Frequency and Severity of Crashes Involving Roadside Safety Hardware by Vehicle Type

JOHN G. VINER, FORREST M. COUNCIL, AND J. RICHARD STEWART

FHWA has issued a final rule in response to Section 1073 of the Intermodal Surface Transportation and Efficiency Act of 1991 legislation requiring rule-making on revised guidelines and standards for acceptable roadside barriers and other safety appurtenances to accommodate vans, minivans, pickup trucks, and four-wheel-drive vehicles. This rule lists *NCHRP Report 350* for guidance in determining the acceptability of roadside safety devices. *NCHRP Report 350* recommends use of a ¾-ton pickup as a replacement for the previously used 4,500-lb car in roadside safety device crash tests. The question of whether there are differences in the relative safety experiences in crashes with roadside safety hardware by vehicle body type is addressed by using data from North Carolina, Michigan, and the Fatal Accident Reporting System, General Estimates System, and R. L. Polk vehicle registration files. The data suggest that the practical worst-case test philosophy of current roadside safety device evaluation procedures has provided about the same level of protection to drivers of pickups, light vans, and utility vehicles as to passenger car drivers if the measure of safety is to be the likelihood of serious (fatal plus incapacitating) injuries. If, on the other hand, the measure of safety is to be the likelihood of fatalities, this does not appear to be the case: drivers of pickups were found to be at greater risk. The likely reason for the greater risk of fatalities found for pickup drivers is ejection in rollovers. Programs to increase seat belt use and other measures to reduce ejection rates in rollovers of pickups should be considered to reduce this risk.

Most roadside hardware acceptance test programs have used the minimum crash test matrix of *NCHRP Report 230* since its publication in 1981 (*1*). This minimum crash test matrix consists of tests using passenger cars in the 1,800- to 4,500-lb range. Section 1073 of the Intermodal Surface Transportation and Efficiency Act of 1991 legislation required the Secretary of Transportation to initiate rule-making on revised guidelines and standards for acceptable roadside barriers and other safety appurtenances to accommodate vans, minivans, pickup trucks, and four-wheel-drive vehicles. On July 16, 1993, FHWA published the final rule in response to this requirement in the *Federal Register* (*2*), listing *NCHRP Report 350* (*3*) "for guidance in determining the acceptability of roadside barriers and other safety appurtenances for use on National Highway System (NHS) projects." In particular, the testing requirements of *NCHRP Report 350* "uses a ¾-ton pickup truck as the standard test vehicle in place of the no-longer available 4,500-lb passenger car to reflect the fact that almost one-quarter of the passenger vehicles on U.S. roads are in the 'light truck' category." This paper examines the relative safety experiences in crashes with roadside safety hardware by these vehicle body types.

J. G. Viner, Turner-Fairbank Highway Research Center, HSR-20, 6300 Georgetown Pike, McLean, Va. 22101. F. M. Council and J. R. Stewart, Highway Safety Research Center, University of North Carolina, Chapel Hill, N.C. 27599-3430.

North Carolina and Michigan state accident data were used to compare the relative severities of roadside safety hardware crashes involving these vehicle types. National counts of driver fatalities from Fatal Accident Reporting System (FARS) data were used both to define the size of the problem by vehicle type and to identify the vehicle types that appear to be overrepresented in hardware-related fatal crashes when compared with the estimated numbers of nationwide crashes into hardware from the General Estimates System (GES) files and with national numbers of registered vehicles from R. L. Polk vehicle registration files.

METHODOLOGY

Potential differences in driver injury by vehicle body type—passenger cars, pickup trucks, utility vehicles, vans, and other light trucks—were examined in crashes involving roadside safety hardware, which included guardrails, median barriers, bridge rails, impact attenuators, sign supports, and luminaire supports. Both state (North Carolina and Michigan) and national (FARS and GES) crash data were analyzed. Polk registration data were also compared with FARS data. The actual objects examined from these different files varied somewhat because of differing data element definitions. For example, luminaire supports were excluded from the Michigan analyses since they are combined with much larger counts of utility poles, which are not breakaway, in the same data element.

