

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN

**A STUDY OF LIGHT TRUCK AND PASSENGER CAR
ROLLOVER AND EJECTION IN SINGLE-VEHICLE CRASHES**

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May 1988

Calspan Report No. 7636

Prepared for the Motor Vehicle Manufacturers Association of the United States, Inc. The Project was supported with funds under MVMA Agreement Number CAL 8717-C7167.

The opinions, findings, and conclusions expressed in this publication are those of the author and not necessarily those of the Motor Vehicle Manufacturers Association, Inc. or its member companies.

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ABSTRACT

This study follows-up previous Calspan research revealing that, while light trucks protect their occupants about as well as cars do in single-vehicle crashes, light trucks had substantially higher rollover and ejection rates than cars. The new research sought to determine (a) the roles of driver, environment, and vehicle factors in the rollovers of light trucks and (b) how occupants are ejected from light trucks. Studied were pickups, vans, and utility vehicles from model years 1979-1986, using data from the 1980-1985 files of the National Accident Sampling System (NASS). To provide additional details about roadsides, rollovers, and ejections, a special clinical file was created by coding from 487 hard-copy NASS cases. In controlling for driver and environmental factors, light truck overturn rates remained higher than car rates, with utility vehicle rates distinctly the highest. Compared to cars, light trucks exhibited more precrash lateral skidding, more on-road rollovers, and more tripping-type rollovers. Occupant ejections were the highest in utility vehicles, somewhat higher in pickups than in cars, and about the same in vans as in cars. Controlling for crash severity indicated that ejections were highly injurious to occupants. Structural failures associated with ejection were doors opening, windows and windshields breaking, and in the case of utility vehicles, roof failures. It was concluded that vehicle factors appear to play a role in

ACKNOWLEDGEMENTS

The special files created for the statistical analyses of NASS data were assembled by Mr. Charles Compton of the University of Michigan Transportation Research Institute.

Clinical analysis and coding of NASS cases to create the "clinical file" used in this study were performed by Nova Engineering of Oakton, Virginia. Mr. Francis A. DiLorenzo, P.E., was the principal analyst.

FOREWORD

The "Study of Light Truck and Passenger Car Rollover and Ejection in Single Vehicle Crashes" presents valuable insights. However, MVMA believes that readers should be aware of the limitations of the database and of the research design, so that its results are not generalized further than warranted, or intended by the researchers.

The study is based on data from the National Accident Sampling System (NASS). The number of NASS cases involving vans and utility vehicles is small and the information on each case is limited. While some information is available on the driver, the environment, and the vehicle, there is no information available on other, sometimes subtle factors, that may influence accident risk and accident type. The cases selected for inclusion in NASS are identified from listings based on police reports. Generally, all injury accidents are reported by police. Reporting of property damage accidents may vary by jurisdiction. Rollovers, with a high injury risk, are more likely to be reported.

Pickup trucks, vans, and utility vehicles are designed to be used differently than passenger cars. They are used in different applications and by different types of drivers although they are sometimes used like passenger cars. These differences in use and users are unlikely to be adequately measured by the limited information available in the NASS data base. To assess the contribution of various factors to accident causation, detailed information on these usage patterns, i.e., exposure, is needed for each vehicle type. Exposure information describes both accident and non-accident situations. Unfortunately, this information is not available. To make valid estimates of the risk of a particular type of crash, e.g., a rollover crash, both accident data and exposure information are needed. The present study is based on accident data alone.

It should be understood that this study was not intended to be a comparison of vehicle types in their relative risks of a rollover accident. To estimate relative risks, exposure data are needed. Because this was not a study of relative risks, it follows that the study does not indicate the influence of environmental and driver factors on those risks. That remains for further research.

It was a research objective to study conditional probabilities--the likelihood of vehicle rollover given that a single-vehicle crash has occurred. Consequently, the study examines various correlates of rollover percentages in single-vehicle crashes. Those percentages estimate, within the sample limitations, the conditional probabilities of rollover. The report refers to these percentages as "rates", which should not be confused with rates based on exposure data and intended to estimate risks.

The study's second conclusion that "Light trucks have a higher single-vehicle-crash overturn rate than cars; while driver and environmental factors play a role in elevating the overturn rates, vehicle factors appear to play a significant role" needs to be placed in context. As discussed above, the study did not control for the influence of driver and environmental factors on the rollover crash risk and the author acknowledges that light truck vehicle factors were not examined as it was beyond the scope of the study. The study, therefore, does not allow definitive statements to be made about the relative contribution of driver, environmental and vehicle factors to the rollover crash risk.

In summary, MVMA believes that the findings, conclusions, and recommendations of the study must be reviewed and interpreted in the context of the limitations of the NASS data, the lack of exposure data, and the limitations of the analytical methods used.

Motor Vehicle Manufacturers Association
of the United States, Inc. (MVMA)

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The Foreword was prepared by the Motor Vehicle Manufacturers Association, and it is included at the request of that organization. The opinions expressed in the Foreword do not necessarily represent the views of the author or the Franklin Research Center. Interested readers will find in Section 4.0 of the report further discussion of some of the issues raised by the Foreword.

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1.0 INTRODUCTION

In previous Calspan research, light trucks were found to protect their occupants better than cars when in two-vehicle crashes (Terhune, Ranney, Smist, and Woodill, 1984). In single-vehicle crashes, however, no clear differences between car and light truck injury rates were found (Terhune, 1986). Pickup and van occupants appeared no more at risk of injury in single-vehicle crashes than did car occupants. Results for utility vehicles were inconclusive, however, because of their small numbers in the sample. Although no overall problem of occupant protection was revealed in light truck single-vehicle crashes, high light truck rollover and ejection rates suggested particular ways in which light truck occupants may be more vulnerable to injury than car occupants. This vulnerability tended to be offset by somewhat better light truck occupant protection in nonrollover crashes.

Despite the fact that the single-vehicle injury rate of cars and light trucks differed little, the interests of light truck safety suggested that high rollover and ejection rates of light trucks merited further investigation. It is important to know whether light truck rollover rates are due mainly to the vehicles, to their drivers, or to their crash environment. It is also important to know specifically how occupants are being ejected from light trucks. Answers in each case may suggest

directions for improving light truck safety. That was the general objective of the study reported here.

1.1 Background

In Terhune's (1985) review and in subsequent research (Reinfurt, Stutts, and Hamilton, 1985; Terhune, 1986; Partyka, Sikora, Surti, and Van Dyke, 1987), rollover rates were consistently found higher in light trucks than in cars. Typically, rollover rates were highest for utility vehicles and second highest for pickups. Vans were usually found to have rollover rates between those of cars and of pickups, in studies of overall rollover rates. In the one study that examined van rollover rates in single-vehicle crashes, however, van rollover rates were second only to the utility vehicle rates (Terhune, 1986).

A fundamental question is whether the high rollover rates of light trucks are due to their intrinsic properties. Since these vehicles typically have high centers of gravity in relation to their track widths, this may make them more susceptible to overturn than cars, as some have suggested (Reinfurt et al., 1985; Robertson and Kelley, 1986). On the other hand, driver characteristics and the conditions in which the vehicles are used may elevate the light truck rates. This possibility has been raised primarily with respect to utility vehicles (Joksch, 1983). Our 1986 report examined this issue

by comparing light truck and car rollover rates while controlling for several non-vehicle factors which could possibly produce roll-rate differentials among the vehicle types; these were driver age, driver gender, and rural-urban crash location. Both State of Washington and National Accident Sampling System (NASS) data were used. Light trucks continued to exhibit higher rollover rates than cars when controlling for the possibly confounding variables, although the NASS data had insufficient sample sizes for some of the breakdowns needed. Especially important, the automated NASS file lacked detail on the environments of single-vehicle crashes, especially in regard to roadside features to which the vehicles were exposed. Hence, our study was unable to refute the idea that high light truck rollover rates may be due to crash circumstances. This remained a subject for further research.

Occupant ejection appears to be an important source of injury in rollovers. For example, 1985 NASS data revealed that 18% of occupants in light truck towaway rollover crashes were ejected, compared to only 1% of those in nonrollovers. Furthermore, 17% of the rollover ejectees were seriously injured (AIS > 3), compared with only 4% of the nonejectees (National Highway Traffic Safety Administration [NHTSA], 1987b). Thus, one may expect that high rollover rates of light trucks will elevate their ejection and injury rates. It is not surprising to learn from a NHTSA report to Congress that "The number of ejections from light trucks is three times that of

passenger cars." (NHTSA, 1987a, p.17). This tendency was also found in Calspan's study of single-vehicle crashes. However, only utility vehicles exhibited ejection rates distinctly higher than car rates, and only the Washington sample size was large enough to show this (Terhune, 1986). So on ejection also, data limitations indicated the need for further study.

