FUTURE OF REAL WORLD ROADSIDE SAFETY DATA

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For roadway design engineers and evaluators interested in the effectiveness of roadside safety treatments, the path to results seems to remain continually perilous. This is related to several factors. The cycle of design and testing, implementation, and evaluation takes a number of years, and this is complicated by seemingly constant changes in the vehicle fleet. Data collection is normally done by police agencies, which normally means variables pertaining to speed and angle of impact into various roadside safety features are missing; thus, crash test and real world comparisons are difficult.

There are a number of research goals related to roadside safety hardware:

- *Determine whether a new design can pass a "practical worst case" scenario* — This is normally done with crash testing in a very limited matrix of test conditions. As an example, for many years the standard strength test for a guardrail face was striking the rail with a 4,500 pound passenger car at 60 miles per hour and 25 degrees. The testing requirements are now more rigorous with the publishing of NCHRP Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features."*(1)* Nonetheless, the current test matrix is not designed (and cannot for cost reasons be designed) to collect information on the wide range of impact conditions occurring in the real world.
- *Determine which roadside features to treat* — This is normally a State transportation department function and usually pertains to a site-specific examination. Typically there is the need to predict the frequency or rate of impacts with fixed objects and the resulting severity, as well as to estimate the injury severity savings associated with a treatment.
- *Determine whether what has been designed using crash tests and simulation works in the real world* — This requires real world severity-based evaluations and, ideally, a developed linkage between crash tests and simulation results and occupant injury when actual ran-off-road events occur. This implies the need for data from crash tests, simulations of crashes, encroachment studies, police or special team crash reports, and roadside inventories.

This paper is an attempt to examine the questions of whether we have adequate data to meet these goals, and if not, what can be done to produce better data. The following text uses crash data and related files to scope the overall roadside safety problem.

CURRENT KNOWLEDGE CONCERNING ROADSIDE OBJECT IMPACTS

Let us first turn to the current status of roadside-object knowledge. That is, what do we know based on current research that will help us determine where emphasis should be placed in future roadside research, evaluation, and implementation activities.

The most recent and most pertinent research related to roadside object crashes was reported by Viner *(2)* at the 1994 A2AO4 summer meeting. In his analysis, Viner used data from the 1985 NASS/CSS files to determine the number and severity of both overturn accidents and accidents involving impacts with roadside objects. He then used comprehensive crash cost figures from Miller *(3)* to derive a total cost of roadside crashes, a cost associated with each object, and the estimated percent of total societal loss for each object. His results are shown in Table 1. Viner then conducts additional analyses concerning categorization of overturns with respect to whether they involved fixed objects or were simply related to the roadside (sideslope) design, an analysis of guardrail ends versus length of need to determine the nature of the economic loss, and provides some discussion of emerging trends that may affect these economic losses in the future — changes in the vehicle fleet, including increased availability of airbags and anti-lock brakes, and vehicle styling.

Under the assumption that one would like to guide the roadside research and implementation program by the economic loss being sustained (which appears to be a valid assumption), it is clear that the Viner estimates provide a great deal of guidance. His analyses indicate a clear need to concentrate research and implementation programs in the reduction of overturn crashes. This would relate both to the redesign of fixed objects such that they would not cause rollover, and also to the need for a more careful look at the design of sideslopes, ditches, and embankments.

With "tree" being the next leading cause of economic harm, it would appear that additional research needs to look at questions of clear zones on both curve

TABLE 1 CRASH LOSSES BY MOST HARMFUL EVENT (MHE) FOR MHEs LARGELY ASSOCIATED WITH ROADSIDE OCCURRENCES — 1985 (OVERTURNS LIMITED TO THOSE THAT OCCURRED ON ROADSIDE) *(2)*

Most Harmful Event	Fatalities	Injuries	PDO Vehicles	Total $Millions	Percent of Loss
Overturn	4,820	134,000	32,000	17,886	27.5%
Tree	3,497	88,000	26,000	12,485	19.3%
Utility pole	1,522	110,000	33,000	8,769	13.6%
Embankment	668	95,000	18,000	6,004	9.3%
Guardrail	600	21,000	17,000	2,435	3.9%
Other traffic rail	18	N/A	N/A	43	
Ditch	353	23,000	16,000	1,932	3.0%
Other fixed object	279	20,000	25,000	1,632	2.7%
Fire hydrant	12	N/A	N/A	29	
Impact attenuator	7	N/A	N/A	17	
Mail box	N/A	2,000	7,000	104	
Other post	277	13,000	19,000	1,295	2.5%
Traffic signal pole	N/A	5,000	3,000	235	
Overhead sign post	15	N/A	N/A	36	
Other noncollision	121	5,000	18,000	551	2.4%
Immersion	394	N/A	N/A	946	
Culvert	302	17,000	4,000	1,514	2.3%
Bridge rail	151	15,000	11,000	1,071	2.1%
Bridge end	115	N/A	N/A	276	
Luminaire support	115	N/A	N/A	427	2.1%
Nonbreakaway	N/A	14,000	3,000	649	
Breakaway	N/A	5,000	5,000	239	
Curb	193	13,000	24,000	1,078	1.7%
Bridge pier	296	4,000	3,000	900	1.4%
Building	174	10,000	4,000	884	1.4%
Concrete barrier	100	N/A	N/A	240	1.3%
Concrete median	N/A	7,000	4,000	329	
Concrete non-med.	N/A	3,000	5,000	147	
Median barrier	N/A	3,000	2,000	141	
Fence	192	8,000	16,000	856	1.3%
Wall	159	7,000	7,000	716	1.1%
Signpost	123	N/A	N/A	295	0.8%
Large sign	N/A	3,000	1,000	140	
Small sign	N/A	1,000	5,000	55	
Shrubbery	15	16,000	12,000	324	0.5%
Total	14,571	642,000	320,000	$64,578	100%

and tangent sections in both rural and urban areas. Viner also points out that "guardrail" is the highest ranked safety hardware device in terms of economic loss, and further notes that guardrail ends appear to be overrepresented. In short, Viner's analysis of the data is indeed quite helpful in helping to decide where emphasis should be placed in future roadside safety programs.

While the authors do not feel that a great amount of information can be added to what was done in the Viner paper, we have taken the liberty to examine a limited number of additional tables of fixed object collisions using data from the Highway Safety Information System (HSIS). These runs were conducted simply to provide additional information concerning what is being struck, how often it is being struck, and under what conditions the striking is occurring. Table 2 on the following page presents the numbers of fixed object impacts for each of six HSIS states. The data shown in this table cover the years of 1985-1989, giving us five years of data in each state.

