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RESOURCE MATERIALS

Development of Severity Indices for Roadside Objects

U.S. Department of Transportation
Federal Highway Administration

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September 1995

FOREWORD

This report documents a study that examined crashes involving roadside objects using data from two state accident databases in terms of driver injury severity levels. Data on crash severity by object struck (severity indices or SI) are needed in cost/benefit studies of options available for designers. Variables that significantly influence driver injury distributions were identified using the CART (Classification and Regression Trees) procedure.

Examination of the limited sample of airbag-equipped vehicles available in the database suggests airbags will significantly reduce SI values. This issue should be explored further as additional crashes with airbag-equipped vehicles are recorded in accident files.

This report is available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Virginia 22161. A small charge will be imposed for each copy.

C. John MacGowan
Acting Director,
Office of Safety and Traffic Operations
Research and Development

NOTICE

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16. Abstract

This study was an attempt to develop severity indices (SI's) for various fixed objects that are impacted when vehicles leave the roadway. The objectives of the study were two-fold, including both the development of new indices with recent data from two states and the exploration of methodological issues related to statistical modeling and a literature-based exploration of unreported crashes. Both a severe injury SI and a cost-based SI were developed for a wide range of crash situations using data from both North Carolina and Illinois, where injury could be more precisely linked to the specific object struck. While the final SI indices developed were not categorized by exactly the same control variables for the two states, the values of the indices were, in general, moderately consistent between the states. Findings from North Carolina and Illinois were also consistent to a significant degree with SI's developed earlier by Mak, et al. (10) using Texas data. In the limited sample of airbag-related impacts with guardrails, trees, and utility poles, it appears that the airbag will significantly reduce the value of the SI, and that the reduction could range from 30 to 70 percent. Additional future research is needed on the effects on SI's of both airbags and unreported crashes.

NOTE: This material is based on work funded by the UNC Injury Prevention Research Center through a grant from the Centers for Disease Control and Prevention, and was supported by the Federal Highway Administration under Grant Agreement No. DTFH61-91-Y-30062. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the Federal Highway Administration.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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Introduction

Highway crashes are the price that society pays for its high level of individual mobility. To the highway engineer/designer/researcher who is interested in increasing the level of safety on the roadways, these crashes can be subdivided into two basic categories — those in which a vehicle strikes another vehicle, and those in which the vehicle strikes other things. The latter category is the topic of interest in this paper — crashes involving roadside objects.

The importance of these roadside object crashes is supported by the number of fatalities accumulated therein. For all roadways in the United States, approximately 30 percent of the total number of traffic fatalities result from crashes with roadside fixed objects (1). For Interstate freeways, where the proportion of vehicle-to-vehicle crashes have been greatly reduced by access control, elimination of at-grade intersections, and traffic flow separation, the proportion of roadside crashes that result in fatalities are even higher. Here, approximately 60 percent of freeway fatalities result from vehicles straying onto the roadside and either impacting a fixed object or overturning. Often, these overturns result from impact with fixed objects or other design features of the roadside.

In order to determine how best to spend the relatively limited number of highway safety dollars available for roadside improvements, the engineer must be able to estimate both the cost of alternative engineering treatments for improving roadside safety and the projected safety consequences of the various treatments. In general, what is needed is some estimate of the proportion of vehicles that will run off the roadway and strike a given fixed object (e.g., a bridge pier) or group of fixed objects (e.g., trees), and a separate estimate of the expected severity of the impact. This latter measure, the average or typical severity of the impact with a given object, is often referred to as a severity index. It is with the development of the severity indices that this paper is concerned.

Turner and Hall (2) recently completed the most detailed examination of existing information on roadside severity indices (and their use by practicing engineers) in a National Cooperative Highway Research Program (NCHRP) report entitled, "Severity Indices for Roadside Features." In this report, the authors examined both existing literature concerning the specific values of severity indices, and questioned engineering and research professionals from across the nation concerning current use of severity indices and issues related to their use. Because a detailed review of key articles was included in that report, it will not be repeated here. However, a number of the key findings and issues in the works reviewed there are pertinent to this current study, and will be summarized briefly below.

The reviewers first note the different methodologies that have been used in the development of severity indices over the last 35 years. In studies conducted in the 1970's and early and mid-1980's, authors such as Glennon (3), Glennon and Wilton (4), Brogan and Hall (5), and Zegeer, et al. (6), all used different types of accident data to produce listings of severity indices for various fixed objects. In some of this work, the severity index was defined by the percent of injury plus fatal accidents in the population of fixed object crashes for a given object. In other studies, the portion of only incapacitating and fatal injuries was used as an index. While some of the earlier severity indices (e.g., Glennon) were developed from multi-state accident data, most were based on data from one state. Given known differences in accident reporting thresholds and reporting completeness from state to state, and in the specificity of the police-reported data that would allow one to attribute the subsequent occupant injury to the fixed object alone, one would expect variation in the results. Indeed, when severity indices from the different studies are compared to each other, there is some consistency for certain objects, and fairly wide ranges for other objects.

Other 1970 studies by authors such as Weaver, Post and French (7), used a different technique to define severity indices. Here, a group of selected traffic engineers and other roadway designers were asked to provide their judgment of the probability of a fatality in an impact with a given object. These probabilities were then converted to a severity index scale between zero and 10. This was the type of severity index was presented in the early versions of the "Barrier Guide"(8). It was incorporated into guidelines to help engineers define whether guardrail and other barriers were needed on a particular roadway location. In a mid-1980's study that combined these judgment-based fatality probabilities with accident data, McFarland and Rollins (9) conducted studies at Texas Transportation Institute (TTI) in which 126,000 roadside accidents in Texas were analyzed to develop accident costs. The accident costs were combined with Weaver's earlier probabilities to define severity indices for a large number of objects.

Perhaps the largest of the data-gathering studies was conducted by Mak at TTI in 1985 (10). Again, the accident data used was from Texas, and the severity index definition was either cost per accident or percent of incapacitating injury/fatal accidents. Mak attempted to define severity indices (SI's) for 14 different objects in each of 37 different combinations of area, vehicle, and roadway type. The findings for the combined SI's (i.e., not categorized by area, vehicle, or roadway type) for 14 fixed objects are depicted in Figure 1. Mak also attempted to use National Accident Sampling System (NASS) data files for the project, but encountered difficulties due to sample size, accuracy and consistency problems.

In a later analysis that used some of the non-accident techniques in the Mak study, Ross, et al. (11) developed several sets of severity indices for use with barriers and traffic control treatments in work zones. Of interest here was the fact that the severity indices were based primarily on crash-test results and related analytical techniques that allowed the authors to relate predicted occupant injury to the results of crash tests. Using this technique (which, as noted by Turner and Hall (2), required many broad assumptions), the authors produced severity indices that were related to both impact angle and impact speed for a number of objects. These variables cannot be incorporated into accident-based SI's since they are not found on police-generated crash forms.

Finally, Turner and Hall also note that there is a series of ongoing internal Federal Highway Administration (FHWA) efforts in which staff have attempted to use their own

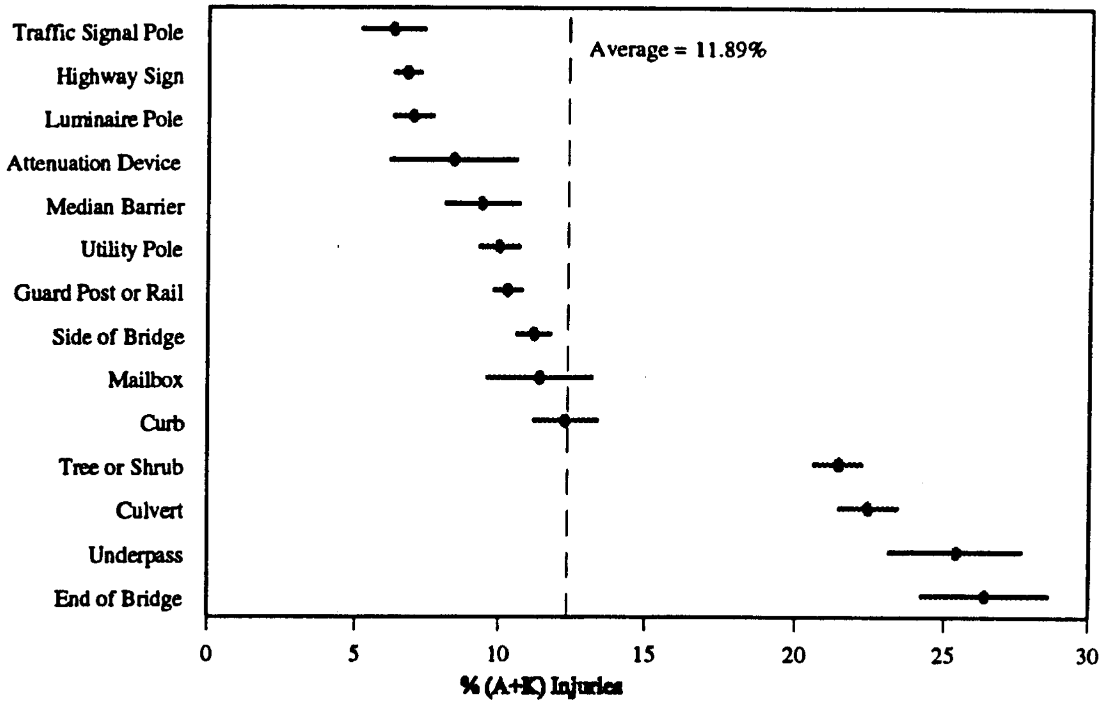

Figure 1. Percent (A+K) injuries for 14 different roadside objects (with 95 percent confidence intervals) — from Mak, et al. (10).

knowledge-based crash test, mechanical engineering findings, engineering judgment, and accident data to support an individual state's use and development of severity indices. Working papers developed by FHWA provide detail that sometimes is not found in other works.

In summary, based on their review of research on SI's and information gathered from users, Turner and Hall conclude that the specific severity index value for some fixed objects varies significantly across past studies (primarily due to differences in the data and methodologies used), and that there is some lack of "faith" in the values provided on the part of users in the field. Nevertheless, there are a substantial number of users who wish more detailed information on severity indices for their own internal economic analyses. In short, the authors conclude that

> "... the severity index has not reached the mature stage of development. Currently, the most widely used values for severity indices are those presented in the Roadside Design Guide, along with those in the Supplemental Information for Use with the ROADSIDE Computer Program. 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 project has confirmed these severity index values as accurate, authoritative, or representative of those crashes that actually occur on American roadsides."

The authors further conclude that we have yet to identify a definitive methodology for determining SI values, that there is a lack of ongoing, consistent work in the field, and that a large and significant research effort is probably necessary to improve the quality and accuracy of severity indices. The latter will require a great deal of forethought to decide the most appropriate methodology to be used.

As can be seen, the Turner and Hall review and the research studies covered therein have helped defined gaps in the current knowledge of severity indices and in the methodologies used to define SI's. These gaps include the need for multi-state accident databases; identification of crashes in which the occupant injury can be directly attributed to the fixed object struck rather than to any preceding or subsequent collision; the need for methodology that will provide not only an average measure of the SI, but a measure of the possible variability of the measure; and a need for SI's that are specific to a large array of crash locations and circumstances, some of which will not be found in crash reports (e.g., SI's for new hardware recently installed in the field, or control variables such as impact angle and speed).

Finally, there is also a need for SI's that can change, based on changes in the vehicle or driver fleet. This is particularly true today, given current changes in the restraint systems in the vehicle fleet. It is clearly the case that even severity indices developed with data from today's fleet may have to be modified in the near-term future (i.e., within the next 5-10 years) simply because of the influx of airbag-equipped vehicles in the fleet. Given that severity indices are based on occupant injury, it is certainly expected that the average level of occupant injury, whether it be severe injury or all injury, will decrease with the advent of airbags. And the change in SI may differ for different objects. For example, while one would expect a significant decrease in average injury for impacts with point objects such as poles, trees, or barrier/bridge rail ends, one might see less effect on angle or side impacts into barrier faces.

The current study described in the narrative below is designed to provide additional information on the severity indices for a certain roadside fixed objects. It is certainly not the large-scale study envisioned by Turner and Hall, nor is it envisioned as a study that provides any final set of indices. However, we anticipate that the results may help fill some of the gaps remaining from the previous work. First, we hope that the use of more recent accident data will at least update severity indices to better reflect the current vehicle fleet. Second, we are attempting to look at changes in SI's due to airbag-equipped vehicles, and hope to at least begin a discussion of this as a necessary factor in future efforts. Third, we will use a more traditional measure of severity index — the proportion of serious and fatal injuries — and also a less-used index — a cost index based on the entire driver injury distribution. Hopefully, this will enlarge the knowledge of differences between SI's for various objects. Fourth, we will be exploring the use of a new methodology to help define severity indices within the large variety of possible accident scenarios that could affect them. More specifically, we will use the Classification and Regression Trees (CART) methodology that will help define the specific location/crash characteristics (i.e., speed limit, a type of vehicle, etc.) that produce a change in the severity index for a given fixed object. Finally, we will be using data from two states, North Carolina and Illinois, in the hope of better verifying or validating the severity indices developed. The police database in these two states will allow us to more clearly define crashes in which we expect the fixed object to be the primary cause of injury — a failing in some past studies that used less precise databases.

Methodology and Data Issues

Overview

The development of severity indices was the second major phase of a larger study involving the development of models relating the results of roadside hardware crash tests with predicted occupant injury in real-world crashes. (The results of this earlier force/injury prediction work can be found in a recent Transportation Research Board (TRB) study by Council and Stewart (12).) The methodology employed in this second phase was modified from original plans due to initial phase results.

Originally, the severity indices were to be developed by combining accident analyses with the force/injury models, similar in some respects to what appears to have been attempted by Ross, et al. (11). In the first phase work, we hoped to be able to combine data from FHWA-sponsored crash tests for a given fixed object with real-world injury data in similar vehicles striking the same fixed object. Using the combined data set, the plan was to then develop models with which one could predict real-world injury outcome. These models would be based on such crash-test variables as direct measures of forces to the vehicle (peak g's) and surrogate measures of occupant injury based on related measures of vehicle accelerations (i.e., change in velocity for occupant at predicted point of impact with vehicle interior, and peak vehicle accelerations during "ride-down" time). The rationale for the initial phase work was that while crash tests have been used for years in roadside hardware testing, there still exist no clearly defined data-supported relationships between the measured forces and predicted injury.

Following the development of the force/injury models, we planned to use accident data from more than one state in a more traditional development of severity indices for as many fixed objects as the data would allow, within as many crash situations as possible. Thus, for a given fixed object, the goal is an SI for each of a number of crash situations. The different situations would be a function of such control variables as vehicle speed (or speed limit as a surrogate), urban/rural location, functional class of highway, vehicle type, etc.

The final step in the process was to involve combining the accident-based SI's with the force/injury model results to produce more precise SI's. It was anticipated that, at times, the SI's for different crash situations would evolve directly from the accident data (where specific data is available). At times, when no accident data existed (say, for a new roadside hardware device not yet in the field), they would evolve directly from the force/injury model. And, at times, the model results could be used to enhance the accident-based SI's to define more specific SI's than the accident data would allow. For example, while the accident data might allow the development of an SI for a large class of guardrail ends, the model outputs could then be used to "calibrate" for specific end-types.

Indeed, we still feel that such a methodology would be quite appropriate for SI development. Unfortunately, as detailed in the above-referenced paper, the force/injury model development process was not successful to the point of being usable in SI development. This was due primarily to the (necessary) limited variability in the crash-test conditions, the lack of information on impact angle and speed in the police data, and the need to perhaps define a better composite measure of "occupant risk" in the crash-test measurements. Thus, the final SI methodology employed only the accident-based development effort.

The Data

The data potentially available for analysis in this effort included state accident data found in FHWA's Highway Safety Information System (HSIS) and data from North Carolina. The HSIS is a multistate research database that includes accident, traffic, roadway inventory, and other related data. The states participating in this system at the time of this study included Maine, Minnesota, Michigan, Illinois and Utah.

The choice of state data to be used was based on the basic goal of this effort — to define SI's for each fixed object that are as "clean" as possible. More specifically, the goal was to limit the analysis to impacts in which the fixed object in question is the sole, or at least the primary, cause of the injury. For this reason, we limited the crashes examined to single-vehicle crashes only, in which an identified fixed object is struck, and is, in effect, the most harmful event in the crash sequence. More specifically, "single-vehicle crashes" were defined by the accident type and/or by the number of vehicles in a crash. The attempt to ensure that the fixed-object impact being analyzed was the most harmful event was more complicated, and required either that a "sequence of events" be available in the crash data, or that some combination of accident type, accident maneuver, and "first harmful event" and "most harmful event" could be used.

Such restrictions eliminate crashes in which vehicles strike each other and then strike the fixed object. This appears appropriate since we would not know the primary cause of injury in such impacts. Indeed, we would often suspect that the primary cause was the vehicle-to-vehicle impact rather than the vehicle-object impact. These restrictions also eliminate those impacts in which a vehicle strikes a fixed object and then rebounds into another vehicle. This restriction appears less optimal, since the rebound is clearly associated with the object impact. However, the probability of injury in such rebound impacts is not only a function of the object impacted, but also a function of the number of other vehicles on the roadway. Finally, these restrictions eliminate, or at least reduce, the impacts in which a vehicle strikes more than one fixed object, and in which it is difficult to specify primary cause of injury (e.g., a luminaire support and a tree in the same collision).

