THE ROADSIDE SAFETY PROBLEM

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The best picture of the nature of the roadside safety problem requires an appropriate use of information of crashes of all severity outcomes - fatality, injury, and property damage only crashes. Comprehensive crash costs present a rational way to combine this information into an overall measure total crash loss by crash type.

Research by Dr. Ted Miller for the Federal Highway Administration (FHWA) to develop comprehensive crash costs is widely recognized (FHWA, NHTSA, NSC, CDC) as providing the best current crash costs.[1] The Tables in this section use these costs (in 1988 dollars) along with 1985 data for: counts of fatalities from the Fatal Accident Reporting System (FARS); and injury and property damage only (PDO) data from the Continuous Sampling System (CSS) of the National Accident Sampling System (NASS). NASS data are from in-depth investigations of a statistical sample of all crashes in the United States. The level of detail in describing fixed objects in the CSS is better than most State accident data, the reliability is much higher due to case quality review procedures used, and of course the data is nationally representative. Data for 1985 were used as this is the last full year of operation of the NASS CSS.

Counts of fatalities, estimates of injuries and PDO vehicles by most harmful event (MHE) are given in Table 18 (Appendix) along with the percent of loss (or harm) based on the comprehensive costs of reference 1. The overturns shown are limited to cases in which the first harmful event (MHE) occurred outside the shoulder.

Examination of this data for all crashes (not just the ran-off road crashes reported here) reveals that unreported accidents are not likely to change the relative importance of crash losses by crash type shown in these Tables. Most unreported crashes are likely to be PDO crashes. Reported PDO crashes were found to account for just 4 percent of overall crash costs (fatalities 41 percent and injuries 55 percent)[2]. If there are twice as many unreported crashes as reported, as thought by some, only about 8 percent of the true crash costs are not accounted for in police reported crashes. Clearly, unknown crash type losses of around 8 percent due to unreported crashes have no practical effect on these findings.

Tables 1-3 summarize the findings of the ran-off-road crash losses of Table 18:

- Table 1 shows six crash types responsible for 77 percent of crash losses,
- The remaining 24 percent of losses are spread out over 14 crash types (Table 2), and
- Roadside safety devices account for only 10 percent of crash losses (Table 3).

The goal of a strategic plan for roadside safety research should be to reduce, in the best possible way, the losses from ran-off-road crashes. Tables 1-3 can serve as a central guide in this effort.

The remainder of this white paper explores: the leading (and rather amorphous at this point!) loss - overturn; the leading roadside safety device loss - guardrails; and emerging trends which may change these 1985 loss figures (increase in light trucks and vans, airbags, anti-lock brakes, and aerodynamically styled vehicle front ends).

OVERTURN - THE LEADING RAN-OFF-ROAD LOSS (27.5 PERCENT OF LOSS)

Crash Types

For practical purposes, ran-off-road crashes can be classified as either: rollover on slopes and ditches; or fixed object crashes which may or may not involve rollover. With the exception of immersion, all other ran-off-road crash types (parked car, non-fixed object, pedestrian, etc.) are of no interest in roadside safety design.

National fatality counts and estimates of crashes in this section are 1991 data.[3] Fatalities are driver fatalities from FARS data, and crashes are from General Estimate System (GES) data.

GES is a statistical sample of police reported crashes. GES can be used to compare overall fixed object crashes with other crash types like rollovers on slopes and ditches. However, specific object struck codes are of limited use as they represent the lowest common denominator of these codes between the State data in the GES. For example, utility pole, sign support, luminaire support, and other poles are all combined into one GES data element.

Slope Rollovers

Table 5 shows slope rollovers to be 3/4 of all ran-off road rollovers and to account for 1/2 of driver fatalities in ran-off-road rollovers. Fixed object rollovers account for the remainder - 1/4 of rollovers, and the other 1/2 of rollover fatalities. These severe fixed object-rollover crashes are of course split over a wide range of specific

TABLE 1 CRASH LOSSES BY MOST HARMFUL EVENT (MHE) FOR MHES LARGELY ASSOCIATED WITH ROADSIDE OCCURRENCES -1985 (OVERTURNS LIMITED TO THOSE WHICH OCCURRED ON ROADSIDE)

Most Harmful Event	Fatalities	Injuries	PDO Vehicles	Total $Millions	Percent of loss
Overturn	4,820	134,000	32,000	17,786	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%
Conc. Median	N/A	7,000	4,000	329	
Conc. Non-median	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%

TABLE 2 LEADING ROADSIDE CRASH LOSSES (1985)

	%
Overturn	27.5%
Tree	19.3%
Utility Pole	13.6%
Embankment	9.3%
Guardrail	3.9%
Ditch	3.0%
Totals	76.6%

