third method uses a market approach. It determines the amount the motorist is willing to pay to avoid the penalty, i.e., the motorist's willingness to pay (WTP) to avoid the risk of death. This method generates the highest estimates for the cost of accidents.

The foregoing discussion illustrates why no consensus has been reached regarding the assignment of cost values to various levels of accident severity. Considerations must be weighed carefully and several possible accident costs must be derived for each. Currently, the WTP concept seems to have emerged as the technique most used by knowledgeable safety analysts and safety-related organizations. It is appropriate for cost-benefit studies involving trade-offs between alternative safety treatments or for regulatory decisions.

The NSC continues to advocate its previous cost-estimation method to measure economic loss to a community from past traffic accidents. However, NSC recommends that these values not be used to compute dollar values of future safety benefits "because they do not include the value of a person's natural desire to live longer. . ." (*47*). NSC recommends the WTP concept for cost-benefit analyses whenever feasible. Similar changes have occurred at NHTSA, which had not previously called its methodology the "willingness to pay" technique. A recent NHTSA report, *The Economic Cost of Motor Vehicle Crashes* (*48*), includes an appendix acknowledging the WTP approach.

Economic values for regulatory and investment analysis studies by US DOT now use the WTP approach. This was stipulated in a memorandum issued jointly by the General Counsel and an Assistant Secretary of Transportation in June 1990. The following year, an FHWA publication (*49*) based on research performed at the Urban Institute reflected 1988 motor vehicle crash costs based on the WTP concept. The report showed average costs of $4,489 for PDO accidents, $72,000 for nonfatal injury accidents, and $2,722,000 for fatal crashes. FHWA indicated that these values were useful for choosing among alternative treatments or projects. A summary of the cost per person and per collision is presented in Table 8.

On January 8, 1993, the US DOT General Counsel and the Assistant Secretary for Policy and International Affairs jointly issued an instructional memo outlining revised economic values and procedural guidance (*50*). This memo contained instructions to use $2.5 million as the WTP value of an averted fatality. The WTP number was to be treated as a threshold. To use the value in a study of alternative treatments, the analyst assigns a monetary value to each benefit and cost of a proposed alternative, then

TABLE 9
US DOT INJURY COST ASSIGNMENTS (*49*)

Abbreviated Injury Scale	Descriptor	Fraction of WTP[a] Value
AIS - 1	minor	0.0020
AIS - 2	moderate	0.0155
AIS - 3	serious	0.0575
AIS - 4	severe	0.1875
AIS - 5	critical	0.7625
AIS - 6	fatal	1.0000

[a]Willingness to Pay

computes the net cost per fatality averted. If this net cost lies below the WTP threshold of $2.5 million, then the proposal passes the benefit-cost test. The FHWA memo was based on further research by Miller, who used 30,000 collisions taken from the NASS file. His study of accident costs was thought to be the strongest ever conducted and led to the assignment of estimated costs for various types of injuries (shown in Table 9).

In summary, the financial values to assign to various collision severities have been controversial for at least 30 years. Various organizations have adopted different methods for estimating costs, published different cost figures, and used these figures for safety studies. Currently, there appears to be a movement toward the WTP concept as most appropriate for economic analyses. The US DOT has adopted the WTP methodology and has assigned a 1993 value of $2.5 million per averted fatality. The US DOT criterion is not well known among practitioners; many have adopted alternative (usually lower) economic values. This lack of consistent economic value criteria certainly leaves room for improvement in the understanding of the costs of collisions, and for a more uniform treatment by analysts at all levels.

Regression to the Mean

Statistical inferences drawn from traffic accident data can be misleading (*51,52*). One problem that has received considerable recent attention is regression-to-the-mean sampling bias, which is caused in part by the traditional methods used to select potential improvement sites. In the typical situation, the highway safety engineer uses accident records to identify locations with an unusually high number of accidents during a *Before* period. These sites are then treated with one or more engineering countermeasures intended to reduce the frequency or severity of crashes, and the accident experience is determined during an *After* period.

The restriction of potential treatment sites to locations experiencing unusually high numbers of accidents violates one of the fundamental assumptions of statistical work, that is, selection of unbiased statistical sites using a random sampling procedure. As suggested by Figure 4, the actual treatment sites form a sample drawn from the upper end of the population distribution of all accidents. The horizontal axis in the figure represents some measure of hazard (such as the number of *Before* accidents), which increases from A to B. The sample C-D represents those locations that are typically selected for the implementation of safety programs. As evidenced by the figure, this is not a random sample selected over the full range of hazard, but rather it is a biased sample. Nevertheless, the engineer might expect that the hazard at these sites *After* the implementation of a treatment would fall closer to the center of the distribution, perhaps in the area shown as E-F.

The technical literature (*53*) shows that a site with an unusually high number of accidents during a *Before* period will, on the average, have a lower number of accidents during the *After* period, even in the absence of any treatment at the site. This phenomenon of regression to the mean, which has long been recognized by statisticians, can be accommodated in highway safety analyses by selecting a pool of hazardous sites; of these, a portion would receive a countermeasure, while the rest would remain untreated and serve as comparison sites. Alternatively, the empirical Bayes procedure, using some other measure of total population hazard, has been recommended by knowledgeable transportation data analysts to address the problem.

Regression to the mean deals with ensuring that all sites are included in the site selection process, not just high-accident sites at the upper end of the site population. This is analogous to ensuring that all accidents are included during determination of severity indices, not just high-severity accidents. It is commonly accepted that many crashes of low to medium severity are not reported; as a result, an important portion of the population is missing. Traditional analysis procedures, based on a disproportionate share of higher severity crashes, have almost certainly generated severity indices that are misleading; advanced analysis techniques have the potential to produce more representative severity indices.

Accident Data Relationship with Severity Indices

This brief discussion has illustrated that existing accident data quality can affect the accuracy of severity indices. Large databases, carefully screened and purified, will be necessary to help offset these difficulties. Accident data must include the MHE if reliable severity indices are to be determined. Accident cost estimates were discussed because they are crucial for the economic evaluation of alternatives. Highway safety analysts have previously used divergent accident cost values, but FHWA's recent adoption of the WTP concept for financial values is expected to create stability in this area. The regression-to-the-mean phenomenon was discussed because it parallels the selection of accident data for severity index determination. Current accident databases omit low-severity colli-

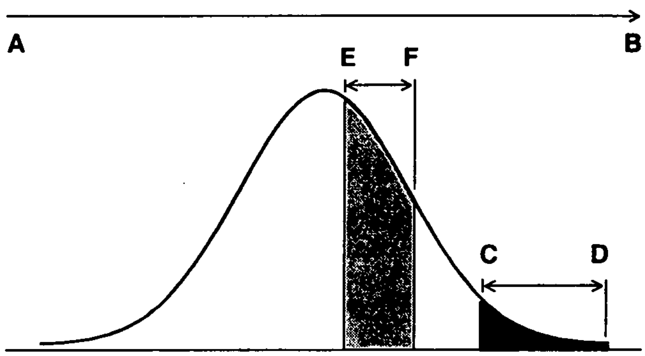

FIGURE 4 Illustration of sample bias.

sions, leaving a biased sample of the most severe collisions. Severity indices developed from these data are likely to overemphasize the probability of an injury or fatality.

CHOOSING THE "BEST" SEVERITY INDEX VALUES

Over the past 30 years, researchers have proposed and developed alternative methods of deriving severity indices, including expert opinion, crash testing, modeling, and simulation. Application of these techniques frequently provided useful information, but unfortunately, it often provided more questions than answers. The lack of direct comparability among the results restricted the acceptance of severity indices and led to some confusion among the ultimate users of this information. The dilemma faced by users in choosing appropriate severity values may be partially appreciated by scanning the example severity indices in Appendix A (Tables A-1 through A-16), noting the similarities and differences, and attempting to choose the "best" value for a particular analysis.

Given the current status of severity indices, how can an analyst, especially a novice, go about selecting the "best" index values for a particular application? There is more than one way to make the decision; this synthesis effort found that no clear and universally accepted method has emerged for severity index decisions for most types of roadside objects. Selecting the "best" index value for a particular application takes hard work. The following statements outline the state of the practice for severity index decisions:

- Currently, the *Roadside Design Guide* methodology appears to be the best available general procedure, especially when used in conjunction with the *Supplemental Information for Use with the ROADSIDE Computer Program.*
- Under some conditions, other severity index values may be more appropriate. Examples include situations where the analyst has advanced expertise in selection of severity indices, has knowledge of research that produced severity indices appropriate to a particular study, or has special knowledge of local site conditions for which a particular set of severity indices is well suited.
- If the user lacks expertise to select severity index values, the explanatory notes accompanying the *Supplemental Information for Use with the ROADSIDE Computer Program* may be very helpful. If additional guidance is needed, it may be secured from FHWA's Division or Headquarters offices.
- Severity indices will continue to evolve in response to technological advances in vehicles. They will also improve over time as more research is conducted and as better techniques are developed.
- As severity index changes occur, it may be necessary to revisit previous research efforts that produced warrants for guardrail. This is especially true for cases in which cost-effectiveness studies were the basis of the research.
- The literature review exposed some of the limitations of current severity index values. The user should be aware of how these limitations affect applications and accuracies of cost-effectiveness studies.

Roadside safety cost-effectiveness studies have a useful and necessary place in roadway decision making. The current methodology can be a reasonable and effective tool in the hands of an informed user; however, the user must recognize that the method has significant limitations.

CHAPTER THREE

QUESTIONNAIRE SURVEY

The technical literature, coupled with the valuable guidance from telephone interviews conducted by the authors, demonstrates that several research teams have examined various aspects of the severity index issue. The most recent AASHTO standards for roadside safety design provide a limited set of severity indices as a function of speed, object type, and impact point (*7*). However, some engineers have expressed concern regarding the validity of the severity indices presented in AASHTO's 1989 *Roadside Design Guide* and have noted the sensitivity of the economic analyses of roadside safety improvements to rather small changes in assumed severity values. The expanded level of detail in the more recent supplemental information (*30*) may have partially offset these concerns, although the telephone interviews provide ample evidence that neither researchers nor practitioners are comfortable with the current severity indices.

TABLE 10
PENNDOT UNIT CRASH COSTS

Crash Severity	Unit Cost
Fatality	$1,259,544
Major injury	310,440
Moderate injury	10,062
Minor injury	3,284
PDO	1,994

Source: Data provided in PennDOT's survey response.

SURVEY OF STATE AGENCIES

In an effort to determine if and how the individual state highway and transportation departments had resolved their concerns, a questionnaire survey was developed and distributed to safety and traffic engineers in these agencies. The survey, shown in Appendix B, was distributed by the NCHRP staff in August 1992, and those who had not responded were recontacted in October. Overall, 38 states responded to the questionnaire survey, although some respondents chose not to answer one or more questions. The following sections summarize their responses.

1. Which of the following does your agency routinely use to assist with roadside safety analyses? Please check all that apply.