These criteria, and the need for adequate sample sizes of fixed-object impacts for analysis, led to the decision to use North Carolina and Illinois state databases in the analysis. The remaining states either had small sample sizes of impacts with important fixed objects and/or did not have a "sequence of events" variable or a usable "most harmful event" variable.

North Carolina (NC) provided a large sample of impacts, a First Harmful Event and a Most Harmful Event variable, a listing of fixed objects and a separate rollover/no rollover variable. Thus, it is almost a "sequence" state. However, in NC, if a vehicle first struck a sign support or a utility pole and then a culvert and then rolled over, under the directions given to the investigating officer, the fixed object struck would be noted as the culvert (if that were judged to be the fixed object causing the most harm), and no mention of the sign or pole would appear. However, since such a sequence would not be expected very often, and since the officer was instructed to note the "most harmful object," the data were judged to be adequate for analysis. It is also noted that NC is the only state that currently distinguished between impacts into barrier ends and faces. Thus, it will be used extensively in defining SI's for barrier ends.

The Illinois file included information on the number of vehicles, the vehicle type, and, unlike most other states in the nation, up to three events in a sequence-of-events variable. Here, the file was first limited to single-vehicle crashes. It was further restricted to accident sequences that involved either (1) first involvement with a fixed object, no other object struck in the second and third involvements, with subsequent rollovers being allowed to remain in the file; or (2) first involvement as ran-off-road, second involvement with a fixed object, and no fixed object impact (but rollovers retained) in the third involvement; or (3) first involvement as ran-off-road, second involvement as ran-off-road or other non-collision (no rollover), and third involvement with a fixed object.

In North Carolina, accident data were available for over 20 years. However, to reduce inconsistencies in the data resulting from accident report form changes, only data from accident years 1980-1992 were used. Illinois data were available in the HSIS for calendar years 1985-1991. As will be noted in the later analyses, the data is further subdivided into crashes occurring prior to 1986 and those occurring in 1986 and later. This was due to the fact that both states passed mandatory occupant restraint laws that would have begun to affect restraint usage in 1986. Because restraint usage can clearly affect driver injury in a crash, and because police-reported restraint use is often in error after a law is passed (due to untrue information from the vehicle driver), the division in the data was felt to be the best manner of controlling for the expected increase in usage.

As noted earlier, in order to develop knowledge about the severity of object impacts for drivers of different vehicle classes, in both states, we included passenger cars (including station wagons), vans, and pickup trucks as classes of interest. In most of the analysis, the vans and pickup trucks were combined into one category.

Finally, in our attempt to develop information on the effect of airbag restraints on the developed Severity Indices, the Vehicle Identification Number (VIN) for North Carolina passenger cars in crashes in 1986 and later were decoded to ascertain whether or not an airbag was present in the car. This was also attempted in Illinois, but the sample of decodable VIN's was too small for analysis.

Definition of "Severity Index"

As noted by Glennon (3), Turner and Hall (2), and other authors, there are a number of different definitions for Severity Indices that can be used. These include such measures as percent of occupants injured, percent seriously injured, average number of fatalities or serious injuries per crash, percent of drivers injured or seriously injured, and others. For this study, it was decided that two different severity indices would be developed — one defined by the proportion of severe injuries experienced in fixed-object crashes, and one related to injury cost for the entire distribution of injuries experienced. In both cases, we are choosing to use driver injury rather than most severe injury in the vehicle (which could be experienced by any occupant). The use of driver injury should lead to more consistent measures since the driver is always present, whereas the most severe injury in the vehicle could be a function of the number of persons in the vehicle and where they are seated, variables that are somewhat uncontrolled, and which thus could lead to inconsistencies in SI's for the same object. That is to say, an SI for a smaller passenger car might be different from the SI for a larger passenger car for the same object simply because of occupancy differences.

It might be hypothesized that such a restriction to driver injury could result in somewhat conservative SI's for guardrails or other barriers if the barriers are predominantly on the right shoulder, in that the driver injury would be expected to be less than injury to a right-front passenger (and thus less than the most severe injury in the vehicle). However, given that severity indices are used in comparisons of objects, it is the relative values of SI's for different objects that are of the most importance. More specifically, if the driver-injury SI for barriers was indeed conservative (when compared to a maximum-injury SI), but the driver injury SI for other objects was not conservative, then the relative comparisons would be somewhat flawed. To test this hypothesis in a general way, Illinois data were used to develop a driver-injury distribution and a maximum-injury distribution for guardrail impacts, tree impacts, and bridge abutment impacts. The latter two objects were chosen for the comparison since it is assumed that both would be struck more often in a head-on impact than would be the case for barriers, which would more often be angle impacts. In head-on impacts, there should be less possible difference in driver and right-front passenger injury. To eliminate other possible factors that might affect the difference between driver and maximum injury, the analysis was restricted to two-lane, rural roads. The results are shown in Table 1. The second column is the percent of drivers experiencing incapacitating or fatal injury, while the third column is the percent of the most-injured occupants in each car (regardless of seating position) who experienced incapacitating or fatal injuries. The final column provides the percent increase in serious plus fatal injury between the driver figure and the all-occupant figure.

Table 1. Comparison of percentage of incapacitating plus fatal injury for drivers versus most seriously injured occupant in the vehicle (Illinois data — two-lane rural roads).

Fixed Object	Percent Incapacitating + Fatal (Driver Injury)	Percent Incapacitating + Fatal (Maximum Injury)	Percentage Increase
Guardrail	14.19%	15.70%	+10.6%
Trees	22.94%	24.92%	+ 8.6%
Bridge Abutments	19.15%	21.28%	+11.1%

As can be seen, the maximum injury for all three objects has a higher percentage of serious injuries. This would be expected in that the more occupants being studied in a vehicle, the more chances for a serious injury to be sustained. What is of interest is the third column. If the guardrail SI based on driver injury alone was significantly more conservative than the SI's of the other objects, the percentage increase incurred by using maximum injury shown should be much greater than for the other two objects. While it is greater than for trees, it is less than the percentage increase for bridge abutments. In short, there is no clear evidence here that the use of driver injury alone will produce significantly biased results for barriers. Because of this and the earlier stated reasons, driver injury was used in both severity indices developed in this research.

The initial SI defined is simply the proportion of drivers experiencing serious or fatal injury in collisions with a given fixed object under a given set of conditions (i.e., vehicle type, urban/rural location, speed limit). The rationale for choosing this measure is that, first, safety hardware (e.g., breakaway luminaire supports) is designed to prevent just such severe injuries. Second, this measure is also the same as has been used in past SI research, such as Mak, et al. (10), allowing for comparison of results. In both North Carolina and Illinois, what we are using as "serious" injury is defined on the crash report form as "Incapacitating." In the related North Carolina police instructions manual, this is defined as

> "Injury obviously serious enough to prevent the person injured from performing his normal activities for at least one day beyond the day of the collision. Massive loss of blood, broken bone, unconsciousness of more than momentary duration are examples."(13)

In Illinois documentation, "Incapacitating injury" is defined as "any injury other than fatal which prevents normal activities and generally requires hospitalization." The two definitions differ slightly. However, given that the officer on the scene is making the judgment (rather than medical personnel), the two levels would be expected to be quite similar.

The second SI definition used is the average societal cost for driver injury in impacts into a given fixed object within a given crash situation. This measure was chosen because it appears beneficial to capture information concerning the full injury distribution associated with impacts with a given object. For example, for all North Carolina impacts into a given object in a specific crash situation, the complete driver injury distribution will be extracted from the database. This "KABCO" injury distribution includes five levels of injury as shown in the table below. The proportion of each KABCO injury level will then be multiplied by the societal cost for that level to define an average driver injury cost for the specific type of impact. Societal costs will be based on work by Ted Miller of the Urban Institute for FHWA. Figures from FHWA's Motor Vehicle Accident Costs (14) will be used.

As an example of how the actual cost-related SI calculation will be carried out, assume that the resulting driver injury distribution for impacts within a given crash situation is as shown below. Also shown are FHWA's cost/injury (since the related cost per crash will often include costs for a second vehicle) and the product of the two columns:

	Injury percentage	Accident cost/person	Product
K (fatal)	1.5%	$2,600,000	$39,000
A (serious injury)	7.8%	180,000	14,040
B (moderate injury)	10.0%	36,000	3,600
C (minor injury)	20.5%	19,000	3,895
O (no injury)	60.2%	2,000	1,204
		Total impact cost:	$61,739

Weighting each injury proportion by Miller's costs, we come up with an average impact cost of $61,739. Such cost figures will be produced for each object/crash situation for each state database. For convenience in presentation, the final SI's will be the dollar value associated with a specific object/situation divided by 1000.

Statistical Methodology

The objective of this work was to obtain estimates of average crash severity resulting from vehicles striking various types of roadside hardware. Crash severity is to be based on serious driver injury, and driver injury cost. For a given crash, these severity indices may depend on a large number of factors in addition to the specific object struck and the vehicle type. Thus, if we consider the collection of all single-vehicle crashes into fixed objects for a state over a given time period, the goal is to compute average crash severities within certain subsets of these data, where subsets may be defined in terms of combinations of the levels of factors, such as highway class, locality, speed limit, roadway feature, and vehicle type.

The primary problem in this type of analysis is that of determining the subsets over which to compute averages in the most meaningful manner. One approach would be to simply subdivide the data by all combinations of levels of all factors of interest. This, however, would result in a very large number of cells, many of which would contain very small crash frequencies. The resulting average crash severities would be highly variable and it would be expected that such a procedure would produce many spurious and counterintuitive results (e.g., crash severity indices on high-speed facilities that are lower than those on low–speed facilities).

Indeed, this was the initial approach attempted in this current effort. A matrix of SI's was developed for each fixed object, with crash situations defined by the following control variables:

- Location: Rural vs. urban
- Highway class: Interstate/Freeway vs. other two-lane vs. multilane
- Speed limit: 88.5 km/h (55 mi/h) vs. other
- Roadway location: Mainline vs. intersection vs. interchange

This resulted in 48 different SI's for each fixed object studied within each state. An attempt was made to define all 48. Due to both sample size insufficiencies and other factors, this resulted in spurious and counterintuitive results in many cases.

Thus, what was needed was a statistical method that would help determine when a certain control variable was truly meaningful, in that different values of the control variable (e.g., speed limit) would result in different SI's for the same object. Such a methodology would define the combination of control variables ("matrix cells") that produced significant differences in the SI's for a given object. If no control variable (or combination of variables) results in different SI's, then the SI for that particular object will have only one value — the overall SI.

While there are a number of statistical methods (e.g., regression analysis, multiway contingency table analysis) that could be used to identify more appropriate data subsets based on significance testing, the methods of generating classification and regression trees developed by Breiman, Friedman, Olshen, and Stone (15) seem ideally suited for this type of application.

In this application, for a given type of object struck or group of object types, two sequences of regression trees would be constructed—one using driver injury at the A or K level (yes or no) as the dependent variable, the other using cost of injury to the driver as the dependent variable. The independent variables induced were locality, number of lanes, speed limit, highway class, specific object struck if more than one, vehicle type (car vs. light truck), vehicle group (pre-1986, post-86 without airbag, post-86 with airbag), and roadway feature. The Classification and Regression Trees (CART) procedure builds the trees through a sequence of binary splits of the data, where each split selected is the one, out of all possible splits based on the values of the independent variables, which yields the biggest reduction in the within-group variation in the dependent variable. The procedure continues until no further splits can be made based on the available data or on predetermined minimal size requirements. The process results in a nested sequence of trees or data partitions.

A major feature of CART is the method used for choosing an optimal tree by evaluating the performance of each tree in the sequence on an independent data set not used in the construction of the trees. Performance is measured in terms of relative error, which is the mean squared error for a given tree divided by the mean squared error for "no tree" (i.e., a tree with a single node). CART calculates this relative error statistic for each tree in the sequence and a standard error for each of these statistics.

There are two different methods by which this independent testing can be accomplished. If the initial data set is sufficiently large, a portion of the data can be randomly selected and set aside to be used as the test sample. Each tree is evaluated by calculating relative errors on this test sample. For smaller initial samples, the procedure uses the method of tenfold cross-validation. When using this method, CART first builds the tree sequence using the entire data set, then the data are randomly divided into 10 approximately equal subsets. CART then repeats the tree-building process 10 times, each time using 9/10 of the data as the learning sample and the remaining 1/10 as a test sample. The average performance over the 10 test samples is then taken as the performance of the original tree.

Means and standard deviations of the dependent variable and sample sizes in each subset of the optimal tree are included in the output from CART. Results produced by CART should be far less susceptible to chance variations and, hence, be more reflective of the real world than results produced through most other approaches.

As an illustration of the procedure described above, consider the CART analyses of the severity of North Carolina crashes involving a vehicle striking a guardrail. In these analyses, the variable object struck took on four values corresponding to guardrail faces and ends on shoulders and in medians, respectively. The other independent variables were:

- Locality (rural, mixed, urban)
- Lanes (two-lane, multilane)
- Speed limit ($<$ 88.5 km/h (55 mi/h), $\geq$ 88.5 km/h)
- Road class (interstate, non-interstate)
- Road feature (intersection, interchange, mainline)
- Vehicle type (car/station wagon, light truck/van)
- Accident year group (pre-1986, post-86 without airbag, post-86 with airbag)

The data set for these analyses contained 12,218 observations. A random subset of 3,980 cases was selected as a test sample, while 8,238 observations were used in the learning sample. When the variable indicating driver injury at an A or K level versus lesser or no injury was used as the response variable, CART selected as optimal a regression tree having six terminal nodes (subsets). Descriptions of these nodes, their sample size, proportion of drivers with A or K injury, and 95% confidence intervals are listed below in Table 2.

In building the tree whose terminal nodes are shown in Table 2, CART first split the data into guardrail faces (median and shoulder) and guardrail ends (median and shoulder). No further splits were made of guardrail faces, meaning that none of the possible control variables (or combinations thereof) resulted in significantly different SI's. In short, the best estimate of a severity index for a guardrail face based on this data is an overall SI of 0.072, which applies to all situations. The data on crashes into guardrail ends were then split on locality, and subsequently, by speed limit, accident year group, and by vehicle type to yield the subsets listed in the table.

Table 2. CART results for percent seriously injured in guardrail crashes.

Node	Description	N	P-AK	C.I.
1.	Guardrail faces (all)	9417	0.072	(0.067, 0.077)
2.	Guardrail ends, Location = urban, speed limit < 88.5 km/h (55 mi/h)	418	0.074	(0.048, 0.099)
3.	Guardrail ends, Location = urban, S.L. ≥ 88.5, acc. yr. = 1986+ (all)	269	0.108	(0.071, 0.145)
4.	Guardrail ends, Location = urban, S.L. ≥ 88.5, acc. yr. = pre-1986	142	0.197	(0.132, 0.262)
5.	Guardrail ends, rural & mixed, vehicle type = cars/station wagon	1629	0.166	(0.148, 0.184)
6.	Guardrail ends, rural & mixed, vehicle type = light trucks/vans	343	0.108	(0.075, 0.141)

It may be noted from the results shown in Table 2 that some of the estimated crash severity indices are very similar, their confidence intervals overlap and some of the final subsets are relatively small. This suggests that the performance of the sequence of subtrees should be examined. As it turns out, a subtree having three nodes performs nearly as well as the optimal tree. That is, the relative error for the tree having three nodes is within one standard error of the relative error of the optimal tree. Here, this "standard error" is the estimated standard error of the relative error of the optimal tree. The three-node subtree results by first splitting the data by guardrail faces versus ends, then splitting ends by locality to yield the three nodes shown in Table 3 below.

Table 3. Secondary CART results for percent seriously injured in guardrail crashes.

Node	Description	N	P-AK	C.I.
1.	Guardrail faces (all)	9417	0.072	(0.067, 0.077)
2.	Guardrail ends, urban	829	0.106	(0.085, 0.127)
3.	Guardrail ends, rural & mixed	1972	0.156	(0.140, 0.172)

An option of CART is to specify a parameter α that results in the procedure selecting as optimal the smallest subtree whose relative error was no greater than α standard errors greater than the minimal relative error. In the analyses described below, $\alpha = 0$ was always used initially, so that the optimal tree was chosen to be the one with the minimum relative error. Subtrees could then be selected manually by examining the sequence of relative errors as illustrated in the example given above.

Potential Biases in the Data

As in most data-based analyses, there are potential biases that might affect the developed severity indices due to the use of police-reported accident data. Two of the more important are possible bias resulting from the use of data from two states, and issues related to unreported crashes.