TABLE 3 OTHER ROADSIDE CRASH LOSSES (1985)

	%
Other fixed object	2.7%
Other post	2.5%
Other noncollision	2.4%
Culvert	2.3%
Bridge rail/end	2.1%
Luminaire support	2.1%
Curb	1.7%
Bridge pier	1.4%
Building	1.4%
Median barrier	1.3%
Fence	1.3%
Wall	1.1%
Sign post	0.8%
Shrubbery	0.5%
Totals	23.6%

TABLE 4 ROADSIDE SAFETY HARDWARE LOSSES (1985)

	%
Guardrail	3.9%
Bridge rail/end	2.1%
Luminaire support	2.1%
Median barrier	1.3%
Sign support	0.8%
Impact attenuator	0.01%

crash types such as guardrail end crashes and off-center impacts with trees.

Table 6 compares slope rollover fatalities with specific fixed object (rollover and non-rollover) fatalities. Slope rollovers are seen to be the leading cause of ran-off-road fatalities.

Two-Lane Rural Roads

Table 7 shows slope rollover fatalities to be disproportionaly on rural 2-lane roads - 72 percent of slope rollovers compared to 55 percent of fixed objects. Table 8 shows curves to be a special problem on 2-lane rural roads for both slope rollovers and fixed object crashes - 35 percent of crashes and 1/2 of fatalities occur on curves for both crash types.

Utah Highway Safety Information System (HSIS) data is being examined in an ongoing FHWA staff research study to examine ran-off-road crash risk by horizontal curvature. Slope rollovers and fixed object crashes are combined in this data.

Figure 1 shows the increase in ran-off-road crash risk (crashes per MVMT) on rural 2-lane roads as curvature increases based on 4,676 crashes and over 6 billion vehicle-miles of travel based on the data in Table 9. For comparison, the curvature adjustments of the Roadside Design Guide, based on much more limited data, are also shown. Utah data cannot separate inside of curve and outside of curve crashes, however Hall and Zador found 2/3 of fatal rollovers on curves to be on the outside of the curve.[5]

Vehicle Pre-Crash Orientation

Computer simulation using vehicle dynamics programs is a useful tool to examine the risk of rollover on specific slope and ditch combinations. Such simulations require knowledge of vehicle trajectory characteristics in actual slope rollover crashes.

Vehicle orientation at crash impact is available in 1,000 single vehicle NASS cases reconstructed by Terhune.[4] Figure 2 was developed from this data and shows around 70 percent of slope rollover vehicles to be in a lateral skid at the point of tripping with less than 15 percent of fixed impact vehicles in a lateral skid.[3] Additional trajectory data are shown in reference 3.

TABLE 5 RAN-OFF-ROAD CRASH TYPE BY DRIVER INJURY SEVERITY

Most Harmful Event	No.	%	All Crashes No.	Driver Fatalities %
Slope - Rollover	148,000	15%	2,186	26%
Fixed Object - Rollover	50,000	5%	2,025	25%
Fixed Object - No Rollover	769,000	80%	4,054	49%

Summary

Most ran-off-road rollovers occur on sideslopes and ditches. This specific crash type is the leading cause of roadside fatalities. The outside of horizontal curves on rural 2-lane roads are areas worthy of special attention in efforts to reduce slope rollovers. Research is needed to re-examine both (1) slope design guidelines, and (2) guardrail warranting criteria to address this problem. Valuable insight on specific slope and ditch combinations can be obtained through computer simulation.

GUARDRAIL - THE LEADING ROADSIDE SAFETY DEVICE LOSS (3.9 PERCENT OF LOSS)

End vs. Length of Need

Tables 10-12 examine guardrail end vs.length of need (LON) crashes. Utah data is from HSIS, North Carolina data was provided by the Highway Safety Research Center, LBSS data are from reference 6 and Texas data are from reference 7.

Table 10 shows the percent of end impacts on guardrails from four sources. The LBSS data are from an in-depth study and end impacts shown are upstream end impacts. Texas data are from a review of hard copy of police reports, while Utah and North Carolina data are coded data from police reports. The Utah data is seen to be an outlier. The data seem to suggest a best current estimate of something like 1/4 of guardrail crashes being end impacts. The median length of guardrail in the LBSS file is 370 ft., illustrating the disproportionate involvement of guardrail crashes on ends based on the relative lengths of ends and LONs.

Table 11 shows crash severity in terms of percent of fatal plus incapacitating injuries from the two States with known guardrail end types. The risk of fatal or incapacitating (K+A) injuries in end impacts with these end types are seen to be about 40 percent higher than LON impacts as shown in Table 12 which summarizes these findings.