As with rollovers, questions may be raised as to the interpretation of higher ejection rates of light trucks. For example, might the higher ejection rates be attributable to the more frequent light truck crashes in rural areas, where accidents are usually more severe? And if ejections occur primarily in severe crashes, would not the ejected occupants have been as seriously injured even had they remained in their vehicles? This seemed to be the implication of ejection research by Huelke, Compton, and Studer (1985). Answers to these questions will help us to understand whether ejection per se is a problem deserving special attention in light trucks. If ejection is a special light truck problem, determining how the ejections occurred should help in finding remedies. These are further matters addressed in this study.

In summary, previous research has found crash rollover and ejection rates to be substantially higher in light trucks than in cars, yet the two vehicle types differed little in overall injury rates. This paradox in itself merits further investigation and explanation. But light truck rollover and

ejection also deserve further study to see if these are special sources of injury potential in light trucks, possibly subject to countermeasures.

1.2 Objectives

As in our previous investigation (Terhune, 1986), this study examined rollover and ejection in single-vehicle crashes, a crash type important for the following reasons:

- o Past research indicated that light truck occupants are fairly well-protected in two-vehicle crashes, but a possible problem may exist in single-vehicle crashes (Terhune, 1985);
- o Rollovers are found to occur mainly in single-vehicle crashes (Huelke, Marsh, and Sherman, 1972; McGuigan and Bondy, 1980), and occupant ejections occur primarily in rollovers (Terhune, 1986);
- o This study was intended to be an in-depth follow-up of our 1986 study, in order to obtain detailed explanations and clarifications of its findings; hence it was important to examine the same types of crashes.

The specific objectives of this study were:

- (1) To determine if differences between light truck and passenger car rollover rates in single-vehicle crashes can be attributed mainly to their drivers and the circumstances in which the accidents occurred;

- (2) To determine if ejection per se is an important injury-producing event in light truck single-vehicle crashes, and if so, to determine how light truck ejections occur.

In addition to pursuing these objectives, we took advantage of an expanded NASS data set to see if our previous findings, comparing light truck and car rollover and injury rates, would be confirmed.

2.0 RESEARCH METHODS

Accident cases from the National Accident Sampling System (NASS) were analyzed to achieve the research objectives. Statistical analyses of rollovers, ejections, and occupant injury examined the relevant NASS variables which could clarify our understanding of differences among light trucks and cars. However, the NASS database does not include critical information on how rollovers and ejections occurred, information desirable to explain differences among the vehicle types. Hence, a special database was created by reviewing the vehicle photographs, scene photographs, scene diagrams, and other information in the original NASS case files, in order to code new rollover and ejection variables not in the automated NASS data files. The new database was subjected to additional statistical analyses addressing our research objectives.

Details of the databases and research methods are provided in the sections which follow.

2.1 Why NASS Data Were Chosen.

Of the many accident data files available for research, the NASS file was selected as the best available, using the criteria as follows.

(a) Inclusion of cars and light trucks. Most of our analyses compare light trucks to cars, which provide a benchmark or standard of comparison. Consequently both vehicle types must be in the database.

(b) Representativeness. The accidents included should comprise an unbiased sample, preferably a nationally representative one. Although it was unavoidable that the samples would omit unreported minor "fender-benders", it was essential that the data sets not be restricted to severe crashes such as towaways. Such data sets introduce biases by selecting only the worst crashes of vehicles less easily damaged.

(c) Current relevance. The accidents had to occur within recent years and involve recent-model vehicles so that results would be relevant to the current vehicle fleet. Consequently, an up-to-date database was essential.

(d) Completeness of variables. Many variables were needed for the analyses (Table 2.1). It was important not only that each variable be recorded, but that it be recorded in sufficient detail on all cases, with few unknowns. Especially troublesome are data sets providing only partial information, e.g., a rollover is recorded only if it is a "First Harmful Event," or restraint system usage is identified only for severely injured occupants.

Table 2.1: Variables Needed for the Data Analyses

1. Vehicle type clearly distinguishing light truck types and passenger cars.
2. Number of vehicles in accident
3. Collision type
4. Occurrence of rollover (overturn)
5. Occupant role/seating location
6. Occupant injury level or outcome
7. Occurrence of ejection, by occupant
8. Occupant age
9. Occupant gender
10. Occupant restraint system use
11. Vehicle model year
12. Accident urban/rural location
13. Ejection details (portals, etc.)
14. Crash severity
15. Roadside characteristics
16. Vehicle actions prior to and during crash

(e) Accessibility. It was necessary that the data be available in a short time and at modest cost.

(f) Sample size. For the detailed breakdowns of the samples that were anticipated, a data file with thousands of accidents was needed.

The major accident data files considered were the NASS, the Fatal Accident Reporting System (FARS), state files, and the Motor Vehicle Manufacturers Association (MVMA) light truck file. The FARS file is widely used, for it includes virtually all fatal highway accidents occurring annually in the U.S. It was not chosen mainly because our interest was in broader crash consequences than just fatalities. The MVMA file was excluded on similar grounds, for that file includes only injury accidents, and no single-vehicle car crashes. State files were considered, but they were rejected on grounds of accessibility or completeness. Some state files are readily accessible through the University of Michigan Automated Data Access and Analysis System (ADAAS), but they were limited in their recording of essential variables like vehicle type, rollover, and/or restraint system use.

The NASS database is nationally representative of police-reported accidents, its data are subjected to extensive quality control, and its variables met most of our

requirements. Needed data that were not in the automated database could be coded from the original files, which include extensive photographs and a scene diagram for most of the crashes.

While the NASS was selected as the best available accident data file, two of its limitations should be noted. First, while NASS now includes many thousands of accidents, light trucks, particularly vans and utility vehicles, comprise only a fraction of the cases. The second limitation is that, while most NASS cases contain complete information, some types of cases lack data needed for our study. These cases are as follows:

(a) Source-document-only (SDO) cases. During NASS work reductions, some cases selected for the sample are designated source-document-only, which means that no vehicle or accident scene examinations are performed; only documents such as police reports and medical records are collected. Data are coded from these source documents, which are then deleted from the files. Because of the lack of complete information in such cases, some variables (e.g., rollover) may be recorded less accurately, while others (e.g., occupant ejection) may be recorded as unknown.

(b) Nontowaways. Vehicle data for vehicles not towed from the accident scene are recorded on a short vehicle form,

which omits the rollover variable contained in the standard form. While we may assume that non-towed vehicles did not overturn, that will sometimes be incorrect. Errors here can be magnified when weighting the data to produce estimates of rollover rates, for nontowaway cases have high weighting factors in the NASS scheme.

Thus, while the NASS database was judged the best available for our purposes, its limitations indicate that some loss of statistical reliability may be expected.

2.2 Data Sets Created.

The NASS data files were accessed through the University of Michigan's ADAAS system, which makes the data readily available at modest cost. From the complete NASS files, three working files were assembled: a vehicle/driver file (RNASTRK3), an occupant file (RNASTRK4), and an injury file (RNASTRK5). They are described in Table 2.2. For comparability with our previous study on light truck single-vehicle crashes, the case-selection criteria for the vehicle/driver file were identical to those in the previous study, with one exception: the earlier study included only 1982-1984 NASS cases, whereas the current study included accidents for the years 1980-1985. Previously, the 1982-1984 cases were examined because the needed NASS variables were identical across those years. There were only 58 vans and 75

Table 2.2: Composition of the Working Files
Selected from the NASS Automated Data Base

A. Selection Criteria

<u>RNASTRK3*:</u> (Vehicle/ driver file)	<u>RNASTRK4*:</u> (Occupant file)	<u>RNASTRK5*:</u> (Injury file)
1. Single-vehicle crashes	Same as RNASTRK3,	Same as RNASTRK4, except all the
2. Occupant role = driver	except all the	injuries of the occupants are
3. Vehicle model years 1979 and newer	vehicle occupants	included. Each case is one injury.
4. Accident years 1980-1985	are included. Each	
5. Passenger cars, vans, pickup trucks, and utility vehicles under 10,000 lb. GVSR	case is one occupant.	
6. Exclude pedestrian, animal, railroad, pedacyclist collisions, and fires/ explosions as first harmful event		

B. Sample Sizes

<u>RNASTRK3</u>	<u>RNASTRK4</u>	<u>RNASTRK5</u>
3,558 passenger cars	4,566 drivers	11,445 AIS1 injuries
749 pickup trucks	2,490 passengers	1,514 AIS2 injuries
108 vans		710 AIS3 injuries
150 utility vehicles		153 AIS4 injuries
		85 AIS5 injuries
<hr/> 4,565 total vehicles	<hr/> 7,056 total occupants	45 AIS6 injuries
		751 inj., AIS unknown
		<hr/> 14,703 total injuries

*The file names are acronyms signifying "revised NASS truck" files.
RNASTRK1 and RNASTRK2 were files used in previous Calspan research.

utility vehicles in the file, however, resulting in small subsamples in data breakdowns. Consequently, the new file was expanded to the years 1980-1985. (The 1979 NASS sample was too small to include, while 1985 was the latest data-year available). However, modifications in variable formats during the sampled years required that there be many recodes to bring all years of data into a common format. This was done, resulting in data files unique to this study.