Overall differences between states. As indicated earlier, one of the advantages of this current study over past efforts lies in the use of data from two states, which will allow for some verification of results. As with any multi-state comparison, there is also the inherent "disadvantage" in that the data may differ due to a number of reasons, including reporting differences, urban/rural differences, and driver/vehicle differences. More specifically, given that the goal of using two states is to allow comparison of SI's for given objects and crash situations between states, the question is whether there are inherent differences in fixed-object crashes that would result in expected differences *a priori*. If such overall differences exist, then one should be aware of them in the comparisons.

For example, if Illinois is more urbanized than North Carolina (which it is), then one might expect that Illinois fixed-object crashes would be at lower speeds, and thus the resulting impacts would be less severe than fixed-object crashes in North Carolina. Similar biases might result if the NC driver pool were more elderly, or if the Illinois vehicle pool were newer, with better occupant protection, or if seat belt usage was higher in one state. There might also be inherent differences arising from the way in which the impacts studied were chosen. That is, the use of the "sequence of events" in Illinois may possibly omit more cases in which a second (different) object is struck, in comparison to the "most harmful event" screen used in North Carolina. Some of these differences will be accounted for in the analysis methodology used, in that the data from both states are examined on certain of these variables (e.g., urban/rural, vehicle type). However, there will be other possible influencing variables that cannot be controlled for, such as driver seat belt use (which is basically unknown in both states after passage of the mandatory use laws), and, perhaps, the methods used in choosing the study sample.

In order to gain some insight into possible differences, a simple run of driver injury distributions for each state was produced for the total population of fixed-object crashes. As shown in Table 4, there are indeed some overall differences in the distributions for the two states.

Table 4. North Carolina and Illinois driver injury distributions for fixed-object impacts.

Injury Level	Injury Distributions			
	North Carolina		Illinois	
	Frequency	Percent	Frequency	Percent
Killed	2,389	1.4	4 30	0.8
Serious Injury	20,751	12.6	5,350	10.1
Moderate Injury	33,742	20.5	6,943	13.1
Minor Injury	27,255	16.5	4,696	8.8
No Injury (PDO)	80,737	49.0	35,743	67.2
TOTAL	164,874		53,162	

North Carolina fixed-object crashes exhibit more serious driver injury, both in terms of the lower percentage of property damage only (PDO) crashes (49.0% vs. 67.2%), and the higher percentage of serious and fatal driver injuries (14.0% vs. 10.9%). While not shown in the table, this difference is due to some extent to differences in urbanization, with Illinois experiencing a higher percentage of fixed-object crashes in urban areas (72.2%) than does North Carolina (34.3%, plus an additional 17.3% in "mixed" localities). As shown in Table 5, when rural crashes are examined alone, the difference in injury distribution is still present, but is lessened to some degree. Here, the percentage of serious and fatal injury in Illinois is slightly lower, but similar. This is important, since it is these two categories that will form one of the severity indices. The larger differences are in the moderate, minor and no-injury crashes, differences that would be expected to affect the second SI related to overall injury cost.

Table 5. North Carolina and Illinois driver injury distributions for rural fixed-object impacts.

Injury Level	Injury Distributions			
	North Carolina		Illinois	
	Frequency	Percent	Frequency	Percent
Killed	1,616	2.0	220	1.7
Serious Injury	10,875	13.6	1,709	13.1
Moderate Injury	16,178	20.3	2,191	16.8
Minor Injury	14,094	17.7	1,140	8.7
No Injury (PDO)	37,076	46.4	7,816	59.8
TOTAL	79,839		13,076	

In summary, as indicated earlier, some of this difference between the two states will be accounted for by the analysis output, when urban/rural is a significant predictor of injury differences for a given fixed object. However, since other possible causes of these differences cannot all be controlled for, this overall trend toward slightly less severe driver injury distributions in Illinois must be kept in mind when comparisons are made.

Unreported crashes. Finally, it is noted that a bias that will be inherently present in this analysis (and any other that uses police-reported crash data) will be that bias resulting from unreported accidents. Because all of these analyses are based on police accident reports, we will be missing accidents that are not investigated by police. The bias that arises here results from the fact that the better the design of hardware (in terms of severity reduction to both the driver and the vehicle), the more likely the accidents will not be reported to the police. Thus, in truly "successful" crashes, the vehicle will drive off before any investigation is done. Past preliminary research by Viner (16) has indicated that this is a particular problem with respect to such devices as crash cushions, where 50 percent of the impacts examined were not reported to the police. Other research by Mak and Mason (17) and Galati (18) indicates problems with point objects, such as poles and signs, and with median barriers. Since this potential bias cannot be controlled for, it will be discussed in greater detail in a later "Results" section of the paper.

Results

As described earlier, there were a number of objects that could potentially have been analyzed in this effort. And, as expected, the categories of objects differ slightly between the two states. For example, North Carolina uses "luminaire support," while Illinois uses "light standard." However, in most cases, the differences were minor. Earlier noted major differences include the Illinois use of "guardrail" to capture both face and end impacts, while North Carolina provides the investigating officer with codes that differentiate between "face" and "end" impacts for guardrail and concrete barrier impacts.

The categories of objects found in the final result tables shown later in this report were sometimes composed by grouping what were thought to be similar objects in the same state database, and letting the CART procedure then determine whether the objects within a given group have significantly different SI's. For example, all guardrail categories in North Carolina were originally grouped together; but as indicated below, CART found significantly different SI's for the faces and ends. In like fashion, light supports and traffic signal supports were grouped together in Illinois, but CART indicated significantly different SI's for the two objects.

Table 6 provides a listing of the object groups analyzed for each of the states. The individual components of each group are also shown as described in the crash report documentation. (As noted above, this does not necessarily mean that the objects remained grouped together in the final results.) However, it is further noted that the definitions used by the officer in completing the crash reports are generic in nature and group all types of a given object together. Thus, "guardrail" might include both w-beam and thrie-beam systems, with and without blockout. What is of most interest to the potential user of the developed severity indices would be the precise descriptions of the specifics of each object, or at least of each category. Unfortunately, like other states, neither North Carolina nor Illinois has any type of fixed-object inventory for all roadways. In an attempt to provide additional information concerning the specifics of the fixed objects, informal interviews with knowledgeable design engineers in each state were conducted concerning the general nature of each of the fixed objects. A summary of this information for each object is also included in Table 6.

For North Carolina, "guardrail" is essentially all w-beam, blockout design. Both steel and wood posts are used, with approximately 75% being steel. There is a very small amount of non-blockout rail on some secondary roads. Approximately 90%-95% of "guardrail ends" are the Breakaway Cable Terminal (BCT) design with 1.2-m (4-ft) flare, with the remaining ends being blunt-end designs. Again, the latter would be found on secondary, low-volume roadways. Approximately 99% of the median and shoulder barriers are of the New Jersey design, and most are associated with construction zones. In these zones, the end treatment is usually the GREAT system. End treatments for the few permanent locations vary, with some simply being carried to a wide section of median, sloped and buried. Bridge rails are less consistent, with the newer ones on higher class roadways being of the New Jersey shape, and the older ones being some type of tubular steel rail design. A high proportion of the transition guardrails on major roads would have

Table 6. Listing and description of objects analyzed in North Carolina and Illinois.

Fixed Object	Description			
	North Carolina		Illinois	
	Crash Report Description	Engineering Description	Crash Report Description	Engineering Description
Guardrail	Guardrail end on shoulder Guardrail face on shoulder Guardrail end in median Guardrail face in median	W-beam, blockout design on most roadways. Mostly steel posts. Small amount of w-beam, non-blockout on secondary roads. BCT ends in 90-95% of cases, with remainder being blunt ends on low–volume secondary roads	Guardrail	W-beam, blockout, steel-post design. Majority of ends are turn-down design, with newer ends being BCT design.
Median and Shoulder Barrier	Shoulder barrier end Shoulder barrier face Median barrier end Median barrier face	Approximately 99% of barriers are New Jersey shape. Mainly in construction zones with GREAT end treatment. Other ends vary.	Concrete median barrier	All barriers are New Jersey shape. End treatments are 50% sand barrel, 50% GREAT system.
Bridge rail	Bridge rail end Bridge rail face	Rail varies. New Jersey shape with BCT on newer, higher class roads. Mixed tubular metal rails on older, lower volume roads. Blunt end or no transition on some secondary roads.	Bridge or bridge guardrail Guardrail on bridge approach	Rails vary. New Jersey shape on Interstate and high-volume primary routes. Tubular steel on others. Transitions reflect guardrail design — primarily turndown.
Underpass Structure	Pier on shoulder of underpass Pier in median of underpass Abutment (supporting wall) of underpass	As described on crash report	Bridge abutment Underpass structure	As described on crash report
Utility Poles	Utility pole (with/without light)	As described on crash report — no breakaway poles	Utility pole	As described on crash report — no breakaway
Trees	Tree	Varies — as described on crash report	Tree	Varies — as described on crash report

Table 6. Listing and description of objects analyzed in North Carolina and Illinois (con't).

Fixed Object	Description			
	North Carolina		Illinois	
	Crash Report Description	Engineering Description	Crash Report Description	Engineering Description
Luminaire Support	Luminaire pole (non-breakaway) Luminaire pole (breakaway)	All shielded or frangible base breakaway design	Traffic signal Light standard	All breakaway, frangible base, except in high-pedestrian urban locations
Highway Signs	Official highway sign (non-breakaway) Official highway sign (breakaway)	Large signs are slip-base breakaway or shielded. Small sign supports vary — U-channel or wood	Highway sign	Large signs breakaway or shielded. Small sign supports vary — U-channel or wood
Commercial Signs	Commercial sign	Varies	Advertising sign	Varies
Traffic Islands	Curb, median or traffic island	Varies	Curb or channelizing island/curb	Varies
Catch Basin/Culvert	Catch basin or culvert on shoulder Catch basin or culvert in median	Flush inlets on freeways, divided highways. Less than 10% 152-mm (6-in) raised inlets, mostly on secondary roads	Culvert headwall	As described on crash report
Construction Barrier	Construction barrier	Varies — primarily plastic barrels, very small number of Type 1 or Type 2 (sawhorse) design	Barricade	Varies — plastic barrels or Type 1 or 2 (sawhorse) design
Impact Attenuator	Crash cushion	Mostly temporary in construction zones — GREAT system. Remainder Hy-dro Cell	Impact attenuator	80-90% sand-barrel design. Remainder are primarily GREAT system, with few Hi-dri Cell systems
Fences — median and other		Varies — as described on crash report	Median fence Fence, other	Varies — as described on crash report

BCT terminals, with the remaining bridge rails (mostly on secondary roads) having either a blunt end or no transition rail.

If not shielded by a barrier, all luminaire supports are frangible-base breakaway design and large signs are slip-base breakaway design. Small sign supports would include some wood supports (e.g., for stop signs on minor roadways), but are mainly steel U-channel designs.

Catch basins would have flush inlets on freeways and divided highways. There are probably a small percentage (< 10%) of raised inlets still existing beside some minor roadways. "Construction barriers" would primarily include plastic barrels, a very small number of Type 1 or Type 2 ("sawhorse") barricades, and perhaps some "miscoded" temporary New Jersey barriers. It is assumed that the latter would normally be coded as "shoulder or median barrier," as described above. Finally, there are very few permanent "crash cushions" in the state. Most installations would be temporary ones associated with construction zones. The permanent attenuators would normally be the Hy-dro Cell design, while the temporary ones are usually the GREAT system.

For Illinois, all "guardrail" is w-beam, blockout, steel-post design. While end impacts cannot be separated from face impacts in the Illinois data, it is noted that during the time of the study, the overwhelming majority of the end treatments in Illinois were "turn-down" ends. This was the standard policy until 1978, when all new or replacement ends became BCT's. It is further noted that the BCT's were installed with a 0.3-m (1-ft) flare, rather than a 1.2-m (4-ft) flare, until the early 1990's.

All median barrier in Illinois is New Jersey shape. Approximately 50 percent of the end-treatments would be a sand-barrel attenuator, with the remaining half being the GREAT system. Bridge rails on Interstates and high-volume major primary routes are New Jersey shape, while rails on other roads are some type of tubular steel rail. Transition guardrails would be close-post-spacing designs, with the ends reflecting those of the guardrails — primarily the turndown design.

Except in urban areas with large pedestrian volumes (where their safety is an issue), all luminaire supports are breakaway design, usually with frangible bases. Large sign supports are also breakaway design on all roadways. Small sign supports are either steel U-channel or wood posts.

"Barricades" would usually refer to either plastic barrels or Type 1 or Type 2 (wooden "sawhorse") designs. Finally, impact attenuators in Illinois are 80-90 percent sand-barrel design, with the remaining 10-20 percent being the GREAT system. Staff indicates that there are a few Hi-dri Cell designs in high-volume urban gore areas.

In summary, most of the objects for North Carolina and Illinois are similar. Guardrail ends in the two states differ, with North Carolina primarily using BCT's and Illinois primarily using turn-down ends. End-treatments on median barriers differ somewhat, with Illinois using more sand-barrel systems. Perhaps the most significant difference is in the impact attenuators used. In North Carolina, most are temporary GREAT systems in construction zones. In Illinois, most are permanent sand-barrel systems. Where pertinent, these differences will be noted in the later discussion of results.

The following results are organized for discussion purposes by the object struck, with a table presented for each of the objects (or groups) in the final CART analysis. The table for each object contains results for both states, and results for both definitions of severity indices — the proportion of serious driver injury, and the average cost of the driver injury. The sample sizes for the final optimum tree from the CART procedure are also provided.

Guardrails

As indicated in Table 7, both Illinois and North Carolina had a significant sample of guardrail impacts for analysis. The Illinois data indicated that there was a significant difference between the guardrail SI's for urban and rural locations. The rural severity index (0.132) based on proportion of serious driver injury is approximately 47 percent higher than the urban index (0.090). In the North Carolina data, guardrail ends were shown to be significantly different from guardrail faces. Here, the severity index, based on severity of injury for faces, was not significantly different in urban and rural locations. However, the index for guardrail ends in rural locations (0.156) was again approximately 47 percent higher than the severity index in the urban locations (0.106).

Table 7. Details of serious injury and cost-related severity indices for guardrail impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Guardrail	1. Faces	0.072	(0.067, 0.077)	9,417	1. Rural	0.132	(0.121, 0.143)	3,790
	2. Ends, urban	0.106	(0.085, 0.127)	829	2. Urban	0.090	(0.083, 0.097)	7,292
	3. Ends, rural & mixed	0.156	(0.140, 0.172)	1,972				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Guardrail	1. Mixed/urban	36.19	(31.15, 41.23)	5,411	No splits	41.00	(3.24, 44.76)	11,082
	2. Faces, rural	44.82	(38.29, 51.55)	5,287				
	3. Ends, rural	96.94	(77.41, 116.47)	1,520				

The cost-related severity indices indicated somewhat similar findings. In North Carolina, the guardrail ends were found to be significantly different from faces in rural areas, with the rural

SI for guardrail ends being approximately twice that of the guardrail faces. Note that this cost-based relationship between ends and faces in rural areas is approximately the same as the serious injury relationship between rural ends and all faces (0.156 vs. 0.072). Ends and faces were not significantly different from each other in mixed and urban areas, with a common value of 36.19.

The overall Illinois data, which did not show any significant split by any of the control variables for the cost-based SI, indicated a dollar cost that was slightly higher than the mixed/urban value in North Carolina, and much lower than the severity index for ends in rural areas in North Carolina. Again, the Illinois data does not allow us to divide end impacts and face impacts.

Concrete Median Barrier

First, as was noted in Table 6, North Carolina data would have allowed for categorizing barrier ends and faces separately. However, as shown in Table 8, the results for the serious injury-based SI's indicate that the CART methodology did not detect significant differences between median and shoulder barrier ends and faces. This is different from what was found in the preceding section with respect to guardrails, but is probably partly a function of the smaller sample size for the median and shoulder barrier impacts.

Table 8. Details of serious injury and cost-related severity indices for concrete barrier impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Median Barrier & Shoulder Barrier	No splits	0.074	(0.063, 0.085)	2,087	1. 2 or 4 lanes	0.061	(0.044, 0.078)	767
					2. 6 lanes	0.124	(0.105, 0.143)	1,106
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Median Barrier & Shoulder Barrier	No splits	33.39	(25.89, 40.89)	2,087	No splits	31.01	(25.14, 36.88)	1,873

What is of interest is that the North Carolina severity index for the total group of median barriers was approximately the same as that for the faces in the preceding guardrail table, and is lower than that for either of the guardrail end groups. The same is true under the NC cost section of the table, where the cost-related severity index for median and shoulder barriers is also less than any of the cost indices for guardrails.

With respect to the Illinois data, while the serious injury-based SI's did not fall into the same categories as in the preceding guardrail table, they are in the same general range of values, or slightly lower. In like fashion, the cost severity index for concrete median barrier for Illinois is significantly lower than the cost index for guardrails in the preceding table.

Bridge Rail

As noted in Table 6 above, this category contains a combination of bridge rail faces and ends in the North Carolina data, and bridge rails and bridge-related guardrails in the Illinois data. The latter presumably refers to guardrails connected to the ends of the bridges. As can be seen in Table 9, there are large sample sizes for almost all of the categories that were identified by the CART methodology.