Summary

Guardrail end impacts represent a disproportionate risk of crash involvement compared to LON based on installed lengths, and the severity of crashes with the most commonly installed end types is higher than LON crashes. Available data are not adequate to determine the relative contributions of specific end design, termination points, and clear zones behind the rail ends in contributing to injuries.

EMERGING TRENDS

Vehicle Fleet Changes

Light Trucks and Vans - In response to the increase in light trucks and vans in the vehicle fleet, NCHRP Report 350 uses a 3/4 ton pickup truck as a replacement test vehicle for the no longer available 4,500 lb car. Examination of six years of accident data involving roadside safety devices in two States (North Carolina - 5,008 crashes, and Michigan - 13,554 crashes) shows no difference in risk of (K+A) driver injury between cars, and light trucks and vans in either State as shown in Tables 13 and 14.[8] Also, no statistically significant differences in risk of K+A injury were found between car and pickup drivers when examined by specific object struck. Table 15 shows the objects closest to showing statistically significant K+A injury risks and an overall comparison of car and pickup truck driver risks.

However, analysis of FARS data in this same study shows drivers in pickups to be at greater risk of fatality in crashes with roadside safety devices than car drivers, Table 16. Ejections in rollovers may explain the differences found in fatalities - 53 percent of pickup driver fatalities were total ejection rollovers compared to 36 percent of car driver fatalities. Seat belt observations in North Carolina indicate pickup drivers have a 20 percent lower belt use rate than car drivers.[9]

Thus, lower belt use rates, combined with the known greater risk of rollover of pickups as compared to cars

TABLE 6 RAN-OFF-ROAD DRIVER FATALITIES BY MOST HARMFUL EVENT

Most Harmful Event	No.	%
Slope-Rollover	2,186	26%
Tree	1,901	23%
Utility Pole	746	9%
Guardrail	576	7%
Slope-No Rollover	457	6%
Culvert	370	4%
Fence	291	4%
Other Objects	1,738	21%
Totals	8,265	100

TABLE 7 DRIVER FATALITIES BY LAND USE AND ROADWAY TYPE

	Rural 2-Lane	Rural Interstate	Rural Other	Urban
Slope Rollover	72%	14%	2%	12%
Fixed Object	55%	6%	3%	37%

TABLE 8 HIGHWAY FEATURE INVOLVEMENT ON 2-LANE RURAL ROADS

	Involved Vehicles		Fatalities	
Highway Feature	Slope Rollover	Fixed Object	Slope Rollover	Fixed Object
Not at junction	94%	85%	97%	96%
55 mph or > speed limit	73%	58%	78%	68%
Dry pavement	60%	57%	85%	81%
Curves	35%	35%	53%	48%
Grades	32%	27%	37%	35%
Construction zone	N/A	N/A	1%	1%

TABLE 9 RUN-OFF-ROAD ACCIDENTS, 2-LANE RURAL ROADS, BY CURVATURE: UTAH, 1985-1987

Degree of Horizontal Curvature	Accidents		Roadway Mileage		Million Vehicle Miles of Travel (MVMT)	Accidents / MVMT
	Total	Percentage	Total	Percentage		
Missing	995	21.3	2204.2	35.8	797.5	1.25
0	2826	60.4	3435.6	55.8	4817.7	0.59
0 - 1	2	0	4.1	0.1	6.3	0.76
1 - 2	7	0.1	12.1	0.2	21.4	
2 - 3	33	0.7	43.4	0.7	46.9	
3 - 4	102	2.2	86	1.4	114.5	
4 - 5	76	1.6	69.2	1.1	80.1	1.09
5 - 6	79	1.7	52.7	0.9	62.4	
6 - 7	71	1.5	47.2	0.8	54.2	1.37
7 - 8	50	1.1	32.3	0.5	34.3	
8 - 9	38	0.8	25.7	0.4	28.8	1.63
9 - 10	45	1	19.6	0.3	22	
10 - 20	231	4.9	87.1	1.4	107.4	2.15
20 - 30	73	1.6	23.1	0.4	21.8	3.2
30 - 40	18	0.4	6.8	0.1	5.3	
40 - 50	15	0.3	4.3	0.1	4	
> 50	15	0.3	6.3	0.1	6.7	
Total	4676	100.0	6159.6	100.0	6231.2	0.75