The data in this table are not as directly related to "loss due to the object" as the data in the earlier Viner paper. That paper included only single vehicle crashes in which the most-harmful-event was the object impact. These data are more directed toward the total size of the problem in that they contain both single vehicle crashes and some number of multivehicle crashes where a vehicle might rebound from the initial crash into a

TABLE 2 LISTING OF FIXED-OBJECT TYPES STRUCK IN CRASHES FROM HSIS STATE ACCIDENT FILES

	STATE						
TYPE OF OBJECT STRUCK	IL	ME	MI	MN	UT	NC	TOTALS
Embankment/Ditch/Stream/Rock Outcrop	5,389	14,608	15,740	12,316	*4,258	73,064	127,269
Snow Bank	352				*288		
Tree (or Shrub)	6506	13,380	7,262	8,592	*2,309	34,625	72,674
Guardrail or Guardpost	12,281	3,912	16,657	3,571	2,978	7,874	47,273
Guardrail End	-	-	-	-	*116	1,872	1,988
Concrete Barrier/Median Barrier	1,703	1,366	11,443	3,887	*1,629	2,416	22,444
Bridge or Bridge Guardrail	2,929	-	-	-	-	-	2,929
Bridge Rail or Deck	-	-	902	-	-	5,587	6,489
Bridge Pier or Abutment	247	1,924	888	4,952		-	8,011
Bridge, Culvert or Other HW Structures	-	-	-	-	1,297 -	-	1,297
Culvert/Headwall	109	446	679	823	-	7,472	9,529
Underpass Structure	625	-	-	-		1,182	1,807
Utility Pole	7,194	9,231	-	5,321	4,474	26,036	52,256
Light Pole or Standard	4,502	871	-	4,302	-	2,571	12,246
Street Light or Utility Pole	-	-	10,554	-	-	-	10,554
Signal or Signal Pole	5,206	255	-	2,429	-	-	7,890
Highway or Railroad Signal	-	-	478	-	-	-	478
RR Crossing Signal or Device	252	122	-	292	-	-	666
Other Pole/post or support	-	1,133	-	1,937	-	-	3,070
Sign Structure or Post	7,362	1,541	12,599	8,718	2,313	8,826	41,359
Advertising Sign	442	-	-	-	-	1,470	1,912
Delineator Post	885			-	2,225	-	3,110
Fence (or Fencing)/Median Fence	4,482	1,053	3,126	2,863	5,259	10,254	27,037
Mailbox or Posts	1,349	1,580	4,450	2,077	*570	6,116	16,142
Safety Island/Curb/Channelizing Island/Traffic Island	603		4,072		2,531	7,806	15,012
Construction Barricades, Equipment, etc.	885	317		1,630		353	3.185
Crash Cushion or Impact Attenuator	228	196		304	*68	129	925
Building or Wall	1,402	1,318	1,677	2,057	*2,355	-	8,809
Hydrant/Parking Meter	1,026	578	-	1,169	-	-	2,773
Machinery	84	-		-	-	-	84
Overhead Fixed Object	-	-	859	-			859
Other (Fixed) Object	14,106	4,565	14,887	3,918	*2,151		39,627

Illinois, Maine, Michigan, Minnesota, Utah Accident Data = 1985-1989 (5 years) except *denotes those not including 1985 data

fixed object, or might hit one fixed object and then rebound into a more- or less-severe fixed object. In general, these figures represent an indication of the first object struck as recorded on the crash form.

The total column provides some overall information related to the frequency of impacts. (We note that these impacts are not weighted by any type of severity as Viner was able to do in his analysis, nor is there any control for exposure to impact — the degree of presence of a given object beside the roadway.) The table is somewhat difficult to read in that there are differences in definitions for the same type of object across the states. For example, if one observes the fourth category down related to bridge structures, one sees a number of different categories used in the different states. In like fashion, utility poles are captured alone in five of the

TABLE 3 FIXED-OBJECT CRASHES BY URBAN AND RURAL LOCATIONS FOR NORTH CAROLINA AND ILLINOIS

TYPE OF OBJECT STRUCK	NORTH CAROLINA		ILLINOIS	
	Rural	Urban	Rural	Urban
Embankment/Ditch	24,559 (94.6)	1,365 (5.4)	2,665 (69.0)	1,200 (31.0)
Tree (or Shrub)	9,792 (82.3)	2,102 (17.7)	1,370 (40.6)	2,001 (59.4)
Guardrail or Guardpost	2,326 (62.3)	1,410 (37.7)	2,285 (34.8)	4,291 (65.2)
Guardrail End	6,291 (63.8)	357 (36.2)		
Concrete Barrier/Median Barrier	413 (35.9)	736 (64.1)	63 (5.2)	1,154 (94.8)
Bridge or Bridge Guardrail			573 (51.8)	534 (48.1)
Bridge Rail or Deck	1,339 (75.0)	447 (25.0)		
Bridge Pier or Abutment	92 (40.0)	138 (60.0)	52 (55.3)	42 (44.7)
Culvert/Headwall /Catch Basin	2,595 (87.8)	362 (12.2)	21 (80.8)	5 (19.2)
Underpass Structure	55 (23.5)	179 (76.5)	99 (18.4)	439 (81.6)
Utility Pole	3,185 (37.4)	5,350 (62.6)	1,061 (31.5)	2,307 (68.5)
Light Pole or Standard	367 (25.9)	1,051 (74.1)	134 (5.5)	2,295 (94.5)
Traffic Signal or Signal Pole			120 (5.4)	2,102 (94.6)
Railroad Signal			30 (10.3)	262 (89.7)
Sign Structure or Post	238 (59.9)	1,593 (40.1)	1,325 (38.7)	2,098 (61.3)
Advertising Sign	283 (48.7)	268 (51.3)	41 (20.6)	158 (79.4)
Delineator Post			367 (73.8)	130 (26.2)
Fence (or Fencing)/Median Fence	2,273 (74.9)	757 (25.1)	1,169 (51.2)	1,116 (48.8)
Mailbox or Posts	1,786 (85.5)	304 (14.5)	374 (58.7)	263 (41.3)
Curb/Traffic Island	520 (16.7)	2,586 (83.3)	145 (7.9)	1,684 (92.1)
Construction Barricades, Equipment, etc.	147 (47.6)	162 (52.4)	269 (27.0)	727 (73.0)
Crash Cushion or Impact Attenuator	16 (38.1)	26 (61.9)	29 (18.2)	130 (81.8)
Building or Wall			135 (18.1)	612 (81.9)
Machinery			143 (30.8)	321 (69.2)
Other (Fixed) Object	5,732 (58.0)	4,138 (42.0)	2,723 (26.2)	7,685 (73.8)
TOTAL	58,490 (71.5)	23,331 (28.5)	15,193 (32.5)	31,556 (67.5)

states, but are captured in the same category with street lights in Michigan. Even with these difficulties, some information concerning the relative size of the impact problem can be gained from the table.

What is immediately obvious is that impacts involving the general category of embankments, ditch banks and other roadside elements (which would clearly include sideslope-related collisions) are the leading category in terms of overall frequency. As in the Viner paper, the second leading category is "trees."

The table also indicates that guardrail, guardposts and median barriers are, as would be expected, another major category of impacted objects. Remember that these are the safety hardware that Viner noted as having the highest economic loss percentage. Other longitudinal barriers such as bridge rail or bridge guardrail do not appear to have near the impact frequency. However, it is noted that structures such as culverts and bridge piers or abutments do experience fairly major numbers of impacts over the five year period.

Turning now to point objects, the table indicates that utility poles, light poles, and other poles beside the roadway are another major problem in terms of frequency of impact. Sign structures and sign posts are also high in terms of number of impacts, but might be assumed to be less severe than the category related to utility poles and luminaires. Moving on down the table, other objects which indicate fairly high numbers of impacts include fences, mailboxes or mailbox posts, and a combined category related to traffic islands and curbs.

Finally, it is of interest to note that there are very few crash cushion/impact attenuator impacts across the five years of data — only 925 as captured in five of the six states. This small number most likely reflects both the small number of these safety devices that are in place across the six states, and, perhaps to some extent, the fact that some of the vehicles which strike them drive away without reporting the crash to police

In addition to this overall table, we also produced a series of additional tables using data from Illinois and North Carolina to provide a limited amount of additional information on conditions pertaining to the impacts. The states were chosen because they represent both a more rural state (North Carolina) and a more urban state (Illinois). In these tables, object struck was again defined using any impact and was not restricted to single vehicle cases, nor was an attempt made to try to more specifically relate a given vehicle to a given object struck. These tables were run using 1990-1992 data from the two states, the most recent years of complete data from both states in the HSIS system.

Table 3 indicates the categorization of fixed objects by urban and rural location within the two states. As can be seen from the last "Total" row, the two states are indeed quite different.