State data were used to compare driver injury severities by vehicle body type by using statistical analyses of two-way and multiway contingency tables. To further investigate the relationships between injury and vehicle type while taking into account interactions with the object struck and highway class (as a surrogate for roadside design), a series of logistic categorical data models was analyzed.

To identify vehicle types that are overrepresented in fatal hardware-related crashes, driver fatalities from the nationwide FARS (fatality) data were compared with both the proportion of body types involved in similar crashes estimated by GES data and the proportion of body types among all nationally registered vehicles obtained from Polk vehicle registration data. Again, contingency tables were used. In addition, counts of driver fatalities (FARS) were used to examine the size of the roadside hardware crash problem by vehicle body type.

There are known limitations to the use of both the state files and the FARS, GES, and Polk files in these analyses. State accident files cannot account for the differences in the percentage of crashes that are unreported that may exist between vehicle types, and thus may distort differences in crash severity comparisons by vehicle type. For example, if a given vehicle type was less likely to sustain major property damage in a low-speed impact or if drivers of a certain vehicle type fail to call police in more crashes involving no or minor injuries, then the severity of crashes in the police-reported accident file would be biased toward the severe end of the injury distribution for that vehicle type. In addition, accident findings in one state may not accurately reflect either the accident experience in another state or the average national experience. Indeed, data from two states were used in this analysis as a check on the consistency of findings.

Vehicle registration data as a surrogate for exposure to crashes into hardware cannot account for differences in driving patterns such as urban and rural usage. Vehicles driven proportionally more in rural locations than in urban locations will have underestimated exposures to rural crashes on the basis of registration numbers and would thus produce inflated rural fatality rates.

GES data can control for driving pattern differences such as rural and urban exposure; however, they are themselves estimates of national numbers of crashes, which are based on samples of police-reported accident files. Thus, numbers derived from GES data should be used in conjunction with their standard deviations to account for sampling error, and GES data are subject to the same underreporting bias as the state data.

FARS data as a census of fatal crashes do not suffer from missing data, national representativeness, or sampling bias problems. However, fatal crashes may have characteristics different from those of nonfatal crashes. For example, the percentage of fatalities from FARS data for certain vehicle–object-struck combinations may differ from the percentage of fatalities for all crash severity levels.

The authors are not aware of any data files that do not suffer from these known defects. However, it is the authors' opinion—even in consideration of these limitations—that these files can provide valuable insight on both the relative risk to occupants in crashes with roadside hardware and the magnitude of the problem by vehicle body type.

THE DATA

State Data

Driver injury observations from North Carolina and Michigan for rural single-vehicle crashes involving the specified vehicle types with selected fixed objects for 6 years (1985 to 1990) were used. Although the North Carolina data were obtained directly from the state, Michigan data were available from FHWA's Highway Information System. Since current crash test procedures call for mostly high-speed (60-mph) testing, the use of only rural data was intended to examine crashes at sites with a greater likelihood of high-speed crashes. Driver injury severity in both cases was taken from the reporting police officer's estimate of injury, using the KABCO injury scale (i.e., with *K* indicating killed, *A*, *B*, and *C* denoting progressively less severe injuries, and *O* representing a property damage-only crash).

The North Carolina data were limited to rural, single-vehicle ran-off-road or fixed-object crashes in which one of the following objects was struck: luminaire support, official highway sign, guardrail face, guardrail end, barrier face, barrier end, or crash cushion. (In cases in which more than one fixed object is struck—e.g., a breakaway sign and then a guardrail end—the North Carolina officer is instructed to code the one causing the most damage, i.e., in this example the guardrail end.) In addition, the cases were restricted to those in which the most harmful event (MHE) was judged by the investigating police officer to be either a fixed object or an overturn. Case vehicles were restricted to 1,800- to 4,500-lb passenger cars (excluding station wagons), pickup trucks, utility vehicles, and vans. The 1,800- to 4,500-lb weight range specified for passenger cars matches the weight range of cars used in *NCHRP Report 230* (*1*) test procedures for roadside safety hardware. The resulting data contained 5,008 records.