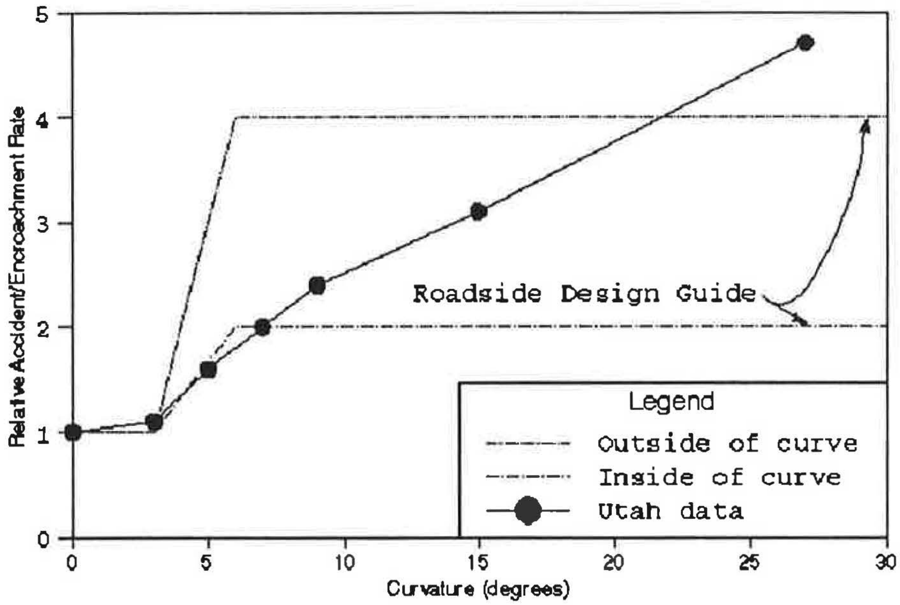

Figure 1 Utah 2-lane rural roads (4676 Accidents/6231 MVMT).

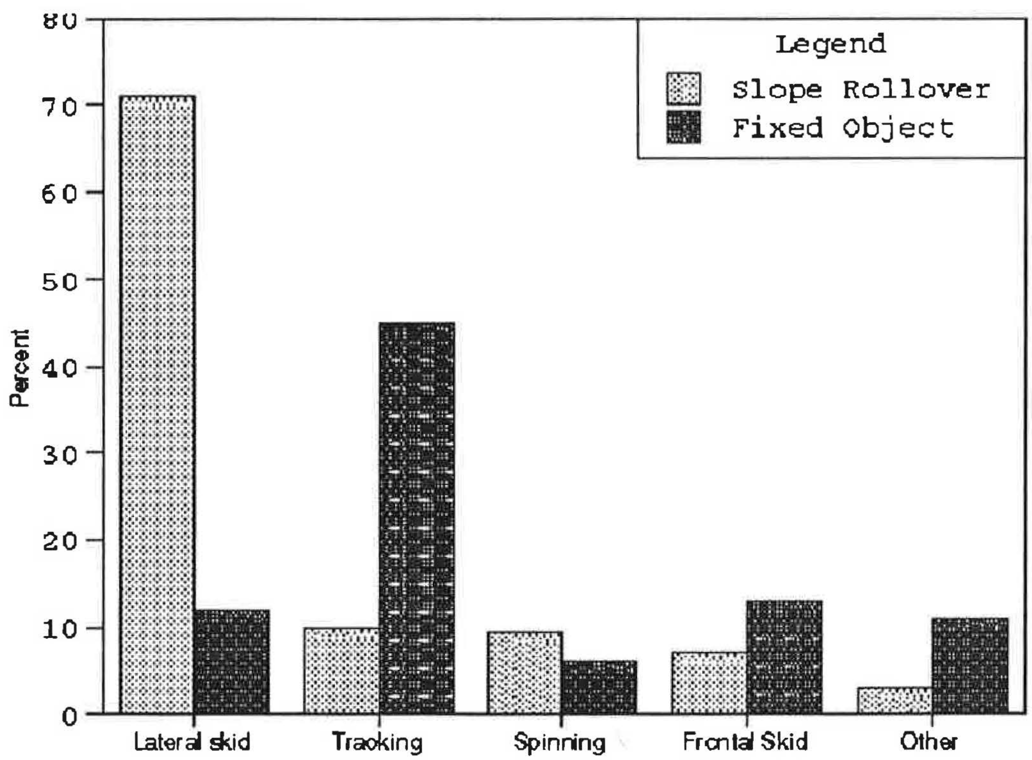

Figure 2 Vehicle pre-crash orientation.

may well explain the differences seen in fatality risk. Redesigning roadside safety hardware to reduce pickup rollover risk may not be cost effective.

Air Bags and Anti-Lock Brakes

Complete conversion of the car, light truck and van fleet to driver and right front air-bags is now well underway. Crash severity reduction achieved by this major change will probably differ by crash type. Air bags are likely to reduce the severity of object crashes more than rollovers.