Table 9. Details of serious injury and cost-related severity indices for bridge rail impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Bridge rail (Ends and Faces) IL also has bridge guardrail	1. Bridge rail face	0.075	(0.068, 0.083)	4,710	No splits	0.113	(0.101, 0.125)	2,538
	2. Bridge rail ends, mixed	0.192	(0.154, 0.230)	418				
	3. Bridge rail ends, rural & urban	0.228	(0.214, 0.242)	3,514				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Bridge rail (Ends and Faces) IL also has bridge guardrail	1. Bridge rail ends	151.09	(135.14, 167.04)	3,932	1. Rural	63.51	(46.07, 80.95)	1,167
	2. Bridge rail faces	40.47	(34.16, 46.78)	4,710	2. Urban	42.85	(31.50, 54.20)	1,371

With respect to the serious injury severity indices, while the Illinois data produced only a general severity index (0.113), the North Carolina data was split on the basis of bridge rail faces vs. bridge rail ends in two different locations. The locational splits (i.e., mixed vs. urban and rural) are not very logical in terms of what one might expect. That is to say, if one assumes "mixed" to be a rural/urban combination, then one would expect greater differences between the rural and urban locations than between these two as a group and the mixed locations. However, the SI's in these two location categories for ends are somewhat similar (0.192 vs. 0.228), suggesting that one SI value for ends might be appropriate.

From a verification sense, it is comforting to note that the value for the bridge rail faces is very similar to the values for guardrail faces and median/shoulder barriers noted in the earlier analysis. Of interest is the fact that the SI for bridge rail faces in NC is only approximately one-third of the value for the bridge rail end, a highly significant difference. This is similar to, but greater than the differences in SI's for guardrail faces versus rural ends seen in Table 7 (i.e., 0.072 vs. 0.156). While no split is possible, the Illinois combined SI for faces, ends and bridge guardrails falls within the range of the North Carolina values.

The differences in faces and ends are even more apparent in the cost-related SI's shown in the lower portion of the table. Here, the Illinois data show differences in urban and rural impacts for all of the combined bridge components, with the rural locations having a cost SI that is approximately 48 percent higher than the urban index. The North Carolina figures indicate almost a fourfold difference between bridge rail faces and bridge rail ends. Indeed, when one compares the cost-related SI's for these bridge rail ends to guardrail ends discussed earlier, the index for bridge rail ends is 56 percent higher than that of the rural guardrail ends (i.e., 151.09 vs. 96.94).

Bridge Underpass Structure

In North Carolina, this category consists of combinations of bridge pier on shoulder or median, and bridge abutments. In Illinois, it is a combination of bridge abutment and underpass structure. As can be seen from Table 10, in no case does CART separate the data into individual severity indices for any of these categories. Instead, all are combined into a category relating to the underpass structure and its components.

Table 10. Details of serious injury and cost-related severity indices for impacts with underpass structures.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Underpass Pier and Abutment	1. < 88.5 km/h (55 mi/h)	0.225	(0.184, 0.266)	395	1. < 88.5 km/h	0.157	(0.129, 0.184)	669
	2. ≥ 88.5 km/h	0.375	(0.239, 0.422)	416	2. ≥ 88.5 km/h Car/s.w.	0.233	(0.136, 0.330)	73
					3. ≥ 88.5 km/h, Pickup/van	0.412	(0.247, 0.577)	34
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Underpass Pier and Abutment	1. < 88.5 km/h	125.61	(81.92, 169.30)	395	1. < 88.5 km/h	95.16	(65.12, 125.20)	669
	2. ≥ 88.5 km/h	373.77	(293.51, 454.03)	416	2. ≥ 88.5 km/h Car/s.w.	217.59	(68.68, 366.48)	73
					3. ≥ 88.5 km/h Pickup/van	509.85	(183.80, 835.90)	34

As can be seen from the table, there are some differences between the severity indices within the two states. In both states, the data are categorized by speed limit and, in Illinois, it is further categorized by vehicle type. In general, the Illinois severity indices for both proportion of serious driver injury and average cost are lower than the North Carolina indices. For example, for speed limits less than 88.5 km/h (55 mi/h), the North Carolina index of 0.225 is approximately 43 percent higher than the corresponding SI of 0.157 for Illinois. Both are based on moderate-sized samples. For speed limits over 88.5 km/h (55 mi/h), the North Carolina severity index of 0.375 falls between that of the car/station wagon and the van groups in the Illinois data. It should be noted that both of the Illinois groups are based on fairly small samples and, thus, have correspondingly wide confidence intervals.

With respect to the cost-based severity indices, the findings are again fairly consistent. The North Carolina cost index is higher for the less than 88.5-km/h (55-mi/h) group, and falls between the two vehicle-type values for speed limit equal to or greater than 88.5 km/h.

Utility Poles

As indicated in Table 11, with respect to the serious injury severity index, the CART methodology indicated significant differences by crash year, vehicle type, and location or speed limit in the North Carolina data. In the Illinois data, there were differences based on urban/rural location, vehicle type, and roadway feature (intersection/interchange vs. mainline locations). In general, the proportion of serious injury was somewhat similar between the two states. Because CART broke down the data in different ways between the two states, it is somewhat difficult to find similar cells for direct comparison. Note that the most appropriate between-state comparisons are between the post-1986 period in NC and the Illinois data (data from Illinois only included the years 1985-1991). Also note that when the CART analysis divides severity indices into pre- and post-1986 crash years, the discussion will generally concentrate on the post-1986 findings. This is done since these are the crashes (and the vehicle fleet) that will be most similar to what will be seen in the future.

Both North Carolina and Illinois data indicated severity indices for pickup trucks and vans that were significantly lower than the corresponding SI's for the passenger car/station wagon groups. In the North Carolina data, the pre- and post-1986 indices for passenger cars are similar in the urban and < 88.5-km/h (55-mi/h) (0.136 and 0.122) and in the rural and ≥ 88.5-km/h pair (0.156 and 0.152). This finding is not unexpected in that speed limit is, to some extent, a surrogate for urban/rural location. In a similar fashion, the pre- and post-1986 pickup/van indices are somewhat similar to each other in urban and rural locations. Thus, in general, the type of vehicle is more important than the year of crash.

In the Illinois data, the major difference noted is that the general severity index for all utility pole impacts in rural areas is significantly higher than the SI for the three groups corresponding to urban areas. The urban severity index that is closest to this rural index is that for the car/station wagons on mainline roads (i.e., away from intersections/interchanges). Again, like in North Carolina, the pickup truck/van group has the lowest severity index calculated.

Table 11. Details of serious injury and cost-related severity indices for utility pole impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Utility Poles	Pre-1986 passenger cars				1. Rural	0.189	(0.173, 0.205)	2,192
	1. Mixed or urban	0.136	(0.131, 0.142)	14,540	2. Urban Car/SW Intersection/ interchange	0.114	(0.097, 0.131)	1,346
	2. Rural	0.156	(0.145, 0.167)	4,030				
	Post-1986 passenger cars							
	1. < 88.5 km/h	0.122	(0.117, 0.127)	14,532	3. Urban Car/SW Mainline	0.165	(0.151, 0.179)	2,803
	2. ≥ 88.5 km/h	0.152	(0.141, 0.163)	4,242				
	Pre-1986 pickup truck/van				4. Urban Pickup/van	0.109	(0.086, 0.131)	753
	1. Urban	0.084	(0.071, 0.097)	1,688				
	2. Mixed & rural	0.138	(0.121, 0.155)	1,506				
	1986 & later pickup truck/van							
	1. Mixed/urban	0.088	(0.078, 0.098)	2,933				
	2. Rural	0.128	(0.110, 0.146)	1,270				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Utility Poles	Pre-1986 passenger cars				1. Intersection or interchange	35.71	(29.55, 41.87)	1,969
	1. < 88.5 km/h	47.17	(44.39, 49.95)	14,718				
	2. ≥ 88.5 km/h	75.12	(65.37, 84.87)	3,852	2. Mainline, Rural	101.40	(83.85, 118.95)	1,829
	Post-1986 passenger cars				3. Mainline, Urban	58.40	(50.24, 66.36)	3,296
	1. Urban	45.63	(42.13, 49.13)	10,805				
	2. Mixed	63.27	(54.26, 72.28)	3,361				
	3. Rural < 88.5 km/h	53.84	(42.56, 66.12)	1,259				
	4. Rural ≥ 88.5 km/h	79.88	(68.75, 91.03)	3,349				
	Pre-1986 pickup truck/van							
	1. < 88.5 km/h	36.67	(29.84, 43.40)	2,352				
	2. ≥ 88.5 km/h	83.70	(59.73, 107.67)	842				
	1986 & later pickup truck/van							
	1. Mixed/urban Intersection or interchange	21.85	(18.33, 25.39)	558				
	2. Mixed/urban Mainline	45.58 82.63	(26.73, 54.43)	2,375				
	3. Rural		(62.80, 102.46)	1,270				

With respect to the cost indices, first, there appears to be slightly greater differential between the severity indices for urban and rural areas in both states than was the case for serious injury-based SI's. In the cost indices, when one compares the urban and rural SI's (or urban versus > 88.5-km/h (55-mi/h) SI's), one sees almost a doubling of the indices in most cases. This is somewhat higher than the 40-60 percent increase that was seen with the proportions. Also of note here is the fact that in the North Carolina cost indices, the rural pickup truck/van group appears to have perhaps slightly higher severity indices than the rural passenger car group, a finding in contrast to what was noted with the serious injury SI's. Since the cost SI's are based on differentiated serious injuries and fatalities,while the serious injury SI's group the two injury classes together, this could be an indication of somewhat higher fatal injuries for the pickup/van group in rural areas.

Trees

As shown in Table 12, with respect to the severity indices for trees, based on proportion of serious driver injury, the methodology subdivided the North Carolina data based on crash year, vehicle type, and speed limit. This is similar to the previous divisions for utility poles. The Illinois data were subdivided based primarily on number of lanes and road features. However, even though categorized somewhat similarly, there do appear to be some differences between the SI's for trees and the earlier described utility poles. In almost every case in both states where groups are similar, both the serious injury and the cost SI's are higher for trees.

With respect to the North Carolina side of the table, it is observed that the severity indices related to cars were not greatly different from that for the pickup trucks/van groups for the crashes occurring after 1986. In addition, in these two groups, it appears that the SI's for the higher speed limits are approximately 21-27 percent greater than for the lower speed limits.

The Illinois data indicate that as expected, for intersections, where speeds would be assumed to be lower, the SI is indeed the lowest calculated. The highest SI is for the mainline sections of multi-lane roadways. The difference between the highest and lowest index in the Illinois group is approximately 43 percent.

With respect to the lower half of the table related to costs, larger differences are seen between certain pairs of severity indices. Again, the North Carolina data were subdivided based on year of crash, vehicle type, and speed limit, with the later-model passenger cars, >88.5-km/h (55-mi/h) group being further categorized by roadway feature. In this case, the Illinois data were subdivided based on number of lanes, rural vs. urban location, and roadway feature. In the North Carolina side of the table, it is again noted that the severity indices for the cars are very similar to those for the pickup truck/van group in the post-1986 crash set. In addition, in contrast with the 21-27 percent difference shown earlier with the serious injury-based SI's, there appears to be a large percent difference between the severity index for the higher speed limit vs. the lower speed limit for both the post-1986 cars (mainline) and post-1986 pickup/vans.

Table 12. Details of serious injury and cost-related severity indices for tree impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Trees	Pre-1986 cars				1. Intersection or interchange	0.151	(0.129, 0.173)	1,023
	1. < 88.5 km/h	0.176	(0.168, 0.184)	8,822				
	2. ≥ 88.5 km/h	0.195	(0.186, 0.200)	13,195				
					2. 2 lanes, mainline	0.173	(0.156, 0.190)	1,976
	Post-1986 cars							
	1. < 88.5 km/h	0.149	(0.143, 0.155)	12,002				
	2. ≥ 88.5 km/h	0.181	(0.175, 0.187)	17,027	3. > 2 lanes, mainline	0.216	(0.202, 0.230)	3,437
	Pre-1986 pickups/vans							
	1. < 88.5 km/h	0.159	(0.139, 0.179)	1,235				
	2. ≥ 88.5 km/h	0.194	(0.180, 0.209)	2,875				
	Post-1986 pickups/vans							
	1. < 88.5 km/h	0.142	(0.122, 0.162)	1,142				
	2. ≥ 88.5 km/h	0.181	(0.172, 0.190)	6,500				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Trees	Pre-1986 cars				1. 2 lanes	62.52	(51.65, 73.39)	2,264
	1. < 88.5 km/h	78.92	(81.40, 86.44)	8,822				
	2. ≥ 88.5 km/h	112.48	105.28, 119.68)	13,195	2. > 2 lanes, Rural	157.71	(135.90, 179.52)	2,290
	Pre-1986 pickups/vans							
	1. < 88.5 km/h	65.84	(51.07, 80.61)	1,235	3. > 2 lanes, Urban, intersection/ interchange	34.37	(28.11, 40.63)	366
	2. ≥ 88.5 km/h	103.90	(89.41, 118.39)	2,875				
	Post-1986 cars							
	1. < 88.5 km/h	69.92	(63.67, 73.97)	12,002				
	2. ≥ 88.5 km/h, intersection/ interchange	70.58	(252.38, 88.78)	1,008	4. > 2 lanes, Urban, mainline	98.05	(78.70, 117.40)	1,516
	3. ≥ 88.5 km/h, mainline	107.86	(101.50, 114.22)	16,019				
	Post-1986 pickups/vans							
	1. < 88.5 km/h	69.23	(57.23, 79.23)	2,500				
	2. ≥ 88.5 km/h	105.69	(94.67, 116.71)	5,142				

Even more striking differences are seen on the Illinois side of the table. In comparison to the 43 percent difference found between the highest and lowest severity indices based on proportion of serious injury, here we have differences that are 100-300 percent. The highest severity index is for multi-lane roads in rural areas, and the lowest is for intersection/interchange locations on urban two-lane roads.

Luminaire Poles

As shown earlier in Table 6, this category consists of breakaway and non-breakaway luminaire supports in the North Carolina data, and both luminaire and traffic signal supports in the Illinois data. In the North Carolina data shown in Table 13 below, there were no significant differences found between the breakaway and non-breakaway groups of luminaire supports. This was probably due to the small sample sizes in the two groups, rather than being a reflection of no difference in the severity index for these two groups.

In the Illinois data, there was a significant difference between light standards and traffic signal supports, with the SI for the traffic signal support being lower than that for the light standard. This could be reflecting the possibility that traffic signal supports are found more often in urban, low-speed locations. Indeed, the indices for the North Carolina luminaire supports and the Illinois light standards are very similar (0.094 vs. 0.110).

Table 13. Details of serious injury and cost-related severity indices for luminaire impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Luminaire Poles & Traffic Signal (IL)	Breakaway & Non-breakaway	0.094	(0.078, 0.110)	1,260	1. Object = traffic signal	0.059	(0.051, 0.067)	3,347
					2. Object = light standard	0.110	(0.100, 0.120)	3,862
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Luminaire Poles & Traffic Signal (IL)	Breakaway & Non-breakaway	47.43	(33.93, 60.93)	1,260	1. Intersection/ interchange	20.05	(18.73, 25.37)	4,653
					2. Mainline	46.92	(38.52, 55.32)	2,646

The cost indices for the two states' data look somewhat different. However, this probably reflects the fact that lower severity traffic signals are combined with a slightly higher severity light standard in the Illinois data.

Highway Signs

In both states, this class of object includes official roadway signs, but does not include commercial signs, which are discussed in the next section. With respect to the serious injury-based severity indices, as shown in Table 14, the North Carolina data were subdivided by the CART methodology into Interstate interchanges, Interstate mainline (rural and urban) and non-Interstate roadways. The Illinois data were simply divided into urban and rural locations.

It must first be noted that the overwhelming majority of signs in the North Carolina sample are on non-Interstate roadways. There are very small samples of signs in the three Interstate categories, meaning that the severity indices calculated there must be viewed with less certainty than if the samples were larger. Given that, of interest is the fact that the serious injury SI for the non-Interstate roadways is not as great as for the Interstate mainline rural locations. This is somewhat surprising in that one would expect there to be more breakaway signs on the Interstate roadways than on non-Interstate roadways and, thus, perhaps a lower SI. However, the overall impact speeds may differ between the two categories.

The Illinois serious injury severity indices are somewhat consistent with the North Carolina indices in that they fall within the same range of values. Indeed, the North Carolina combined SI for non-Interstate roadways falls between urban and rural values in the Illinois data.

The cost-based SI's for the two states follow similar patterns. The Illinois cost SI (21.68) is somewhat lower than the corresponding value for North Carolina.