The Michigan data were limited to rural, single-vehicle accidents in which the accident type was either an overturn or a fixed-object accident and in which one of the following objects was struck: guardrail or guard post (with ends not separated from faces), highway sign, or median barrier. The vehicle types examined were passenger car, pickup truck, utility (jeep-type) vehicle, and passenger van, as defined by the investigating officer. The resulting data contained 13,554 records.

The constraints to single-vehicle crashes and to those in which the MHE involved either a fixed object or a rollover limit the data, as close as possible, to cases in which the cause of greatest harm is the fixed object of interest. In addition, in many, perhaps most, rollovers that occur subsequent to striking a fixed object, the vehicle tripping mechanism is the impact with the object, and thus the object can be said to be the cause of greatest harm in the crash. However, some intervening impact with a feature such as a ditch could also be the cause of rollover.

Michigan data, however, unlike North Carolina data, do not allow one to identify the most harmful object in crashes in which more than one object is struck. Multiple struck objects are a rather common occurrence. For example, Illinois data show that 41 percent of 411 crashes fatal to the driver or Type A injury crashes in which the first harmful event was a highway sign also involved a second crash event with some other object. Michigan data were not used to examine crash severity by type of object struck in this study since the Michigan data are not as specific as the North Carolina data in terms of linking driver injury to a specific object.

FARS, GES, and Registration Data

The fatal crash data are 1988 driver fatalities from single-vehicle FARS crashes in which the first harmful event (FHE) involved an impact attenuator, bridge rail, guardrail, concrete traffic barrier, sign support, or luminaire support. The cases were restricted to those in which the MHE was identical to the FHE or was a rollover, under the same logic cited earlier. Unlike the state data, which covered the 6-year period between 1985 and 1990, the FARS analysis is for 1988 because later years of Polk data were not available. Unlike fatalities obtained from the state data, all fatalities (rural and urban) were examined to look at the national extent of the problem by body type. FARS comparisons with GES data and Polk registration data were limited to rural crashes for consistency with analyses of the state data.

The GES data are from the 1988 file and are as similar as possible to the FARS data and state data cited earlier. The GES data base is a companion to the FARS data and represents a probability sample of all severities of police-reported traffic crashes in the United States. The data are captured from state crash files by NHTSA-contracted coders and are reviewed and checked for quality control by NHTSA. The FHEs used in the GES (and in the FARS data when they are compared with GES data) were limited to guardrails, median barriers, and impact attenuators. Bridge rails were eliminated because they are combined in the same GES data element as bridge piers and abutments, which are not roadside safety hardware. Similarly, sign and luminaire supports were excluded because they are combined in the same GES data element with (the much more numerous) utility poles.

The 1988 Polk data used were extracted from vehicle registration data files compiled by Polk for every year since 1975. The data are counts of registered vehicles in each state in the United States as of July 1 of each year. Polk data include vehicle body type, manufacturer, model, model year, curb weight, and wheel base.

RESULTS

State Data

North Carolina Data

Initial analysis involved examination of two-way contingency tables to examine the relationship of driver injury to vehicle type, object struck, highway class, and rollover presence and the relationship of each of these variables to each other. The purpose was to define the variables that are important to the issue of differences in injuries due to vehicle type and to define the other control variables that must be included in a more detailed examination. These analyses indicated the following.

First, when all roadside objects are grouped together, the data and associated statistical tests (i.e., χ^2 statistic) suggest that overall, without taking into account any potentially intervening variables (although the pickups, utility vehicles, and vans appear to have slightly more severe serious injury distributions), injury severity does not vary significantly among vehicle types (Table 1).

As expected, the data indicated a strong association between rollover and driver injury when all vehicles are grouped, with rollover resulting in more severe injuries and the likelihood of rollover differing by vehicle type. Utility vehicles are most likely to roll over (43.1 percent of the impacts), passenger cars are least likely to roll over (13.5 percent of impacts), and the likelihood of rollover for the other two vehicle types is about midway between those for utility vehicles and passenger cars (i.e., pickups, 25.7 percent; vans, 24.7 percent).