Section B of Table 2.2 shows the sample sizes in the working files. It may be noted that the total of 4,565 single vehicle crashes is nearly double the NASS sample size of our previous study. Nevertheless, the 108 vans and 150 utility vehicles are fairly small numbers to work with, although those samples also are about double those in our previous study.

Vehicle types were classified by the same criteria used in the earlier study. The coding rules are shown in Table 2.3.

The clinical file. The NASS automated data lacked certain rollover and ejection details, such as how the rollovers happened, and whether structural failures facilitated ejection. Since the needed information was extractable from the photographs and scene diagrams in NASS cases, the original cases were individually examined at the NASS storage-site in Arlington, Virginia. The University of Michigan computer system was used to identify random samples of the crashes from

Table 2.3: Coding Rules for Light Truck Identification:
NASS 1980-1985

<u>Vehicle Type</u>	<u>NASS Classification</u>	<u>Numbers in RNASR3 Sample</u>
Passenger Car	(a) Convertible (excludes sun-roof, t-bar)	19
	(b) 2-door sedan, hardtop, coupe	1256
	(c) 3-door/2-door hatchback	958
	(d) 4-door sedan, hardtop	798
	(e) 5-door/4-door hatchback	270
	(f) Station wagon (excluding van and truck based)	221
	(g) Other automobile type	1
	(h) Unknown automobile type	35
Pickup	(a) Auto based pickup (includes El Camino, Caballero, Ranchero, Brat)	27
	(b) Pickup (includes open box and caps)	722
Van	(a) Van (includes VW bus, Vanagon, Kombi, Beauville, Chateau, Club Wagon, Sportsman; excludes moving van)	98
	(b) Van-commercial cutaway (includes box van, multi-stop, parcel, van pickups)	5
	(c) Other van type	2
	(d) Unknown van type	3
Utility Vehicle	(a) Short utility - not truck based (includes Jeep CJ-5, Jeep CJ-7, Renegade, Landrover, Landcruiser)	48
	(b) Truck based station wagon (includes Suburban, Travelall, Wagoneer)	13
	(c) Truck based utility (includes Blazer, Bronco-78 on, Jimmy, Ranchanger, Cherokee, Trailduster, Scout)	89

those in the RNASTRK3 file. Selected for examination were 50 rollover and 50 nonrollover crashes of cars, pickups, vans, and utility vehicles respectively. These cases were then pulled from the Arlington files. When cases were missing (e.g., SDO cases) they were replaced, to the extent possible, with cases from a backup list.

Each selected case was individually reviewed and the variables in Table 2.4 were coded using a data form specially designed by Calspan for this study (Appendix A). A coding manual was used for reference in coding (Appendix B). All coding was performed by an experienced accident investigator from Nova Engineering of Oakton, Virginia. Training and quality control were conducted by Calspan. Training comprised a discussion of the coding manual definitions and a coding review of individual cases. Quality control consisted of an in-depth review of the first 100 cases, with returns for correction of all cases exhibiting inconsistencies, ambiguities, or other errors. Spot-checks were used for the remaining cases.

Since only a portion of the selected cases involved occupant ejection, a supplementary random sample of light truck crashes involving ejection was identified. In these cases, only the ejection questions (numbers 28 and 29) on the data form were coded. The samples were limited by the number of ejection cases available for each vehicle type.

**Table 2.4: Variables Extracted from the NASS Cases
Through Clinical Case Examination**

1. Predominant land use
2. Pre-crash travel surface
3. Roadside features
 - a. Ditch depth
 - b. Curb height
 - c. Edge dropoff distance
 - d. Side slope type
 - e. Side slope angle
 - f. Density of narrow fixed objects
 - g. Longitudinal objects present
 - h. Other objects present
4. Vehicle preimpact travel orientation
5. Collision type
6. First harmful event
7. Surface at first harmful event
8. Roadside features traversed/contacted by vehicle
9. Rollover
 - a. Occurrence
 - b. Type
 - c. Feature producing rollover
 - d. Surface roll trigger
10. No. doors opening during crash
11. No. windows open before crash
12. Occupant ejection
 - a. Occurrence
 - b. Seating position of ejected occupant
 - c. Effect of vehicle damage/failure

Because sophisticated judgments had to be made for many of the variables on the coding form, the resulting data file is referred to as "the clinical file." Data of the primary clinical sample were entered into an automated data file for subsequent statistical analysis, while the supplementary ejection cases were used for individual inspection and hand tabulations only. Table 2.5 gives the sample composition.

2.3 Weighted vs. Unweighted Data.

A judgment had to be made as to whether the analyses should use data weighted in accordance with the NASS sampling fractions and annual sample sizes. NASS, it should be understood, uses a stratified sample, resulting in unequal representations of different kinds of accidents. Accidents of greater interest, such as fatal accidents, are more extensively sampled. With such a sample, it is necessary to weight each case by the inverse of its sampling fraction in order to estimate parameters in the national accident population. When using several years of NASS data, weights are assigned according to the annual sample sizes. To make valid unbiased comparisons among vehicle types, such as on rollover, ejection, and injury rates, the weighted data must be used. This was done in Calspan's 1986 light truck study.

Table 2.5: Composition of the Clinical File

A. Primary Sample (Data were entered into automated database)

	<u>Non-Rollovers</u>	<u>Rollovers</u>	<u>Totals</u>
Cars	62	57	119
Pickups	49	52	101
Vans	60	37	97
U-Vehs	39	46	85

B. Light Truck Ejection Cases (Vehicles)

	<u>Primary Sample</u>	<u>Supplementary Sample*</u>
Pickups	13	66
Vans	5	0
U-Vehs	21	19

*Not entered into automated database; ejection details only.

In examining the details of rollover and ejection cases, use of weighted data is more problematic. Weighting multiplies individual cases by dozens, hundreds, or even thousands of times, depending on the sampling fractions used in NASS. A case error in sampling, measurement, or coding will be multiplied by the weighting factor. This has the potential of creating large distortions when examining small samples, as when determining ejection rates of vans and utility vehicles. Consequently, for most of the analyses in this study, we examined unweighted data, and indicate this in our data tables. Only when we are interested in gross population estimates, such as in comparing rollover rates in this study with those in our 1986 report, were weighted data used. All tables and figures have the use of weighted or unweighted data clearly labelled.

The rationale for using unweighted data applies particularly to the clinical case file, which comprises but a fraction of the NASS sample. Here again, our purpose was not to generate national estimates, but to learn more about the rollover and ejection phenomena. However, some weighting of the clinical data was necessary, as described next.

Clinical file weighting. Since, to the extent possible, approximately equal numbers of overturn and nonoverturn cases were selected in creating the clinical file, this would distort the rollover rates of each vehicle type. To examine the effects of various factors on rollovers, it was necessary to

adjust the data for the case-selection process. Consequently, in analyses of rollover rates, the clinical data were weighted to make them representative of the RNASTRK3 sample. Thus, the rollover results with the weighted clinical file can be directly compared with the results from the unweighted RNASTRK3 file.

3.0 RESULTS

The results of our analyses are given in three main sections below. First, a partial replication of analyses in our previous study of single-vehicle crashes (Terhune, 1986) is presented to see if the earlier findings were upheld. Second, detailed examinations of rollover crashes are made to indicate the roles of vehicle, driver, and environmental factors in explaining light truck rollover rates. Third, occupant ejections are examined in detail to see if a light truck problem is indicated.

Our detailed analyses of rollover and ejection used both the large NASS databases described in section 2.0, and the smaller clinically-derived database formed from a subset of the larger file. Results from each data set are presented in the rollover and ejection sections (3.2 and 3.3).

3.1 Replications of Analyses in Calspan's 1986 Report

Our analyses determined whether the fundamental findings of our 1986 light truck study were upheld with the 6-year NASS sample of the study. That is:

- (a) Did light truck injury rates still differ little from the car rates?

(b) Did light trucks continue to exhibit rollover rates substantially higher than car rates? And were there significant differences among pickups, vans, and utility vehicles?

(c) If the injury and rollover findings were upheld, why were not the higher rollover rates of light trucks associated with higher injury rates?

These are addressed in the following sections.