☐ AASHTO Roadside Design Guide, 1989	32	84%
☐ Other technical reference:	13	34%
☐ ROADSIDE Computer Program	15	39%
☐ Other computer software:	12	32%

The responses clearly indicate that the AASHTO *Roadside Design Guide* is the primary document used by the responding highway agencies to perform roadside safety analyses. Thirteen respondents indicated that they rely in part on other technical documents, the most common being the 1977 AASHTO Barrier Guide (*6*), which was cited by three states. Two states mentioned the *Supplemental Information for Use with the ROADSIDE Computer Program* (*30*), including its Appendix C, FHWA Technical Advisory T7570.1 on Motor Vehicle Accident Costs. Several states indicated that they use their own design or traffic engineering manuals. Nearly 40 percent of the respondents indicated that their states use the ROADSIDE computer program. This statistic probably overstates the program's use, however, since many of the affirmative responses were accompanied by qualifiers such as "occasionally," "not routinely," or "optional."

The reported limited use of ROADSIDE was unexpected, since it clearly simplifies the computational aspects, especially when multiple alternatives are being considered. A dozen states use other computer software in their roadside safety analyses. Based on the comments provided by the respondents and several follow-up telephone interviews, much of this appears to be software that was developed in-house to satisfy particular conditions. For example, several states reported using specialized software to analyze accident records, and two used special software to calculate the length of need for guardrail.

Several survey responses offered alternative methods for the identification of problem locations and the development of corrective actions. For example, Indiana has developed its own *Roadside Design Guide* (*54*), combining elements of AASHTO's publication (*7*) and the Indiana DOT's (INDOT's) clear-zone policy. The new guide incorporates the severity indices in FHWA's supplemental information (*30*). However, INDOT employed existing data and made several assumptions to estimate the severity indices for certain proprietary guardrail end treatments. The Indiana guide will be applicable for most new, noninterstate construction and resurfacing, restoration, and rehabilitation work.

The Nevada DOT (NDOT) developed and uses a PC Basic program called "Potential," which calculates hazard indices for roadside features (*55*). The program helps NDOT perform "what if . . ." analyses for proposed treatments based on the design and operating features of the road. Nevada does not use ROADSIDE but rather relies on AASHTO's 1977 Barrier Guide.

Pennsylvania employs an alternative approach for evaluating roadside safety. The Pennsylvania DOT (PennDOT) uses its accident record system together with the assumed unit costs of crashes shown in Table 10 to estimate the average cost of impacts with nine different object types in both urban and rural areas. Although the unit costs have not been revised recently, average crash costs

TABLE 11
RESPONDENTS EXPERIENCING PROBLEMS IN SELECTING PARAMETERS

Encounter Problems	Rarely	Occasionally	Often
Design Traffic Volume	90%	7%	3%
Roadway Curvature	90%	3%	7%
Roadway Gradient	93%	0%	7%
Design Speed	77%	19%	3%
Baseline Encroachment Rate	61%	21%	18%
Encroachment Angle	45%	28%	28%
Hazard Offset	79%	21%	0%
Dimensions of the Hazard	83%	17%	0%
Lateral Extent of Encroachment	62%	28%	10%
Severity Indices	27%	30%	43%
Expected Accident Costs	47%	23%	30%

Source: Survey responses

are updated annually to reflect the actual severity of reported crashes. The resultant costs, which serve as surrogates for severity, were formerly used in benefit-cost analyses; PennDOT only implemented treatments with B/C>2. Pennsylvania, which currently emphasizes safety improvements along corridors, has developed Cluster Parameters (e.g., 5 hit tree accidents per 0.3 km per year) for identifying problem locations. Corridors with multiple accident clusters are reviewed in the field by safety engineers.

2. If you use the Roadside Design Guide or ROADSIDE software in conducting evaluations and making decisions regarding roadside safety, do you have problems in selecting or justifying values for the following parameters?

From the perspective of this synthesis effort, this was the seminal question in the survey. The items enumerated in this question represent the minimum data requirements (or assumptions) required by an analyst to conduct roadside safety evaluations using the AASHTO methodology. Several of the data parameters (e.g., roadway gradient, traffic volume) are clearly within the purview of the highway agency; if the agency does not have the information, it cannot expect to find the information in secondary sources. On the other hand, it would not be realistic for highway agencies to develop several other parameters (e.g., encroachment rates and angles) that are required in the model. Regardless of the source of the information, the question sought to establish the ease with which the respondent could obtain justifiable values for these parameters.

Of the 33 agencies that reported using either the *Roadside Design Guide* (*7*) or the ROADSIDE computer program, between 28 and 31 rated each of the parameters. Table 11 shows the percentage responding as indicated.

As expected, the questionnaire responses reflect a high level of confidence in the site-specific parameters such as roadway alignment, traffic volume, and object dimensions and placement. As suggested by Figure 5, about 40 percent of the respondents encounter some problems in establishing the encroachment rate and lateral extent. Over half experienced difficulty in selecting or justifying values for the angle of encroachment and the cost of a single-vehicle ROR accident. As clearly demonstrated by Figure 5, highway agencies have the least degree of confidence in severity indices for fixed object impacts. As noted in Chapter 2, both the severity index and the accident costs can have a significant effect on the outcome of a roadside safety analysis.

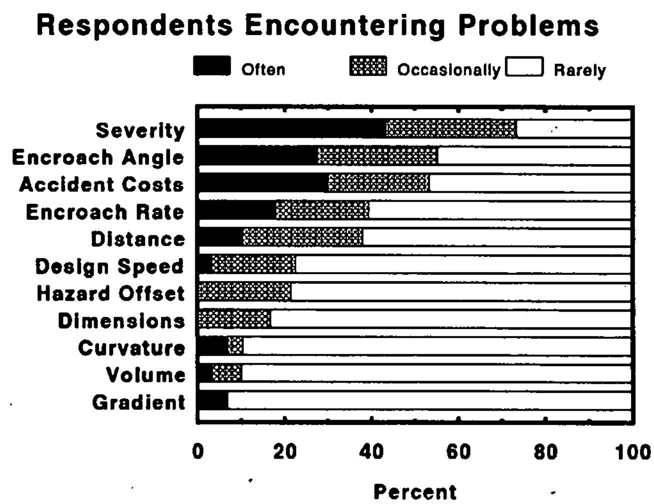

Figure 5 Problems in roadside safety analysis.

3. What would be required to reduce or eliminate these problems and improve your confidence in assessing the safety effectiveness of roadside improvements?

The 24 states that responded to this question offered a variety of suggestions, but by far the most common, given by 12 (50 percent) of those responding, dealt with severity indices. Most of the 24 respondents would agree with those who called for a "well-documented set of severity indices" for a "wider variety of objects." Additional respondents expressed their general frustration with the apparent subjectivity of the values presented in the *Roadside Design Guide* by calling for better field data, not only for severity indices but also for encroachment parameters and accident costs.

A couple of respondents expressed frustration with the substantial amount of engineering judgment required by the current methods of roadside safety analysis. Conversely, others felt that the rigidity of the *Roadside Design Guide* and ROADSIDE stifled their exercise of engineering judgment. "*Informed* engineering judgment" is a fundamental component of the profession. What differentiates the informed, educated opinion of an engineer from the guess of a typical citizen is a readily available, credible, and comprehensive set of evidence, which the engineer can apply to the problem at hand. Survey responses indicate that many engineers feel this necessary informational base is inadequate in the case of severity indices.

Questions of this type permit the responding engineers to mention issues that have created recent difficulties for them. Isolated points mentioned by one or two persons who make significant use of the AASHTO procedures could reflect real problems that might lend themselves to simple correction. Responses that fall within this category include the following:

- Clarify the proper use of design versus operating speed
- Provide for traffic volumes greater than 20,000
- Give more information on encroachment angle-runout length relationship
- Include data on barrier repair costs.

4. Appendix A of the AASHTO Roadside Design Guide provides a limited set of severity indices as a function of object type, impact location, and design speed:

	Yes	No
a. Do you use this information?	42%	58%
b. Do you have a high level of confidence in this information?	19%	81%
c. Have you developed alternate information on severity indices that you feel is more reliable?	23%	77%

In contrast to the 33 states who indicated in question 1 that they used the *Roadside Design Guide* or ROADSIDE, only 15 of the 36 respondents to question 4a claimed to use the severity index information in Appendix A of the *Roadside Design Guide*. The states have little confidence in the quality of the severity index information; only 5 of the 27 respondents indicated a high degree of confidence.

Despite the impression given by the responses to question 4c, it appears that most of the states responding positively had not actually developed alternate values for severity indices but rather were using the values contained in FHWA's supplemental information (*30*). PennDOT provided information from its accident record system for a limited number of roadside obstacles that could be used to develop severity indices.

5. In your opinion, what specific revisions are needed to make fixed object severity indices more useful in the analysis of roadside safety improvements?

Responses to this question varied greatly. By far the most common request was for severity indices for a more extensive set of objects. Several respondents mentioned specific objects, including trees by diameter, different barrier designs, and combined effect of embankment height and slope. Related topics of interest included more information on severity indices as a function of speed, angle of impact, and the roadside slope between the traveled way and a rigid object. Several respondents volunteered that the greater number of objects included in the FHWA supplemental information (*30*) was quite helpful, although it still had significant gaps.

The lack of data credibility evident in the replies to question 4b was also obvious in these responses, where the need for reliable, justifiable severity indices that reflect real-world conditions was mentioned by several respondents. The concept of using a more scientific approach to determining severity indices and carefully explaining the process and the results to the end user was also suggested by several respondents. Some respondents felt that the whole methodology in the *Roadside Design Guide* needs to be better explained.

Survey respondents offered divergent opinions on the issue of providing discrete severity indices versus a range of values. One respondent argues convincingly that the presentation of single severity indices, as in Table A.3 of the *Roadside Design Guide*, gives a designer the false impression that severity indices are absolute. Another respondent contends that ranges of values, as given in FHWA's supplemental information, create an undue burden for the typical user who has insufficient expertise to make a choice among the severity indices in a range. These differences of opinion are simply diverse perspectives on how well (or poorly) the AASHTO guidelines accommodate "informed engineering judgment."

Respondents offered four additional suggestions that appear to deserve consideration in any effort to enhance roadside safety analysis:

- The existing process is too vague. A pair of competent engineers using these standards to evaluate a particular situation can arrive at dramatically different results.
- The *Roadside Design Guide* needs to be clearer on the proper method for evaluating multiple roadside obstacles at a location.
- Application of the roadside safety evaluation procedures over an extended section of highway is extremely time-consuming.
- A table showing what options are cost-effective at various design speeds would be a useful addition.

6. Are you aware of any severity index tabulations for roadside obstacles that could be used to supplement or corroborate those presented in the AASHTO *Roadside Design Guide*? If so, would you please indicate the source of the information?