The results presented to this point may seem puzzling. In particular, pickups, vans, and other light trucks are more likely to roll over, and rollover results in more severe injuries. However, no differences in overall injury severity by vehicle type are found in these collisions. This issue is addressed in Table 2. In Table 2, pickup trucks, utility vehicles, and vans are combined (PUVs) for comparison with passenger cars. (In a second set of analyses the pickup trucks alone were compared with the passenger cars.) The injury severity variable was also dichotomized as no injury, Type C injury, or Type B injury versus Type A injury or K (minor to moderate injury versus incapacitating and fatal injuries). The latter combined category will be referred to as serious or $A + K$ injuries in the remainder of the paper.

Table 2 is a three-way breakdown of injury severity by vehicle class for rollover crashes and non-rollover crashes, separately. The 3,481 observations in Table 2 reflect the fact that approximately 28 percent of the rollover variable observations were uncoded. In the data that were coded, PUVs were again found to have significantly higher rollover rates (26.8 percent) than cars (13.2 percent). Note that crashes with cars resulted in slightly (but not significantly) higher serious injury rates in both subtables.

Expressions for probabilities of injuries in cars and PUVs can be written in terms of conditional probabilities of rollovers as

$$P(\text{injury/car}) = P(\text{injury/rollover, car})\, P(\text{rollover/car}) + P(\text{injury/no rollover, car})\, P(\text{no rollover/car})$$

$$P(\text{injury/PUV}) = P(\text{injury/rollover, PUV})\, P(\text{rollover/PUV}) + + P(\text{injury/no rollover, PUV})\, P(\text{no rollover/PUV}).$$

Use of proportions from the generated tables as estimates of the conditional probabilities gives

$$P(\text{injury/car}) = (0.2167)\,(0.1322) + (0.0601)\,(0.8678) = 0.0808$$

$$P(\text{injury/PUV}) = (0.1970)\,(0.2678) + (0.0486)\,(0.7322) = 0.0883$$

TABLE 1 Driver Injury Severity (KABCO) by Vehicle Type (North Carolina data)

Vehicle Type	Injury Severity					
Frequency Row Pct	None	C	B	A	K	Total
Car	2293 62.19	631 17.11	485 13.15	254 6.89	24 0.65	3687
Pickup Truck	562 63.36	145 16.35	107 12.06	62 6.99	11 1.24	887
Utility Vehicle	68 62.39	20 18.35	10 9.17	9 8.26	2 1.83	109
Van	89 63.12	19 13.48	22 15.60	10 7.09	1 0.71	141
Total	3012	815	624	335	38	4824

χ^2(12 d.f.) = 9.2   p = .69

TABLE 2 Driver Injury Level by Rollover and Vehicle Class (North Carolina data)

Rollover Status	Vehicle Class	Injury Severity Level		
		None, C, B	A, K	Total
Rollover	Car	282 78.33	78 21.67	360
	PUV	163 80.30	40 19.70	203
	Total	445	118	563
		χ^2_1 = 0.304	p = .582	
No Rollover	Car	2221 93.99	142 6.01	2363
	PUV	528 95.14	27 4.86	555
	Total	2749	169	2918
		χ^2_1 = 1.124	p = .289	
Total		3194	287	3481

Thus, although PUVs have significantly higher rollover rates and significantly higher injury rates are associated with rollovers, PUVs have slightly lower serious injury rates given rollover and given non-rollover crashes. These two effects tend to cancel each other to yield roughly similar overall injury rates, the result being about a 9 percent higher rate for crashes involving PUVs than for those involving cars (8.8 versus 8.1 percent).

To see if this canceling effect continues to hold when other factors are taken into account, a series of logistic categorical data models were analyzed. Although the details of this analysis are not presented here, models examining injury with and without rollover as a predictor variable indicated the same findings as those obtained in the analyses presented earlier. First, the driver injury proportions vary significantly with object struck, but not with vehicle type. Second, although predicted rollover rates were higher for PUVs than for cars in every subpopulation examined and although rollover is a very powerful predictor of injury, injury rates for the PUVs were not higher than the injury rates for cars.

Michigan Data

As noted earlier the basic data file was created to be as similar as possible to the North Carolina data file, using similar accident years and crash-type restrictions. The resulting data file contained records for 13,554 vehicles involved in crashes.

As was the case with North Carolina data, the overall distributions of driver injury severity do not differ significantly by vehicle type (Table 3). The injury distributions for cars and pickup trucks are virtually identical, as are those for vans and utility vehicles, with the latter groups having less severe injuries.