Currently, 40 percent of new cars are equipped with anti-lock brakes which reduce skidding risk. The NHTSA has published an advanced notice of proposed rulemaking on the issue of requiring antilock brakes to reduce rollover risk.(10) Figure 2 shows that anti-lock brakes have the potential to reduce slope rollovers more than fixed object crashes.

Aerodynamic Vehicle Front End Styling

Wedge-shaped front profiles of cars, a style once seen only in sports cars, are an increasingly large segment of new car sales. These vehicles can present underride problems in crashes with traffic rails such as the G1 cable guardrail, and guardrail ends such as the BCT or eccentric loader terminal, figures 3 and 4.(11,12)

Emerging trends such as the compatibility of wedge-shaped cars with these specific safety hardware types are topics worthy of research, however it is impractical to answer these kinds of questions through any kind of accident research.(13)

Summary

The "practical worst case" test philosophy of NCHRP Report 230 has provided about the same level of protection to drivers of pickups, vans and cars if the measure of safety is likelihood of serious (K+A) injury. It may prove impractical to provide equal levels of protection against fatality as differences in inherent vehicle stability combined with belt use rates seem to be the major factor in these differences. This then raises the question, will the resources spent to comply with the NCHRP Report 350 pickup tests improve safety?

An air bag equipped vehicle fleet with a growing percentage of anti-lock brakes will change the current ran-off-road loss picture. Ran-off-road losses should be re-examined in a few years when enough data becomes available. Also, the injury tolerance standards of NCHRP Report 350 may need to be revised as they assume unbelted vehicle occupants. Put another way, will decisions based on the injury criteria of NCHRP Report 350 prove to be cost effective as cars and light trucks become driver and right front air-bag equipped by the time these devices are deployed in any number?

TABLE 10 GUARDRAIL END CRASHES PERCENT OF ALL GUARDRAIL CRASHES

	All	Percent on Ends
Utah	2,482	5
North Carolina	2,360	26
LBSS	993	33
Texas	834	21

TABLE 11 GUARDRAIL CRASH SEVERITY PERCENT (K+A) INJURIES

	End	LON
Turned Down (TX)	14.3%	10.6%
BCT/Blunt (NC)	13.5%	9.1%

TABLE 12 GUARDRAIL END VS. LENGTH OF NEED

	End	LON
Number	1/4	3/4
(K+A) Injuries	14%	10%

TABLE 13 DRIVER INJURY BY VEHICLE TYPE, NORTH CAROLINA

	Car	Pickup	VanUtil.
K	0.7%	1.2%	1% 2%
A	6.9%	7.0%	7% 8%
B	13.1%	12.1%	16% 9%
C	17.1%	16.4%	13%18%
O	62.2%	63.4%	63%62%
N3,687	887	141	109
	p=0.38 NS		

TABLE 14 DRIVER INJURY BY VEHICLE TYPE, MICHIGAN

	Car	Pickup	Util.Van
K	0.4%	0.5%	1% 0
A	3.5%	3.2%	2% 2%
B	7.0%	7.8%	6% 5%
C	10.1%	10.4%	9% 8%
O	78.9%	78.1%	83%84%
No.	10,731	2,388	244191
		p=0.50 NS	

TABLE 15 CARS VS. PICKUP TRUCKS BY OBJECT STRUCK, NORTH CAROLINA

Object	Vehicle	(K+A)	Number	p
Guardrail face	Car	6.1%	1,623	0.14
	Pickup truck	8.2%	429	
Guardrail end	Car	18.7%	475	0.16
	Pickup truck	13.0%	93	
Median barrier	Car	5.0%	185	0.16
	Pickup truck	12.0%	42	
All	Car	7.5%	3,687	0.68
	Pickup truck	8.2%	887	

TABLE 16 RURAL DRIVER FATALITIES (FARS) AND CRASHES (GES) GUARDRAIL, MEDIAN BARRIERS, IMPACT ATTENUATORS

	Fatalities		Crashes		
	Number	Percent	Number	Percent	
Cars	223	70%	46,600	88%	
Pickup	75	24%	4,600	9%	(1)
Van	12	4%	1,500	3%	
Utility	9	3%	500	1%	
Totals	319	100%	53,200	100%	