Of the 37 responses to this question, 13 (35 percent) indicated an awareness of supplemental severity index information. Most of these responses identified FHWA's *Supplemental Information for Use with the ROADSIDE Computer Program* (*30*), but it was clear that some agencies did not have the most recent version of this document. Other respondents mentioned a computer program developed by the University of Kansas, some research results from

Vanderbilt University, the New York DOT accident reduction factors, and AASHTO's 1977 Barrier Guide (*6*). One state agency noted that its accident records included cost and casualty information that could be used for this purpose.

7. Are you aware of any ongoing projects or studies, either within or outside your agency, that are attempting to improve the understanding, usefulness, or quality of roadside severity index information? If so, can you identify a specific individual that we should contact to obtain further information on this subject?

Only 3 of the 37 respondents indicated an awareness of ongoing activities related to roadside safety. The projects included some research at Vanderbilt University and NCHRP Projects 22-8 and 22-9. These sources were contacted and their relevant efforts are cited in Chapter 2.

8. If you were given the authority to define the next major research project addressing the weaknesses of existing severity index and/or roadside safety information, what would be the primary focus of the research?
9. Do you have any other comments or suggestions related to severity indices, roadside safety, establishing priorities, or cost-effective treatments?

The responses to both of these questions tended to offer suggestions concerning where additional improvements could be made in the roadside safety analysis process. Some of the issues raised require research for their resolution, whereas others might be resolved through administrative or educational initiatives.

Five respondents suggested that the primary focus of a new research project should be verification of projected severity indices, preferably through an evaluation of actual improvements that were selected on the basis of the *Roadside Design Guide* methods. The skepticism expressed by many state agencies could potentially be resolved through a validation project. Four respondents recommended efforts to simplify the analysis methods and four proposed studies to develop severity indices for objects that are not included in the current guidelines. Two states suggested that the primary need is to establish more credible information on encroachment rates and angles, whereas two others feel that improved accident cost estimates should be a priority topic. Other issues recommended for additional study include methods and data for speeds less than 70 km/h, determination of cost-effective clear roadside widths, and the redirection capabilities of backslopes.

Although it is not a research topic, several states mentioned a need to improve the user interface and operation of the ROADSIDE computer program. In addition, some respondents expressed concern that engineers within their agencies do not have a good understanding of the factors associated with roadside safety; the simplicity of the ROADSIDE program could lead the unwary to erroneous conclusions. In the absence of "informed engineering judgment," ROADSIDE simply allows the analyst to make mistakes faster.

QUESTIONNAIRE EPILOGUE

Responses to this survey of state traffic and highway safety engineers provide a reasonably comprehensive picture of the roadside safety analysis methods used by these agencies. A majority of respondents clearly look to AASHTO for guidance on the issue of designing for roadside safety; this would be expected, given the association's historical involvement (*3*) in this area. Survey responses indicate that the 1989 *Roadside Design Guide* and the companion ROADSIDE computer program are the authoritative, most commonly used technical references on roadside safety issues. The respondents have relatively high degrees of confidence in the values of those analysis parameters, such as traffic volume and roadway alignment, that they can readily collect for their road system. On the other hand, respondents express valid concerns about several analysis parameters that are not specific to a particular study site; prime examples include severity indices, roadside encroachment characteristics, and accident costs.

In an effort to maximize the response rate, the survey instrument developed and distributed as part of this synthesis project was kept relatively short. The 76 percent response rate suggests that this strategy worked well in generating input from virtually all of the states that have a sincere interest in this topic. While input from the remaining states would have been welcomed, there is no reason to believe that additional responses would have substantially altered the questionnaire survey findings discussed previously.

Finally, it is appropriate to note that the questionnaire was sent to prominent, upper-level highway and traffic engineers at each state highway or transportation agency. In some cases, these individuals responded to the survey, while in others the task of responding was delegated to subordinates who may work more closely with the day-to-day task of assessing roadside safety. These latter individuals may be in a better position to address the technical issues raised by the survey, although they may lack the background to respond to policy questions. In other words, certain responses may be strongly supported by facts, while others simply represent the opinion, informed or otherwise, of the respondent.

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

This synthesis was prepared to provide insight into the development of the severity index as an integral component of roadside safety analysis. Previous chapters introduced the concept, identified and critiqued several severity index research efforts, and outlined the results of a survey of state highway agencies.

CONCLUSIONS

Traditional techniques for identifying locations where roadside obstacles constitute a special problem and for assessing the merits of alternative forms of corrective action rely on assumptions about the likely outcome of a vehicle encroaching onto the roadside. Severity indices provide a common method for describing the expected consequences of a vehicle leaving the traveled way and impacting a fixed object. Glennon's early work (*10*) identified a number of competing ways to describe severity, with the preferred method depending on the availability of reasonably complete and reliable data. Since that time, additional studies have made attempts to describe severity in terms of alternative measures.

Early research found that defining severity index as the portion of all accidents resulting in a fatality or an injury was simple but potentially misleading. It was simple in that the index could be calculated from any accident database in which the analyst had confidence. It was misleading because researchers have since established that results vary from state to state—on different road systems, at different highway speeds, for different classifications of the objects—and from year to year. Severity indices calculated in this manner were also sensitive to the exclusion of minor PDO collisions from the accident database, which had the effect of artificially raising the severity indices. The various research efforts are reviewed in Chapter 2.

In an effort to correct these shortcomings, severity indices advocated by AASHTO are now defined using a relative ranking of the expected degree of damage and injury, with the results based more on intuitive judgment than on crash statistics. The inherent flexibility of this approach overcomes many of the perceived problems with accident data quality and completeness; the knowledge (or assumption) that 10 percent, 20 percent, or even 50 percent of the accidents with a particular object are unreported can easily be incorporated in these severity indices. Likewise, alternative sources of information, such as crash test results, have been used to extend a basic table of severity indices to include objects or field conditions for which actual accident data are limited or nonexistent. The references (*7,30*) used by most states in their roadside safety analyses are quite forthright in informing the user that the severity indices are guides, rather than exact values, and that they may not be fully supported by any existing accident databases. Nevertheless, the questionnaire survey responses suggest that a substantial number of the persons using these references are not aware of this distinction.

The survey of state highway and traffic engineers who make use of AASHTO's *Roadside Design Guide* or the ROADSIDE computer program found that these individuals had an extremely difficult time in selecting and justifying their choices of severity indices, accident costs, and encroachment parameters. Certain factors incorporated in the roadside analyses, such as traffic volume and roadway alignment, can be readily determined by making physical measurements at a site. However, the typical analyst is not in a position to verify the more general factors, such as severity indices. When roadside safety calculations produce nonintuitive results, or support treatments with excessive costs, the skeptical analyst may simply be inclined to blame those parameters that are difficult or impossible to validate.

Despite concerns with severity index accuracy, there was considerable sentiment among survey respondents for an expanded severity index list. As long as severity indices are not tied directly to crash experience, it should be possible to incorporate additional objects, different object designs, other speeds, and similar parameters in such a list. The material presented in Table A-16 represents a positive step in this direction.

CURRENT STATUS

In spite of previous efforts to define, develop, and test severity indices, this research found that the severity index has not reached a mature stage of development. Currently, the most widely used values for severity indices are those presented in the *Roadside Design Guide* (*7*), along with those in the *Supplemental Information for Use with the ROADSIDE Computer Program* (*30*). The developers of these indices based them on expert opinion, tempered with an understanding of general accident study methodologies and results. To date, no research effort has confirmed these severity index values as accurate, authoritative, or representative of those crashes that actually occur on American roadsides.

No analytical technique has yet been identified as the definitive method for determining severity index values. Multiple investigative efforts have produced divergent answers. In at least two instances (*22,28*), researchers found greatly different results by employing different methods to develop severity indices from a single data set. The values were divergent in numerical scores, rank orders, and relative weights.

State highway safety analysts and designers are the most frequent users of severity indices. A national survey found that these individuals have greater problems with severity indices than with any other aspect of roadside cost-effectiveness studies. Their responses indicated uncertainty, and in some cases confusion and frustration, about these types of studies, the ROADSIDE computer model, and especially about use of severity indices. Clearly there is a need for improvement in the understanding and use of these safety tools.

Typically, synthesis research projects identify trends that allow the future to be forecast. Often a prominent research direction or pattern of research is found to offer the most effective route for future advancements in the understanding of a technical issue. That has not been the case with this synthesis. Despite numerous and progressively more complex research efforts, no clear path has emerged as the best direction for future efforts. Much work remains to be done before values of severity indices gain widespread acceptance.

RECOMMENDATIONS

The desirability of additional research is evident from the findings cited in this synthesis. The following projects offer promise for improving the acceptance, quality, and usefulness of severity indices:

- It appears that a major research effort is needed to convince the users that the roadside cost-effectiveness methodology is appropriate. The research could employ a *Before* and *After* study with control sites and appropriate statistical analyses to assess the actual outcome of improvement projects, as compared to those predicted by the *Roadside Design Guide* and the ROADSIDE computer model. If the current guidelines are found to grossly underestimate or overestimate benefits, research attention should be turned to areas other than severity indices until the procedure is shown to predict future accident levels with reasonable certainty.
- Many users of the ROADSIDE program would like to have an expanded severity index list; this appears to be a desirable research product. The users also seek guidance in using such a list. Apparently, many of them do not have experience in roadside safety analysis, or they lack appropriate databases, or they need other information to make fine-level decisions about appropriate severity indices for a particular study.
- It would be useful to develop intelligent, user-friendly software to help analysts choose severity indices, encroachment parameters, and other input required for conducting roadside safety cost-effectiveness studies. This software might be in the form of an input subroutine for the ROADSIDE program, a similar approach for other existing software, or a completely new computer program. For example, one computer screen could determine the expertise of the user. An extremely knowledgeable analyst with access to a large database could be routed by the computer program through a series of questions that would lead to finely-detailed severity index values appropriate for the site currently under study. An analyst with little familiarity or data could be routed through a different series of questions focusing on broad areas, with coarser levels of severity index choices. The software could probably assign some level of confidence to the severity index values so that the expert analyst could express greater confidence in the results than could the novice analyst.
- Based on the results of the survey of state highway agencies, additional training efforts appear to be warranted relative to the entire roadside cost-effectiveness methodology, and in particular to severity indices. There is no uniform understanding about roadside safety study procedures, databases, and information necessary to make optimum use of safety funds. Highway safety analysts need a better understanding of not only the mechanics of performing roadside safety studies but also the limitations of the analysis methodology. For example, users need to understand the extreme cost sensitivity of small changes at the upper end of the severity index scale.
- A large and significant effort is necessary to substantially improve the quality and accuracy of severity indices. Several types of studies may be possible. One example could involve a comprehensive analysis of previous research efforts and existing severity index databases. The existing data sets could be automated so that they could be compared, merged, or manipulated to draw conclusions. Although such a study might identify the most appropriate directions for future research, it appears to have a low probability of significantly advancing the current state of knowledge.