Rollover rates again differ significantly by vehicle type, with the rank order for Michigan (from low to high) of car (1.88 percent),

TABLE 3 Driver Injury Severity by Vehicle Type in Michigan Fixed-Object Crashes

Vehicle Type	Injury Severity					
Frequency Row Pct	No Injury	Possible Injury	Non-incap. Injury	Incapac. Injury	Fatal	Total
Car	8469 78.92	1088 10.14	757 7.05	371 3.46	46 0.43	10731
Pickup Truck	1867 78.18	248 10.39	185 7.75	76 3.18	12 0.50	2388
Utility Vehicle	202 82.79	21 8.61	14 5.74	5 2.05	2 0.82	244
Van	161 84.29	16 8.38	10 5.24	4 2.09	0 0.00	191
Total	10699	1373	966	456	60	13554

X^2_{12} = 11.34 p = .500

pickup truck (3.76 percent), vans (3.80 percent), and utility vehicles (5.46 percent) being the same as that for North Carolina. North Carolina rollover rates, however, were much higher (by a factor of about 6) than the Michigan rollover rates. This difference may be due mostly to varying accident type classifications. Although there is a separate variable for rollover in the North Carolina file (which measures rollover cases in combination with any accident type), rollover is noted as an accident type only in Michigan. This could mean that vehicles that strike fixed objects and that then overturn (the cases of interest) may be classified as fixed-object crashes rather than overturn crashes. Since the Michigan rollover variable is of questionable validity for the purpose of this study, no further analysis of rollovers was done.

From the tables presented, it seems clear that the likelihood of A + K driver injury in roadside appurtenance impacts does not differ appreciably between passenger cars, pickup trucks, vans, and utility vehicles. The relationships between vehicle type and driver injury found in the Michigan data are in very good agreement with those found in the North Carolina data. The major differences in the two data sets are the generally more severe crashes (in terms of driver injury) and the much higher rollover rates for North Carolina (likely due to coding differences).

Pickup Trucks Versus Passenger Cars

Taken together the (*a*) large proportion of pickup trucks in the non-passenger car PUV groups, (*b*) results of FARS analysis presented later in this paper, and (*c*) selection of a pickup truck as the replacement test vehicle for the 4,500-lb car in *NCHRP Report 350* (*3*) indicate a need to compare pickup trucks with cars by using state data. Object struck by vehicle type and by driver injury for North Carolina data is examined in Table 4. Again, driver injury is dichotomized as A + K (serious) injury versus lesser or no injury.

For the North Carolina data there are no statistically significant differences between injury within any of the five object types. A Cochran–Mantel–Haenzel statistic summarizing across all objects likewise shows no statistical significance ($p = .318$), indicating no overall difference in serious injuries between the two vehicle types.

Guardrail face crashes were explored further with regard to rollover since the table for guardrail faces had the largest χ^2 value and the largest frequencies and the pickup $A + K$ injury percentage was higher (8.2 versus 6.1 percent).

When striking a guardrail face, pickup trucks were three times more likely to roll over than cars (24.1 versus 8.0 percent). However, the percentage of serious $A + K$ injuries in rollovers in pickup trucks

TABLE 4 Object Struck by Vehicle Type and Driver Injury (North Carolina data)

Object		Not Serious	Serious	Total		
Luminaire	Car	87 (91.58)	8 (8.42)	95	$X^2 = .448$	p = .503
	P.T.	12 (85.71)	2 (14.29)	14		
Signs	Car	1224 (94.44)	72 (5.56)	1296	$X^2 = .182$	p = .670
	P.T.	288 (93.81)	19 (6.19)	307		
G.R. End	Car	386 (81.26)	89 (18.74)	475	$X^2 = 1.934$	p = .164
	P.T.	81 (87.10)	12 (12.90)	93		
G.R. Face	Car	1524 (93.90)	99 (6.10)	1623	$X^2 = 2.238$	p = .135
	P.T.	394 (91.84)	35 (8.16)	429		
Barrier	Car	175 (94.59)	10 (5.41)	185	$X^2 = 2.026$	p = .155
	P.T.	37 (88.10)	5 (11.90)	42		
Combined (pooled)	Car	3409 (92.46)	278 (7.54)	3687	$X^2 = .473$	p = .683
	P.T.	814 (91.77)	73 (8.23)	887		