Table 14. Details of serious injury and cost-related severity indices for highway sign impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Highway Signs	1. Interstate, Intersection/ interchange	0.041	(0.019, 0.063)	314	1. Rural	0.074	(0.063, 0.085)	2,181
					2. Urban	0.035	(0.029, 0.041)	4,052
	2. Interstate, Mainline, Urban	0.048	(0.010, 0.086)	124				
	3. Interstate, Mainline, Rural/mixed	0.126	(0.090, 0.162)	334				
	4. Not Interstate	0.050	(0.046, 0.054)	9,793				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Highway Signs	No splits	28.17	(26.78, 31.56)	10,565	No splits	21.68	(17.93, 25.43)	6,233

Commercial Signs

Both North Carolina and Illinois have a category of fixed object that includes non-official, commercial signs. As is noted in Table 15, the North Carolina sample size is significantly larger than the Illinois sample size, but the values found for the SI's are fairly consistent between the two states. The North Carolina average-cost SI is higher than the Illinois average-cost SI.

Table 15. Details of serious injury and cost-related severity indices for commercial sign impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Commer. Signs	No splits	0.115	(0.099, 0.131)	1,552	No splits	0.090	(0.057, 0.123)	289
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Commer. Signs	No splits	52.17	(39.78, 64.56)	1,552	No splits	39.35	(14.02, 64.68)	289

<u>Traffic Islands</u>

Both states have categories of curbs and traffic islands that were combined into one group of objects. As can be seen from the table, the only categorization of the data by the CART methodology was to separate cars/station wagons from pickups/vans in the severe injury index for Illinois. The North Carolina severe injury SI falls between the two proportions for the Illinois data, but is somewhat closer to the pickup/van group than it is for the car/station wagon. Since this would not be expected given that the majority of North Carolina impacts would, in all likelihood, involve cars and station wagons, it is an indication that the North Carolina SI is probably slightly higher than that for Illinois. This is supported by the results of the cost-based SI's, where the North Carolina index is over three times that of Illinois.

Table 16. Details of serious injury and cost-related severity indices for impacts with traffic islands.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Traffic Islands/ Curbs	No splits	0.081	(0.074, 0.088)	5,775	1. Cars & s.w. 2. Pickups & vans	0.026 0.088	(0.019, 0.033) (0.047, 0.129)	2,148 181
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Traffic Islands/ Curbs	No splits	41.72	(35.82, 47.62)	5,775	No splits	12.13	(8.80, 15.46)	2,329

Catch Basin/Culvert Headwall

Here, there is somewhat of a difference in the composition of the groups that are shown in the table. In North Carolina, police code either "catch basin or culvert on shoulder" or "catch basin or culvert in median." In Illinois, the coding only includes "culvert headwall." Presumably, catch basins in Illinois would fall into the "other object" category. Culvert headwalls would, in general, be expected to result in somewhat more severe injury than catch basins, particularly if the catch basin is covered. Thus, it is of little surprise that the severity index from the Illinois data is significantly higher than that for North Carolina, both in terms of serious driver injury and average cost.

Table 17. Details of serious injury and cost-related severity indices for impacts with catch basins and culverts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Catch Basins (IL has Culvert Headwall)	1. < 88.5 km/h 2. ≥ 88.5 km/h	0.128 0.176	(0.118, 0.138) (0.168, 0.184)	4,649 9,103	No splits	0.258	(0.171, 0.345)	97
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Catch Basins (IL has Culvert Headwall)	No splits	83.98	(78.27, 89.69)	13,752	No splits	156.26	(53.93, 258.59)	97

The North Carolina data are broken down for highways with speed limits of < 88.5 km/h and ≥ 88.5 km/h. Its two values of 0.128 and 0.176, respectively, are approximately one-half to two-thirds the value of the Illinois SI (0.258) where no split occurs. In like fashion, the average-cost data are not subdivided in either state. Here, the SI for Illinois is almost twice the North Carolina figure. Thus, it would appear that the Illinois data are indeed more related to culvert headwalls, while the North Carolina data are some combination of culverts and catch basins. This is further underlined by the fact that the Illinois sample size is quite small, while the North Carolina sample sizes are very large.

Construction Barriers

This category contains "construction barrier" in North Carolina, and "barricade" in Illinois. As can be seen, both the severity indices for North Carolina are over twice the index for Illinois.

This could be due to differences in the objects included. Literally taken, the "construction barrier" in NC could include both concrete barriers and barricades. In Illinois, one would expect that the latter are more likely to be included, while construction barriers might be coded under "concrete

Table 18. Details of serious injury and cost-related severity indices for construction barrier impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Construct. Barricade	No splits	0.076	(0.051, 0.101)	435	No splits	0.033	(0.022, 0.044)	1,003
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Construct. Barricade	No splits	29.00	(16.62, 41.38)	435	No splits	10.82	(8.81, 12.83)	1,003

median barrier." Indeed, the North Carolina indices are similar to those noted earlier for shoulder and median barriers (0.074 and 33.39, respectively).

Impact Attenuators

Table 19 presents the data for "crash cushions" in North Carolina and "impact attenuators" in Illinois. In North Carolina, the data for serious injury proportion are split by urban (with mixed) and rural locations, and the SI for the latter is almost nine times the former. Note, however, that the sample sizes are very small and, thus, that the confidence intervals are quite large. The Illinois SI for serious injury is very close to the rural value for North Carolina, a somewhat surprising finding in that Illinois may be more urbanized. Indeed, the cost value for Illinois is approximately 45 percent higher. As noted earlier, there are fairly significant differences in the types of attenuators in the two states. The North Carolina attenuators are more likely to be temporary installations of the GREAT system in construction zones. The Illinois attenuators are more likely to be a permanent sand-barrel system, with a smaller number of GREAT and Hi-dri Cell systems in construction zones.

Table 19. Details of serious injury and cost-related severity indices for impacts with impact attenuators.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Impact Attenuat.	1. Mixed/urban	0.016	(0.000, 0.047)	64	No splits	0.135	(0.071, 0.199)	111
	2. Rural	0.143	(0.027, 0.259)	35				
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Impact Attenuat.	No splits	22.06	(13.68, 30.44)	99	No splits	31.87	(20.80, 42.94)	111

Fences—Median and Other

As can be seen from Table 20, there is no code for fences in the North Carolina accident file. For Illinois, the group contains both "median fences" and "other fences." While the CART methodology did not split the two types of fences from each other, it is clear from single-variable tabulations not shown in this report that the overwhelming majority of fences included are not median fences, but fences alongside the roadway. Clearly, this could include a wide variety of designs since fencing is not a standard highway roadside object.

Table 20. Details of serious injury and cost-related severity indices for fence impacts.

	North Carolina				Illinois			
Fixed Object	Node Description	Prop	95% C.I.	N	Node Description	Prop	95% C.I.	N
Median & Other Fences					No splits	0.070	(0.062, 0.078)	4,099
		Avg. Cost	95% C.I.	N		Avg. Cost	95% C.I.	N
Median & Other Fences					No splits	27.50	(22.84, 32.16)	4,099

Based on a large sample of such impacts, the average severity index based on serious injury is somewhat similar to that found for guardrails, median barriers, and bridge rail faces. The cost value is very close to what was found earlier for concrete barriers in Illinois (i.e., 31.01).

Comparison of Serious Injury and Cost SI's

The preceding sections presented results based on both a serious injury-based severity index and a cost-based severity index. The focus of those sections was the actual value of the developed indices. A methodological question of interest is how these two SI's compare in terms of providing information to the user. They are clearly different in terms of the actual value of the index and the range, but the question of interest is whether or not they provide better, or at least different, information.

In examining this issue, we looked at three questions. The first question involved which of the two indices better reflected "intuition," based on the more urban character of Illinois. The second involved whether or not the use of the two different severity indices would result in different ranks of hazardousness. The third question concerns whether one of the two severity indices provides more detailed, useful information than does the other.

First, as noted in many of the individual discussions, both the serious injury and cost indices were fairly consistent between the states. As was discussed in an earlier section, given the more urban nature of Illinois, one might have expected the overall Illinois values to be slightly lower (if location is not controlled for). As is noted in Table 21 below, which provides overall indices for the 13 objects common to both states, this is the case for cost-based SI's, but does not appear to be the case for the proportions of serious injury. In the latter case, the Illinois proportions are actually higher in 7 of the 13 cases. Some of these higher proportions may be the result of differences in the nature of the object (e.g., turn-down guardrail ends and sand-barrel attenuators in Illinois versus BCT's and GREAT systems in North Carolina). However, there is little obvious reason why objects such as trees and utility poles should have produced slightly higher proportions in the Illinois data. In contrast, the Illinois cost-based indices are lower in all but four cases — utility poles, trees, culverts and attenuators. In the first two, the difference is only slight. In the third and fourth, culverts and attenuators, there may be basic differences in the objects being struck in the two states as discussed above. However, in general, the cost-based SI's seem to more closely reflect "intuition."

With the respect to the second issue, ranking of hazardousness, Table 21 also shows the ranking for the 13 categories that are common to North Carolina and Illinois. In this ranking, the fixed object with the lowest value has been assigned rank number "1." Thus, rank "1" denotes the least hazardous fixed object and rank "13" the most hazardous. A rank is provided for the serious injury-based SI and for the cost-based SI within each state. In this case, highway signs were ranked as the least hazardous fixed object based on proportion of injury in North Carolina, while impact attenuators were ranked least hazardous based on cost. What is of primary interest in this analysis is the comparison of the two sets of rankings within each state.

Here, examining the second and fourth columns in the North Carolina section of the table, one notes that the driver injury and cost-based ranking are different, but are fairly consistent between objects. That is to say, in general, the ranking for each of the fixed objects are within one or two of each other when ranked by either of the methods.

Table 21. Comparison of rankings based on serious injury and cost-based SI's (North Carolina and Illinois data).

Fixed Object	North Carolina				Illinois			
	Prop.	Relative Rank	Avg. Cost	Relative Rank	Prop.	Relative Rank	Avg. Cost	Relative Rank
Guardrail	0.088	6	47.52	7	0.101	6	41.00	8
Median/Shoulder Barrier	0.074	3	33.39	4	0.098	5	31.01	4
Bridge Rail (with Bridge Guardrail in Illinois)	0.144	10	90.80	11	0.113	8	52.35	9
Underpass (Pier/ Abutment)	0.296	13	252.90	13	0.188	11	124.85	12
Utility Poles	0.129	9	53.43	9	0.153	10	63.19	10
Trees	0.176	12	93.99	12	0.192	12	102.52	11
Luminaire Poles/ Light Standard	0.094	7	47.43	6	0.110	7	31.07	5
Highway Signs	0.052	1	28.17	3	0.048	3	21.68	3
Commerc. Signs	0.115	8	52.17	8	0.090	4	39.35	7
Traffic Islands	0.081	5	41.72	5	0.029	1	12.13	2
Catch Basins/ Culverts	0.160	11	83.98	10	0.258	13	156.26	13
Construction Barricade/Barrier	0.076	4	29.00	2	0.033	2	10.82	1
Impact Attenuator	0.065	2	20.06	1	0.135	9	31.87	6

The results of comparisons of ranking were somewhat different in the Illinois data. Again, like North Carolina, the lowest ranked fixed object differs between the two severity indices, with traffic islands being lowest in a proportional measure and construction barricades being lowest based on the cost. In general, the rankings are again somewhat consistent between the two categories. However, unlike North Carolina, there is a fairly major difference in rankings for impact attenuators and commercial signs, depending on which of the two severity indices is used.

While commercial signs have a lower relative severity index based on proportion of injury and a slightly higher rank based on cost, the reverse is true for impact attenuators. More specifically, while the attenuator is ranked sixth least hazardous on the cost scale, it is ranked ninth least hazardous (and thus, fifth most hazardous) on the serious injury scale. Thus, even though this cost-based ranking is more in line with the two rankings for attenuators in North Carolina (i.e., rank "1" in North Carolina based on cost), it still differs significantly. Again, part of the difference may be the result of the nature of the attenuators in the two states (i.e., sand-barrel systems in Illinois versus GREAT systems in North Carolina). However, even given this possible partial explanation, it would appear that the cost-based index, which takes into account the full injury distribution for attenuators, results in a slightly more "correct" indication of hazardousness.

Let us turn now to the third question,which is related to the amount and quality of the information provided by the two types of indices. Given the differences in sizes and ranges for the two indices, it is difficult to conduct a direct visual comparison of the two. To facilitate this comparison, Table 22 presents a "relative index" for each of the two SI's within each state. The relative index was calculated by taking the fixed object with the lowest proportion of driver injury (or the lowest cost) and assigning it a value of 1.00. Indices for other objects were then calculated by dividing their proportion (or cost) by the lowest proportion or cost, respectively. Thus, the relative index for guardrails, shown in the first row of the table, indicates guardrails to be 1.69 times as hazardous as highway signs, based on the proportion of serious injury, and 2.37 times as hazardous as impact attenuators, based on cost. Again, the basic comparison here is between the two relative indices within a given state.

First, note that the ranges of relative indices for serious injury and cost differ. In North Carolina, the highest index, based on serious driver injury, is 5.69 times the lowest index. It is 12.61 times the lowest index, based on cost. In Illinois, the highest index is 8.9 times the lowest index, based on driver injury, and 14.44 times the lowest, based on cost. Thus, the cost-based indices provide a wider range of values and, thus, to some extent, a greater degree of differentiation between objects.

Now, given the wider range, it is interesting to compare the two relative indices to each other within the same state. This information is also plotted in Figures 2 and 3. In these figures, the left-most end of the line shown for a given object represents the lesser of the two indices, while the right-most end represents the relative index, which is larger. Each end of the line is coded as either an "s" (i.e., severe injury index) or a "c" (i.e., cost index). Of importance in the table and the figures are both the spread between the indices (i.e., the length of the line) and the patterns related to which index is less or greater.

In general (as perhaps would be expected based on the ranges), the injury-based indices for a given object are virtually the same as, or generally lower than, the relative indices based on cost. Indeed, in some cases, the serious injury indices are only approximately half as great as cost-based

Table 22. Comparison of relative values of serious injury and cost-based SI's (North Carolina and Illinois data).

Fixed Object	North Carolina				Illinois			
	Prop.	Relative Index	Avg. Cost	Relative Index	Prop.	Relative Index	Avg. Cost	Relative Index
Guardrail	0.088	1.69	47.52	2.37	0.101	3.48	41.00	3.79
Guardrail Face	0.072	1.38	39.11	1.95				
Guardrail End	0.142	2.73	76.18	3.80				
Med/Shld. Barrier	0.074	1.42	33.39	1.66	0.098	3.38	31.01	2.87
Bridge Rail (with Bridge Guardrail in Illinois)	0.144	2.77	90.80	4.53	0.113	3.90	52.35	4.84
Bridge Rail Face	0.075	1.44	41.34	2.06				
Bridge Rail Ends	0.226	4.35	151.54	7.55				
Underpass (Pier/ Abutment)	0.296	5.69	252.90	12.61	0.188	6.48	124.85	11.54
Utility Poles	0.129	2.48	53.43	2.66	0.153	5.28	63.19	5.84
Trees	0.176	3.38	93.99	4.69	0.192	6.62	102.52	9.48
Luminaire Poles/ Light Standard	0.094	1.81	47.43	2.36	0.110	3.79	31.07	2.87
Traf. Signal Pole					0.059	2.03	19.78	1.83
Highway Signs	0.052	1.00	28.17	1.40	0.048	1.66	21.68	2.00
Commerc. Signs	0.115	2.21	52.17	2.60	0.090	3.10	39.35	3.64
Traffic Islands	0.081	1.56	41.72	2.08	0.029	1.00	12.13	1.12
Catch Basins/ Culvert	0.160	3.08	83.98	4.19	0.258	8.90	156.26	14.44
Med/other Fences					0.070	2.41	27.50	2.54
Construction Barricade/Barrier	0.076	1.46	29.00	1.45	0.033	1.14	10.82	1.00
Impact Attenuator	0.065	1.25	20.06	1.00	0.135	4.66	31.87	2.95

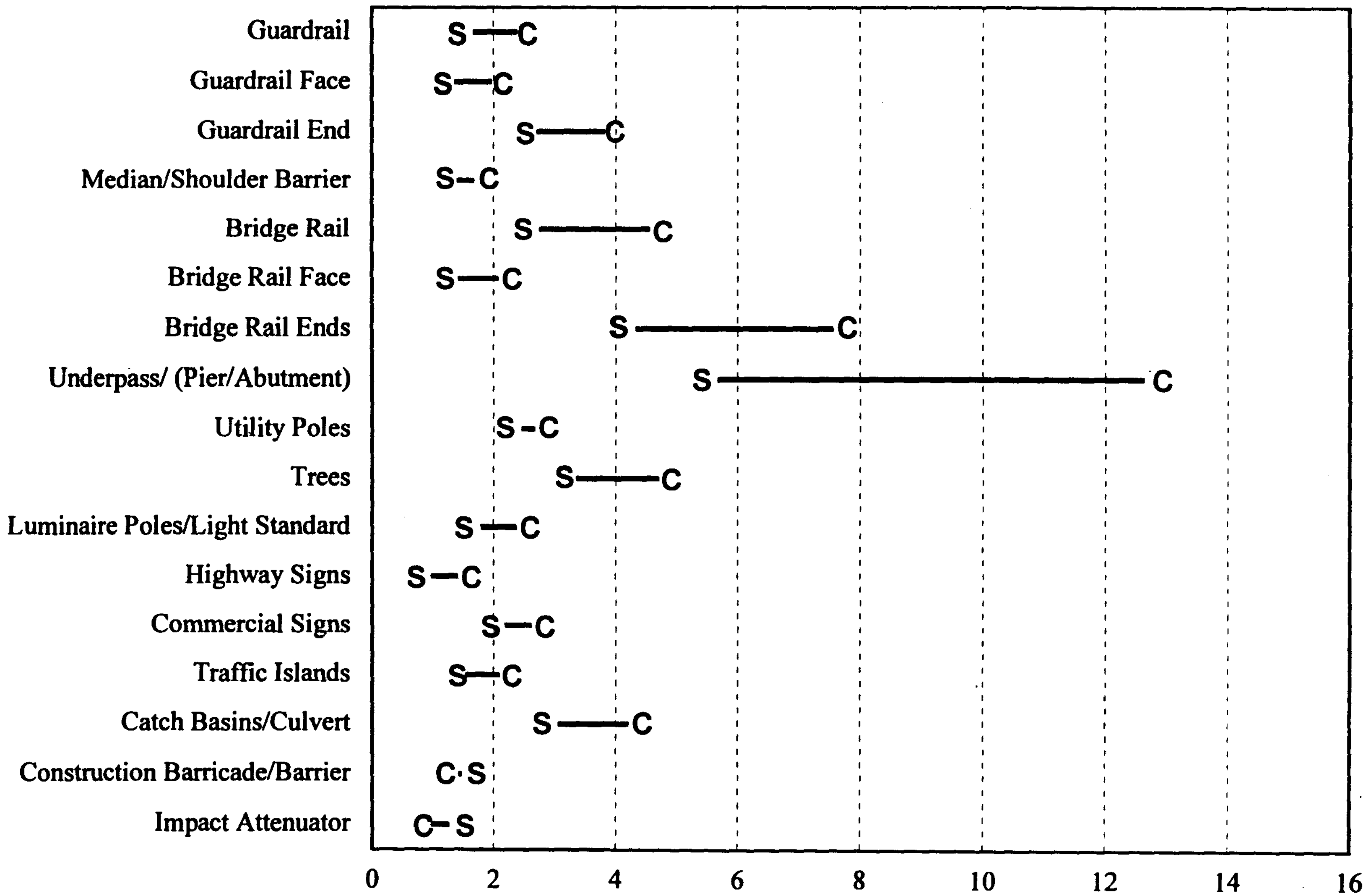

Figure 2. Comparison of relative indices for SI's based on severe injury ("s") and cost ("c") – NC data.