  An alternative effort might involve a comprehensive, substantial analysis of accident information to improve the quality of severity indices. A massive, detailed field exercise would be necessary to secure data about objects, slopes, distances, and similar roadway information needed for the study. A substantial, highly-detailed accident database would also be necessary. The researchers would have to overcome the difficulties of previous studies caused by errors and other problems in accident data. Appropriate adjustments would have to be made for nonreported accidents, changes in vehicle design, the emergence of occupant restraints and airbags, and other limitations of previous studies. The probability of immediate success for such a study does not appear to be great, given the difficulties encountered with the smaller-scale efforts discussed in Chapter 2.

Alternative research approaches could also yield useful incremental improvements in severity indices. Guided by the information in this synthesis and by the results of ongoing projects, researchers and practitioners are encouraged to identify specific topics with the potential for generating real improvements in the quality and usability of severity indices. It is expected that future projects will investigate changes in the road/vehicle environment (e.g., the effects of airbags or new roadside hardware designs) as well as direct research on the nature of severity indices (e.g., how best to define and quantify them).

GLOSSARY

Accident A unplanned happening that usually results in damage or injury. Except where specifically noted, this synthesis uses the terms accident, crash, and collision interchangeably.

Airbag A safety device that, upon vehicular impact, inflates suddenly to prevent a vehicle occupant from striking the dashboard; it then releases gas at a controlled rate to absorb impact energy and diminish occupant injury.

Abutment The supporting structure at the end of a bridge; commonly used to describe the visible concrete curb, sidewalk, barrier, or support structure at the end of a bridge.

Backslope The sloping earth surface that lies between the bottom of the ditch and the natural grade of the adjacent land.

Barrier A device that provides a physical limitation through which a vehicle would not normally pass. It is intended to contain or redirect an errant vehicle.

Breakaway A design feature of a sign, luminaire, traffic signal support, or similar device that allows it to yield or separate upon impact. The release mechanism may be a slip plane, plastic hinges, fracture elements, or a combination of these.

Bridge Railing A longitudinal barrier whose primary function is to prevent an errant vehicle from going over the side of the bridge structure.

Clearance Lateral distance from the edge of the traveled way to a roadside object or feature.

Clear Zone The total roadside border area, starting at the edge of the traveled way, available for safe use by errant vehicles. This area may consist of a shoulder, a recoverable slope, a nonrecoverable slope, and/or a clear run-out area. The desired width depends on traffic volumes and speeds, and on the roadside geometry.

Cost-Effective Refers to an item or action whose tangible benefits, often measured in nonmonetary units, exceed the resources required to build and operate it.

Crash Cushion A device that prevents an errant vehicle from impacting a fixed object hazard by gradually decelerating the vehicle to a safe stop or by redirecting the vehicle away from the hazard.

Crash Tests Vehicular impact tests used to determine the structural and safety performance of roadside barriers and other highway appurtenances. Three evaluation criteria are considered: structural adequacy, impact severity, and vehicular postimpact trajectory.

Design Speed The speed selected and used for correlation of those physical features of a highway that influence vehicle operation. It is the maximum safe speed that can be maintained over a specified section of highway when conditions are so favorable that the design features of the highway govern.

Drive-Away Accident A collision of such low severity that the operator elects to drive the vehicle away from the scene without reporting the accident.

Embankment A negative roadside slope, typically in conjunction with a roadway constructed on a fill section.

Empirical Bayes Procedure A statistical procedure to overcome the regression-to-the-mean difficulty by using reference and treatment groups together to estimate the unknown parameters of the total study population.

Encroachment A vehicular movement beyond the traveled way and toward the roadside, usually occurring gradually or at shallow angles.

First-Harmful Event The initial damage-causing impact to occur in any vehicular accident.

Front Slope The graded sloping earth surface between the outside edge of the shoulder and the inside edge of the adjacent ditch (in a cut section) or the toe of the slope (in a fill section).

Guardrail As used in this synthesis, guardrail has the same meaning as barrier.

Hazard Any roadside feature that could cause injury to the occupants of an impacting vehicle. Used interchangeably in this synthesis with obstacle.

Impact Angle For a longitudinal barrier, it is the angle between a tangent to the face of the barrier and a tangent to the vehicle's path at impact. For a crash cushion, it is the angle between the axis of symmetry of the crash cushion and a tangent to the vehicle's path at impact.

Impact Attenuator See Crash Cushion.

Longitudinal Barrier A barrier whose primary function is to prevent penetration and to safely redirect an errant vehicle away from a roadside or median hazard.

Median The portion of a divided highway separating the traveled ways for traffic in opposite directions.

Median Barrier A longitudinal barrier used to prevent an errant vehicle from crossing the highway median.

Most-Harmful Event That impact in the sequence of harmful events of each involved vehicle that causes the greatest amount of injury and property damage.

Nonrecoverable Slope A roadside slope that is considered traversable but on which the errant vehicle will continue on to the bottom. Embankment slopes between 4:1 and 3:1 may be considered traversable but nonrecoverable if they are smooth and free of fixed object hazards.

Offset The distance between the traveled way and a roadside barrier or other obstacle.

Operating Speed The highest speed at which reasonably prudent drivers can be expected to operate vehicles on a section of highway under low traffic densities and good weather. This speed may be higher or lower than posted or legislated speed limits or nominal design speeds where alignment, surface, roadside development, or other features affect vehicle operations.

PDO A Property Damage Only accident, involving no personal injury.

Recoverable Slope A roadside slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle. Slopes flatter than 4:1 are generally considered recoverable.

Recovery Area Generally, synonymous with Clear Zone.

Regression to the Mean A widely observed phenomenon in which sites that appear to be unusually hazardous during one time period will, on the average, improve during a subsequent analysis period, even in the absence of a treatment.

Remediate To provide a remedy, or to provide a special course of action to overcome a deficiency.

Ridedown Acceleration The deceleration that a vehicle experiences during a collision, more particularly the part of the deceleration that occurs between the initial impact and the actual stopping of the vehicle; the term is usually applied to crashes with barriers.

Roadside That area between the outside shoulder edge and the right-of-way limits.

ROADSIDE A computer program that facilitates the analysis of alternative safety treatments for fixed objects and roadside slopes.

Roadside Barrier A longitudinal barrier used to shield roadside obstacles or nontraversable terrain features. It may occasionally be used to protect pedestrians or bystanders from vehicle traffic.

Roadway The portion of a highway, including shoulders, for vehicular use.

ROR A Run-off-the-Road accident, often involving overturning or impact with a fixed object on the roadside; most involve a single vehicle.

Severity Index A means of categorizing accidents by the probability of their causing property damage, personal injury, or a fatality, or any combination of these possible outcomes. The resultant value can then be translated to an accident cost, and the relative effectiveness of alternate safety treatments can be estimated.

Shielding The introduction of a barrier or crash cushion, between the vehicle and an obstacle or area of concern, to reduce the severity of impacts of errant vehicles.

Slope The relative steepness of the terrain, typically expressed as the horizontal distance required for a unit change in elevation. Slopes may be categorized as positive (backslopes) or negative (foreslopes), and as parallel or cross slopes in relation to the direction of traffic.

Temporary Barrier A type of barrier used to prevent vehicular access into construction or maintenance work zones and to contain or redirect an impacting vehicle while minimizing damage to the vehicle and injury to occupants and workers.

Traffic Barrier A device used to prevent a vehicle from striking a more injurious obstacle or feature located on the roadside or in the median, or to prevent crossover median accidents. As used in this synthesis, there are four classes of traffic barriers: roadside barriers, median barriers, bridge railings, and crash cushions.

Transition A section of barrier between two different barriers or, more commonly, where a roadside barrier is connected to a bridge railing or to a rigid object such as a bridge pier. The transition should produce a gradual stiffening of the approach rail so vehicular pocketing, snagging, or penetration at the connection can be avoided.

Traveled Way The portion of the roadway for the movement of vehicles, exclusive of shoulders and auxiliary lanes.

Traversable Slope A slope from which a motorist will be unlikely to steer back to the roadway but may be able to slow and stop safely. Slopes between 4:1 and 3:1 generally fall into this category.

Vehicle A motorized unit for use in transporting passengers or freight, ranging from a 700 kg (1,500 lb) automobile to tractor-trailer combinations weighing 36 000 kg (80,000 lb) or more.

Warrants The criteria by which the desirability or necessity of a safety treatment or improvement can be determined.

Willingness to Pay A methodology used to estimate the costs of vehicular accidents on the basis of the price that the motorist is willing to pay to avoid the risk of death or injury.

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APPENDIX A

SAMPLE SETS OF SEVERITY INDICES

This synthesis located complications of severity indices produced by numerous research projects. The scope and size of the databases used to develop these indices, the analysis methods, and even the severity index definitions were not consistent from one study to the next. Nevertheless, the compilations provide a useful indicator of the type and range of available information. Selected tabulations are included in this Appendix. Before using any of these values, the reader is advised to review the related technical reference to ensure an appreciation of the limitations of the original study.

TABLE A-1
1967 Fixed Object Severities by Glennon and Tamburri (*9*)

Fixed Object Type	Number of Accidents Fatal	Injury	PDO	TOTAL	Severity Index (SI)
Bridge-Rail Ends	19	79	75	123	7.9
Guardrail at Bridge-Rail Ends	16	191	199	406	4.3
Abutments and Piers	51	183	59	293	8.3
Guardrail at Abutments and Piers	8	36	28	72	6.2
Light Poles	26	401	305	732	4.6
Guardrail at Light Poles	1	23	13	37	4.8
Steel Signposts Adjacent to Shoulder	11	112	146	269	4.1
Guardrail at Steel Sign Posts Adjacent to Shoulder	1	36	31	68	4.0
Steel Sign Posts in Gore Area	7	27	17	51	7.0
Guardrail at Steel Sign Posts in Gore Area	15	220	116	351	5.2
TOTAL	155	1,308	939	2,402	5.3
Timber Sign Posts	3	165	624	792	2.1

TABLE A-2
Glennon's 1974 Severity Indices (*10*)