While 71.5% of the North Carolina objects are struck in rural areas, 67.5% of the Illinois objects are struck in urban areas. Given these differences, which reflect where roadway mileage (and objects) are located and where crashes occur, one is not surprised to find that the patterns for individual objects sometimes reflect the overall urban/rural breakdowns within each state. What is of some interest are the cases where an object has a significantly higher proportion of strikes within either the urban or rural category than the state "average" would suggest. Here, for example, the category of roadside embankment/ditch is overrepresented in rural areas in each state, suggesting relatively high impact speeds. In similar fashion, impacts with trees, culvert/catch basins, and mailboxes are somewhat overrepresented in rural areas in both states.

On the other hand, median barriers, underpass structures, utility poles (in North Carolina), light poles, traffic signal poles (in Illinois), curbs/traffic islands, and impact attenuators appear to be overrepresented in urban impacts. This would imply lower impact speeds for most of these objects, although the speed limit data presented below modify this conclusion for median barriers and crash cushions.

Table 4 provides additional information on speeds in fixed object impacts, using the speed limit variable in the more rural North Carolina data. While police reports cannot provide accurate estimates of impact speed, speed limit at least provides some general information on the approximate impact speeds. Since the primary interest is in the distribution of impacts by speed limit for each object, the percentages of total impacts (rather than frequencies) are shown in each cell. The majority of objects (56%) are struck in locations where the speed limit is 50-55 mph. Over 20% are struck on roadways with speed limits are 35 mph or less, or urban areas. With respect to specific objects, and consistent with the North Carolina urban/rural findings above, bridge piers/abutments, underpass structures, utility and luminaire poles, and traffic islands are more likely to be in areas with lower speed limits. This perhaps implies lower impact speeds for these objects.

Also supporting the earlier findings, ditch banks, trees, guardrail ends and faces, bridge rails, catch basins/culverts, and construction barriers have a high proportion of their crashes in locations with speed limits of 50 mph or greater, implying higher impact speeds. In addition, median barriers and crash cushions, which were noted above as experiencing more urban crashes, are shown to more likely be struck on higher speed roads. Here, over 50% of the crash cushion impacts and more than 60% of the median barrier impacts are in locations with speed limits above 50 mph. This supports the earlier hypothesis that these objects are on the higher speed urban roadways, and would be impacted at higher, rather than lower, speeds.

To examine the issue of curvature and grade as related to fixed object impacts, Table 5 provides North Carolina information on object struck classified by curvature and some measure of grade as provided by the investigating police officer. Note that this was not done by linking crashes with a curvature/grade file, but is simply an indication as provided by the officer as to whether he feels that crash occurred on a curve or a tangent section. Thus, in all likelihood, minor curves may be classified as tangents. While "level" is as specified, the term "other" includes grades, sags, and crests. Again, only the (row) percentage of crashes falling within each category are presented in the table.

As can be seen from the bottom row of the table, approximately 65% of all objects struck are on tangents, while 35% are on curves. Of some interest are the cells in the table which are greatly different from the overall percentages at the bottom of the column. For example, it appears that ditch banks, trees, and fence posts are more likely to be struck on curves, in comparison to other objects. In contrast, underpass structures, luminaire supports, traffic islands, construction barricades, crash cushions, and, to a more limited extent, guardrails and sign supports are more likely to be struck on tangent sections. These findings are somewhat difficult to interpret, since what is not known, of course, is the distribution of curves and tangents, or the distributions of objects on curves versus tangents. For example, luminaire supports would be more likely found

TABLE 4 PERCENT OF FIXED OBJECT CRASHES WITHIN SPEED LIMIT CATEGORIES — NORTH CAROLINA DATA

	SPEED LIMIT					
TYPE OF OBJECT STRUCK	Not Stated	< =35 mph	40-45 mph	50-55 mph	> 55 mph	Total
Ditch Bank	0.35	6.06	14.20	77.05	2.33	25,969
Tree	0.63	17.14	16.04	61.50	4.69	11,914
Guardrail Face	0.88	8.10	10.02	59.67	21.31	3,740
Guardrail End	1.52	9.03	10.04	55.07	24.34	986
Median/Shoulder Barrier	1.21	19.98	17.02	58.64	3.12	1,151
Bridge Rail End or Face	1.23	14.77	13.70	59.50	10.79	1,788
Bridge Pier or Abutment	0.87	25.22	20.87	39.13	13.91	230
Catch Basin/Culvert	0.24	10.63	19.51	66.37	3.24	2,962
Underpass Structure	0.85	61.54	8.97	18.80	9.83	234
Utility Pole	1.32	55.35	19.85	23.42	0.07	8,550
Luminaire Pole	5.43	51.73	19.24	20.08	3.52	1,419
Sign Structure or Post	0.58	27.15	22.75	45.08	4.45	3,982
Advertising Sign	1.81	36.17	24.05	35.80	2.17	553
Fence or Fence Post	1.32	24.93	17.38	53.97	2.41	3,033
Mailbox	0.62	15.60	24.59	59.19	0.00	2,090
Traffic Island	1.32	54.99	29.21	12.64	1.83	3,108
Construction Barrier	1.29	11.33	11.97	69.58	5.83	309
Crash Cushion	2.38	28.57	14.29	45.24	9.52	42
Other (Fixed) Object	2.81	33.43	16.81	41.72	5.23	9,889
TOTAL	860 (1.05)	17,911 (21.86)	13,824 (16,87)	45,858 (55.96)	3,496 (4.27)	81,949

in urban areas with fewer curves. In like fashion, traffic islands are more likely to be at intersection (tangent) locations.

Thus, more detailed inventory data are needed to truly define the differential risk of object impact on curves and tangents. However, the figures in the table do provide at least some insight into where the various objects are being struck, given the current distributions of objects and curves in a rural state.

Also of interest in the ongoing discussions of the specifics of impact is the question of the distance of the impact from the edge of the roadway. Very few states capture any such information in their accident reporting/investigating procedures. However, North Carolina does have a police-reported variable titled "Distance to object struck." Unfortunately, rather than a simple estimate of distance, the variable is categorized, with the first category being "in road," and the second being "0-10 ft." For general information, Table 6 provides a summary of this distance-related data for all objects combined in urban and rural areas. The percentages shown are row percentages, indicating the urban/rural breakdown. Again, it is noted that this is an *estimate* provided by the officer, rather than a measured distance.

What is of initial interest here are the overall figures for distance as shown in the final total column. Here, summing the objects on both sides of the roadway, approximately 46% of the objects struck are within 10 ft of the roadway. Approximately 43% of the objects struck in rural areas are within the same distance. An additional 32% of the total objects struck are estimated as being between 11 and 30 feet from the edge, and approximately 8% of the objects struck are estimated to be at distances greater than 30 feet.