3.1.1 Injury Rates.

To address the first question, we replicated an analysis from our 1986 report, wherein injuries of a predominant occupant group -- male unrestrained drivers -- were examined. The results (Table 3.1) maintained previous indications of minor differences in injury rates between cars and light trucks. In the rural crashes, the injury rates among vehicle types were very similar, except for vans. Since that rate was based on only 21 drivers, the reliability of the result is uncertain. In the urban crashes, however, all the light truck types had injury rates slightly lower than cars. Judging from the results, the urban crashes were generally less severe than the rural ones.

Table 3.1: Driver injury rates by vehicle type, with controls for gender, restraint system use and environment: MASS 1980-1985.

(RNASTRK4 file: Weighted data)

Conditions:

- (a) Vehicle model years 1979 and newer
- (b) Single-vehicle crashes
- (c) Male
- (d) No driver restraint system in use

Rural Crashes

	<u>Passenger Cars</u>	<u>Pickup Trucks</u>	<u>Light Vans</u>	<u>Utility Vehicles</u>
Sample size (drivers)	691	370	21	45
Average annual estimated population size (drivers)	52,700	26,500	1,500	3,000
Drivers fatal/hospitalized	11.9%	12.2%	17.1%	11.1%

Urban Crashes

Sample size (drivers)	854	182	34	30
Average annual estimated population size (drivers)	59,100	15,200	1,300	2,100
Drivers fatal/hospitalized	8.5%	6.6%	7.6%	7.2%

3.1.2 Rollover Rates.

The overall weighted rollover rates were as follows:

Cars:	19.6%	overturned
Pickups:	33.0%	overturned
Vans:	31.8%	overturned
Utility vehicles:	43.4%	overturned

The car and pickup rates are very close to their values in our 1986 report, while the van and utility-vehicle rates are lower than their levels of 38.2% and 52.0% in our earlier report. The current values should be more reliable because of the larger samples.

The larger utility-vehicle sample permitted its separation into 102 truck-based and 48 not-truck-based vehicles. The truck-based version had a weighted rollover rate of 34.3%, similar to the vans and pickups. The non-truck-based, shorter utility vehicles had a 64.3% rate, much higher than the other light truck rates. In summary, light trucks continued to exhibit rollover rates higher than car rates. Now, however, pickups, vans, and truck-based utility vehicles had rollover rates of 32-34%, while the non-truck-based utility vehicles had an overturn rate nearly twice that of the other light trucks.

3.1.3 Effects of Rollover on Injuries

Turning now to the third question of our replication analyses, we examine rollover in relation to injury rates. Figure 3.1 compares the vehicle types in rural crashes, with injury rates shown for unrestrained drivers. (No other controls were imposed because of insufficient numbers of vans and utility vehicles.) All light truck rollover rates were substantially higher than the car rate of 30.7%. The rollover effects on injuries for each light truck type are described as follows:

(a) Pickups. While the pickup rollover rate was 1.5 times the car rate, the injury rate of pickups was only 1.1 times the car rate. The effect of the rollover differences was partially offset by pickups having a slightly lower injury rate than cars in nonrollovers.

(b) Vans. Here an unusual picture is presented. Vans had the highest rollover rate, but the lowest injury rate within rollovers. Further, the injury rate in nonrollovers was much higher than in rollovers. Such atypical results may be due in part to the small rural sample of vans. In any case, the net result was a fairly high van injury rate.

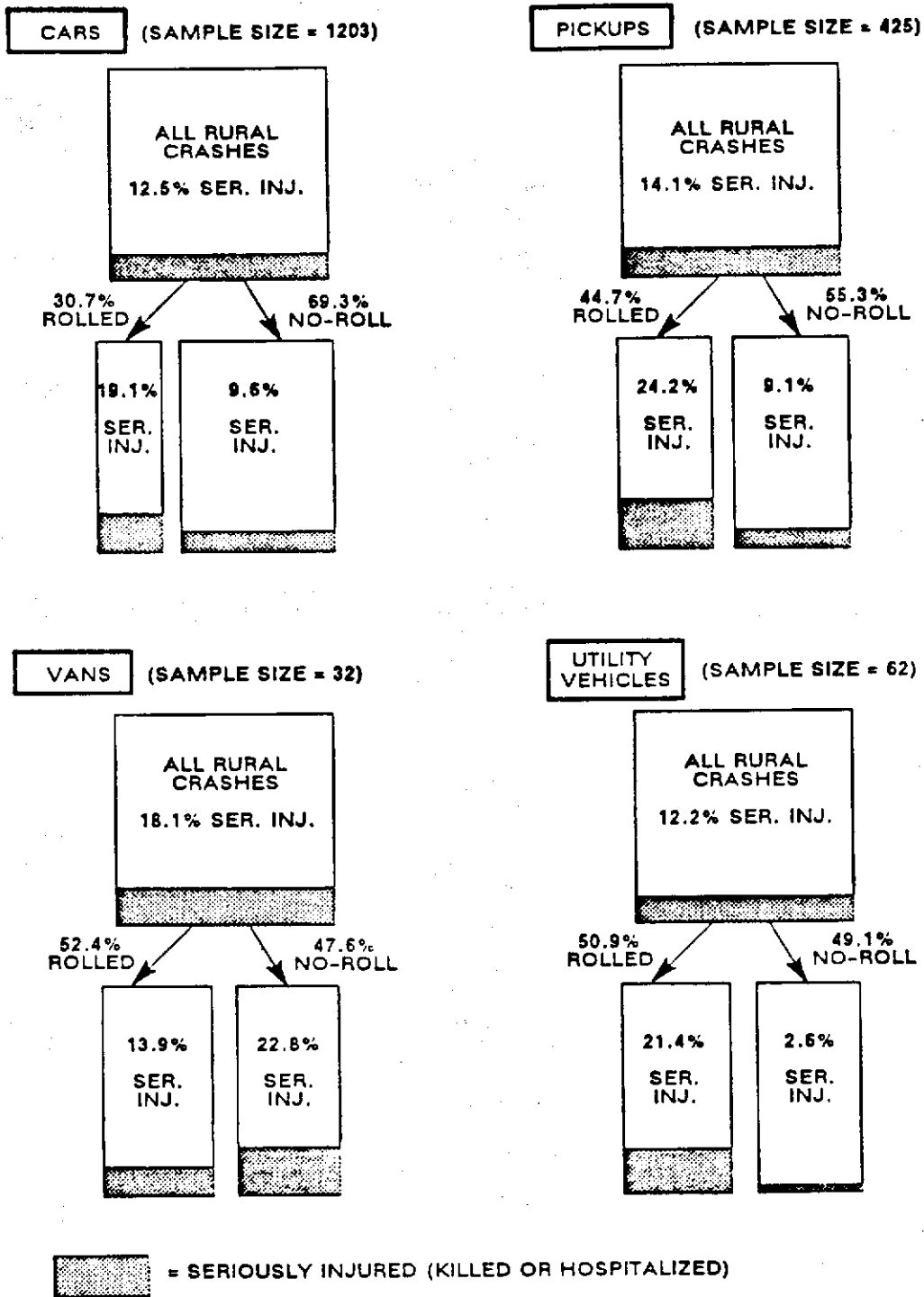


Figure 3.1. Rural Rollovers and Driver Injury:
 NASS 1980-1985 Unrestrained Drivers in Single - Vehicle
 Crashes (RNASTRK4 file; weighted data.)

(c) Utility vehicles. The high rollover rate of the utility vehicles appears to have contributed substantially to the driver injuries in the rural crashes, but this was offset by the remarkably low injury rate in nonrollovers. Consequently, the net injury rate of utility vehicles in rural crashes was nearly identical to the car rate.

Next, we consider the results in urban crashes. As suggested earlier, these are probably less severe crashes than the rural crashes. Results (Figure 3.2) were as follows:

(a) Pickups. Although the pickup rollover rate was nearly double the car rate, this was offset by a rollover injury rate only half that of cars. Also, with a nonrollover injury rate slightly lower than the car rate (as in the rural crashes), the net effect was a pickup injury rate somewhat lower than in cars.

(b) Vans. The urban rollover-injury pattern of vans resembled that of pickups, with an especially low injury rate in nonrollovers. Consequently, the van urban injury rate was the lowest of all the vehicle types. Note also that the van rollover rate was nearly identical to the pickup rate and much lower than the utility vehicle rate.