(1) 95% confidence limits -- 4.4% to 13.3%

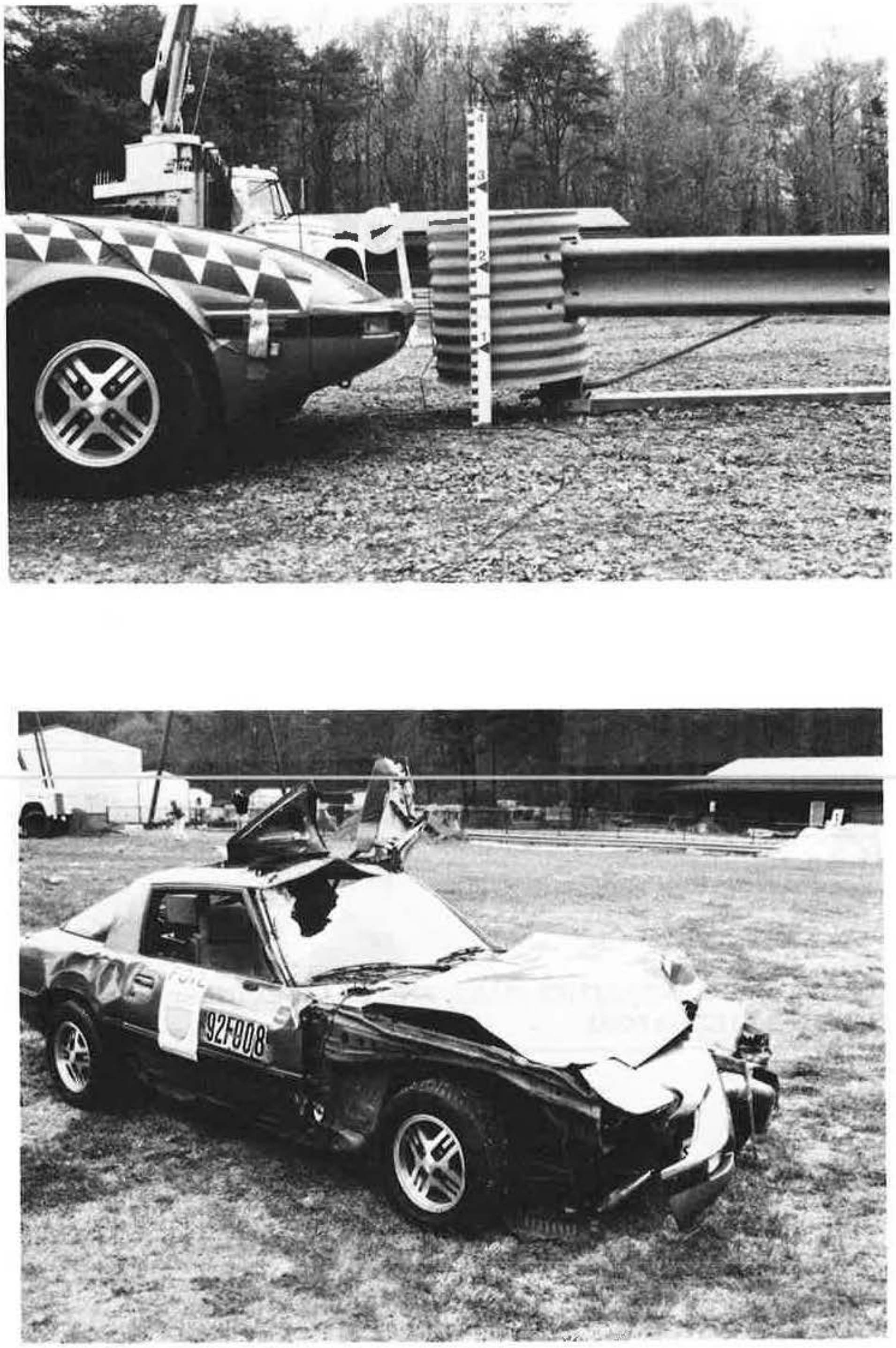

Figure 3 Wedge-Shaped Vehicle and Eccentric Loader Terminal.