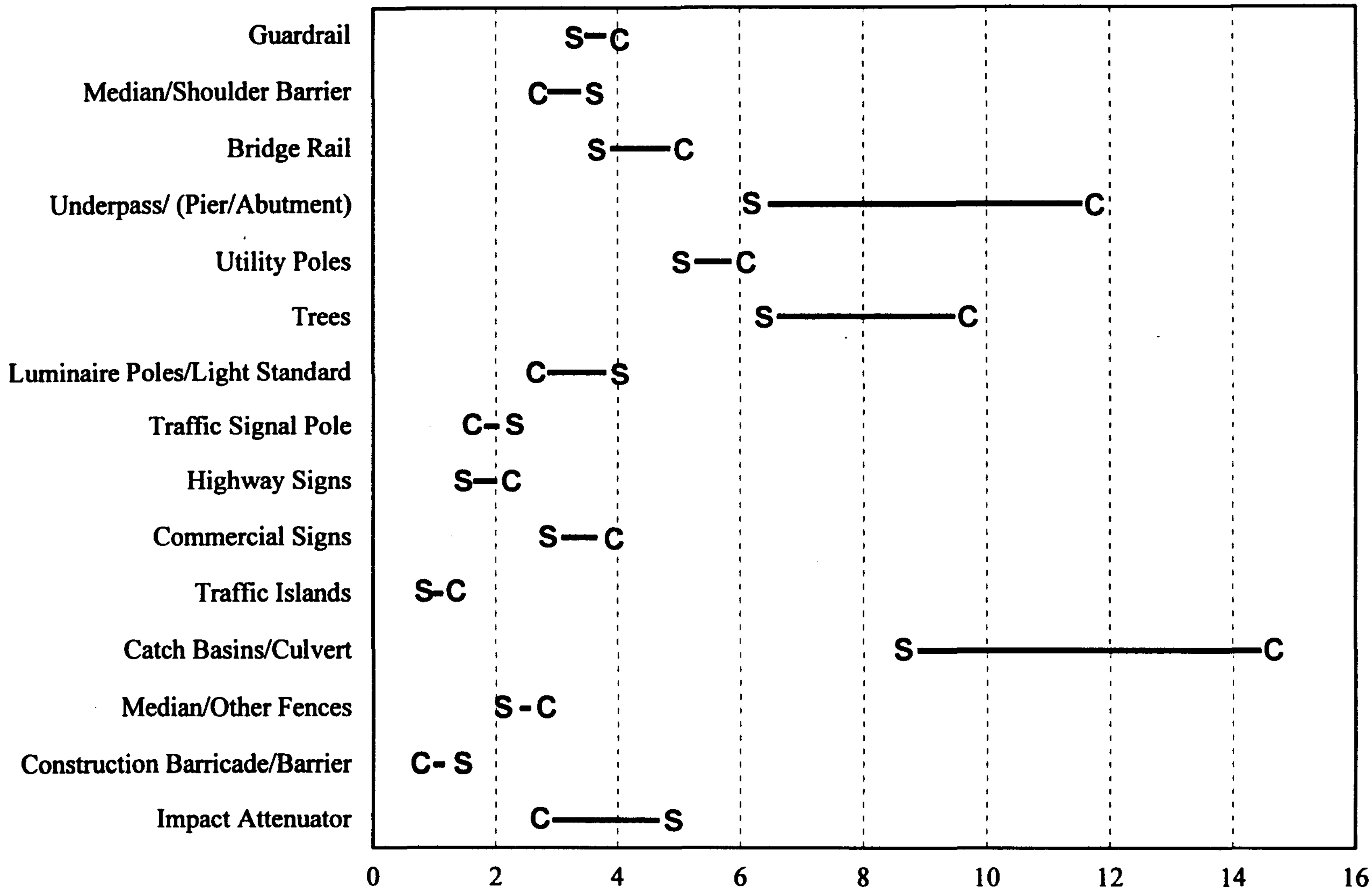

Figure 3. Comparison of relative indices for SI's based on severe injury ("s") and cost ("c") – Illinois data.

indices. The major exception to this trend is again found in the Illinois indices for impact attenuators, where the cost-based index is much lower than the index based on proportion of injury.

Finally, it must also be noted that cost-based measures are somewhat more sensitive to small samples than the proportion-based measure. Since the assigned fatality cost is 15 to 30 times as high as the cost of a serious injury, a major determinant of the average cost for impacts into a fixed object is the number, and thus proportion, of fatalities in the sample under investigation. Given that fatalities would only be expected in 1 to 3 percent of the fixed-object impacts, the larger the sample being used in the calculation of the severity index, the more stable the proportion of fatalities, and thus, the more stable the cost estimate. In smaller samples of, say, 100 impacts, where only one or two fatalities would be expected, in reality, there is a greater chance of the sample (randomly) containing either more or less fatalities than should be the case. A severity index based on cost is more sensitive to this phenomenon than an index based on the proportion of serious plus fatal injuries, since the number of serious injuries will always be substantially larger than the number of fatalities, thus overcoming the effect of an erroneously low or high number of fatalities to some extent. In short, cost estimates should be viewed with more skepticism for small samples.

In summary, it is very difficult to say whether one of the two index methods is better than the other, particularly given that we're only comparing a relatively small set of fixed objects in only two states. What is apparent is that the cost-based figures do indeed provide a wider range of values for indices, they seem to follow "intuition" somewhat better with respect to urban/rural character of the two states, and, at least for Illinois, they appear to provide what might be considered a "more accurate" index of relative hazardousness for impact attenuators. However, when small samples are being compared, it would appear that the severe injury index is superior in that it is less sensitive to random fluctuations of fatalities in these small samples.

Comparison with Texas Data

As noted earlier, one of the more comprehensive efforts aimed at severity indices was conducted in the mid-1980's by Mak, et al. (10). The work of those authors is paralleled by much of the work in the current effort. The major differences in the two studies are that: (1) the severity indices developed with state data in the earlier report were not based on any sequence of events or "most harmful event" variable, and (2) the current effort is based on more recent crash data. Mak used a methodology in which 37 severity indices were developed for each major fixed object, with the 37 categories defined by control variables related to highway type, vehicle type, urban/rural location, and point of impact.

For comparison purposes, Table 23 shows the severity indices based on the proportion of serious and fatal driver injury for all three states, along with the 95 percent confidence intervals

Table 23. Proportions of serious and fatal injury in fixed-object impacts for North Carolina, Illinois, and Texas data.

Fixed Object	North Carolina		Illinois		Texas	
	Prop.	95% C.I.	Prop.	95% C.I.	Prop.	95% C.I.*
Guardrail	0.088	(0.083, 0.093)	0.101	(0.096, 0.106)	0.103	(0.098, 0.108)
Guardrail Face	0.072	(0.067, 0.077)				
Guardrail End	0.142	(0.129, 0.155)				
Med/Shld. Barrier	0.074	(0.063, 0.085)	0.098	(0.085, 0.111)	0.094	(0.081, 0.107)
Bridge Rail (with Bridge Guardrail in Illinois)	0.144	(0.137, 0.151)	0.113	(0.101, 0.125)		
Bridge Rail Face	0.075	(0.068, 0.083)			0.112	(0.106, 0.118)
Bridge Rail Ends	0.226	(0.213, 0.239)			0.264	(0.242, 0.286)
Underpass (Pier/ Abutment)	0.296	(0.267, 0.325)	0.188	(0.162, 0.214)	0.254	(0.231, 0.277)
Utility Poles	0.129	(0.126, 0.132)	0.153	(0.145, 0.161)	0.100	(0.093, 0.107)
Trees	0.176	(0.173, 0.179)	0.192	(0.183, 0.201)	0.214	(0.206, 0.222)
Luminaire Poles/ Light Standard	0.094	(0.078, 0.110)	0.110	(0.100, 0.120)	0.070	(0.063, 0.077)
Traf. Signal Pole			0.059	(0.051, 0.067)	0.063	(0.052, 0.074)
Highway Signs	0.052	(0.048, 0.056)	0.048	(0.043, 0.053)	0.068	(0.063, 0.073)
Commerc. Signs	0.115	(0.099, 0.131)	0.090	(0.057, 0.123)		
Traffic Islands (Curb in Texas)	0.081	(0.074, 0.088)	0.029	(0.022, 0.036)	0.123	(0.112, 0.134)
Catch Basins/ Culvert	0.160	(0.154, 0.166)	0.258	(0.171, 0.345)	0.224	(0.214, 0.234)
Med/other Fences			0.070	(0.062, 0.078)		
Construction Barricade/Barrier	0.076	(0.051, 0.101)	0.033	(0.022, 0.044)		
Impact Attenuator	0.065	(0.018, 0.112)	0.135	(0.071, 0.199)	0.084	(0.062, 0.106)

*Note that 95% Confidence Intervals for the Texas SI's are approximate in that they were scaled from a figure in the TTI report.

for the estimates. (It should be noted that the confidence intervals shown for the Texas data are approximate in that they had to be extracted from a figure in that report.) Figures 4, 5, and 6 plot the same information graphically. As can be seen, there are some object categories that are common to all three states and some that are not. For example, we were not able to break down the Illinois data into bridge rail ends and bridge rail faces, and North Carolina does not have a category for traffic signal supports. While the indices appear fairly consistent across the three states, there are some notable differences across the three states.

Within the upper part of the table that refers to different types of barriers, there is a fair amount of consistency among the readings. In Texas, the bridge rail face and bridge rail end impacts appear to be slightly more severe than is the case in North Carolina. The underpass structure impacts in Illinois are also less severe than in North Carolina or Texas. With respect to the point objects found in the center part of the table, the proportions of serious injury for utility poles are slightly higher in North Carolina and Illinois than in Texas, while the tree impacts produce slightly lower serious injury proportions. Luminaire supports/light standard impacts are fairly consistent across the three states, with Texas indices being slightly lower.

The major differences among the three states are found in the lower part of the table. First, the indices for the traffic island/curb category do differ across the states. In Illinois, this category concerns primary traffic islands. In North Carolina, it concerns traffic islands, curbs, or raised medians. In Texas, the category only refers to curbs. Thus, differences in the definitions could lead to some of the differences seen. However, it is not clear why the Illinois index would be only approximately one-fourth of the North Carolina level and one-sixth of the Texas level. This difference could result from the fact that Illinois is the only state in which the sequence of events allows us to limit the impact to traffic islands only, without subsequent impacts into other objects. This is partially the case in North Carolina where we used the most harmful event as judged by the officer, but was not clearly the case in Texas. Since the data were not restricted to a sequence or most harmful event in Texas, there could have been another object impacted after the curb was struck. Indeed, one would expect there to be subsequent impacts in some curb-related cases given the fact that curbs often are in front of bridge rails, utility poles, or other more substantial objects.

As noted earlier, there also appear to be some differences in the severity indices for the catch basins/culverts group. As discussed earlier, the differences between North Carolina and Illinois, and perhaps Texas, could well result from the fact that most of these impacts in the latter two states were with culverts or culvert headwalls, while a large number of impacts in North Carolina might possibly be with the less hazardous catch basins.

Finally, there is the continuing question concerning why there is almost a twofold increase in the Illinois severity index for impact attenuators over what is seen in North Carolina and Texas. It is noted that the sample sizes for these devices are fairly small in all three states, possibly leading to some "random" differences. It is also the case that the nature of the attenuator is different in North Carolina (i.e., primarily the GREAT system in construction zones) and Illinois

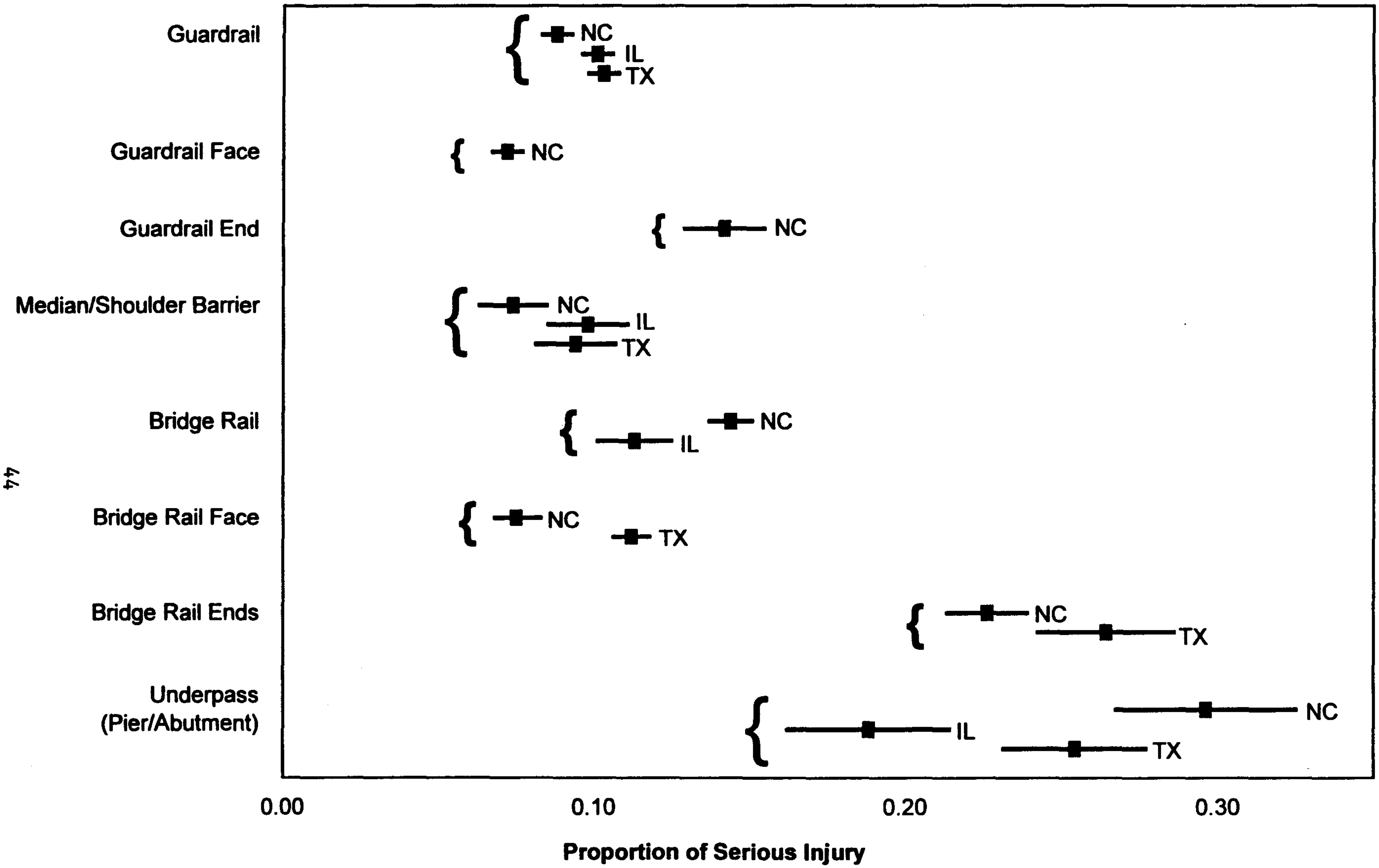

Figure 4. Proportions (and 95 percent confidence intervals) for barrier-type objects (NC, IL, and TX data).