Mantel-Haenszel $X^2 = .998$ p = .318 (across objects) is less than half that of passenger cars (13.9 versus 31.2 percent). For nonrollovers the percentage of serious injuries was slightly (but not significantly) higher for pickups than for cars (5.3 versus 4.9 percent). Putting all of this together seems to show that the higher serious injury rates for pickup trucks hitting guardrail faces are primarily due to their much higher rollover rates, even though the chances of serious injury are considerably lower for the driver of a pickup truck that rolls over than for the driver of a car that rolls over. When no rollover occurs, the serious injury rates are very similar.

For Michigan data a Cochran–Mantel–Haenszel statistic summarizing across all objects was not significant ($p = .600$), again indicating no overall difference in serious injury rates between the two vehicle types.

In summary, this analysis of pickup trucks and passenger cars also indicates no significant differences in serious injury to the driver.

National Data

Size of Problem by Body Type

Driver fatalities by FHE (1988 FARS data) are given in Table 5 to examine the national size of the roadside safety hardware problem by body type. Unlike the other analyses in this paper, Table 5 shows urban as well as rural fatalities and fatalities by all vehicle body types, not just cars and light truck types. Twenty percent of these fatalities by FHE involve light trucks: pickups, 15 percent; vans, 3 percent; utility vehicles, 2 percent. Motorcycles account for about as many fatalities as pickups (161 versus 167). Medium and heavy trucks together account for 6 percent of the fatalities (70 fatalities). These 1,101 fatalities were split almost evenly between rural (54 percent) and urban (46 percent) crashes.

For crashes involving roadside safety hardware impacts, guardrail, sign support, and bridge rail FHE impacts are the types resulting in the most fatalities. The category Other in Table 5 provides data on fatalities in crashes involving concrete traffic barriers, luminaire supports, and impact attenuators. In 58 percent of the cases shown in Table 5 the cause of death (MHE) was the indicated object struck (FHE); in the remaining 42 percent the cause of death was overturn. Overturn was the cause of death in 63 percent of crashes involving sign supports, 42 percent involving guardrails, and 31 percent involving bridge rails. Little change in speed occurs in impacts with breakaway supports. Thus, for many, and perhaps most, overturns involving breakaway sign supports, the cause of vehicle tripping and thus the ultimate cause of death could well be subsequent vehicle involvement with other roadside features such as slopes and ditches. Accordingly, the size of the sign support problem is most likely overstated in Table 5.

Crash Severity by Body Type

In these analyses (*a*) national counts of rural driver fatalities in crashes with roadside safety devices in cars and light trucks (FARS) were compared with vehicle registration data (Polk) as one measure of exposure, and (*b*) national counts of fatalities in the guardrail, median barrier, and impact attenuator impact subset (FARS) were compared with national estimates of all such crashes (GES) as a second measure of exposure (Table 6). Only rural cases are shown to more closely parallel the original state-based analysis. The proportion of pickup driver fatalities in the roadside safety hardware impact group (25 percent) is substantially greater than the proportion of registered pickups (15.6 percent). In addition, for the guardrail, median barrier, and impact attenuator impact subgroup, the proportion of pickup driver fatalities (24 percent) is much higher than the estimated proportion of pickups involved in all such crashes (an estimated 9 percent). The 95 percent confidence limits of the GES estimate of crash involvement is 4.4 to 13.3 percent (8.7 ± 4.3 percent). Thus, the percentage of fatalities of pickup truck drivers in roadside safety hardware crashes is significantly in excess of what would be expected from an examination of all such crashes.