Object	SI Range	SI
Utility poles, 8-10"	0.47-0.59	0.53
Luminaire supports:		
rigid	0.47-0.59	0.53
breakaway	0.18-0.26	0.22
Curbs	0.40-0.46	0.43
Guardrail:		
at fixed objects, 25' x 1'	0.47-0.59	0.53
at fixed objects, 37' x 1'	0.40-0.46	0.43
at fixed objects, 75' x 1'	0.27-0.39	0.33
at embankments	0.27-0.39	0.33
Bridges:		
abutment/wall faces	0.40-0.46	0.43
abutment ends/pier ends	0.60-0.80	0.70
pier faces	0.60-0.80	0.70
rail faces, newer type	0.40-0.46	0.43
rail faces, old parapet type	0.60-0.80	0.70
rail ends	0.60-0.80	0.70
Raised drop inlets	0.60-0.80	0.70
Embankment slopes:		
≥2:1 fill	0.60-0.80	0.70
3:1 fill	0.47-0.59	0.53
4:1 fill	0.40-0.46	0.43
5:1 fill	0.27-0.39	0.33
≤6:1 fill	0.18-0.26	0.22
0.5:1-1:1 cut	0.60-0.80	0.70
1.5:1 cut	0.47-0.59	0.53
2:1 cut	0.40-0.46	0.43
3:1 cut	0.27-0.39	0.33
≤4:1 cut	0.18-0.26	0.22
Trees:		
≥13" dia	0.60-0.80	0.70
11-12" dia	0.47-0.59	0.53
8-10" dia	0.40-0.46	0.43
5-7" dia	0.27-0.39	0.33
2-4" dia	0.18-0.26	0.22
Signposts:		
triple steel, ≥9"	0.60-0.80	0.70
6-8"	0.47-0.59	0.53
3-5"	0.40-0.46	0.43
breakaway	0.18-0.26	0.22
triple wood, ≥14" dia	0.60-0.80	0.70
10-13" dia	0.47-0.59	0.53
7-9" dia	0.40-0.46	0.43
6" dia	0.27-0.39	0.33
8x8", 6x6", 4x4"	0.27-0.39	0.33
breakaway	0.18-0.26	0.22

Note: 1 ft = 0.3048 m, 1 inch = 25.4 mm

TABLE A-3
Glennon's 1974 Severity Indices (*11*)

Object	Freeway	Rural Highway	Urban Street
Utility poles	0.55	0.45	0.40
Trees (> 6" dia)	0.60	0.50	0.45
Rigid signposts:			
Large, ≥6" steel, ≥10" wood	0.60	0.50	0.45
Small	0.35	0.30	0.25
Breakaway	0.20	0.20	0.20
Light poles, signal poles, RR signal poles			
Rigid	0.50	0.40	0.35
Breakaway	0.20	0.20	0.20
Curbs	0.40	0.35	0.30
Guardrail:			
Short (<100'), Safety end treatment	0.40	0.35	0.30
No safety end treatment	0.50	0.45	0.40
Long (>100'), Safety end treatment	0.35	0.30	0.25
No safety end treatment	0.40	0.35	0.30
Roadside slopes			
Fill slopes, ≥2:1	0.70	0.60	0.50
3:1	0.55	0.45	0.40
4:1	0.40	0.35	0.30
5:1	0.30	0.25	0.20
≤6:1	0.20	0.15	0.15
Cut slopes, ≥1:1	0.70	0.60	0.50
1.5:1	0.55	0.45	0.40
2:1	0.40	0.35	0.30
3:1	0.30	0.25	0.20
≤4:1	0.20	0.15	0.15
Washout ditch	0.50	0.45	0.40
Culverts, lateral and longitudinal	0.55	0.45	0.40
Raised drop inlets	0.55	0.45	0.40
Bridge abutments and piers	0.70	0.60	0.50
Roadway over bridge structure			
Open gap between parallel bridges	0.60	0.50	--
Bridge rail—smooth	0.40	0.35	0.30
Parapet-type bridge rail	0.60	0.40	0.45
Bridge rail end or gore abutment	0.60	0.50	0.45
Retaining walls and fences	0.40	0.35	0.30
Fireplugs	--	0.30	0.25

Note: 1 ft = 0.3048 feet, 1 inch = 25.4 mm

TABLE A-4
Weaver's 1975 Severity Indices (*13*), used in AASHTO Barrier Guide (*6*)

Object	Description	SI
Utility poles		7.1
Trees		3.0
Rigid signposts:	single	4.7
	double	7.2
	triple	7.2
	cantilever	7.2
	sign bridge	8.1
Rigid luminaire supports		7.5
Curbs:	mountable	2.4
	non-mountable	4.1
	barrier	3.7
Guardrail/median barrier:	W-section, standard post spacing	3.3-5.7[a]
	W-section, not standard spacing	3.5-5.9[a]
	approach rail, decreased post spacing	3.2-5.6[a]
	approach rail, not decreased spacing	3.3-5.7[a]
	post & cable	3.9
	metal beam fence (median) barrier	4.0-5.7[a]
	CMB or equivalent median barrier	4.2
Roadside slope:	sod, positive slope	3.0
	sod, negative slope	3.0
	concrete-face, positive slope	2.5
	concrete-face, negative slope	2.5
	rubble rip-rap, positive slope	5.1
	rubble rip-rap, negative slope	5.1
Ditch, not formed by front and back slopes		0.0
Culverts:	headwall or exposed pipe end	7.9
	gap between pipes on parallel roadways	5.5
	sloped pipe with grate	3.3
	sloped pipe without grate	7.7
Inlets:	raised drop inlet	5.7
	depressed drop inlet	3.1
	sloped inlet	3.3
Roadway under bridge:	bridge piers	9.3
	abutment, vertical face	9.3
	abutment, sloped face	2.5
Roadway over bridge:	open gap between parallel bridges	7.2
	closed gap between parallel bridges	5.5
	rigid bridge rail, smooth & continuous	3.3
	semi-rigid rail, smooth & continuous	3.0
	other rail, possible snag, penetrate, etc.	9.3
	elevated gore abutment	9.3
Retaining wall:	face	3.3
	exposed end	9.3
Ditches:	front slope 6:1, back slope 6:1	2.2
See Barrier Guide	front slope 6:1, back slope 3.5:1	3.0
for other examples.	front slope 4:1, back slope 6:1	2.6
	front slope 4:1, back slope 3.5:1	4.0
	front slope 3:1, back slope 6:1	3.6
	front slope 3:1, back slope 3.5:1	4.8
Crash cushion		1.0

[a]Varies with guardrail end treatment

TABLE A-5
1985 Severity Indices by McFarland and Rollins (*19*)

Type of Accident	Indicated Severity Index Urban	Rural
Railroad Crossing Gates	0.0	0.0
Overhead Obstruction	1.2	0.0
Attenuation Device	2.2	0.0
Construction Material	7.2	1.9
Fence	1.0	2.4
Highway Sign	2.0	2.0
Mail Box	1.9	2.5
Railroad Signal Pole	4.5	3.3
Curb	3.8	4.0
Utility Pole	3.2	4.8
Commercial Sign	8.9	5.1
Other Objects	3.1	5.1
Luminaire Pole	3.6	5.7
Other Fixed Objects	3.3	5.7
Side of Bridge	7.0	6.9
Guard Post or Rail	6.2	7.1
Overturned	8.4	7.5
Culvert	7.8	7.8
Tree	7.6	8.0
Traffic Signal Pole	1.6	8.5
Bridge End	9.4	8.9
Underpass	9.3	9.3

TABLE A-6
Severity Index changes recommended by McFarland and Rollins (*20*)

Object	Description	Urban	Rural
Utility poles		3.2	4.8
Trees		7.6	8.0
Signposts:	breakaway	0.0	0.0
	single	4.7	4.7
	double	7.2	7.2
	triple	7.2	7.2
	cantilever	7.2	7.2
	sign bridge	8.1	8.1
Luminaire poles	varies by pole types and treatments	0.0-8.6	0.0-8.6
Traffic signal poles:	breakaway	0.0	0.0
	rigid	1.6	8.5
RR signal poles:	breakaway	0.0	0.0
		4.5	3.3
RR crossing gate		0.0	0.0
Mailboxes:	safety treated	0.0	0.0
	nonsafety treated	1.9	2.5
Fence		1.0	2.4
Curbs:	mountable	2.4	2.4
	nonmountable	4.1	4.1
	barrier	3.7	3.7
Guardrail/median barrier:	W-section, standard post spacing	3.6-6.0[a]	4.5-6.9[a]
	W-section, nonstandard spacing	3.8-6.2[a]	5.0-7.4[a]
	approach rail, decreased post spacing	3.6-5.9[a]	4.4-6.8[a]
	approach rail, not decreased spacing	3.6-6.0[a]	4.5-6.9[a]
	post and cable	4.2	5.1
	metal beam fence (median) barrier	4.3-6.0[a]	5.2-6.9[a]
	CMB or equivalent median barrier	4.5	5.4
Roadside slope:	sod, positive slope	3.0	3.0
	sod, negative slope	3.0	3.0
	concrete-face, positive slope	2.5	2.5
	concrete-face, negative slope	2.5	2.5
	rubble rip-rap, positive slope	5.1	5.1
	rubble rip-rap, negative slope	5.1	5.1
Ditch, not formed by front and back slopes		0.0	0.0
Culverts	headwall or exposed pipe end	7.9	7.9
	gap between pipes on parallel roads	5.5	5.5
	sloped pipe with grate	3.3	3.3
	sloped pipe < 3', w/o grate	7.7	7.7
	sloped pipe > 3', w/o grate	5.0	5.0
Inlets	raised drop inlet	5.7	5.7
	depressed drop inlet	3.1	3.1
	sloped inlet	3.3	3.3
Roadway under bridge:	bridge piers	9.4	9.3
	abutment, vertical face	9.4	9.3
	abutment, sloped face	5.5	5.5

TABLE A-6 (*Continued*)

Roadway over bridge:	open gap between parallel bridges	7.2	7.2
	closed gap between parallel bridges	5.5	5.5
	rigid bridge rail, smooth & continuous	6.3	6.3
	semirigid rail, smooth & continuous	6.0	6.0
	other rail, possible snag, penetrate, etc.	9.3	9.3
	elevated gore abutment	9.4	9.3
Retaining wall:	face	5.5	5.5
	exposed end	9.3	9.3
Ditches:	front slope 6:1, back slope 6:1	2.2	2.2
	front slope 6:1, back slope 3.5:1	3.0	3.0
	front slope 4:1, back slope 6:1	2.6	2.6
	front slope 4:1, back slope 3.5:1	4.0	4.0
	front slope 3:1, back slope 6:1	3.6	3.6
	front slope 3:1, back slope 3.5:1	4.8	4.8
Construction material		7.2	1.9
Commercial sign		8.9	5.1
Crash cushion		0.0	0.0

[a]Varies with guardrail end treatment
Note: 1 ft = 0.3048 m

TABLE A-7
Mak's 1985 Severity Measures for 14 Texas Roadside Objects (22)

Object Struck	% Fatal or Incapacitating		Relative Severity Index		Average Cost Per Accident	
End of bridge	26.41	(1)	7.98	(1)	68,366	(2)
Underpass	25.42	(2)	7.60	(2)	69,378	(1)
Culvert	22.37	(3)	6.32	(3)	32,651	(4)
Tree or shrub	21.43	(4)	5.89	(4)	39,789	(3)
Curb	12.32	(5)	0.35	(5)	15,702	(8)
Mailbox	11.36	(6)	-0.46	(6)	15,749	(7)
Side of bridge	11.16	(7)	-0.63	(7)	19,430	(5)
Guard post or rail	10.34	(8)	-1.40	(8)	18,111	(6)
Utility pole	9.95	(9)	-1.78	(9)	13,458	(11)
Median barrier	9.40	(10)	-2.35	(10)	13,798	(10)
Attenuation device	8.40	(11)	-3.48	(11)	14,699	(9)
Luminaire pole	7.01	(12)	-5.28	(12)	12,240	(12)
Highway sign	6.80	(13)	-5.58	(13)	11,032	(13)
Traffic signal pole	6.26	(14)	-6.42	(14)	9,362	(14)
Average	11.89		0.00		$ 20,028	

Numbers in parentheses represent object rank within group.
All area types, highway types and vehicle types are represented in the table.