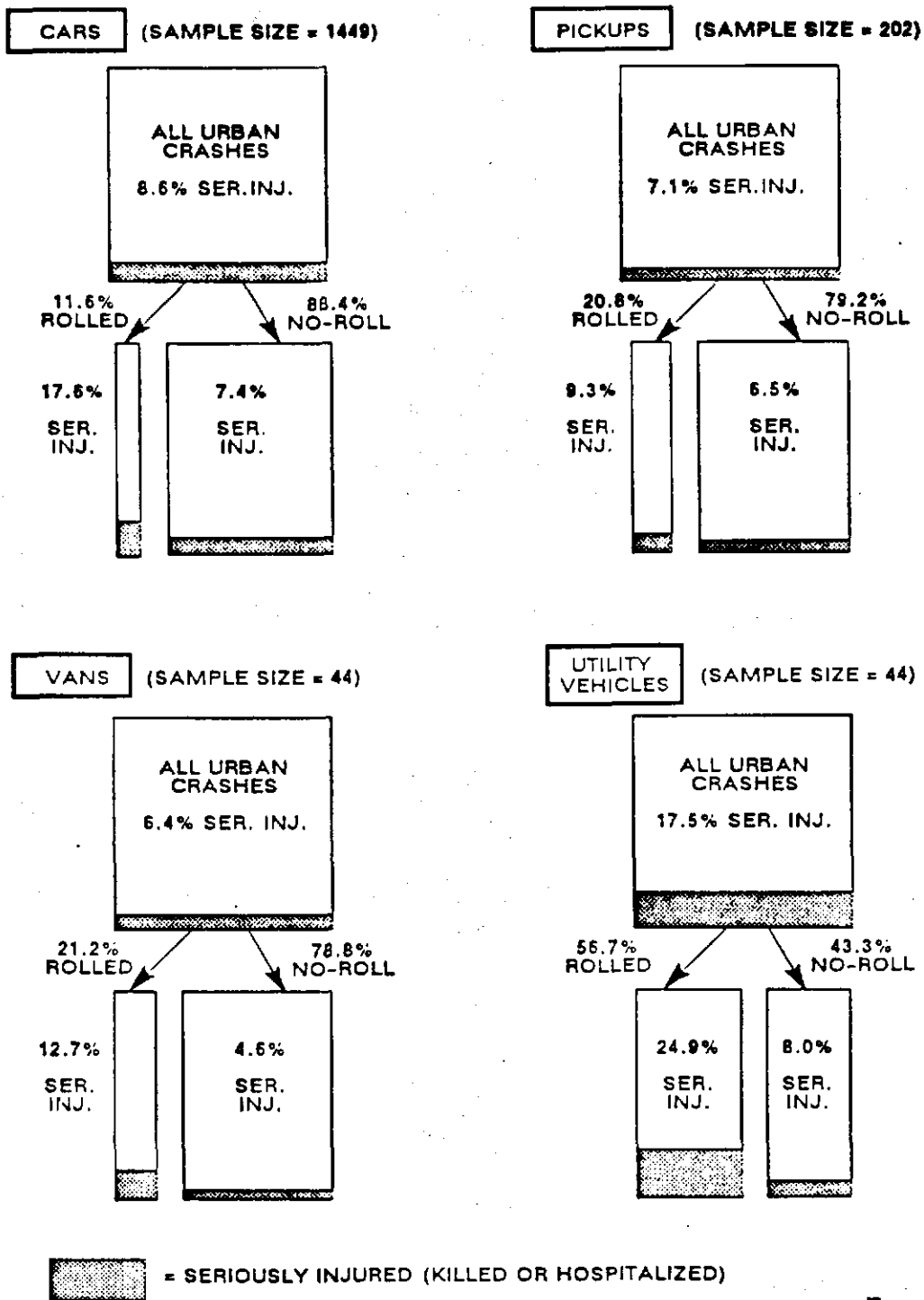


Figure 3.2. Urban Rollovers and Driver Injury:
 NASS 1980-1985 Unrestrained Drivers in Single - Vehicle
 Crashes (RNASTRK4 file; weighted data.)

(c) Utility vehicles. The utility vehicles deviated sharply from the other vehicles, with a net injury rate of 17.5%. The reliability of this figure is suspect, however, since it differs greatly from the urban utility vehicle rate in Table 3.1. (Figure 3.2 includes male and female drivers, while Table 3.1 includes males only.) This suggests both small-sample statistical unreliability and possible effects of confounding variables. In any case, the high rollover rate, accompanied by a high injury rate in rollovers, was the main source of the high overall injury rate in the utility vehicle crashes.

Reviewing the rural and urban results, it appears that the high rollover rates of light trucks do contribute to their injury rates, since in all cases except the possibly anomalous van rural data, injury rates were considerably higher in rollovers than in nonrollovers. The effect of rollovers is muted, however, because the nonrollover injury rates of light trucks were usually equal to or below the car rates. The van rural crashes deviated from this pattern with their high injury rate in nonrollovers. In general, however, it is now easier to see why light trucks, despite their having much higher rollover rates than passenger cars, did not have equally elevated net injury rates.

3.1.4 Summary.

The replications of analyses in our 1986 report yielded results generally consistent with the previous findings. Injury rates in light trucks and passenger cars still differed little, with the exception of a high van rural injury rate, which may be unreliable. Rollover rates of the light trucks were again found much higher than the car rates. Now, however, the van and pickup rollover rates appeared more similar, and well below the rate of the utility vehicles. And among the latter, the truck-based utility vehicles had a rollover rate similar to the vans and pickups, leaving the short, non-truck-based utility vehicles standing out with the highest (64%) overturn experience.

The seeming paradox in which high light truck rollover rates did not substantially raise their injury rates became more understandable. The light truck rollover rates did contribute many injuries (with the odd exception of van rural rollovers), but lower injury rates in nonrollovers tended to offset the rollover effects.

These findings support the importance of learning more about the causes of light truck rollovers, which are considered in the next section.

3.2 Comparisons of Car and Light Truck Rollovers

For an in-depth examination of why light trucks overturn more frequently than passenger cars, we used a fourfold strategy, as follows:

(1) All driver and environmental variables distinguishing rollover from nonrollover crashes were identified through statistical analysis, and then the passenger car and light truck crashes were compared to see if they differed on the rollover-related variables. This was done with the RNASTRK3 (driver-vehicle) file.

(2) With details from the clinical file, the relative risk of rollover within various environments was identified. These environments were then controlled in comparing the overturn rates of cars and light trucks.

(3) Using the clinical data, the sequence of crash events was traced for rollover and nonrollover crashes. Light trucks and cars were compared to see if they differed in the events leading to rollover.

(4) Concentrating on just the rollover crashes in the clinical data, the light trucks and cars were compared to see if they differed in the vehicle dynamics identified by the clinical analysts.

As noted in Chapter 2, sample data were used in these analyses, so the numbers do not represent population estimates. Because of the NASS sampling process, fatal crashes, injury accidents, and towaways are represented more heavily than non-towaway crashes.

Results from the four approaches are presented in the sections which follow.

3.2.1 Effects of Driver and Environmental Variables

For rollover rates of light trucks and cars to differ as the result of a confounding nonvehicular variable, two conditions must be met:

- (a) the nonvehicular variable must be correlated with rollover; and
- (b) light truck and car crashes must differ with respect to the nonvehicular variable.

To examine condition (a), the NASS driver and environmental variables possibly related to rollover were identified (Table 3.2). Crosstabulations were used to determine which variables were related to rollover. Chi-squares were used to index the strength of the

**Table 3.2 NASS Variables Examined for Their
Relationship to Vehicle Overturn**

Driver Variables

Age

Gender

Months driving experience

Frequency driving road

Crash alcohol involvement

Environmental Variables

Land use (urban-rural)

Number of travel lanes

Road divided/undivided

Horizontal alignment

Vertical alignment

Atmospheric condition (rain, etc.)

Road surface type

Road surface condition
(dry, icy, etc.)

Light condition

relationships, but the probabilities associated with chi-square must be considered suggestive only, because of the stratified NASS sample. Table 3.3 shows all the variables with a significant relationship for both cars and light trucks. Distinguishing rollover from nonrollover crashes were four roadway variables and two driver variables. The most pronounced effect was the tendency of rollover crashes to occur on rural roads. Rollovers also occurred more frequently in darkness and on two-lane roads, which may simply reflect the rural nature of rollover crashes. Curves were also associated with the overturns. As for the driver variables, rollovers were found somewhat more frequently on roads unfamiliar to the drivers, and the drivers in rollover crashes tended to be younger.

Variables in Table 3.2 but not in Table 3.3 are those which exhibited no differences between rollover and nonrollover crashes, or the effects were very slight. (The data are shown in Appendix C.) Of interest is the fact that rollover was not related to driver gender. Also, overturns were slightly more likely to involve alcohol-influenced drivers in the car crashes, but there was no such relation in the light truck crashes.