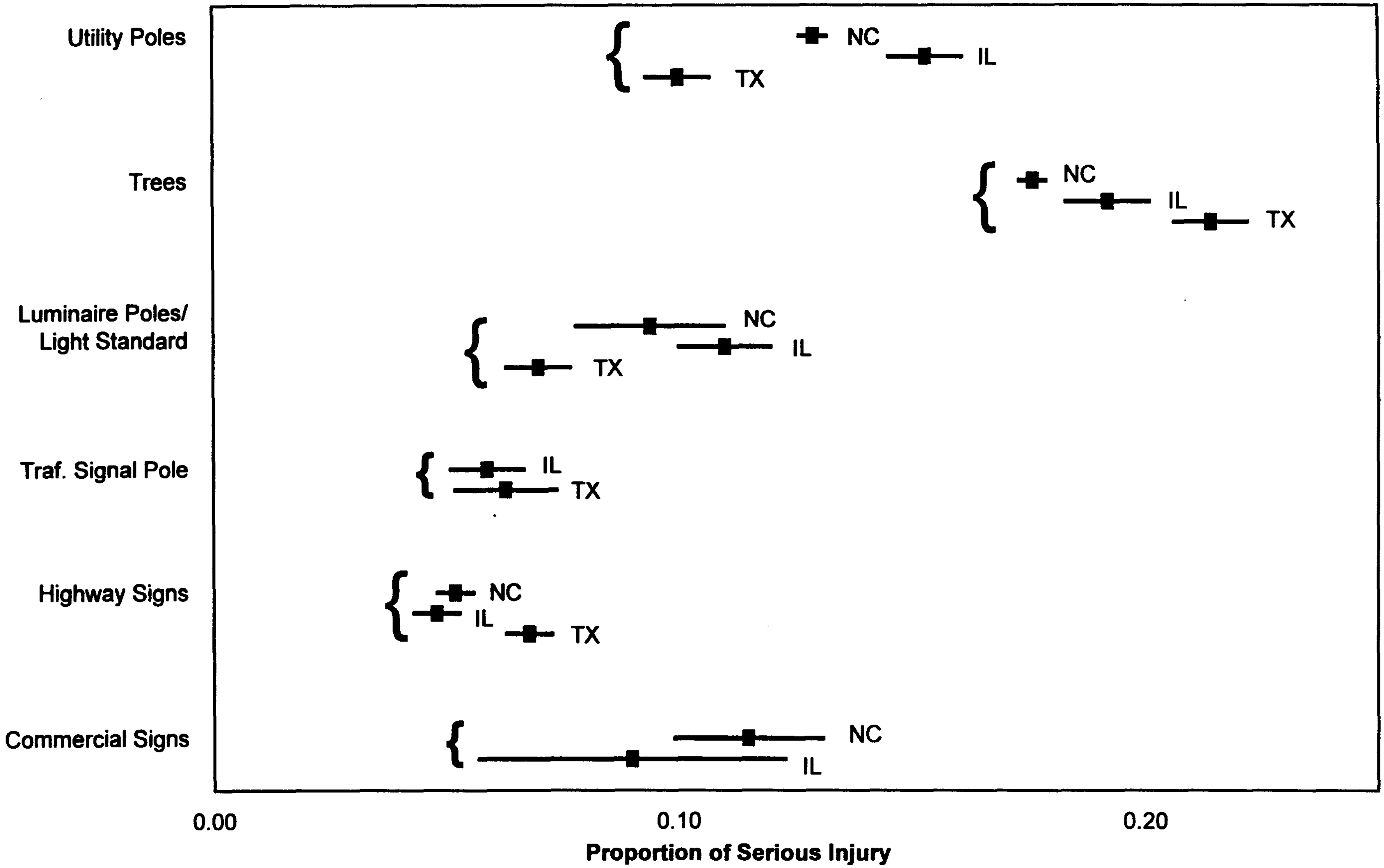

Figure 5. Proportions (and 95 percent confidence intervals) for point-type objects (NC, IL, and TX data).

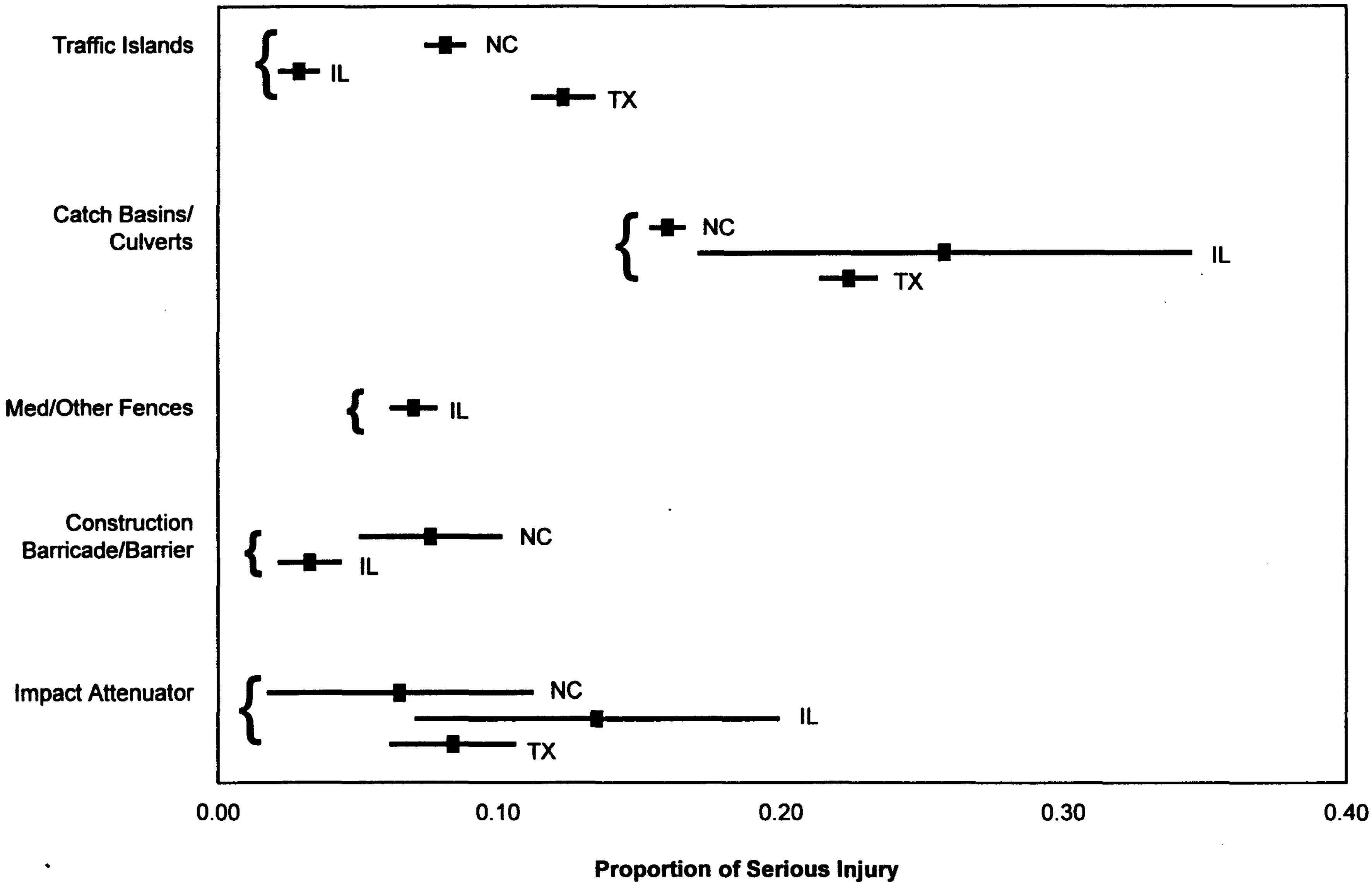

Figure 6. Proportions (and 95 percent confidence intervals) for other objects (NC, IL, and TX data).

(primarily "permanent" sand-barrel systems). Unfortunately, the Texas report did not include information on the basic nature of the attenuator.

These consistencies and inconsistencies are further noted in Table 24, which provides a ranking of the serious injury-based SI's for the 10 objects that are common to all three states. One can again note that the major differences are the higher (more severe) ranking for impact attenuators in Illinois and the lower ranking for traffic islands in Illinois.

Table 24. Ranking of common fixed-object SI's for North Carolina, Illinois, and Texas data.

Fixed Object	Rank		
	NC	IL	TX
Highway Signs	1	2	1
Impact Attenuator	2	6	3
Median/Shoulder Barrier	3	3	4
Traffic Islands (Curb in Texas)	4	1	7
Guardrail	5	4	6
Luminaire Poles/ Light Standard	6	5	2
Utility Poles	7	7	5
Catch Basins/ Culvert	8	10	9
Trees	9	9	8
Underpass (Pier/ Abutment)	10	8	10

In general, while there are the differences noted, there is some degree of consistency across these three states even though some slightly different methodologies and time periods were used in defining severity indices. This is very encouraging in that the consistency across these states lends additional support to the use of the calculated indices for other states.

Airbag-Related Severity Indices

As noted in the earlier methodology section, one of the goals of this analysis was to attempt to develop severity indices for vehicles that are equipped with airbags. Since the entire vehicle fleet is moving toward airbag-equipped cars, it is clear that future severity indices should be based on such a fleet.

Because there were not enough decodeable vehicle identification numbers (VIN's) in the Illinois data, the data that were available for the airbag analysis were all from the North Carolina accident files. Here, airbag-equipped vehicles (which were all involved in accidents in the post-1986 era) were identified through decoding the VIN's in the file, and an attempt was made to develop severity indices based on the proportion of serious and fatal driver injury for all of the fixed objects seen in the preceding sections. As would be expected, sample sizes for most of the fixed objects were so small that meaningful indices could not be developed.

However, as shown in Table 25 below, there were at least somewhat sizable samples of airbag-related fixed-object impacts for guardrails, trees, and utility poles. Fortunately, this provides at least some information on one barrier-type object and two point objects. The CART methodology was used to attempt to find significant splits in the samples, but none was found. This could be because of the small sample sizes available, but also it could be because there are less differences in serious injury severity across crash situations when airbags are present. Additional data will need to be collected to resolve this question.

Table 25. Severity indices for passenger cars/station wagons equipped with airbags (North Carolina data).

Fixed Object	Node Desc.	Airbag Prop	95% C.I.	N	Non-Airbag Prop.	95% C.I.	N	% Decrease
Guardrails (Ends and faces)	No splits	0.023	(0.000, 0.058)	87	0.088	(0.083, 0.093.)	12,131	73.9
Trees	No splits	0.113	(0.077, 0.149)	292	0.176	(0.173, 0.179)	62,772	35.8
Utility Poles	No splits	0.075	(0.036, 0.114)	173	0.129	(0.126, 0.132)	44,894	41.9

First, as expected (and as shown in Figure 7), the airbag-related proportion of severe and fatal injury that is shown in the third column of the table is consistently lower than the corresponding non-airbag proportion shown in the sixth column of the table. Since there is no

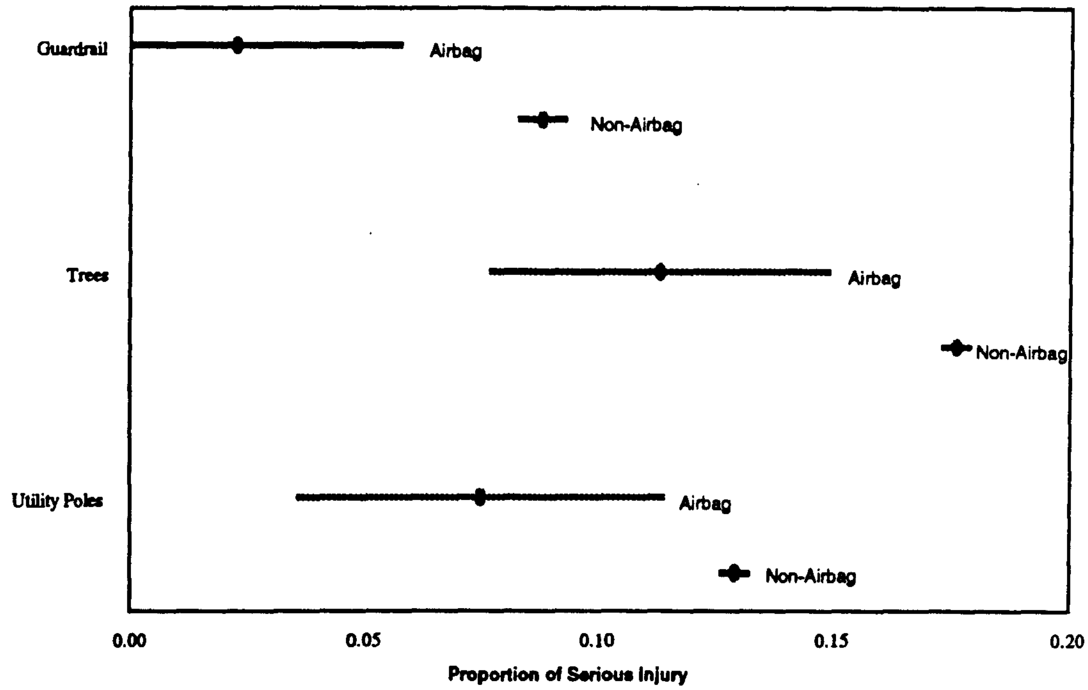

Figure 7. Severity indices (and 95 percent confidence intervals) for airbag and non-airbag passenger cars/station wagons (NC data).

apparent reason to assume that the guardrails, trees, or utility poles struck by cars equipped with airbags would be necessarily different from those struck by cars not equipped with airbags, the difference seen is, in all likelihood, related to the protective effects of the airbags themselves.

The final column of the table presents the percent decrease in the proportion of serious and fatal driver injury shown by the cars equipped with airbags. As is seen, the severity index for guardrails shows the greatest decrease, with the airbag index being approximately 74 percent lower than the corresponding non-airbag index. The percent decrease for the two classes of point objects — trees and utility poles — is less than for the guardrails. However, the airbag severity indices are still 36 and 42 percent less than the corresponding indices for the vehicles not equipped with airbags. Unfortunately, the reason for the difference in the decreases between guardrails and trees and utility poles cannot be determined from the data. For example, it would be of interest to determine what the decrease would be for guardrail ends vs. faces, and for guardrails, trees, and utility poles in urban versus rural areas where speed limits, and thus crash speeds, would be expected to be different. The size of the data samples does not allow us to look at these cases.

What is clear here is that there is indeed a difference in the proportion of drivers who are seriously injured in the cars equipped with airbags vs. the cars not equipped with airbags. Clearly, severity indices developed for the future fleet of vehicles will be lower than the current values shown in either this current work or any other past research. The question that remains is whether or not the shift to airbags will lead to consistent decreases across all objects or, as these data indicate, to differential effects between classes of objects.

If one were to take the values in the above table as being accurate (even though they are known to be based on very small samples of the data), then one might assume that these severity indices shown in the preceding tables for barrier-type objects might be expected to have future severity indices lower that are by a fairly sizable proportion — a 50-75 percent decrease. On the other hand, impacts with point objects might be expected to see a 30-50 percent savings in the severity index values. Clearly, additional research is needed to better determine what the SI's for the future fleet will be. However, even this preliminary data does provide some insight into what the field may be looking at in the future, and, indeed, it looks very positive.

Effects of Unreported Crashes

As noted in earlier discussion, a bias that is inherently present in the results cited in this study is the bias resulting from unreported accidents. Because all of these analyses were based on police accident reports, we are, by definition, missing accidents that are not investigated by police. Many of these accidents would be property-damage-only crashes in which the vehicle is driven from the scene rather than calling (or waiting) for a police investigation. For the analyses involving the proportion of serious and fatal driver injury, this underreporting would result in higher SI's than would actually be the case, since the proportion of serious and fatal injuries would be inflated by the loss in PDO and, thus, total cases. The same overestimate would be true for the cost-based SI, since this measure is again based on proportions of injury within each level. With lower numbers of PDO crashes in the data set, the proportions of the higher cost severe injuries would be inflated.

Thus, to reduce this bias, one would search for a data set that captures as many crashes within each injury level as possible, or one that at least captures an equal proportion of crashes within each injury level. Since virtually all fatalities and almost all serious injury crashes are reported in most police files, this appears to translate into needing to capture virtually all of the minor injury and PDO crashes.