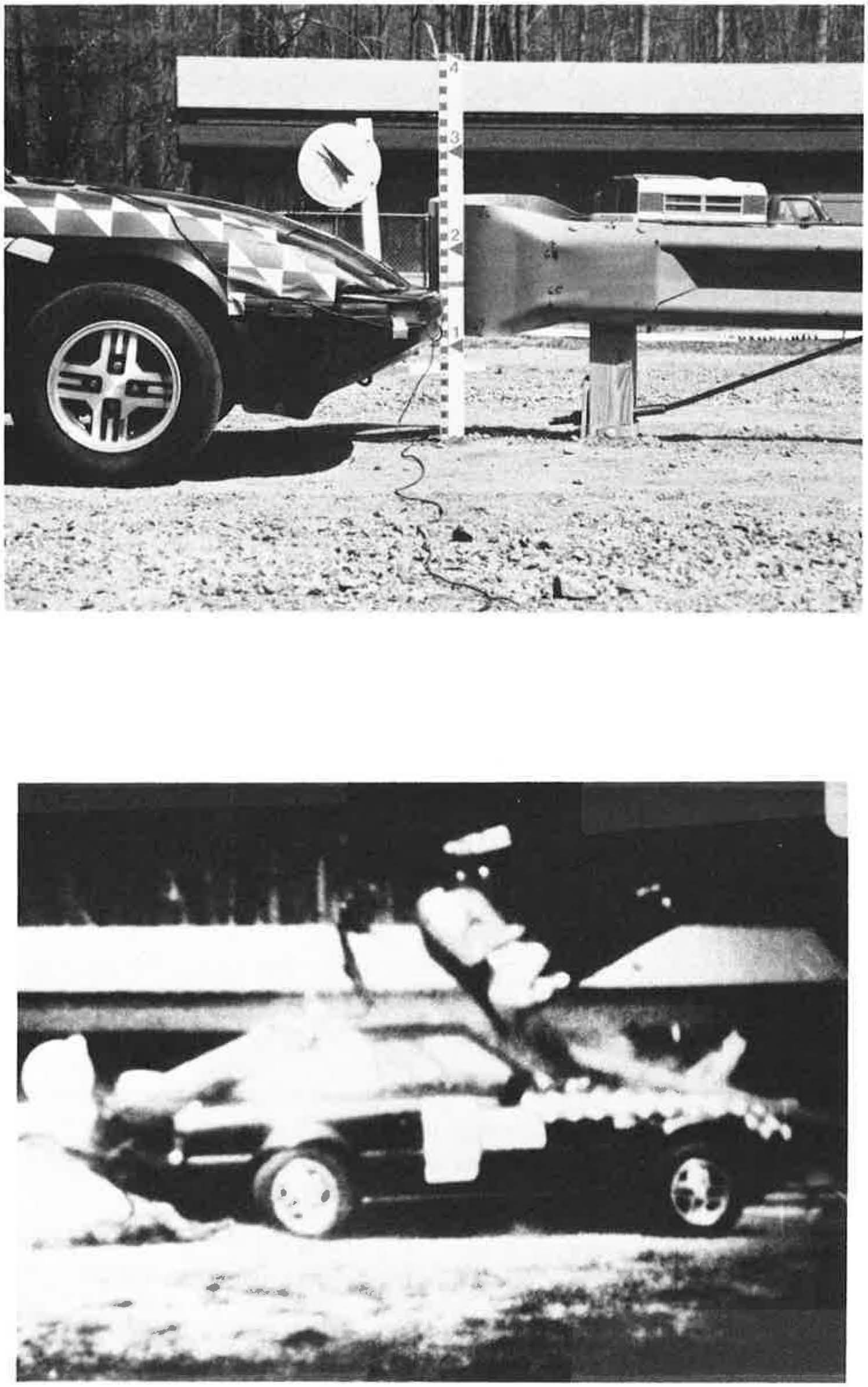

Figure 4 Wedge-Shaped Vehicle and Breakaway Cable Terminal.

TABLE 17 MEASURES TO ADDRESS THE LEADING RAN-OFF-ROAD-CRASH LOSSES

Overturn	27.5%
●Rollovers on sideslopes and ditches (3/4 of overturns)	
- Slope design standards	
- Guardrail warrants	
Tree	19.3%
●Review clear zone standards	
Utility pole	13.6%
●Implementation - bury, relocate, make breakaway	
Embankment/Ditch	12.3%
●Slope design standards	
●Guardrail warrants	
Guardrail	3.9%
●End impacts	
- Termination points - clear zones	
- In service performance of existing designs	

TABLE 18 ROADSIDE SAFETY HARDWARE LOSSES

Guardrail	3.9%
Bridge rail/end (includes unshielded ends)2.1%	
Luminaire support (includes non-breakaway supports)2.1%	
Median barrier	1.3%
Sign post (includes non-breakaway supports)0.8%	
Impact attenuator	0.01%
Total	10.2%

TABLE 19 EMERGING ISSUES

Air bags in 100% of vehicle fleet - revising crash severities
●Updated severity indices needed
●Reduce severity of object crashes more than rollovers?

Anti-lock brakes - 40% of new cars
●Reduce number of rollovers more than fixed object crashes?

More light trucks and vans in fleet
●Will resources spent to comply with NCHRP Report 350 improve safety?

A PROGRAM TO ADDRESS THE PROBLEM

Tables 17-19 address, in outline form, findings and recommendations from this look at the roadside safety problem. Table 17 presents suggestions to address the leading losses of Table 2.

Both re-examining slope and ditch design standards and guardrail warrants are recommended to identify cost effective solutions to the leading roadside safety problem - slope rollovers. These efforts might also be helpful for crashes coded as embankment or ditch.