Next, the variables in Table 3.3 were compared across the vehicle types (Table 3.4.) Only four of the variables exhibited significant differences. Pickup and utility vehicle crashes were more common in rural environments, while car and van

Table 3.3: Variables Distinguishing Rollovers from Other Single-Vehicle Crashes

(RNASRKS data file; unweighted data)

	<u>Cars</u>		<u>Light Trucks</u>	
	<u>No Roll</u>	<u>Roll</u>	<u>No Roll</u>	<u>Roll</u>
<u>Land Use</u>				
Urban	62.7%	32.1%	49.4%	25.0%
Rural	37.3	67.9	50.6	75.0
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	263.1 (P=0)		64.4 (P=0)	
<u>Light Condition</u>				
Daylight, dawn, dusk	42.3%	41.5%	40.1%	42.6%
Dark, but lighted	27.8	12.4	23.0	8.2
Dark, unlighted	29.9	46.1	36.9	49.2
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	123.4 (P=0)		139.6 (P=0)	
<u>Number of Travel Lanes</u>				
One	4.2%	2.9%	2.6%	4.2%
Two	75.7	87.3	82.0	91.2
>2	20.1	9.8	15.4	4.6
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	55.1 (P=0)		32.0 (P=0)	
<u>Horizontal Alignment</u>				
Straight	59.8%	49.9%	61.9%	54.5%
Curved	40.3	50.1	38.1	45.5
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	25.9 (P=0)		5.3 (P=.0200)	

Table 3.3 (Continued)

	<u>Cars</u>		<u>Light Trucks</u>	
	<u>No Roll</u>	<u>Roll</u>	<u>No Roll</u>	<u>Roll</u>
<u>Driver Age</u>				
Under 25	43.7%	47.1%	38.4%	46.4%
25-39	34.6	37.3	39.7	38.7
40 & older	21.7	15.7	21.9	14.9
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	15.8 (P=.0007)		10.4 (P=.0061)	
<u>Frequency Driving Road</u>				
Daily	41.1%	32.5%	45.1%	36.2%
Weekly	22.5	20.9	20.8	24.1
Once per month, or less	36.4	46.6	34.1	39.7
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Chi-Square*	23.7 (P=.0001)		5.9 (P=.0510)	
Total Vehicles in Sample	2602	956	506	501

* Probabilities associated with the chi-square values must be considered suggestive only, because of the stratified MASS sample.

Table 3.4: Cars vs. Light Trucks on Rollover-Related Variables

(RNASTRK3 data file; unweighted data)

<u>Land Use</u>	<u>Cars</u>	<u>Pickups</u>	<u>Vans</u>	<u>U-Vehs</u>	<u>Chi-Square</u>
Urban	54.5%	33.9%	55.6%	40.7%	111.6
Rural	45.5	66.1	44.4	59.3	(P=0)
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
<u>Light Condition</u>					
Daylight, dawn, dusk	42.2%	37.7%	52.8%	46.0%	60.7
Dark, but lighted	23.6	14.6	22.2	16.0	(P=0)
Dark, unlighted	34.2	46.6	25.0	38.0	
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
<u>Number of Travel Lanes</u>					
One	3.8%	3.4%	4.9%	2.2%	42.0
Two	78.8	88.4	75.7	86.3	(P=0)
>2	17.4	8.2	19.4	11.5	
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
<u>Driver Age</u>					
Under 25	44.6%	46.0%	24.3%	37.2%	
25-39	35.3	36.3	54.2	42.8	26.0
40 & older	20.1	17.6	21.5	20.0	(P<.001)
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
<u>Frequency Driving Road</u>					
Daily	38.8%	41.2%	41.6%	36.4%	9.5
Weekly	22.1	24.1	22.1	15.0	(N.S.*)
Once per month or less	39.2	34.7	36.4	48.7	
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
<u>Horizontal Alignment</u>					
Straight	57.1%	56.8%	64.1%	60.7%	2.7
Curved	42.9	43.2	35.9	39.3	(N.S.*)
	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	
Total Vehicles in Sample	3558	749	108	150	

*N.S. - Not significant by usual statistical standards; probabilities associated with the chi-square values must be considered suggestive only, because of the stratified MASS sample.

crashes occurred more in urban settings. The number of travel lanes reflects that finding. With regard to light conditions, the pickup crashes exhibited a tendency to occur in darkness more than the other vehicle crashes, and that too seems to reflect the rural effect. As to the driver variables, only driver age showed a difference among the vehicle types; drivers of vans and utility vehicles tended to be older*. No significant differences among the vehicle types were found with respect to road curvature or the driver's familiarity with the road.

Since urban-rural landuse and driver age were the main variables which could confound rollover-rate comparisons among the vehicle types, the overturn rates were standardized by adjusting for those two variables. Table 3.5 shows how this was done, and it presents both the unadjusted and standardized roll rates. Surprisingly, the effects of standardizing are slight, indicating that landuse and driver age had little effect on the vehicle rollover rates. The largest effect of standardizing was to lower the pickup rates somewhat.

To better indicate rollover rates in the crash population, the method of Table 3.5 was applied to the data weighted by the NASS weighting factors. The resulting standardized rollover rates were as shown on page 41.

* With weighted data, the utility vehicle drivers had an age distribution similar to the car drivers.

Table 3.5 Generation of Rollover Rates Adjusted
for Driver Age and Land Use

(RNASTRK3 data file; unweighted data)

A. All crash vehicles, divided into driver-age-landuse groups

Driver Age Land use	<25 Urban	25-39 Urban	40+ Urban	<25 Rural	25-39 Rural	40+ Rural	Total
No. crash vehicles	931	885	463	1059	746	426	4510
Relative frequency	.206	.196	.103	.235	.165	.095	1.000

B. Rollover rates within driver-age-landuse groups

	<25 Urban	25-39 Urban	40+ Urban	<25 Rural	25-39 Rural	40+ Rural	Overall Unadjusted Roll Rate*	Overall Adjusted Roll Rate*
Cars	17.7%	16.8%	10.4%	39.1%	44.9%	35.1%	27.0%	27.8%
Pickups	33.0	29.8	23.3	64.3	56.6	44.8	48.8%	43.8%
Vans	25.0	27.8	14.3	50.0	54.5	43.8	36.4%	37.0%
U-vehs	59.1	68.0	27.3	75.0	73.0	77.8	67.6%	65.4%

Explanation: The rollover rates are adjusted to show the values they would have if each vehicle type were distributed among the driver age-landuse groups as shown in section A above. This is done by weighting the rollover rates within each age-landuse group by the overall relative frequency of that group. For example, the pickup adjusted rate is calculated as follows:

$$(.206) (.330) + (.196) (.298) + (.103) (.233) + (.235) (.643) + (.165) (.566) + (.095) (.448) = 43.8\%$$

* Since unweighted data are used, the rollover rates here are not population estimates, and they differ from the rates presented in section 3.1.2. See text for adjusted roll rates with weighted data.

cars	- 20.3%	} Standardized rollover rates with weighted NASS data
pickups	- 30.5%	
vans	- 36.4%	
utility vehicles	- 43.8%	

The main effect of standardizing was to have lowered the pickup rate slightly, and to have raised the van rate. The weighted, standardized data order the vehicles as they were in our previous light truck study (Terhune, 1986).

The implication of this analysis is that it is hard to attribute the elevated rollover rates of light trucks to confounding effects of the driver and environmental variables. Utility vehicles especially maintained high overturn rates, even after adjusting for landuse and driver age.

Incidentally, it has sometimes been noted that utility vehicle accidents tend to occur more frequently on roads covered with snow and ice, compared with other vehicles. The RNASTRK3 file showed that was true in single-vehicle crashes. The data were not shown here, because snow and ice conditions were not found related to rollover of light trucks (see Appendix C).

3.2.2 Controlling for Environmental Roll Risk

Instead of using the simpler NASS urban-rural distinction, the clinical coders used the accident-scene photographs to separate the crash environments into the six categories below.

- o residential-urban
- o manufacturing or commercial
- o residential-rural
- o farming
- o undeveloped, open
- o undeveloped, treed or forested

The overturn rates of all vehicles in the clinical data file were computed for each of the categories, with results as shown in Table 3.6, part A. There were wide differences in the rollover rates, suggesting that the environments differ considerably in their rollover risks. Doubtless, the differences are influenced by many factors, such as typical travel speeds, road widths, visibility, and roadside terrain. The six environments divide readily into the four risk levels shown in Table 3.6. Part B of the table shows how the single-vehicle crashes of cars and light trucks were distributed among the four risk environments. The pickup and utility vehicle crashes were found somewhat more frequently in the highest-risk environment, indicating that environment could have elevated the overall rollover rates of those vehicles.

Table 3.6 Environmental Categories and Single-Vehicle-Crash Rollover

(Clinical data file, weighted to be representative of the RNASR3 data file.)