With respect to the distributions of distance within urban/rural category, those objects struck in urban areas are more likely to be closer to the roadway, as would be expected based on encroachment speeds and on "normal" placement of objects. While 59% of the urban

TABLE 5 FIXED OBJECT CRASHES BY POLICE-REPORTED CURVATURE AND GRADE CATEGORIES — NORTH CAROLINA DATA

TYPE OF OBJECT STRUCK	CURVATURE/GRADE CATEGORY				
	Straight, level	Straight, other	Curve, level	Curve, other	Total
Ditch Bank	39.43	16.03	24.26	20.27	25,927
Tree	37.44	16.72	23.01	22.83	11,888
Guardrail Face	47.56	25.94	8.72	17.78	3,728
Guardrail End	50.56	23.65	8.87	16.92	981
Median/Shoulder Barrier	52.09	23.73	8.81	15.36	1,146
Bridge Rail End or Face	52.22	21.59	10.79	15.40	1,779
Bridge Pier or Abutment	51.30	22.17	16.52	10.00	230
Catch Basin/Culvert	39.84	21.14	20.49	18.53	2,957
Underpass Structure	51.50	32.19	8.15	8.15	233
Utility Pole	51.51	21.03	15.51	11.95	8,529
Luminaire Pole	67.45	21.73	4.60	6.23	1,419
Sign Structure or Post	55.72	20.34	12.11	11.83	3,972
Advertising Sign	50.64	21.96	15.79	11.62	551
Fence or Fence Post	39.29	17.83	20.53	22.35	3,029
Mailbox	43.10	19.51	21.00	16.40	2,090
Traffic Island	61.25	23.18	7.90	7.67	3,102
Construction Barrier	55.19	26.30	12.34	6.17	308
Crash Cushion	45.24	30.95	11.90	11.90	42
Other (Fixed) Object	54.20	21.00	12.78	12.01	9,856
TOTAL	37,244 (45.55)	15,611 (19.09)	14,958 (18.30)	13,944 (17.06)	81,757

TABLE 6 DISTANCE FROM ROADWAY THAT FIXED OBJECT IS STRUCK, BY URBAN/RURAL CATEGORIES — NORTH CAROLINA DATA

DISTANCE TO OBJECT	LOCATION		Total
	Urban	Rural	
None or Not Stated	2,629 (64.44)	1,451 (35.56)	4,080 (4.99)
In Road	2,268 (46.46)	2,614 (53.54)	4,882 (5.97)
0-10 ft Right of Road	9,729 (40.20)	14,473 (59.80)	24,202 (29.58)
0-10 ft Left of Road	3,669 (26.56)	10,143 (73.44)	13,821 (16.88)
11-30 ft Right of Road	2,050 (13.68)	12,930 (86.32)	14,980 (18.31)
11-30 ft Left of Road	1,151 (10.18)	10,156 (89.82)	11,307 (13.82)
>30 ft Right of Road	721 (20.47)	2,801 (79.53)	35,22 (4.30)
>30 ft Left of Road	561 (19.40)	2331 (80.60)	2892 (3.53)
TOTAL	22,778 (28.59)	56,899 (71.41)	79,677

objects struck are within 10 feet of the roadway, only 43% of the rural objects are. In contrast, while 41% of the rural objects struck are estimated to be between 11 and 30 feet, only 14% of the urban objects are in this range.

In summary, the above data provide some indication of the nature of fixed object impacts. The data in this compilation are limited to only two states, Illinois and North Carolina, with the majority of the tabular information being from the more rural North Carolina database. While not provided in this paper, databases from six other HSIS states could be examined to provide similar or additional data if specific questions of interest can be identified.

Finally, of a more philosophical nature, one question raised by Viner's work and the above tables concerns the basis on which the decision of program direction should be made. In short, should we base fixed object research and implementation programs on frequency of crash (as in these tables), impact severity, a combination of frequency and severity (as in the Viner work), or some other basis? While we do not profess to have the answer to this question, it would appear that one should consider not only the loss being incurred, but also the cost of making an improvement to a given object or roadside design, and the probability of success one can expect from the expenditures. For example, although both the Viner analysis and our analysis indicates the roadside design (e.g., sideslopes, embankments and ditches) to be the leading "cause" of harm, the questions remaining concern whether the design can be feasibly changed, and what the related estimated costs and potential benefits would be. In like manner, can "trees" be successfully removed from the roadway? Or could we devise a relatively inexpensive but effective utility pole treatment that might be implemented rapidly to affect a sizable portion of the lower-rated utility pole harm? In short, it appears to these authors that some form of economic analysis needs to be considered which factors in the *probability of success*, both in terms of crash loss reduction per treatment and the chances of the treatment being implemented in the real world. This is certainly not to say that we should not consider clear zone, sideslope and ditch design as high priorities, but that we might be better served by extending our analysis at least one more step in determining program direction.

STATUS OF ROADSIDE RESEARCH DATA

Having now conducted a limited exploration of the current problem in the sense of what roadside objects are being struck, let us now return to the overall question concerning whether we have adequate data to conduct the necessary research to identify the problems and find the solutions that are needed.

Site Identification and Examination

As noted in the introduction, the first type of research needed is aimed at determining whether a specific site should be improved and the benefits of a particular treatment. This site-specific research requires the development of a model which would predict how often an impact will occur with a given fixed object, and how severe the resulting impact is likely to be. This prediction effort can be done in at least two different ways — through the use of an encroachment type model or through the use of a detailed accident-based model.

The encroachment type model has been referenced in a number of studies including an early study by Glennon *(4)*. These models predict impact with an object of specific dimensions and specific distance from edge of pavement by estimating the number of vehicles that would encroach from the road at a given angle and to a given distance from the edge of the pavement. The use of this model requires good data on the rate of encroachments per passing vehicle, the distribution of angles at which the vehicles leave the roadway during the encroachment event, and the distribution of the distances that the vehicles travel.

To develop an accident-based model whose goal is to predict the probability of impact with a specific class of object, detailed data would be required. The model would be "section based," predicting the number of impacts per object per passing vehicle. The data required would include information on fixed-object crashes by object type, traffic volumes, and information on how many objects there are beside the roadway to be struck (i.e., a roadside inventory file).

There are clearly existing gaps in the available data for both these models. Available encroachment data is often based on older studies, primarily Hutchinson and Kennedy *(5)*. These data were collected on multilane roads during snow season, and at least one of the authors has questioned the suitability of using the data in very detailed, deterministic models. It also appears that current attempts to develop encroachment data through a number of different studies have been less than totally successful. In short, there is a continuing need to collect better encroachment data. With respect to the data needed in the accident model, while most accident reports include a list of generic types of fixed objects which could be used in the modelling exercise, and while the number of passing vehicles can be estimated from available AADT data, we know of only one state (Michigan) that has any kind of roadside