TABLE 5 Driver Fatalities (Rural plus Urban) by Body Type and FHE (1988 FARS data)

	First Harmful Event									
Body Type	Guardrail		Sign Support		Bridge Rail		Other		Totals	
	Number	%	Number	%	Number	%	Number	%	Number	%
Automobile	357	54%	92	50%	52	55%	123	73%	624	57%
Pickup	98	15%	34	19%	20	21%	15	9%	167	15%
Motorcycle	99	15%	36	20%	7	7%	19	11%	161	15%
Medium/Heavy Truck	47	7%	9	5%	10	11%	4	2%	70	6%
Van	20	3%	4	2%	0	0%	4	2%	28	3%
Other	20	3%	6	3%	2	2%	0	0%	28	3%
Truck Based Utility	15	2%	2	1%	3	3%	3	2%	23	2%
Totals	656	100%	183	100%	94	100%	168	100%	1,101	100 %

TABLE 6 Rural Roadside Safety Hardware Driver Fatalities (FARS), Involved Vehicles (GES), and Total Registered Vehicles (Polk)

Body Type	Driver Fatalities (FARS)				Involved Vehicles		Registered Vehicles (Polk)
	All		Guardrail, median barrier, impact atten.		Guardrail, Median Barrier, Impact Atten. (GES)		
	Number	%	Number	%	Number	%	%
Auto	315	69%	223	70%	46,600	88%	77.4%
Pickup	116	25%	75	24%	4,600	9%	15.6%
Van	15	3%	12	4%	1,500	3%	4.7%
Utility	13	3%	9	3%	500	1%	2.3%
Total	459		319		53,200		

DISCUSSION OF RESULTS

The analyses presented earlier appear to indicate contrasting findings between national data (FARS, GES, and Polk data) and state-based data in crashes with roadside safety hardware. The significant overrepresentation of drivers of pickups in the rural FARS data—only 9 percent of crashes and 15.6 percent of registrations but 25 percent of fatalities (Table 6)—was not found from the analyses conducted with data from either of the state files. The overall distributions of driver injury severity across objects did not differ significantly by vehicle type in the state data (Tables 1 and 3). Overall differences in the percentage of serious driver injuries found between drivers of pickup trucks and drivers of passenger cars were nearly identical in both states (Table 4 and earlier text).

Because of this contrast in findings, the proportions of fatalities alone for cars and PUVs in the North Carolina and Michigan data were compared. Because of small sample sizes of driver fatalities, no meaningful rollover–nonrollover analyses could be made with the North Carolina data [i.e., 9 fatalities of car drivers in 360 rollovers (2.5 percent) versus 7 fatalities of PUV drivers in 203 rollovers (3.45 percent)]. When all objects are combined without respect to rollover for the North Carolina data, 1.2 percent of the PUV crashes resulted in fatalities (14 fatalities), whereas 0.65 percent of the car crashes resulted in fatalities (24 fatalities), a difference nearing statistical significance ($p = .066$). Examination of the combined data for Michigan indicated no significant difference in fatality rates [0.51 percent for PUVs (14 fatalities) versus 0.44 percent for cars (45 fatalities); $p = .626$]. Thus, there is a suggestion of increased fatalities among drivers of PUVs involved in accidents for North Carolina but not for Michigan, at least in an overall sense.

A likely reason that pickup drivers were found to be overrepresented in FARS fatality data but not in the analyses of serious injuries conducted with state data is ejection of unbelted drivers in rollovers. Counts of driver fatalities by rollover and ejection outcome for the 315 car and 116 pickup cases in Table 6 are given in Table 7. The numbers of rollovers that occurred before contact with the roadside safety device (first event) and after contact (subsequent event) are given in Table 7, as are the numbers of total and partial ejections. Rollovers occurred in 82 percent of the fatal pickup and 62 percent of the fatal automobile crashes given in Table 7. In contrast, in the North Carolina data covering the full injury distribution, rollovers occurred in only 26 percent of the pickups and 13 percent of the passenger car crashes. In the FARS data, both rollover and ejection (total and partial) occurred in 62 percent of all pickup fatalities (72 of 116 cases) and 41 percent of all car fatalities (196 of 315 cases). Thus, the ejection–rollover combination is seen to be associated with a large percentage of these fatalities. Terhune (*4*) examined rollover cases in National Accident Sampling System data and concluded that ejection accounted for about half of all $A + K$ injuries in car rollovers, and on the basis of limited data, ejection appeared to be the predominant factor in light truck A + K injuries. Kahane's (*5*) review of the literature concludes that ejection increases the risk of fatality of passenger car occupants by 380 percent. Although no hard data are available, it is also possible that ejection would increase the probability of fatality more than the probability of incapacitating injury, since a crash sequence violent enough to result in ejection would present a high risk of incapacitating injury even if the occupant remained in the car. Thus, the number of incapacitating (i.e., Type *A*) injuries might be expected to increase less than the number of fatal injuries when ejection occurs.