A. Overall Rollover Rates Within Environmental Categories

<u>Environment</u>	<u>% Rollovers in S.V. Crashes*</u>	<u>"Rollover Risk Level"</u>
Manufacturing - commercial	17.0%	} Low
Residential - urban	17.7%	
Residential - rural	33.9%	Moderate
Undeveloped - treed	41.7%	} High
Undeveloped - open	43.9%	
Farming	71.2%	Very high

B. Distribution of Crashes Among Environmental Categories

<u>"Rollover Risk Level"</u>	<u>Cars</u>	<u>Pickups</u>	<u>Vans</u>	<u>U-Vehs</u>
Low	42.5%	32.9%	49.8%	39.9%
Moderate	19.8	19.8	6.1	6.4
High	30.5	34.6	38.9	36.9
Very High	7.2	12.8	5.1	16.8
Total	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
No. of Vehicles Represented	3535	734	107	135
No. of Vehicles in Sample	119	101	97	85

*S.V. = Single-Vehicle

Interpretive example: 17.0% of all single-vehicle crashes occurring in a manufacturing-commercial environment involved rollover.

Table 3.7 shows the overturn rates of the vehicle types within each of the environmental risk categories. Undoubtedly, the small samples within the clinical data file lower the stability of the individual rates, but previous patterns are upheld. The utility vehicles generally had high rollover rates, even in the lowest environmental risk group. Pickups, vans, and cars exhibit successively lower rates.

Summarizing, this analysis has shown that there are clear differences among road environments in the rates with which vehicles overturn in single-vehicle crashes. Pickup and utility vehicle crashes were found somewhat more frequently in the environments apparently conducive to overturn. When controlling for the crash environment, however, light trucks continued to exhibit rollover rates higher than passenger cars.

3.2.3 The Event Sequence of Rollovers

The first matter of interest regarding the event sequence concerns where the overturns happen, in relation to the roadway. Table 3.8 shows that nearly all car rollovers were produced by features off the road, while approximately one-fifth of light truck overturns resulted from on-road features. Later, we shall examine evidence to see what happened in the on-road rollovers, but first we will examine the majority --the off-road overturns.

Table 3.7 Single-Vehicle Rollover Rates of Vehicle Types Within Environmental Rollover Risk Categories

(Clinical data file, weighted to be representative of the RNASTRK3 data file)

<u>"Rollover Risk Level"</u> **	<u>% Vehicles Overturning**</u>			
	<u>Cars</u>	<u>Pickups</u>	<u>Vans</u>	<u>U-Vehs</u>
Low (Vehicles represented in denominator)	14.9% (1501)	25.7% (242)	18.4% (53)	53.3% (58)
Moderate (Vehicles represented in denominator)	29.5 (701)	54.5 (145)	65.9 (7)	23.9 (6)
High (Vehicles represented in denominator)	35.0 (1079)	65.6 (253)	54.2 (42)	82.5 (54)
Very High (Vehicles represented in denominator)	67.6 (254)	94.0 (94)	59.1 (5)	90.4 (17)

*See Table 3.6, part A, for definitions of "Rollover Risk Level".

**Example of how to read table: of all the car single-vehicle crashes occurring in an environment having low rollover risk, 14.9% involved rollover.

Table 3.8 Locations of Features Producing Rollovers*

(Clinical data file, weighted to the representative
of the RMASTRK3 file)

	<u>Cars</u>	<u>Pickups</u>	<u>Vans</u>	<u>U-Vehs</u>
On road	3.5%	19.2%	18.9	24.4
Off road	96.5	80.8	81.1	75.6
Total	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
No. of Vehicles Represented	980	374	40	100
No. of Vehicles in Sample	57	52	37	45

* On-road features include the pavement.

The light truck and car crashes were compared to see if they differed in the role that roadside features played in the rollovers. The analysis was based on the following model:

$$\begin{aligned} \text{The \% overturns involving contact with feature}_i = \\ \text{pr}\{\text{feature}_i\} \times \text{pr}\{\text{feature}_i \text{ contact} | \text{feature}_i\} \times \\ \text{pr}\{\text{rollover} | \text{feature}_i \text{ contact}\} \end{aligned}$$

where..

$\text{pr}\{\text{feature}_i\}$ = probability that the feature was present at the crash site

$\text{pr}\{\text{feature}_i \text{ contact} | \text{feature}_i\}$ = probability that the feature is contacted, given its presence

$\text{pr}\{\text{rollover} | \text{feature}_i \text{ contact}\}$ = probability of rollover, given feature contact

The clinical data file included all the data needed to generate the probability estimates for the model, so they were calculated for each vehicle type and each roadside feature in the clinical file. The detailed results are provided in Appendix D, but here they are presented in a form easier to follow.

From averaging across vehicle types, the probabilities below estimate the risk of rollover, given vehicle contact with each of the roadside features examined:

cut slope (slopes upward from road)	- 0.64
fill slope (slopes downward from road)	- 0.58
ditch	- 0.58
fence	- 0.54
bridge rail or other longitudinal objects	- 0.48
misc. fixed object	- 0.33
divider, barrier	- 0.29
narrow fixed object	- 0.27
guardrail	- 0.23
curb	- 0.19

It should be understood that because these estimates are based on crash data, they are probably higher than estimates that would be obtained if the data included road departures that did not result in a police-reported crash. It should also be noted that these aggregate data may include urban-rural effects. The results do, however, provide a useful indication of the rollover hazard presented by each of the objects. Sideslopes, both cut and fill types, as well as ditches, fences, and bridge rails, were associated with the greatest risk of overturn. In contrast, guardrails and curbs apparently offer relatively slight risks.

A question pertinent to this study is whether the high rollover rates of light trucks may be attributed in part to light truck crash occurrence on roads where there is high

exposure to rollover-conducive roadsides. The $pr(\text{feature})$ parameter, expressed as the percent of crashes where each roadside feature was present, is an indicator of this. Figure 3.3 shows the parameter for the five roadside features with the highest rollover rates. In general, the light trucks did not appear much more exposed to the features than did the passenger cars. The pickups were slightly more exposed to cut slopes, fill slopes, and ditches than cars were, so the pickup rollover rates could have been elevated somewhat by that exposure. The vans were less exposed to cut slopes than cars were, which might reduce their rollover rate slightly. The most pronounced difference between cars and a light truck type was the much greater exposure of utility vehicles to ditches, a difference which may have elevated the utility vehicle net overturn rate.

Another relevant question is whether light trucks exhibited a greater tendency to overturn than cars, when contacting any of the roadside features. This is indicated by the $pr(\text{rollover}|\text{feature contact})$ parameter in our model, and its values are estimated by the rollover percentages associated with each feature-contact. The results are shown in Figure 3.4, which shows the following:

- (a) For every roadside feature, rollover rates were highest for the utility vehicles. Even for curbs, the feature least hazardous for