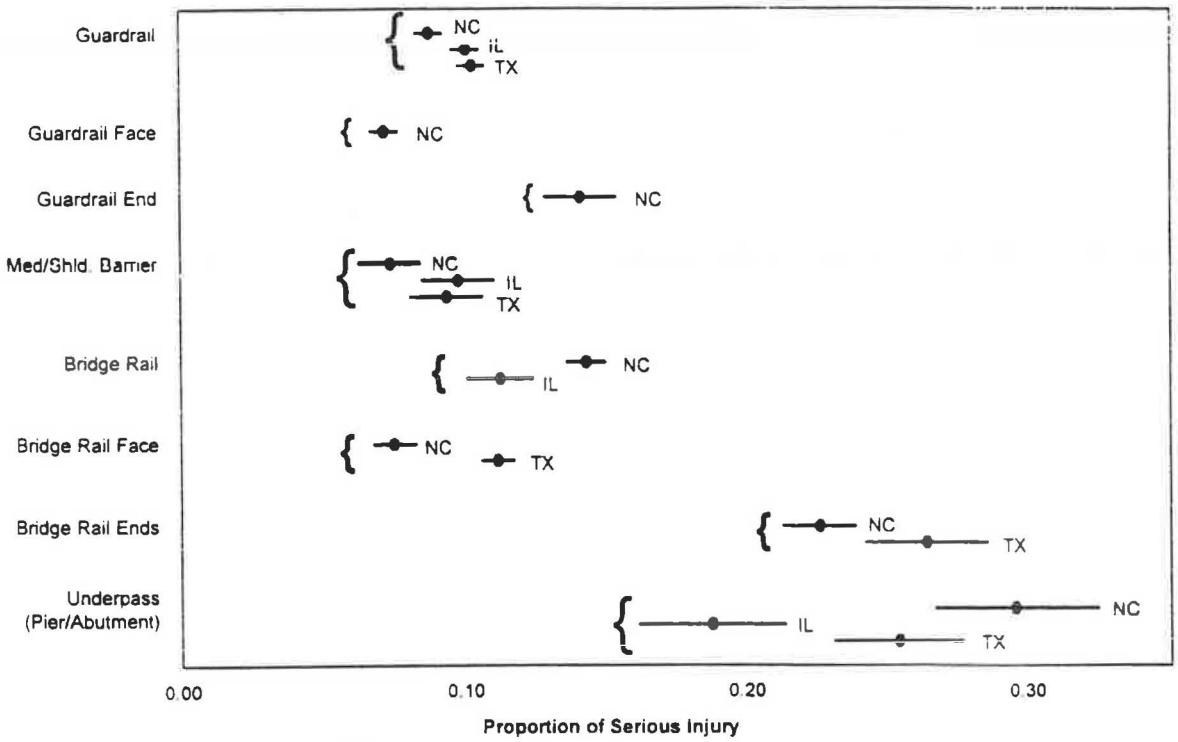

FIGURE 1 Proportions and 95 percent confidence intervals for barrier-type objects (North Carolina, Illinois, and Texas data) *(6)*.

inventory that would allow one to develop a measure of exposure to the objects. Here, for example, one would need to know the beginning and ending milepoints for longitudinal barriers in order to produce a model that predicted impacts into the barrier per million passing vehicles. In short, roadside inventory data are sorely needed in this effort and currently exist in only a limited fashion.

The second set of data needed to produce the final output from both the encroachment and accident models is related to the severity of an impact given a fixed object has been struck. Here, detailed "severity indices" are needed for a wide variety of objects. Indeed, for the encroachment model to predict as it should, these severity indices need to be further categorized by encroaching vehicle speed, angle and vehicle type.

With respect to such severity index research, a recent paper by Council and Stewart *(6)* is now under review by FHWA and will be converted into a TRB paper. The study used data from Illinois and North Carolina, where the specific injury to the driver could be fairly accurately specified as having resulted from the impact with the object being studied. This was done through the use of the most harmful/first harmful event in North Carolina, and through a sequence of events in the Illinois data. While more detailed indices for specific vehicle types, speed limits, road classification and roadway locations are presented in the paper, the "average" severity indices from these two states and from earlier research by Mak et al. *(7)* using Texas data are included in the three figures that follow.

The continuing problems noted in this recent research include the need for more detailed descriptions of certain fixed objects (e.g., whether a "guardrail" is a w-beam, blockout or non-blockout, etc.), more complete indication of unreported crashes which will affect the severity-based indices, and the need to modify the indices based on changes in the vehicle fleet.

In short, there are continuing data needs for both the encroachment-based model and the accident-based model, and for more complete severity indices required by both models.

In-Service Evaluations of Hardware

In-service evaluations of hardware have been promulgated by the last two guidelines for crash testing, NCHRP *Reports 230 (8)* and *350 (1)*. To perform such studies requires quality evaluations of operational and crash severity for specific pieces of hardware (e.g., breakaway cable terminal (BCT) versus turn-down end

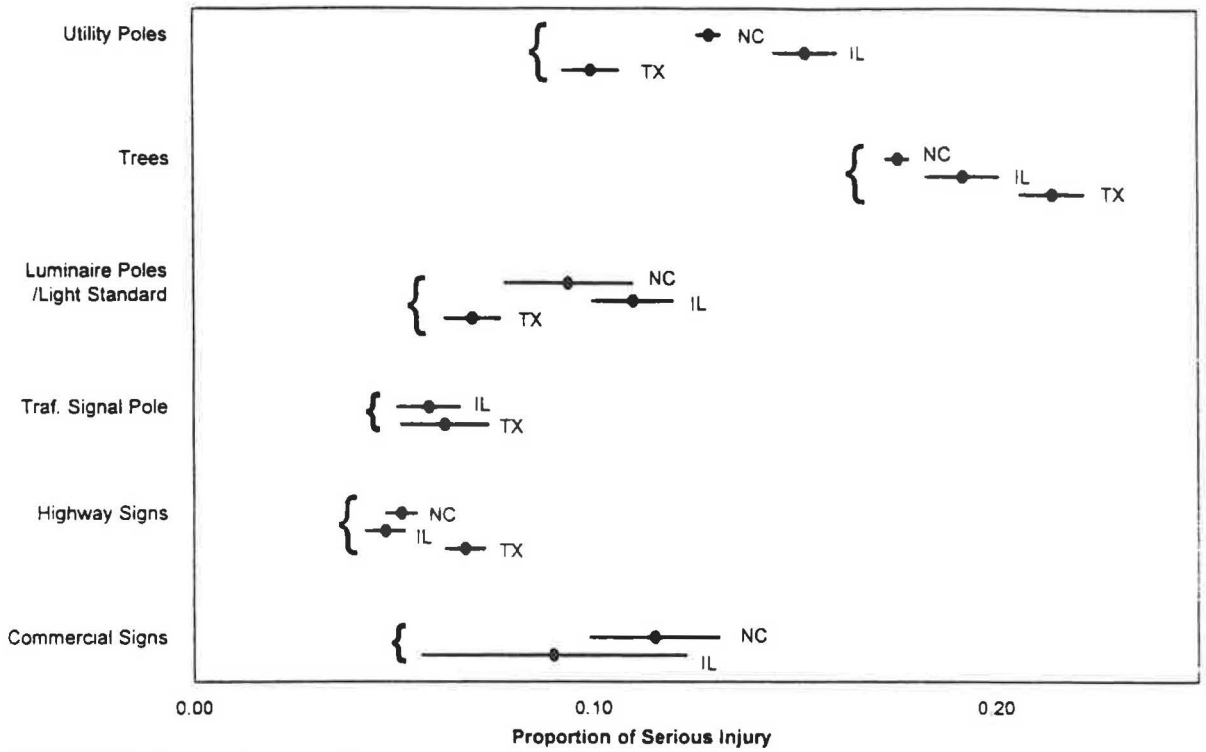

FIGURE 2 Proportions and 95 percent confidence intervals for point-type objects (North Carolina, Illinois, and Texas data) *(6)*.