Ejections are greatly reduced by seat belt use. Seat belt observations in North Carolina indicate belt-wearing rates for drivers of pickup trucks and utility vehicles approximately 20 percent lower than the usage rate for drivers of passenger cars (*6*). Thus, the greater ejection risk for pickup drivers than for car drivers because of lower seat belt use rates and higher rollover rates, coupled with the likely differential increase in fatalities over serious injuries in ejections, could result in greater pickup overrepresentation in the FARS data than in the state data (serious injuries plus fatalities). This is particularly true since the state data have a relatively low percentage of fatalities in the severe injury groupings examined. Examination of fatality data for North Carolina also suggests such a possible overrepresentation for PUVs.

The analysis of national data (and to a limited extent the North Carolina data) presented here supports the decision made in

TABLE 7 Rural Fatally Injured Drivers (FARS) by Rollover and Ejection for Pickups and Cars

PICKUPS

Rollover	Ejection				Totals	
	No	Total	Partial	Unk		
No	14	5	2	0	21	18%
First Event	3	1	1	0	5	4%
Subs. Event	20	60	10	0	90	78%
Totals	37	66	13	0	116	100
Percent	32%	57%	11%	0%	100%	

CARS

Rollover	Ejection				Totals	
	No	Total	Partial	Unk		
No	91	23	4	1	119	38%
First Event	1	5	1	0	7	2%
Subs. Event	64	107	17	1	189	60%
Totals	156	135	22	2	315	100%
Percent	50%	43%	7%	1%	100%	

NCHRP Report 350 (*3*) to use a pickup truck as the standard test vehicle in crash testing. FARS data demonstrate the importance of pickups in crashes with roadside safety devices. Pickups dominate the light truck driver fatality totals: 15 percent of all body types compared with 3 percent for vans and 2 percent for utility vehicles. Pickups accounted for 25 percent of the rural car–light truck group fatalities, even though they were involved only in an estimated 10 percent of such rural crashes. No attempt was made in this paper, however, to address the question of the representativeness of a pickup truck as a substitute for the previously used 4,500-lb car in crash testing as recommended in *NCHRP Report 350* (*3*).

In summary, with respect to the major question of interest, neither set of state data indicates differences in serious driver injury severity (A + K percentages) by vehicle type either when the special vehicles are grouped or when the pickup trucks were analyzed separately. On the other hand, the FARS analysis indicates an overrepresentation of pickup truck fatalities when compared with both GES-based national estimates of hardware-related crashes and Polk registration data. Known differences in seat belt use rates and risks of fatality by ejection in rollovers suggest that these findings may not be in conflict.

The higher rollover risk found for pickups compared with that found for cars in roadside hardware crashes is consistent with findings for ran-off-road crashes in other studies (*7,8*). Thus, differences in rollover outcome in crash testing may be experienced when using a ¾-ton pickup as a substitute for the previously used 4,500-lb car as recommended in *NCHRP Report 350* (*3*).

In short, the data suggest that the practical worst-case test philosophy of current roadside safety device evaluation procedures has provided about the same level of protection to drivers of pickups, light vans, and utility vehicles as to drivers of passenger cars if the measure of safety is to be the likelihood of serious (A + K) injuries.

If, on the other hand, the measure of safety is to be the likelihood of fatalities, then drivers of pickups are at greater risk. Thus, although the use of pickups in crash tests appears to be warranted, it may be the case that redesigning roadside safety hardware to reduce the rollover risk of pickups is not the most cost-effective solution to this problem. Programs to increase pickup stability, to increase seat belt use, and other measures to reduce ejection rates in rollovers of pickups also need to be considered in this regard. Such programs would affect not only injuries in crashes related to safety devices but also the larger number of injuries and fatalities seen in other pickup crashes.

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