TABLE A-8
Mak's Severity Measures from NASS Data *(22)*

First Harmful Event	Number of Accidents	%A+K	A+K RSI	%AIS ≥3	AIS RSI	Average Cost per Accident
Longitudinal Barrier	599	11.22 (5)	-0.37 (5)	8.85 (3)	2.92 (3)	$13,276 (5)
Pole	1244	10.29 (6)	-1.23 (6)	5.53 (6)	-1.78 (6)	11,360 (7)
Culvert/Ditch	369	14.74 (2)	2.36 (2)	4.77 (7)	-3.26 (7)	11,951 (6)
Curb	340	8.93 (8)	-2.65 (8)	3.75 (8)	-5.67 (8)	10,259 (8)
Abutment/Wall/Bridge Support[a]	78	14.03 (3)	1.87 (3)	12.25 (1)	6.17 (1)	26,653 (1)
Embankment	396	16.13 (1)	3.26 (1)	7.50 (4)	1.26 (4)	17,765 (2)
Tree/Shrubbery	692	13.91 (4)	1.78 (4)	8.91 (2)	2.99 (2)	14,030 (3)
Other Object	843	9.92 (7)	-1.60 (7)	5.86 (5)	-1.20 (5)	13,885 (4)
Average	570	11.64	0.00	6.61	0.00	$13,324

[a]Based on only 50-99 observations, may be somewhat unstable.
Table covers all area, roadway, functional class and vehicle types.
Numbers in parentheses represent object rank within severity measure group.

TABLE A-9
Special Report 214 Suggested Consequences of Roadside Accidents (*23*)

Type of Hazard	Accidents per Collision		Casualty Accidents per accident (11)
	Zegeer and Parker	Extrapolated (17)	
Utility pole	0.90		0.45
Trees (>6 in.)		0.95	0.50
Rigid signposts			
Steel (≥6 in.)		0.95	0.50
Timber (≥10 in.)		0.95	0.50
Small		0.55	0.30
Breakaway		0.20	0.20
Light or signal pole			
Rigid		0.75	0.40
Breakaway		0.20	0.20
Fixed object	0.90		
Nonclear zone	0.50		
Curb	0.10		0.35
Guardrail			
Short (<100 ft)			
Safety end		0.35	0.35
Nonsafety end		0.45	0.45
Long(>100 ft)			
Safety end		0.30	0.30
Nonsafety end		0.35	0.35
Fill Slope			
10:1	0.05		0.15
6:1	0.20		0.15
5:1		0.25	0.25
4:1	0.30		0.35
3:1	0.60		0.45
2:1 or steeper			0.60
Cut slope			
6:1	0.05		0.15
4:1	0.20		0.15
3:1	0.30		0.25
2:1	0.60		0.35
1.5:1		0.70	0.45
1:1 or steeper		0.90	0.60
Washout ditch			0.45
Culvert (lateral or longitudinal)		0.85	0.45
Raised drop inlet		0.85	0.45
Bridge abutment or pier		1.00	0.60
Roadway over bridge			
Structure			
Open gap between parallel bridges		0.95	0.50
Bridge rail			
Smooth		0.35	0.35
Parapet-type		0.40	0.40
End		0.95	0.50
Gore abutment		0.95	0.50
Retaining wall or fence		0.65	0.35
Fireplug		0.55	0.30

Note: 1 ft = 0.3048 m, 1 inch = 25.4 mm

TABLE A-10
Fixed-Object Accident Severities by Object Type (*25*)

Accident Type	Accident Severity	Percent of Total Accidents		
		Michigan	Utah	Washington
Utility/Light Pole	Injury	45	39	47
	Fatal	0.8	1.2	1.6
Guardrail	Injury	35	42	41
	Fatal	0.7	4.2	1.7
Sign	Injury	25	24	40
	Fatal	0.4	1.3	1.4
Fence	Injury	28	35	40
	Fatal	0.2	1.0	1.7
Tree	Injury	47		53
	Fatal	1.8		3.4
Culvert	Injury	49		64
	Fatal	3.3		2.1
Bridge Rail	Injury	41		41
	Fatal	0.7		1.6
Bridge Column	Injury			54
	Fatal			6.1
Bridge End	Injury			53
	Fatal			5.2
Barrier Wall	Injury			41
	Fatal			0.5
Earth Embankment	Injury			53
	Fatal			1.6
Rock	Injury			49
	Fatal			1.1
Mailbox	Injury			40
	Fatal			0.0
Fire Hydrant	Injury			30
	Fatal			0.7

TABLE A-11
1989 *Roadside Design Guide* Suggested Severity Indices (7)

	40 mph			50 mph			60 mph			70 mph		
	Sides	Corners	Face	Sides	Corners	Face	Sides	Corners	Face	Sides	Corners	Face
Longitudinal Barrier												
Safety Treated Terminal	2.6	2.6	2.2	2.8	2.8	2.4	3.0	3.0	2.7	3.2	3.2	2.9
Untreated Terminal	3.2	3.2	2.2	3.5	3.5	2.4	3.8	3.8	2.7	4.2	4.2	2.9
Rigid Object	4.0	4.0	4.0	4.7	4.7	4.7	5.6	5.6	5.6	6.7	6.7	6.7
Breakaway Hardware	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.4	2.4	2.4
Foreslopes (Fill)												
10:1	0.9	0.9	0.9	1.2	1.2	1.2	1.7	1.7	1.7	2.3	2.3	2.3
6:1	1.3	1.3	1.3	1.8	1.8	1.8	2.4	2.4	2.4	3.0	3.0	3.0
5:1	1.5	1.5	1.5	2.1	2.1	2.1	2.7	2.7	2.7	3.4	3.4	3.4
4:1	1.8	1.8	1.8	1.8	1.8	1.8	3.2	3.2	3.2	4.0	4.0	4.0
3:1	2.4	2.4	2.4	3.1	3.1	3.1	3.9	3.9	3.9	4.9	4.9	4.9
2:1	3.3	3.3	3.3	4.3	4.3	4.3	5.4	5.4	5.4	6.0	6.0	6.0
Backslopes (Cut)												
4:1	0.9	0.9	0.9	1.2	1.2	1.2	1.7	1.7	1.7	2.1	2.1	2.1
3:1	1.4	1.4	1.4	1.4	1.4	1.4	2.2	2.2	2.2	2.5	2.5	2.5
2:1	2.2	2.2	2.2	2.5	2.5	2.5	2.9	2.9	2.9	3.2	3.2	3.2
Crash Cushions	2.3	2.3	2.3	2.5	2.5	2.5	2.8	2.8	2.8	3.1	3.1	3.1
Culverts (Projecting)												
Diameter < 36 in.	3.2	3.2	3.2	3.5	3.5	3.5	4.0	4.0	4.0	4.6	4.6	4.6
Diameter > 36 in.	3.6	3.6	3.6	4.1	4.1	4.1	4.8	4.8	4.8	5.7	5.7	5.7

Note: 1 mph = 1.609 km/h, 1 inch = 25.4 mm

TABLE A-12
Kentucky Severity Indices for Fixed Objects and Embankments (*26*)

Fixed Object[a]	%Fatal	%Injury	SI
Guardrail	1.48	37.3	2.67
Bridge	1.95	39.7	2.95
Tree	2.76	52.1	3.52
Utility Pole	0.69	40.6	2.68
Sign	0.64	21.3	1.91
Culvert/Headwall	1.99	50.8	3.38
Curbing	0.91	26.5	2.16
Earth Embankment/ Rock Cut/Ditch	1.26	49.3	3.14
Building/Wall	0.21	14.3	1.56
Crash Cushion	1.83	34.1	2.56
Fence	0.66	23.1	1.96
Median Barrier	0.83	36.9	2.59
Fire Hydrant	0.33	18.6	1.70

[a]Based on 57,556 fixed-object accidents

Embankment Height	Embankment Slope			
	3:1	2:1	1.5:1	1:1
3 ft	2.47	2.71	2.96	3.44
8	2.51	2.75	2.99	3.47
15	2.56	2.80	3.04	3.52
25	2.63	2.87	3.11	3.59
35	**	2.94	3.18	3.66
45	**	3.01	3.25	3.74
60	**	3.12	3.36	3.84

** No data
Note: 1 ft = 0.3048 m

TABLE A-13
1991 FHWA *Supplemental Information for use with the Roadside Program* (30)