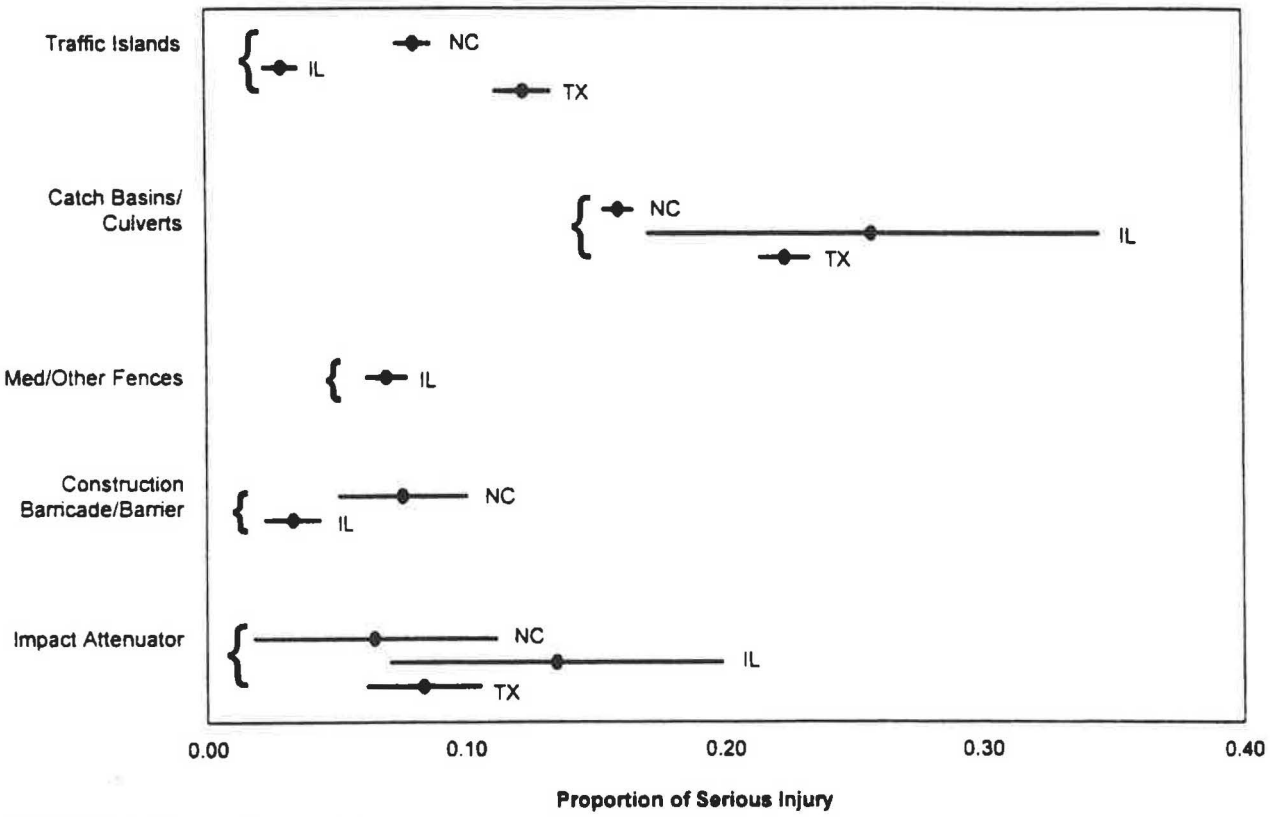

FIGURE 3 Proportions and 95 percent confidence intervals for other objects (North Carolina, Illinois, and Texas data) *(6)*.

treatments). The normal sequence of evaluation would be determination of the function of the device, development of preliminary designs, the conduct of laboratory and crash tests, redesign and retesting if necessary, installation of feature and in-service evaluation, declaration of operational status if warranted, and then further observation of the device to determine if there are other problems. The problem is that few in-service evaluations of quality have been done. Some that can be named include the State of Connecticut's evaluation of the Connecticut Impact Attenuation System (CIAS), where a series of studies was performed *(9)(10)(11)(12)(13)*; barrier system studies using maintenance personnel in New York State *(14)*; and end treatment studies in Kentucky *(15)*.

The BCT is a device that has received a good bit of scrutiny over the years. This is probably the most widely used end treatment in existence, but a design which has all too often resulted in improper installation because of the necessity of a 4-foot parabolic flare. Many BCT's have been installed with a 1-foot parabolic flare and others with no flare whatsoever. Poor performance of these non-standard designs has been noted when evaluations have been performed (15). The field of roadside safety knowledge would be potentially farther advanced if more in-service evaluations were routinely done and reported in the literature.

As with any kind of evaluation, there are factors that must carefully be considered with in-service performance. Since comparisons between treatments are generally relative, and since some hardware, if designed properly, leads to vehicle "driveaways," the evaluation method must assure that the same threshold of reporting is taking place. Put another way, are the same levels of property-damage-only (PDO) crashes being captured (or are the same levels of crash energy being captured)? Matching on PDO crash levels is generally not a problem, as many police reporting agencies adopt $500 as a threshold value, but this should be verified. The "driveaways," or unreported crashes, present another problem, in that ascertaining the actuality of these events is relatively difficult. Actuated cameras have been used to record vehicles striking crash cushions, a device that can certainly lead to driveaways. For barrier impacts, maintenance personnel have been utilized to record scrapes or gouges on barriers, and one Southwest Research Institute (SwRI) study *(16)* actually instrumented a section of guardrail to record impacts. One problem with the latter approach was that intended encroachments (e.g., pulling onto the shoulder to allow a following vehicle to pass) were difficult to interpret.

Before any new piece of hardware is put into service, laboratory and crash tests are usually performed to assess whether the device is acceptable from a human tolerance standpoint. The problem here is twofold: (1) the devices are struck in a variety of ways in the real world that cannot currently be cost-effectively crash tested, and (2) the linkage between measured crash test forces to the vehicle and ultimate occupant injury has yet to be effectively defined. (It is also not clear that modern simulation developments are reducing this gap). A related problem is that much crash testing takes place with older vehicles that are more affordable, but which may have decidedly different characteristics than the current fleet. An example is the ever increasing frequency of air-bag-equipped vehicles on the road.

Thus, in-service evaluations are not without problems. The cycle of design, testing, and implementation may be lengthy (perhaps 5-10 years), and during this time vehicle fleet characteristics may tend to change. It is difficult for the roadway designer to keep up with the system — the target appears always to be moving.

FUTURE DATA PROSPECTS

So where is the field heading in regard to future data collection. This will be discussed from the aspects of data file possibilities and innovative means of collecting and analyzing data.

Data Files

There are various data files that can be used to study the roadside safety problem. In regard to crash data, the HSIS offers a capable set of police files that come from states with good roadside data. Missing ingredients include better information about impact conditions (primarily speed and angle data) and more detail about specific hardware (e.g., type of guardrail struck, rail height, post spacing, standard design or not). It is not clear that other federal files, an example being the General Estimates System (a refinement of the earlier NASS PSU data), would be of any more value than working with the HSIS data, except for a better estimate of national frequency of these kinds of crashes.

The Longitudinal Barrier Special Study (LBSS) files were created to collect just the kind of hardware specificity mentioned above but tended to be biased toward the more severe crashes. These data were collected from 1982-1986 but are still quite valuable from a clinical standpoint. Hunter, Stewart and Council *(17)* recently performed a comparative analysis of barrier and end treatment types using the LBSS file.

Unreported crashes pose yet another problem to be dealt with in roadside safety studies. (For discussion purposes, unreported should be assumed to mean crashes above some minimum reporting threshold.) The

problem is that unreported (presumably PDO-type) crashes tend to inflate the proportion of serious and fatal and other injuries, and thus inflate severity indices based on these severe injuries. Another question is whether various fixed objects are underreported to differing degrees. For example, it is presumed that breakaway support and other attenuating devices have more propensity for driveaway events than collisions with barriers and other non-breakaway designs (see Mak and Mason, 1980 *(18)*.

It appears that the best source of data for unreported crashes is maintenance data of the type used in previous studies (Galati, 1970 *(19)*; Carlson, Allison, and Bryden, 1977 *(14)*), where maintenance personnel regularly monitored impacts with objects. Assuming that a maintenance organization exists which regularly monitors their roadside objects, and that a computerized record system tracks the damage and repairs to such objects, then one should be able to extract usable information on a per object basis. A key to such a data collection effort is establishing some value of damage severity or repair amount which can be used as a threshold value above which crashes should be reported by the police. 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 which should be countable in an analysis of unreported crashes.

The maintenance-based analysis should be conducted in a state (or states) whose police data can be used in the development of severity indices. This means data with a relatively low reporting threshold, with a large variety of fixed objects, and with the ability to link injury directly to a given object.

Another type of data file pertinent to roadside safety analysis is roadside inventory information, or a record of what actually exists on the roadside. To produce such a file is a laborious process that sometimes is simplified through sampling. Once obtained, the inventory data must be linked with crash data.