However, the problem is slightly more complex than this. If, as Glennon (3) hypothesizes, SI's are to be used only in relative comparisons of different objects, then a problem only arises if underreporting differs by object. That is, to say, if all objects were characterized by the same degree of underreporting of PDO crashes, then while the developed SI's would be erroneous in the absolute sense (in that the proportion of serious and fatal injuries and the cost would be inflated), they would remain accurate in relative comparisons since the degree of inflation would be equal across objects.

Let us look at these two issues of overall underreporting and differential underreporting separately. With respect to the basic issue of overall underreporting of PDO crashes, it is first noted that no reporting data base will capture all crashes. Instead, crashes will be captured above a certain amount of property damage or if injury is present. Thus, by definition, there will be unreported crashes below the minimum property damage cutoff value — the reporting threshold. Thus, for the discussion that follows, "unreported" must be assumed to mean crashes above the reporting threshold.

And, given that we are attempting to capture as many impacts as possible, the lower the threshold, the better. The threshold values used in the states in this analysis are quite low. North Carolina had a $200 threshold for the 1980-1982 years, and a $500 minimum property damage level for the remaining years. Illinois had a $250 minimum property damage cutoff value for all years used in this analysis. Both of these values should be low enough to capture the overwhelming majority of impacts that we wish to study. That is, to say, none of the fixed objects should, by definition, reduce damage to such a minimum level that it would be below the threshold values in a large proportion of the impacts. Given that police are supposed to investigate at these levels, the question then becomes how often they fail to do so or, perhaps more accurately, how often the police are not called by the involved party to conduct the investigation.

In terms of general information, a study conducted by House and Waller in North Carolina in 1974 (19) indicated that a fairly sizable portion of accidents that were reported to insurance companies were indeed found in the official North Carolina accident file. When they extracted a sample of insurance reports from companies and matched these with the accident file, the authors found that 85 percent of the accidents that should have been reported on police reports were ultimately found in these files. The figure was slightly lower for property-damage-only crashes, where 78 percent of the PDO's that were reported to insurance companies found their way into the official police reports. The study further noted that lower reporting of total and PDO crashes was found more often in urban collisions.

Of more interest to this current study is information related to specific reporting levels for the fixed objects for which severity indices are being developed. Galati (18) indicated that, in general, only one out of eight impacts with a median barrier were reported as an official crash. In this study, a technician walked a 15.13-km (9.4-mile) stretch of box beam median barrier each month to determine where, and how severely, the barrier had been impacted during the month. While the final conclusion of the authors was that 84 percent of the impacts were not found in the official accident files, it is noted from the details of the data that 75 percent of the total impacts with the box beam were minor scrape or scratch impacts with no post damage. Of the 51 impacts with the barrier that resulted in moderate or severe damage to the barrier (i.e., post and/or beam damage), 33 were found on police accident reports. Thus, rather than 7/8 of the impacts being unreported, it appears that perhaps only 35 percent of the crashes that would have resulted in some moderate level of damage to the vehicle were indeed unreported.

Mak and Mason (17) studied impacts with various types of poles. While the study was not designed to be representative of the nation, it included data from both rural and urban areas drawn from one county in Texas and nine counties in Kentucky. The authors concluded that approximately 30 percent of pole collisions are unreported in police files. They further conclude underreporting ranges from 11.2 percent for utility poles to 68 percent for small sign supports. Similar to the Galati study, this study was based on maintenance agency records with impacts being recorded where the impact was severe enough for the maintenance agency to be called in for some type of replacement or repair. In the study, there were 1,637 reported impacts that required such maintenance and 761 unreported impacts, resulting in an overall non-reporting of 31.7 percent.

In order to extract additional information on these unreported crashes by object type, data were extracted from Table 4.9 and Table E-13 (of Appendix E) of the Mak and Mason reports. These data are shown in Table 26 below. As can be seen, as noted by the authors, the data clearly indicate differences in the percent of unreported impacts by type of object struck. Impacts with luminaries and traffic signals appear to be unreported less than 6 percent of the time. Non-reporting for utility poles is approximately 11 percent. There are also differences between breakaway and non-breakaway objects. As would be expected, the breakaway objects have a higher level of non-reporting since impacts for these objects would result in more driveaway cases than would be the case with the non-breakaway variety. For example, observe the difference in non-reporting for luminaries — 30.9 percent for the breakaway luminaries vs. 5.6 percent for the non-breakaway luminaries.

Table 26. Frequency and percent of reported and unreported pole crashes (data from Mak and Mason (16)).

Pole Category	Pole Type	Total Impacts	Reported Impacts	Percent of Total	Unreported Impacts	Percent of Total
Non-Breakaway	Utility Pole	1,238	1,099	89.0	139	11.0
	Luminaire	107	101	94.4	6	5.6
	Sign	670	160	23.9	510	76.1
	Traffic Signal	42	40	95.2	2	4.8
Breakaway	Luminaire	194	134	69.1	60	30.9
	Sign	145	101	69.7	44	30.3

Also of interest are the differences in reporting for signs. The major unreported category is the non-breakaway signs. Interestingly, non-breakaway signs are only unreported in approximately 30 percent of the cases, almost exactly the same as for breakaway luminaries. It may well be the case that the breakaway signs are larger signs with breakaway bases that result in driver injury or severe damage to the vehicle much more often than do the smaller non-breakaway signs found in the data.

In conclusion, it appears that the details shown in this table provide some additional information to the discussion concerning underreporting — information that leads to slightly different conclusions than does the earlier-cited general findings. While non-reporting clearly exists, non-reporting for non-breakaway objects such as utility poles, traffic signals and non-breakaway luminaries is fairly low. (It must also be noted that it is not possible to determine the proportion of impacts recorded by the maintenance personnel that would have resulted in less-than-threshold vehicle damage.) Based on these data, the major problem noted is in the development of severity indices for small non-breakaway signs and for breakaway luminaries and other sign supports.

In one of the later studies using information on unreported crashes, Michie and Bronstad (20) extracted information from a number of studies to make the case that guardrail impacts are not as severe as has been reported in publications related to severity indices. More specifically, the authors site the above-noted study by Galati (18) and a similar study by Carlson, et al. (21) in concluding that 90 percent of longitudinal barrier impacts are never reported in police files. Using the 90 percent unreported figure and assuming that all reported accidents are PDO's, Michie and Bronstad then recalculate earlier severity indices for guardrails, reducing the value by more than half.

However, a detailed review of the Carlson, et al. study leads one to question their conclusions, at least with respect to biases that may arise in developing severity indices that will be used in relative comparisons. Like the Galati study, the Carlson study conducted in the early 1970's was based on comparison of New York state maintenance records with police data. Maintenance records for sections of guardrail on both the New York Thruway and on state highways were collected for all impacts that resulted in some damage to median barriers or guardrails. A record was filed by the maintenance personnel for any impact resulting in more than a 5.08-cm (2-inch) alignment change in the barrier. The maintenance records were then compared to police accident records to determine the proportion of reported impacts.

What is of note here is that the 90 percent figure cited for unreported crashes comes from the state highway part of the analysis. According to the report, what is pertinent in this discussion is the fact that police in New York State are only required to file an accident report if there was injury requiring medical attention. In non-injury cases, the state law requires that the driver file a report when he damages the property of others. Thus, given the fact that driver reports are questionable in all states, what existed in New York was a situation where the threshold for crash reporting was essentially driver or occupant injury. Based on this fact, it is clearly not justifiable to extrapolate the 90 percent non-reporting to other databases, such as the North Carolina and Illinois databases, where state law requires reporting by the investigating officer for a given level of property damage. It is also questionable whether the 90 percent unreported figure should be used to adjust the severity indices developed in other studies. In short, the Carlson data, as used by Michie and Bronstad, provide little information that is directly applicable to the Illinois, North Carolina, or Texas databases.

In summary, the studies conducted to date do provide some insight into the degree of unreported fixed-object crashes. As indicated in the paragraphs above, based on Galati (18) and Mak and Mason (17), one might assume that approximately 30-40 percent of impacts with guardrails and median barriers may be unreported in some databases, 10-15 percent of utility pole impacts might go unreported, 4-8 percent of non-breakaway traffic signals and luminaire supports might go unreported, and 30 percent of breakaway devices might be unreported. One could also assume that a much higher level of underreporting is present for objects such as small signs, delineators, and other objects that very seldom lead to driver or occupant injury. However, these data are based on the studies that are quite old (early 1970's and 1980's) and the maintenance-based data cannot clearly separate out below-threshold impacts from those that should, in actuality, be in the police files. There is clearly a need for not only more definitive, but more current, data on underreporting of fixed-object impacts.

The question is how to successfully collect data in order to develop better information on unreported crashes. It is first noted that the use of states with different reporting thresholds does not appear to be a solution to the problem. More specifically, one might first assume that the use of a state with a towaway threshold would at least ensure that all vehicles that sustain a certain amount of damage are more likely to be reported to police. However, if a given fixed object is more forgiving than other objects, then it is clearly less likely to result in damage to the vehicle that would result in the need for the car being towed. Thus, threshold is not the answer to the problem.

There is also the possibility of collecting information on unreported crashes from insurance companies. As noted earlier, a study was conducted in North Carolina in which insurance company cases were compared to official state accident files. It is noted, however, that in order to collect the needed information, one would need to be able to determine the specific fixed object involved in an unreported (and reported) crash. Unfortunately, information from insurance specialists indicates that most insurance files would not capture or computerize information on the object struck. Instead, they retain in their files copies of police accident reports. This results in a "Catch-22" situation in that if the accident is unreported, no police accident report will exist.

In addition, for insurance data to provide accurate information on unreported crashes, one would have to assume that people would be willing to report differently to insurance companies than to police agencies. However, it can be hypothesized that people fail to call an investigating police officer in order to both reduce the amount of time and effort (hassle) to themselves and to reduce costs. Unfortunately, the costs being reduced not only include court costs and fines related to any citations that might be issued by the police and the cost of damage to fixed objects that might have to be paid to the state agency, but also costs related to increases in insurance.

Indeed, in much highway safety activity, when one is trying to determine what sanctions a driver is more likely to be affected by, what is found through discussions with drivers is that they are very often affected by increases in their insurance costs. Indeed, in current telephone surveys of seatbelt non-use in North Carolina, the non-users state that it is not the cost of court or the fine that affects them, but the points on their driver's record that later become insurance points and result in increased insurance premiums that would be more likely to change their behavior. Clearly, if the goal of the non-reporting driver is to keep insurance points down, then to assume that they would report more often to their insurance agency than to police is somewhat questionable.

In summary, it appears that perhaps the best data source for unreported accidents is the maintenance data that have been used in past studies. If it is assumed that a maintenance organization can be found that regularly monitors their roadside objects and that a computerized record system tracks the damage and repairs to such objects, then one might be able to extract usable information on a per object basis. As discussed above with respect to the Galati and Carlson studies, the key to such a data collection effort will be in establishing some value of damage severity or repair amount that could be used as a threshold above which accidents should indeed be reported to the police. Clearly, not all cases of minor damage would fit the description of unreported in a state with a property damage value of $500 or more. A clearly defined and justified threshold is needed to define the impact that should be countable in an analysis of unreported accidents.

It is also important in the planning of this effort that the maintenance-based analysis be conducted in a state whose police data are, or can be, used in the development of severity indices. That is to say, police data with a relatively low reporting threshold, with a large variety of fixed objects (including the ability to separate barrier ends from faces), and with the ability to link injury directly to a given object. Because of differences in state accident systems and differences between maintenance systems, it would be less justifiable to use maintenance data collected in one state and police accident data from a second state. However, even with these issues, maintenance data do appear to be the best data source for future work.

Summary and Discussion

Given that, as Turner and Hall (2) note, "the severity index has not reached the mature stage of development," this current study was an attempt to fill in at least some of the gaps found in past development efforts. While this is not the large-scale study envisioned by Turner and Hall, nor a study that is designed to provide any final set of indices, the goals of this study included (1) the use of more recent accident data to update severity indices to better reflect the current vehicle fleet; (2) the use of state databases that would help ensure that the injury sustained was the result of the specific object being studied; (3) the use of two different severity indices — the proportion of serious and fatal injury, and the cost of injury — and the comparison of the indices; (4) the development of indices for a large array of crash locations and situations; (5) the use of data from two states to better verify/validate the indices developed; and (6) initial exploration into the development of severity indices for airbag-equipped vehicles. We feel that the study was successful in at least some of these endeavors.

Indeed, two different severity indices were developed for a wide range of crash situations using data from both North Carolina and Illinois, states where injury could be more precisely linked with the object struck. While the final severity indices developed were not categorized by exactly the same control variables for the two states, the values of the indices were, in general, moderately consistent between the states. In addition, findings from North Carolina and Illinois were also consistent to a significant degree with severity indices earlier developed by Mak, et al. (10) using Texas data. As noted earlier, this consistency of measures across states lends additional support to the use of the developed indices for other states not included in the database.

There were some inconsistencies between the two states. These included the fact that indices based on the proportion of serious driver injury for impact attenuators and catch basins/culverts were higher in Illinois than in North Carolina, and that the severity index for traffic islands/curbs was lower in Illinois. The difference in traffic islands and curbs may have resulted from the increased ability to link the injury to these specific objects in the Illinois data, and the difference in the culvert/catch basin group may have resulted from the fact that the Illinois group is primarily culvert headwalls, while the North Carolina group may contain a higher proportion of less severe catch basins. Again, part of the difference between the SI's for crash attenuators in the two states may possibly be the results of the different systems used — sand-barrel systems in Illinois versus GREAT systems in North Carolina.

In addition to updating severity indices that were developed in past research, this study was also able to at least begin the development of severity indices for airbag-equipped vehicles. For the guardrails, trees, and utility pole classes where sufficient samples existed, it appears clear that the airbag will significantly reduce the value of the severity index, and that the reduction could range from 30 to 70 percent.

This study was designed not only to provide specific information concerning severity indices for fixed objects under a variety of crash situations, but also to attempt to examine new methodologies that might be used in future research and related issues that future research should be designed to overcome. We were successful in doing this in that this study was the first to use the CART methodology for the development of the indices, and it did at least consider the effects of unreported crashes on severity index values.

CART was found to be a very helpful methodology in better defining where significant differences in indices truly exist for a given fixed object. That is to say, rather than artificially defining crash situations *a priori*, the methodology allowed the data itself to determine where a significant difference exists for a given fixed object. The difficulty in using the methodology was in comparing across states, since it produced different subcategories within each state at times. However, to some extent, these differences were somewhat helpful in the analysis because they forced a closer examination of the categories developed to see if they were logical. In many of the cases, even though the specific categories defined were different, the underlying variable definitions were quite similar (i.e., rural/urban vs. speed limit), and the general values for the indices fell within the same ranges.

With respect to comparisons of the two severity indices used in this study, it is noted that conclusions concerning which would be "better" in future work are difficult to draw. What we did find was that, perhaps as expected, the range of indices, based on the cost data, is wider than the range based on the proportion of serious injury data, even when compared on a relative scale. In some ways, this may mean that more sensitive information is being provided by the cost data. The cost data seemed to provide rankings that were basically consistent with the rankings for the proportion of serious injury indices, but also seemed to provide more logical information for crash attenuators in Illinois where the proportion of serious injury index was not consistent with the North Carolina or Texas data. However, there remains the issue of using cost-based indices with small samples, where the number of fatalities may bias the results.

With respect to examination of unreported crashes, there is no doubt that there is a continuing critical need to develop better information concerning unreported accidents and, more specifically, to determine how non-reporting differs by object. On a somewhat encouraging note, closer examination of past studies indicates that the problem may not be quite as large as has been cited by other authors. However, it is clearly still large enough to warrant additional research. It was also concluded that the best data with which to develop new information would be maintenance information.

With respect to suggestions for future research, two points immediately come to mind — the need to develop severity indices in the near future based on an airbag-equipped fleet and the above-noted need for additional information on unreported crashes that can be combined into this airbag effort. With respect to the former, given the current rapidly moving change in the vehicle fleet to airbags, and given the preliminary information developed in this report that airbag-related severity indices may be only one-third to one-half as large as traditional indices and the effect of the airbag may differ from object to object, there is a critical need to include the redevelopment of severity indices for the airbag fleet in the ongoing severity index development program. The work will require identifying a state that has a large sample of vehicles that have airbags and in which the accident data can be decoded to identify these vehicles. There will also be a continuing need to have large sample sizes, sound injury severity data, and the ability to directly link the subsequent driver/occupant injury to the fixed object struck (i.e., the need for a sequence of events or most harmful event code in the data). It is noted that both the CART methodology used in this current study and the two state databases used herein (given time to accumulate additional airbag crashes) might be useful in the future airbag work.

Finally, as discussed in detail above, there is a continuing need to develop information related to the effects of unreported crashes on severity indices. As noted, the most appropriate database would appear to be maintenance information collected in a well-designed computerized system. There is also a need to conduct the maintenance data collection effort in a state whose accident data can be used in the severity index development effort.

In summary, this study has attempted to fill in some of the gaps that existed in the development of severity indices. Hopefully, it is one of a continuing set of steps aimed at improving the quality of measurement of average crash severity — measures that are needed by the roadway engineer/designer to better design and modify the roadside.

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