TYPE OF HAZARD	FACE SIDE BOTH	40 MPH RANGE	40 MPH AVG.	50 MPH RANGE	50 MPH AVG.	60 MPH RANGE	60 MPH AVG.	70 MPH RANGE	70 MPH AVG.
LONGITUDINAL BARRIER									
3-Strand Cable	Face	2.0 - 2.4	2.2	2.2 - 2.8	2.5	2.4 - 3.2	2.8	2.6 - 3.6	3.1
W-Beam (Weak)	Face	2.2 - 2.6	2.4	2.4 - 3.0	2.7	2.8 - 3.6	3.2	3.0 - 4.0	3.5
Thrie Beam (Weak)	Face	2.2 - 2.6	2.4	2.4 - 3.0	2.7	2.6 - 3.4	3.0	2.8 - 3.8	3.3
Blocked-out W-Beam (Strong)	Face	2.4 - 2.8	2.6	2.8 - 3.4	3.1	3.2 - 4.0	3.6	4.0 - 4.5	4.3
Blocked-out Thrie-Beam (Strong)	Face	2.4 - 2.8	2.6	2.8 - 3.4	3.1	3.2 - 4.0	3.6	3.8 - 4.8	4.3
Concrete Safety Shape	Face	1.8 - 2.8	2.3	2.4 - 3.0	2.7	3.0 - 3.8	3.4	3.8 - 4.8	4.3
Stone Masonry Wall	Face	2.4 - 2.8	2.6	2.8 - 3.4	3.1	3.4 - 4.2	3.8	4.0 - 5.0	4.5
Retaining Wall/Vertical Barrier	Face	2.4 - 2.8	2.6	2.8 - 3.4	3.1	3.4 - 4.2	3.8	4.0 - 5.0	4.5
BARRIER TERMINAL									
3-Strand Cable	Side	2.0 - 2.6	2.3	2.4 - 3.2	2.8	3.0 - 4.0	3.5	3.8 - 5.0	4.4
W-Beam									
Anchored in Backslope	Side	2.4 - 3.0	2.7	2.8 - 3.6	3.2	3.4 - 4.4	3.9	4.0 - 5.2	4.6
Breakaway Cable Terminal	Side	2.4 - 3.0	2.7	2.8 - 3.6	3.2	3.4 - 4.4	3.9	4.0 - 5.2	4.6
Turned-Down	Side	2.6 - 3.2	2.9	3.0 - 3.8	3.4	3.6 - 4.6	4.1	4.2 - 5.4	4.8
Concrete Safety Shape									
80 ft. Sloped End	Side	2.6 - 3.2	2.9	3.0 - 3.8	3.4	3.6 - 4.6	4.1	4.2 - 5.4	4.8
Obsolete/Nonfunctional	Side	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
CRASH CUSHION									
Hi-Dro Cell	Both	2.0 - 2.6	2.3	2.4 - 3.0	2.7	2.6 - 3.4	3.0	2.8 - 3.8	3.3
G-R-E-A-T System	Both	2.0 - 2.6	2.3	2.4 - 3.0	2.7	2.6 - 3.4	3.0	2.8 - 3.8	3.3
Hex-Form Sandwich	Both	2.0 - 2.6	2.3	2.4 - 3.0	2.7	2.6 - 3.4	3.0	2.8 - 3.8	3.3
Sand-Filled Plastic Barrels	Both	2.0 - 2.6	2.3	2.4 - 3.0	2.7	2.6 - 3.4	3.0	2.8 - 3.8	3.3
PARALLEL SLOPES									
Foreslope									
10:1	Face	0.2 - 0.6	0.4	0.4 - 1.0	0.7	0.6 - 1.4	1.0	0.8 - 1.8	1.3
6:1	Face	0.4 - 0.8	0.6	0.8 - 1.4	1.1	1.2 - 2.0	1.6	1.5 - 2.5	2.0
4:1	Face	1.0 - 1.4	1.2	1.4 - 2.0	1.7	2.0 - 2.8	2.4	2.5 - 3.5	3.0
3:1	Face	1.6 - 2.0	1.8	2.2 - 2.8	2.5	2.8 - 3.6	3.2	3.5 - 4.5	4.0
2:1	Face	2.4 - 2.8	2.6	3.2 - 3.8	3.5	4.0 - 4.8	4.4	5.0 - 6.0	5.5
Backslopes									
4:1	Face	0.6 - 1.0	0.8	0.8 - 1.4	1.1	1.2 - 2.0	1.6	1.5 - 2.5	2.0
3:1	Face	1.0 - 1.4	1.2	1.4 - 2.0	1.7	2.0 - 2.8	2.4	2.4 - 3.4	2.9
2:1	Face	1.8 - 2.2	2.0	2.2 - 2.8	2.5	3.0 - 3.8	3.4	3.6 - 4.6	4.1
Vertical Rock Cut									
Smooth	Face	2.4 - 2.8	2.6	2.8 - 3.4	3.1	3.2 - 4.0	3.6	4.0 - 4.6	4.3
Rough	Face	2.8 - 3.2	3.0	3.4 - 4.0	3.7	4.0 - 5.0	4.5	4.6 - 6.0	5.3
CROSS SLOPES									
Embankment (Uphill)									
10:1	Side	0.2 - 0.6	0.4	0.8 - 1.4	1.1	1.4 - 2.2	1.8	2.0 - 3.0	2.5
6:1	Side	1.0 - 1.4	1.2	1.4 - 2.0	1.7	2.2 - 3.0	2.6	2.6 - 3.6	3.1
4:1	Side	1.8 - 2.2	2.0	2.4 - 3.0	2.7	3.2 - 4.0	3.6	4.0 - 5.0	4.5
3:1	Side	2.0 - 2.4	2.2	2.8 - 3.4	3.1	3.6 - 4.4	4.0	4.4 - 5.4	4.9
2:1	Side	3.2 - 3.6	3.4	4.0 - 4.6	4.3	5.0 - 5.8	5.4	6.0 - 7.6	6.8
Vertical Rock Cut	Side	4.2 - 5.0	4.6	5.0 - 6.0	5.5	6.0 - 7.2	6.6	7.2 - 8.6	7.9

TABLE A-13 (*Continued*)

TYPE OF HAZARD	FACE SIDE BOTH	40 MPH RANGE	40 MPH AVG.	50 MPH RANGE	50 MPH AVG.	60 MPH RANGE	60 MPH AVG.	70 MPH RANGE	70 MPH AVG.
Ditch									
Foreslope Backslope									
3:1 3:1	Face	1.8 - 2.4	2.1	2.2 - 3.2	2.7	3.0 - 4.2	3.6	3.6 - 5.0	4.3
4:1	Face	1.2 - 1.8	1.5	1.8 - 2.6	2.2	2.4 - 3.6	3.0	2.8 - 4.2	3.5
6:1	Face	1.0 - 1.6	1.3	1.4 - 2.2	1.8	2.0 - 3.2	2.6	2.4 - 3.8	3.1
4:1 3:1	Face	1.2 - 1.8	1.5	1.8 - 2.6	2.2	2.4 - 3.6	3.0	2.8 - 4.2	3.5
4:1	Face	1.0 - 1.6	1.3	1.4 - 2.2	1.8	2.0 - 3.2	2.6	2.4 - 3.8	3.1
6:1	Face	0.8 - 1.4	1.1	1.2 - 1.8	1.5	1.6 - 2.6	2.1	2.0 - 3.2	2.6
6:1 3:1	Face	1.0 - 1.6	1.3	1.4 - 2.2	1.8	2.0 - 3.2	2.6	2.4 - 3.8	3.1
4:1	Face	0.8 - 1.4	1.1	1.2 - 1.8	1.5	1.6 - 2.6	2.1	2.0 - 3.2	2.6
6:1	Face	0.6 - 1.2	0.9	1.0 - 1.6	1.3	1.4 - 2.2	1.8	1.8 - 2.8	2.3
CULVERT OPENING									
Cross Culvert									
Pipe End Dia. < 3 ft.	Both	1.6 - 2.8	2.2	1.8 - 3.2	2.5	2.2 - 3.8	3.0	2.6 - 4.4	3.5
Pipe End Dia. > 3 ft.	Both	2.8 - 4.0	3.4	3.2 - 4.6 -	3.9	3.8 - 5.4	4.6	4.4 - 6.2	5.3
Sloped w/Bar Grates	Both	<---------- USE VALUES FOR APPROPRIATE PARALLEL SLOPE ---------->							
Parallel Culvert									
Pipe End Dia. < 3 ft.	Side	1.8 - 3.0	2.4	2.0 - 3.4	2.7	2.4 - 4.0	3.2	2.8 - 4.6	3.7
Pipe End Dia. > 3 ft.	Side	3.0 - 4.2	3.6	3.4 - 4.8	4.1	4.0 - 5.6	4.8	4.5 - 6.4	5.5
Sloped w/Bar Grates	Side	<------------ USE VALUES FOR APPROPRIATE CROSS SLOPE ------------>							
MISC DRAINAGE ITEMS									
Raised Inlet w/Grate	Both	<--- USE VARIABLE HEIGHT VALUES WITH APPROPRIATE HEIGHT --->							
Rip-rap									
Avg. Dia. < 6"	Both	0.4 - 1.0	0.7	1.0 - 1.8	1.4	1.4 - 2.4	1.9	1.8 - 3.0	2.4
Avg. Dia. = 6" - 10"	Both	1.0 - 2.6	1.8	1.4 - 3.2	2.3	1.8 - 3.8	2.8	2.2 - 4.4	3.3
Avg. Dia. > 10"	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Permanent Stream/Pond									
Depth < 3 ft.	Both	1.0 - 5.0	3.0	1.6 - 5.6	3.6	2.2 - 6.2	4.2	3.0 - 7.0	5.0
Depth > 3 ft.	Both	5.0 - 6.0	5.5	5.6 - 6.8	6.2	6.2 - 7.6	6.9	7.0 - 8.6	7.8
RIGID OBJECTS									
Tree									
Dia. < 4 in.	Both	0.4 - 2.6	1.5	0.6 - 3.2	1.9	0.8 - 3.8	2.3	1.0 - 4.4	2.7
Dia. > 4 in.	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Utility Pole	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Bridge Pier	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Rigid Sign Support									
Single/Multiple	Both	2.2 - 4.6	3.4	2.8 - 5.6	4.2	3.6 - 7.0	5.3	4.2 - 8.4	6.3
Cantilever/Overhead	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Breakaway Sign support									
Fracture	Both	0.6 - 1.0	0.8	0.8 - 1.4	1.1	1.2 - 2.0	1.6	1.6 - 2.6	2.1
Mechanical/Yielding	Both	0.8 - 1.2	1.0	1.0 - 1.6	1.3	1.4 - 2.2	1.8	1.8 - 2.8	2.3
Rigid Base Luminaire Support	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Breakaway Luminaire Support	Both	2.0 - 2.4	2.2	2.2 - 2.8	2.5	2.4 - 3.2	2.8	2.6 - 3.6	3.1
Headwall, Pedestal, Foundation									
Height < 4"	Both	0.6 - 1.0	0.8	1.0 - 1.8	1.4	1.4 - 2.4	1.9	1.8 - 3.0	2.4
Height = 4"-10"	Both	1.0 - 2.6	1.8	1.8 - 3.2	2.5	2.4 - 3.6	3.0	3.0 - 4.4	3.7
Height > 10"	Both	2.6 - 5.0	3.8	3.2 - 6.0	4.6	3.8 - 7.2	5.5	4.4 - 8.6	6.5
Edge Drop-Off									
Height < 4"	Face	0.4 - 1.0	0.7	0.6 - 1.4	1.0	0.8 - 1.8	1.3	1.0 - 2.2	1.6
Height = 4"-10"	Face	1.0 - 1.6	1.3	1.4 - 2.2	1.8	1.8 - 2.8	2.3	2.2 - 3.4	2.8
Height > 10"	Face	1.6 - 2.2	1.9	2.2 - 3.0	2.6	2.8 - 3.8	3.3	3.4 - 4.6	4.0
Curb									
Mountable (< 6 in.)	Face	0.6 - 1.0	0.8	1.0 - 1.8	1.4	1.4 - 2.4	1.9	1.8 - 3.0	2.4
Non-Mountable (6-10 in.)	Face	1.2 - 2.6	1.9	1.6 - 3.2	2.4	2.0 - 4.0	3.0	2.4 - 4.6	3.5
Barrier (> 10 in.)	Face	2.6 - 3.2	2.9	3.0 - 3.8	3.4	3.6 - 4.6	4.1	4.2 - 5.4	4.8
Fire Hydrant	Both	1.8 - 2.4	2.1	2.2 - 3.0	2.6	2.6 - 3.6	3.1	3.0 - 4.2	3.6
Mail Box	Both	1.2 - 2.2	1.7	1.6 - 2.8	2.2	2.0 - 3.4	2.7	2.6 - 4.2	3.4
Chainlink Fence	Face	1.4 - 1.8	1.6	2.0 - 2.6	2.3	2.4 - 3.2	2.8	2.6 - 3.6	3.1