Files based on encroachment data are also difficult to obtain but represent another way to examine the problem. TTI has been active for many years with developing these encroachment models. A current NCHRP cost effectiveness study (Project 22-9) is being completed based on an improved encroachment probability model.

Innovative Means of Collecting and Analyzing Data

Innovative can mean many things. This section will start with comments about working with recent hi-tech developments and then move to a brief discussion concerning the use of traditional police reporting systems in innovative ways

Hi-Tech Innovations — A recent FHWA study by Bellomo-Mcgee and the UNC Highway Safety Research Center *(20)* provided information about new and emerging technologies for improving accident data collection. The document is extensive and covers techniques that include use of portable computers, location systems such as Loran-C and GPS/GPI, cellular phones, black box recorders for vehicles, and other automated incident detection systems. While innovative, the technology is so costly in general that widespread use will be difficult to obtain. However, two techniques appear promising. GPS/GPI systems are not prohibitively expensive and are gaining rapid acceptance and use in transportation settings. There is promise for use of such technology in improving the location of reported crashes. Such improved locations would be helpful in studies of roadside safety devices, providing that an inventory is in place. In addition, laptops, notebooks, and pen-based computers can be used by police to collect data electronically at the scene of a crash. Software can be used to create special forms for entry, such as a barrier special study form. Pop-up menus can also be used to prompt the investigator to obtain pertinent data for crashes of interest, such as guardrail type, rail height, post spacing, end treatment, etc. in a barrier study.

Improved Detail on Police Forms — An improvement that would be quite valuable is the more widespread use of detailed sequence of events protocols by crash investigators. Most state data files are not sophisticated enough to enable an analyst to precisely link a crash injury with a specific fixed object, especially if there are multiple impacts taking place. Most states only have an "accident type" which indicates the first harmful event. North Carolina is like some states in having a "first harmful event" and "most harmful event" recorded. This is helpful but not as good as the event sequence used in Illinois, where 3 or 4 events may be recorded (e.g., vehicle ran off road and struck small sign, then struck a guardrail, and then overturned). Such a sequence allows the analyst to screen out unwanted occurrences. For example, the analyst could accept only cases in which the first and only impact was with a guardrail. Then the analyst would be reasonably confident that any resulting driver or other occupant injury would be related to the guardrail.

Improved detail can also be obtained through better designed crash reporting forms or supplemental forms. For example, if several states were participating in a study of barriers, it might be possible to redesign the basic state form to include specific lines of questioning if a vehicle struck a barrier, such as barrier type, barrier height, distance from edge of pavement, etc. Of course

this additional detail would much more likely be gained through use of a supplemental form to be filled out in the event of a barrier crash. As noted above, special prompting is also available through the use of portable computers for crash reporting, where menus can appear to lead one through a series of questions for certain kinds of crashes.

Roadside Inventory — As mentioned earlier, collecting roadside inventory information is labor intensive. One way of gathering this data is through use of photologs, videologs or videodiscs. Such a project is currently being conducted as part of the HSIS project at FHWA. Staff are viewing a videolog from Minnesota and then coding/entering information concerning various features on a computer keypad, with the milepost information being automatically extracted from the videodisk system. Such a system could be used to build a file of various kinds of barriers or other fixed objects. The ARVAN vehicle, an automatic recording vehicle connected to GPS/GPI systems, is currently used to collect videolog and pavement information. Conceivably a distance-measuring beam could be focused to the side as the vehicle travels along the roadway so that distance to objects could be obtained as well.

A second possible source of roadside inventory data are computerized state maintenance files. Unfortunately, the maintenance files that the authors are familiar with are usually based on "maintenance sections," with counts for various objects within the section. For example, a section might be one mile in length, and the file would contain counts (but not locations) of the number of feet of guardrail, the number of breakaway signs, the number of catch basins, etc. Since these objects are not tied to a location, it would be difficult to link a specific crash to a specific object. However, these data may be useful in severity related studies since they provide a more detailed description of the object than is found on the accident form and, with some thought and planning, might be useful in accident-based modelling efforts.

Clinical Examination of Police Reports — Police data are not as complete as special supplemental data, but a good bit of clinical information can be obtained from these reports. Highway Safety Research Center staff once used hard copies of barrier crashes in North Carolina to aid Southwest Research Institute in a study concerned with vehicle redirection after a barrier crash *(21)*. A possible study using HSIS data could involve the clinical examination of over 900 impact attenuator crash reports from six different states.

Factors Affecting Current and Future Research

In his paper for this committee last year, Viner (2) noted three factors which may affect both the frequency and severity of roadside object impacts in the future. These include the increased proportion of light trucks and vans in the vehicle fleet, the effects of airbags and anti-lock brakes on the severity and type of hardware impacts, and the effects of aerodynamic front-end styling.

Little can be added to what was noted in the Viner paper concerning the effects of light trucks and vans. As noted there, a TRB paper recently published using North Carolina and Michigan state data and FARS and GES national data examined this issue *(22)*. The overall results indicated that there was no significant difference in the risk of serious and fatal injury between car and pickup drivers when examined for all objects struck or by specific object type. Of interest was the fact that although pickups experienced more rollovers in almost all types of object impacts, the proportion of serious and fatal (A+K) injury for pickups was lower in rollover crashes when compared to rollover crashes for passenger cars. This probably is related to the higher amount of energy required to overturn a passenger car. In essence, the higher rollover risk coupled with the lower rollover injury rates for pickups resulted in the finding of no significant difference between the driver injury for the pickup and the passenger car groups.

However, there was an indication of difference in fatal accidents when the FARS data were compared to exposure based on GES and vehicle registration data. It was concluded that the increase in pickup fatality rate could very well have resulted from the increased risk of ejection in pickups.

The final conclusion drawn was that even though there appears to be a higher risk of fatalities for pickup drivers in impacts with roadside safety hardware, redesign of the hardware may not be the most effective way to solve the problem. Instead, programs aimed at either improving basic vehicle stability or increasing the use of occupant restraints may be more cost effective means. However, given the difficulty that we are now experiencing in increasing use of seat belts among pickup drivers, and the question of whether the automobile industry can indeed improve the basic stability of the vehicle, this issue should not be disregarded by the roadside safety community. In fact, it is the subject of a current NCHRP study.

With respect to the issue related to anti-lock brakes, where reduction in skidding and yawing under hard braking may indeed affect "if" and "where" rollovers occur, there is little additional data that can be added to that developed in the Viner paper. The same is true with the question of whether or not the wedge-shaped profiles of new cars, which are now becoming an increasingly large segment of new car sales, will result in increased problems with cable guardrails and guardrail end systems such as the BCT. While Viner concluded that it will be impractical to answer these kinds of

TABLE 7 SEVERITY INDICES FOR PASSENGER CARS/STATION WAGONS EQUIPPED WITH AIRBAGS — NORTH CAROLINA DATA

Fixed Object	Airbag SI	95% C.I.	N	Non-AB SI	95% C.I.	N	% Decrease
Guardrails (Ends and faces)	0.023	(.000,.058)	87	0.088	(.083, .093)	12,131	73.9%
Trees	0.113	(.077,.149)	292	0.176	(.173,.179)	62,772	35.8%
Utility Poles	0.075	(.036,.114)	173	0.129	(.126, .132)	44,894	41.9%

questions through accident research, we note that it might be worthwhile to at least explore the possibility of developing additional information on these issues. For example, HSIS contains vehicle identification number (VIN) files for the states of North Carolina, Illinois, Utah and Michigan. While none of these states have cable guardrails as a standard roadside safety device, it may be possible to explore the question of whether they do use the BCT end treatment. More specifically, approximately 90% of all guardrail end systems in North Carolina are BCT's, and the North Carolina accident report form separates end impacts from guardrail face impacts. If one could get listings from automobile manufacturers of the vehicles that have this wedge-shaped front profile, and if the sample of these vehicles has now become large enough, it may be possible to extract a subsample of these crashes and examine vehicle damage, rollover, and driver injury in either a clinical study of accident reports or through tabular statistical analysis.