Updating clear zone standards is a suggested way to address the tree problem. NCHRP Project 17-11 is currently soliciting proposals on this topic.(14) Due to funding limitations of this effort, a follow-on study may be needed in this area.

The utility pole problem might be best addressed by implementing what we already know. Burial of utility lines creates aesthetic as well as safety advantages, relocation and collocation of poles and breakaway supports are other safety options.

Research needed to make meaningful improvements to roadside benefit/cost models such as NCHRP Project 22-9 and FHWA's Interactive Highway Safety Design Model research program should aid implementation efforts to reduce these losses.(15,16)

Altogether, roadside safety structures account for an estimated 10.2 percent of ran-off-road crash losses (Table 18). Overturns subsequent to impact with these structures are not included in this estimate and would increase these totals. However, unshielded bridge ends, and non-breakaway sign and luminaire support crashes are unavoidably included in these figures and would reduce this estimate. Study of termination points, clear zones and in-service performance of newer guardrail end designs would seem to be the highest priority to reduce these losses.

Excluding guardrail, roadside safety device losses account for 6.3 percent of ran-off-road crash losses. Clearly research in this area should be focused on specific identified problems such as those relating to emerging wedge-shape car front profiles.

Emerging issues are summarized in Table 19. Introduction of airbags and anti-lock brakes will create a need to update crash test injury evaluation criteria, severity indices and to re-examine overall ran-off-road crash losses. Compliance testing to meet the pickup test requirements of NCHRP Report 350 may not improve safety.

REFERENCES

1. *The Costs of Highway Crashes,* T. Miller, J. Viner, S. Rossman, N. Pindus, W. Gellert, J. Douglas, A. Dillingham, and G. Blomquist, FHWA-RD-91-055, October 1991.
2. *Harmful Events in Crashes,* John G. Viner, Accident Analysis and Prevention, Vol. 25, No.2, pp.139-145, 1993.
3. *Rollovers on Sideslopes and Ditches,* John G.Viner, 38th Annual Proceedings, Association for the Advancement of Automotive Medicine, September 21-23, 1994, Lyon, France.
4. *Crash Avoidance Research - Stability and Control, Task 2, Contributions of Vehicle Factors and Roadside Features to Rollover,* by K.W. Terhune, National Highway Traffic Safety Administration, January 1991.
5. *A Survey of Single Vehicle Fatal Rollover Crash Sites in New Mexico,* J.W. Hall and P. Zador, Insurance Institute for highway Safety, November 1980.
6. *An Analysis of Guardrail and Median Barrier Accidents Using the Longitudinal Barrier Special Studies (LBSS) File,* Olugbenga Erinle, William Hunter, Maurice Bronstad, Forrest Council, Richard Stewart, and Kathleen Hancock, FHWA-RD-92-098, February 1994.
7. *An Analysis of Accidents on Turned Down Guardrail Ends in the State of Texas (Calendar Year 1989),* Lindsay I. Griffin, III, Texas Transportation Institute, Report 9901-H, May 1991.
8. *Frequency and Severity of Crashes Involving Roadside Safety Hardware by Vehicle Type,* John G. Viner, Forrest M. Council, and J. Richard Stewart, Paper 940894, Transportation Research Board, January 1994.
9. *Occupant Restraint Monitoring Program,* D. W. Reinfurt, J.Stewart, N.Weaver, and A.Green, Highway Safety Research Center, November 1991.
10. Advanced Notice of Proposed Rulemaking, *Federal Motor Vehicle Safety Standards: Antilock Brake Systems for Light Vehicles*, NHTSA, Docket 93-94; Notice 1, Federal Register, January 4, 1994.
11. *Importance of Vehicle Structure and Geometry on the Performance of Roadside Safety Features,* M. H. Ray, M. E. Bronstad, and J.G. Viner, SAE Paper 870076, February 1987.
12. *Low Profile Vehicle Crash Tests into Guardrail Terminals*, Christopher Brown, DTFH61-91-Z00002, Test Report, April, 1992.
13. *Overview on Use of In-Depth Accident Data,* King K. Mak and John G. Viner, SAE Paper 870076, February 1987.
14. *Recovery-Area Distance Relationships for Highway Roadsides,* NCHRP Project 17-11.
15. *Improved Procedures for Cost-Effectiveness Analysis of Roadside Safety Features,* NCHRP Project 22-9.
16. *The Interactive Highway Safety Design Model: Designing for Safety by Analyzing Road Geometrics,* Jerry A. Reagan, Public Roads, Vol.58, No.1, pp.37-43, Summer 1994.