Note: 1 ft = 0.3048 m, 1 mph = 1.609 km/h

TABLE A-14
Ross's 1991 Severity Indices for Concrete Safety Shape Barrier (*31*)

Impact Angle	Impact Speed = 30 mph		Impact Speed = 40 mph		Impact Speed = 50 mph		Impact Speed = 60 mph	
	V (ft/sec)	SI	V (ft/sec)	SI	V (ft/sec)	SI	V (ft/sec)	SI
10	7.2[a]	0.9	10.7[a]	1.3	14.0[a]	1.8	16.6[a]	2.1
20	11.9[a]	1.5	13.3[a]	1.7	16.8[a]	2.1	20.3[a]	2.5
30	15.7[a]	2.0	18.4[a]	2.3	23.1[a]	2.9	27.8[a]	3.5
40	21.9[b]	2.7	25.9[b]	3.2	31.4[b]	3.9	37.9[b]	4.7
50	29.6[b]	3.7	37.8[b]	4.7	48.3[b]	6.0	57.7[b]	7.2

[a] Lateral component
[b] Longitudinal component
Note: 1 ft/sec = 0.3048 m/sec., 1 mph = 1.609 km/h

TABLE A-15
Severity Indices for Full-Array Inertial Crash Cushion (*31*)

Impact at Tub No.	Cushion Orientation Angle = 0 degrees				
	Impact Angle, Θ (degrees)				
	5	15	25	35	45
1	3.8	3.8	3.4	3.4	3.4
2 & 3	3.8	4.3	4.1	4.1	4.0
4 & 5	3.2	6.4	5.0	4.9	4.8
6	3.2	4.5	7.5	7.0	6.7
7	3.2	4.5	5.6	9.9	9.7
	Cushion Orientation Angle = 10 degrees				
1	3.8	3.8	3.8	3.4	3.4
2 & 3	3.2	4.4	4.3	4.1	4.1
4 & 5	3.2	4.5	6.4	5.0	4.9
6	3.2	4.5	5.6	7.5	7.0
7	3.2	4.5	5.6	6.7	9.9

[a]Data in this table are based on 100 km/h (60 mph) impacts.

TABLE A-16
Example Severity Indices, 1992 FHWA Office of Engineering

SUGGESTED SEVERITY INDICES
Parallel Ditches

Hazard Type and Characteristics			Hazard Surface [a]	Severity Index			
				Design Speed - mph			
Foreslope	Backslope	Depth (ft)		40	50	60	70
2:1 slope	2:1 slope	0.5	F	1.6	2.0	2.6	3.5
		1.0	F	1.9	2.1	2.7	3.6
		2.0	F	2.1	2.3	2.9	3.7
		3.0	F	2.2	2.4	2.9	3.7
		4.0	F	2.3	2.5	3.0	3.8
	3:1 slope	0.5	F	1.5	1.9	2.4	3.2
		1.0	F	1.8	2.1	2.6	3.3
		2.0	F	2.0	2.2	2.7	3.5
		3.0	F	2.1	2.3	2.7	3.6
		4.0	F	2.2	2.4	2.8	3.7
3:1 slope	2:1 slope	0.5	F	1.6	2.0	2.6	3.5
		1.0	F	1.8	2.0	2.6	3.5
		2.0	F	2.0	2.1	2.7	3.5
		3.0	F	2.1	2.2	2.7	3.5
		4.0	F	2.2	2.3	2.8	3.5
	3:1 slope	0.5	F	1.5	1.9	2.4	3.2
		1.0	F	1.7	2.0	2.5	3.2
		2.0	F	1.9	2.1	2.5	3.2
		3.0	F	2.0	2.2	2.6	3.2
		4.0	F	2.1	2.2	2.6	3.3
	4:1 slope	0.5	F	1.4	1.7	2.1	2.8
		1.0	F	1.6	1.9	2.2	2.9
		2.0	F	1.8	2.0	2.3	2.9
		3.0	F	2.0	2.1	2.3	3.0
		4.0	F	2.0	2.2	2.4	3.0
4:1 slope	2:1 slope	0.5	F	1.5	1.9	2.5	3.3
		1.0	F	1.5	1.9	2.5	3.3
		2.0	F	1.6	2.0	2.5	3.3
		3.0	F	1.6	2.0	2.5	3.2
		4.0	F	1.6	2.0	2.5	3.2
	3:1 slope	0.5	F	1.3	1.6	2.1	2.8
		1.0	F	1.4	1.7	2.1	2.8
		2.0	F	1.4	1.8	2.2	2.8
		3.0	F	1.5	1.9	2.2	2.8
		4.0	F	1.5	2.0	2.2	2.8
	4:1 slope	0.5	F	1.2	1.5	1.9	2.4
		1.0	F	1.3	1.6	2.0	2.4
		2.0	F	1.4	1.7	2.1	2.4
		3.0	F	1.4	1.8	2.1	2.5
		4.0	F	1.5	1.9	2.2	2.5

TABLE A-16 *(Continued)*

SUGGESTED SEVERITY INDICES Traffic Barriers					
Hazard Type and Characteristics	Hazard Surface[a]	Severity Index[b]			
		Design Speed - mph			
		40	50	60	70
Longitudinal Traffic Barriers					
Uniform Section					
For all currently accepted barriers, guardrails, bridge rails, median barriers, apply the basic SI to that percentage of impacts estimated to be contained by the barrier. For that percentage of impacts estimated to penetrate an SI appropriate for the shielded hazard should be used to adjust the effective barrier SI. Basic SI	F	2.1	2.3	2.6	3.1
Non-blocked out w-beam on strong posts with 12'6" post spacings (adjust for estimated penetrations) Basic SI	F	2.2	2.4	2.9	3.4
Cable on strong posts (adjust for estimated penetrations) Basic SI	F	2.3	2.6	3.0	3.5
For walls and parapets with irregular surfaces estimate SI's by referring to vertical backslopes.	F	-	-	-	-
Guardrail to Parapet Transitions					
Treat the same as currently acceptable longitudinal barriers if transition meets crash test acceptance requirements and adjust for estimated penetrations.	F	2.1	2.3	2.6	3.1
For substandard transitions consider a section of the face of the approach guardrail as having the severity of a fixed object. This section of barrier would nominally be part of a continuous barrier face, thus the corner and side SI's would be zero.					
Examples: Standard, strong-post, w-beam guardrail, blocked out with two spaces at 3' 1 1/2" and full-strength attachment to parapet.	F	0.5' @ 2.1	1.5' @ 2.4	3.0' @ 2.8	5.5' @ 3.3
Standard, strong-post, w-beam guardrail, blocked out with 6' 3" post spacing and no connection parapet.	F	3' @ 2.4	5' @ 2.8	8' @ 5.2	12' @ 4.0
Three cable guardrail, 16' post spacing, attached to parapet end	F	10' @ 3.6	12.5' @ 4.3	16.5' @ 5.2	24' @ 6.1
Terminals (approach end except where noted)					
Stand-up w-beam, unanchored, with no safety treatment and no flare. The first few feet of the unanchored rail will have diminished effectiveness and have a higher SI than the remainder of the guardrail. The values given here for that section of guardrail may require adjustment for penetration to the shielded hazard	C&S	4.4	4.7	5.2	5.7
	F	6' @ 2.6	9' @ 3.0	12' @ 3.3	18' @ 3.9
BCT <u>without</u> diaphragms (properly installed with recommended flare.	C&S	3.4	3.9	4.2	4.6
	F	6' @ 2.4	6' @ 2.7	6' @ 3.1	6' @ 3.6
Turned-down w-beam (25 foot twist)	C&S	3.0	3.3	3.9	4.4
	F	18' @ 3.1	18' @ 3.4	18' @ 4.0	18' @ 4.5

[a] S = Approach Side, C = Corner, F = Traffic Face
[b] Dimension above "@" sign is length of device to be analyzed using the noted severity index.
Note: 1 ft = 0.3048 m, 1 inch = 25.4 mm, 1 mph = 1.609 km/h

APPENDIX B

NCHRP PROJECT 20-5
TOPIC 23-09
Severity Indices for Roadside Safety

1. Which of the following does your agency routinely use to assist with roadside safety analyses? Please check all that apply.
   - ☐ AASHTO Roadside Design Guide, 1989
   - ☐ Other technical reference: ____________________
   - ☐ ROADSIDE Computer Program
   - ☐ Other computer software: ____________________

2. If you use the Roadside Design Guide or ROADSIDE software in conducting evaluations and making decisions regarding roadside safety, do you have problems in selecting or justifying values for the following parameters?

	Encounter Problems		
	Rarely	Occasionally	Often
Design Traffic Volume	☐	☐	☐
Roadway Curvature	☐	☐	☐
Roadway Gradient	☐	☐	☐
Design Speed	☐	☐	☐
Baseline Encroachment Rate	☐	☐	☐
Encroachment Angle	☐	☐	☐
Hazard Offset	☐	☐	☐
Dimensions of the Hazard	☐	☐	☐
Lateral Extent of Encroachment	☐	☐	☐
Severity Indices	☐	☐	☐
Expected Accident Costs	☐	☐	☐
Other ____________	☐	☐	☐

3. What would be required to reduce or eliminate these problems and improve your confidence in assessing the safety effectiveness of roadside improvements?
   ____
   ____
   ____

4. Appendix A of the AASHTO Roadside Design Guide provides a limited set of severity indices as a function of object type, impact location, and design speed:

	Yes	No
a. Do you use this information?	☐	☐
b. Do you have a high level of confidence in this information?	☐	☐
c. Have you developed alternate information on severity indices that you feel is more reliable?	☐	☐

5. In your opinion, what specific revisions are needed to make fixed object severity indices more useful in the analysis of roadside safety improvements?
   ____
   ____
   ____

6. Are you aware of any severity index tabulations for roadside obstacles that could be used to supplement or corroborate those presented in the AASHTO Roadside Design Guide? ☐ Yes ☐ No
   If so, would you please indicate the source of the information? ____________________
   ____

7. Are you aware of any ongoing projects or studies, either within or outside your agency, that are attempting to improve the understanding, usefulness, or quality of roadside severity index information? ☐ Yes ☐ No
   If so, can you identify a specific individual that we should contact to obtain further information on this subject? ____________________
   ____

8. If you were given the authority to define the next major research project addressing the weaknesses of existing severity index and/or roadside safety information, what would be the primary focus of the research? ____________________
   ____

9. Do you have any other comments or suggestions related to severity indices, road-side safety, establishing priorities, or cost-effective treatments? ____________________
   ____

10. Please identify the person completing this questionnaire:
    Name: ____________________ Phone: (   ) ____________
    Title: ____________________ Fax: (   ) ____________
    Agency: ____________________
    Address: ____________________

Please return the completed survey to:
J. W. Hall
Department of Civil Engineering
University of New Mexico
Albuquerque, NM 87131-1351
or FAX the survey form to (505)123-4567.

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