Viner also noted that the conversion of the car, light truck, and van fleet to airbags is now well underway, and that this should result in injury reductions in roadside impacts. Preliminary information on such effects was developed in the soon to be published paper by Council and Stewart (6). In this paper, airbag-equipped vehicles (which were all involved in accidents in the post-1986 era) were identified by decoding VIN's in the North Carolina file. They were then compared to non-airbag vehicles in crashes during the same time period. An attempt was made to develop severity indices for a large number of fixed objects. As would be expected, airbag-related sample sizes for most of the objects were so small that meaningful indices could not be developed.

However, as shown in Table 7, there were somewhat sizable samples of airbag-related fixed object impacts for guardrails, trees, and utility poles. Fortunately, this provides at least some preliminary information on both a barrier-type object and on two point objects. The severity indices are defined as the proportion of serious and fatal driver injury in the impacts.

First, as expected, the airbag-related proportion of severe and fatal injury, which 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. Figure 4 provides the same information graphically. Since there is no apparent reason to assume that the guardrails, trees, or utility poles struck by airbag cars would be necessarily different from those struck by non-airbag cars, the difference seen is, in all likelihood, related to protective effects of the airbags themselves.

The final column of Table 7 presents the percent decrease in the proportion of serious and driver injury shown by the airbag cars. 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 non-airbag vehicles. 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 versus 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 factors with confidence.

What is clear is that there is indeed a difference in the proportion of those drivers who are seriously injured in the airbag cars versus those in the non-airbag cars. 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 still remains unanswered

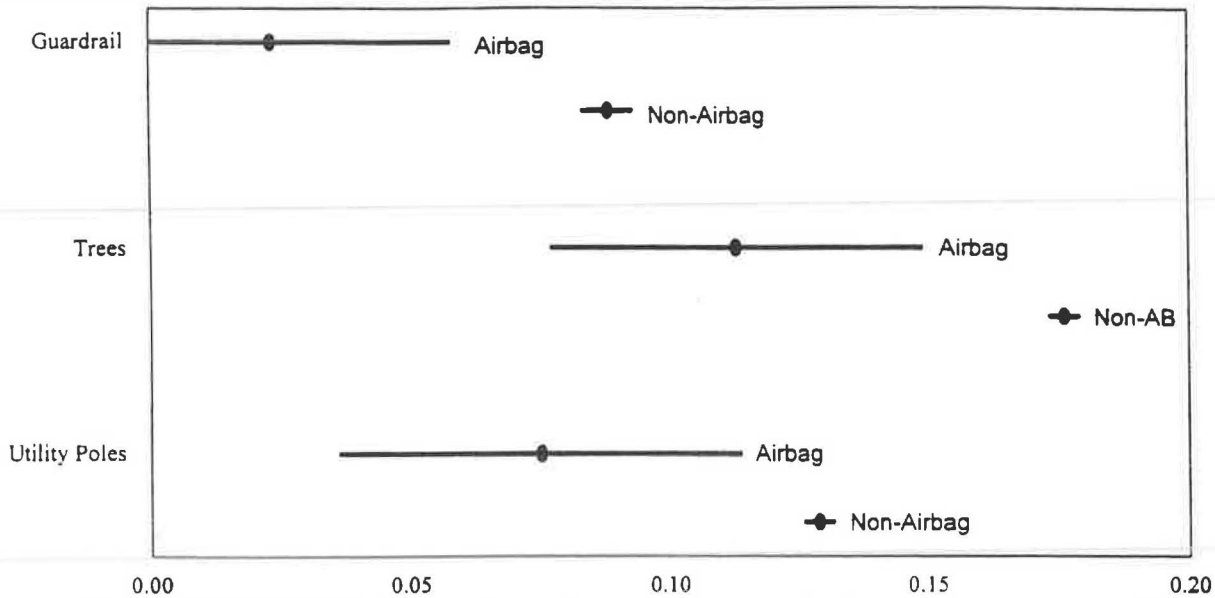

FIGURE 4 Severity indices for airbag and non-airbag passenger cars/station wagons (North Carolina data).

is whether or not the shift to airbags will lead to consistent decreases across all objects or, as these data indicate, lead to differential effects between classes of objects.

Furthering Knowledge

Current NCHRP Projects — The NCHRP has at least the following projects ongoing or planned in regard to roadside safety, which are pertinent to the issues addressed in this paper:

- Project 17-11 — Recovery-Area Distance for Highway Roadsides;
- Project 17-12 — Improved Safety Information to Support Highway Design;
- Project 22-9 — Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features;
- Project 22-11 — Evaluation of Roadside Features to Accommodate Vans, Minivans, Pickup Trucks, and 4-Wheel Drive Vehicles;
- Synthesis Project 20-5 — Highway Guardrail and Median Barrier Crashworthiness;
- Project 22-12 — Guidelines for the Selection, Installation and Maintenance of Highway Safety Features;
- Project 17-13 — Strategic Plan for Improving Roadside Safety;
- Project 17-14 — Effect of Median Width and Slope on the Frequency and Severity of Cross-Median Accidents on Rural Roadways; and
- Project 22-13 — Performance of Roadside Barriers.

The last in the list is a new project that can consider many of the thoughts offered in this paper. There will be an opportunity to plan for and collect a variety of data pertaining to longitudinal barrier and end treatments. There will be an emphasis on barrier condition prior to the crash and performance during the crash. Data will be collected and analyzed on some 1,500-2,000 crashes.

Need for More In-Service Evaluations — In a paper prepared for the A2A04 Committee's 1994 summer meeting *(23)*, Hayes Ross offered the following:

> Both [NCHRP] Reports 230 and 350 pointed out that field evaluation was the final and perhaps most important step in the evaluation of a feature. Both reports provided guidelines by which a feature could be field evaluated. However, to a large extent, field evaluation remains the weak link in the assessment of a feature's performance and suitability for use.

There evidently needs to be a better way to get these evaluations planned and implemented. Perhaps FHWA should take a stronger hand in emphasizing their importance. Perhaps NCHRP pooled fund studies are an outlet by which more could actually be performed, where various states who have features of interest and good records systems would participate. An excellent candidate feature is the single slope concrete median barrier, which is believed to have improved impact performance, especially for small vehicles, when compared to the New Jersey shape. The barrier is gaining increasing acceptance in the U.S.

SUMMARY

With the ever changing fleet and its ever changing safety features, there continues to be the need for studies of the performance of roadside safety features. Real world ran-off-road-crashes occur in many ways, some of which are far removed from the practical worst case scenario embodied in crash tests. What are the effects of more vehicles with air bags and antilock braking systems? What will happen when side air bags become more prominent? What about a proliferation of electric vehicles?

Researchers need to be innovative in using data or data collection techniques not used extensively in the past, such as maintenance data or maintenance personnel to define roadside inventories, encroachments and/or crashes, to help fill gaps. New data will also need to be collected and should be coordinated with existing databases to maximize efficient use of resources. An example would be collecting roadside inventory data in HSIS states and then matching to their crash files. However, before any data are collected, the roadside safety field needs to decide what basic questions are most deserving of answers. For example, what hardware is most important, and what do we know least about? What is deserving of priority treatment?

In summary, there are clear gaps in our existing knowledge of roadside safety measures, and there are gaps in the databases used to build this knowledge. However, with properly targeted funding and creative thought about both new data and use of existing data, the gaps in our knowledge can be filled.

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