VERTICAL SCALES:
% OF CRASHES
WHERE ROADSIDE
FEATURE WAS
PRESENT AT
ROADSIDE

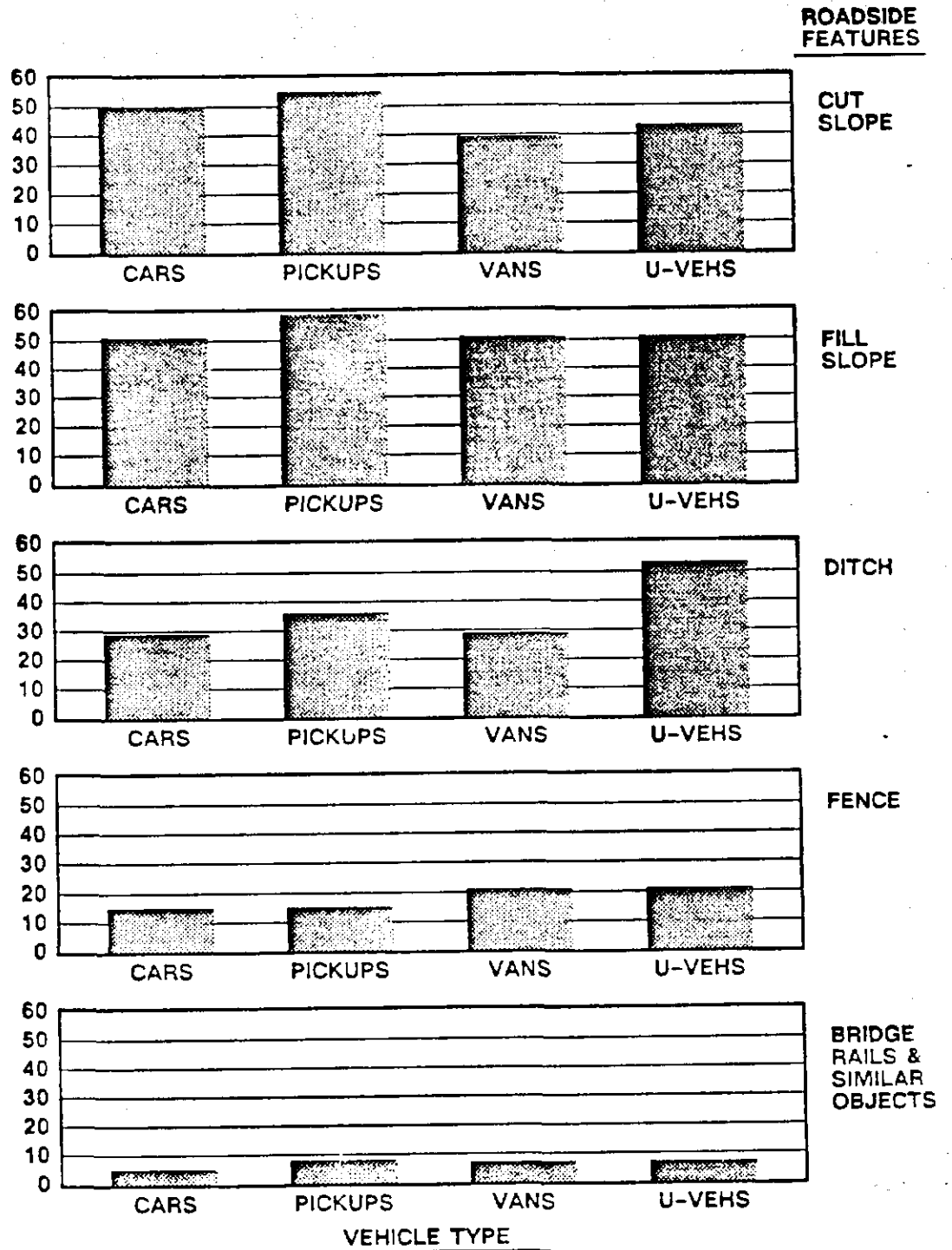


Figure 3.3. Crash Exposure of Vehicles to Roadside Rollover Hazards
(Clinical data file, weighted to be representative of the RNASR3 file.)

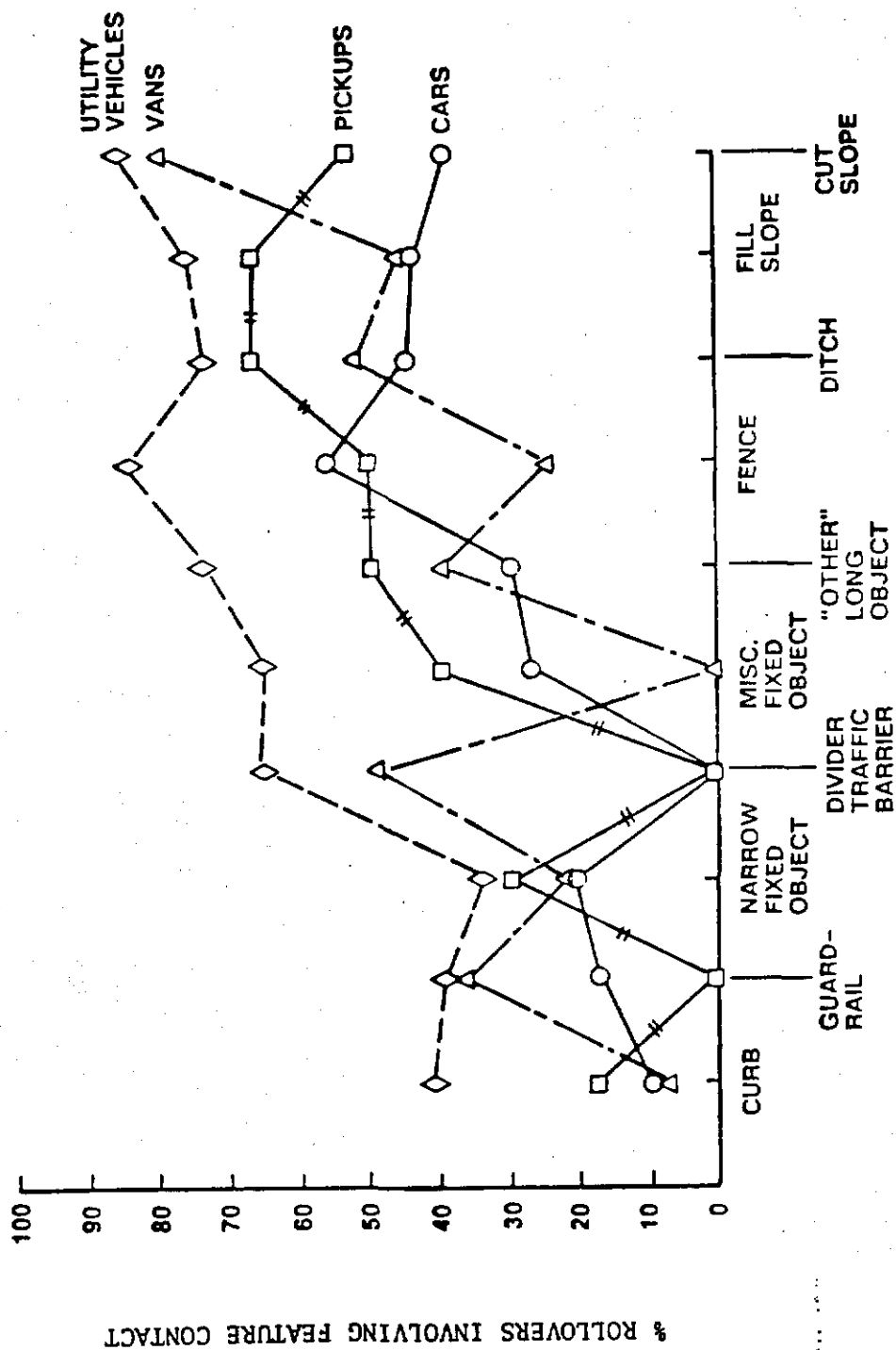


Figure 3.4. Estimated Probability of Rollover, Given Roadside Feature Contact (Clinical data file, weighted to be representative of the RNASTRK3 file.)

rollovers, utility vehicles were distinctly more inclined to overturn after contact.

- (b) Pickups had the second highest rollover rate for most of the roadside features.

(c) Vans overturned much more frequently than cars when contacting cut slopes, dividers, and guardrails; for all other features, they overturned at similar or lower rates than cars.

While the probabilistic model used in the preceding analysis suggests causal linkages between the roadside features and rollovers, the data do not conclusively establish causation. To provide further evidence on the causes of rollovers in car and light trucks, the clinical analysts judged which feature of road or roadside produced each rollover. The results (Table 3.9) modify our understanding of the "triggers" of light truck and car rollovers. Note the following points in the table:

(a) Judged most frequently as triggers of overturn were fill slopes, ditches, and the road pavement. Fill slopes were more important to car than to light truck rollovers, whereas ditches and the road pavement were definitely more relevant to light truck rollovers. Pavements

Table 3.9 Causes of Rollovers as Judged in Clinical Analysis

(Clinical file, weighted to be representative
of RMASTRK3 data file)

<u>Attributed Rollover Cause</u>	<u>Cars</u>	<u>Pickups</u>	<u>Vans</u>	<u>U-Vehs</u>
Fill slope	33.3%	28.9%	21.6%	22.2%
Ditch	15.8	28.9	24.3	28.9
Pavement on road	3.5	17.3	18.9	24.4
Level ground	1.8	3.8	13.5	6.7
Embankments	12.3	3.8	0	2.3
Cut slope	10.5	7.7	13.5	6.7
Narrow fixed object	8.8	1.9	0	0
Curb	0	1.9	2.7	4.4
Guardrail	1.8	0	0	2.2
Divider	0	0	5.4	0
Wall	3.5	0	0	0
Edge dropoff	1.8	0	0	0
Fence	0	1.9	0	0
Other	7.0	3.8	0	0
Totals	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>	<u>100.0%</u>
Total number of vehicles	57	52	37	45

were, in fact, almost negligible in car rollovers, whereas they were the second most prevalent trigger of utility vehicle overturns. Notice also that level ground was identified as a rollover trigger. Taking pavement and level ground together, fully 32.4% of the van overturns and 31.1% of the utility vehicle overturns were attributed to those sources.

(b) While previous indications suggested that cut slopes present a high rollover hazard, the clinical judgments indicated that cut slopes were infrequent rollover causes. An implication is that while overturn crashes frequently involved contact with a cut slope, the rollovers were produced in most of these cases by something else, such as the ditch which usually is at the base of a cut slope.

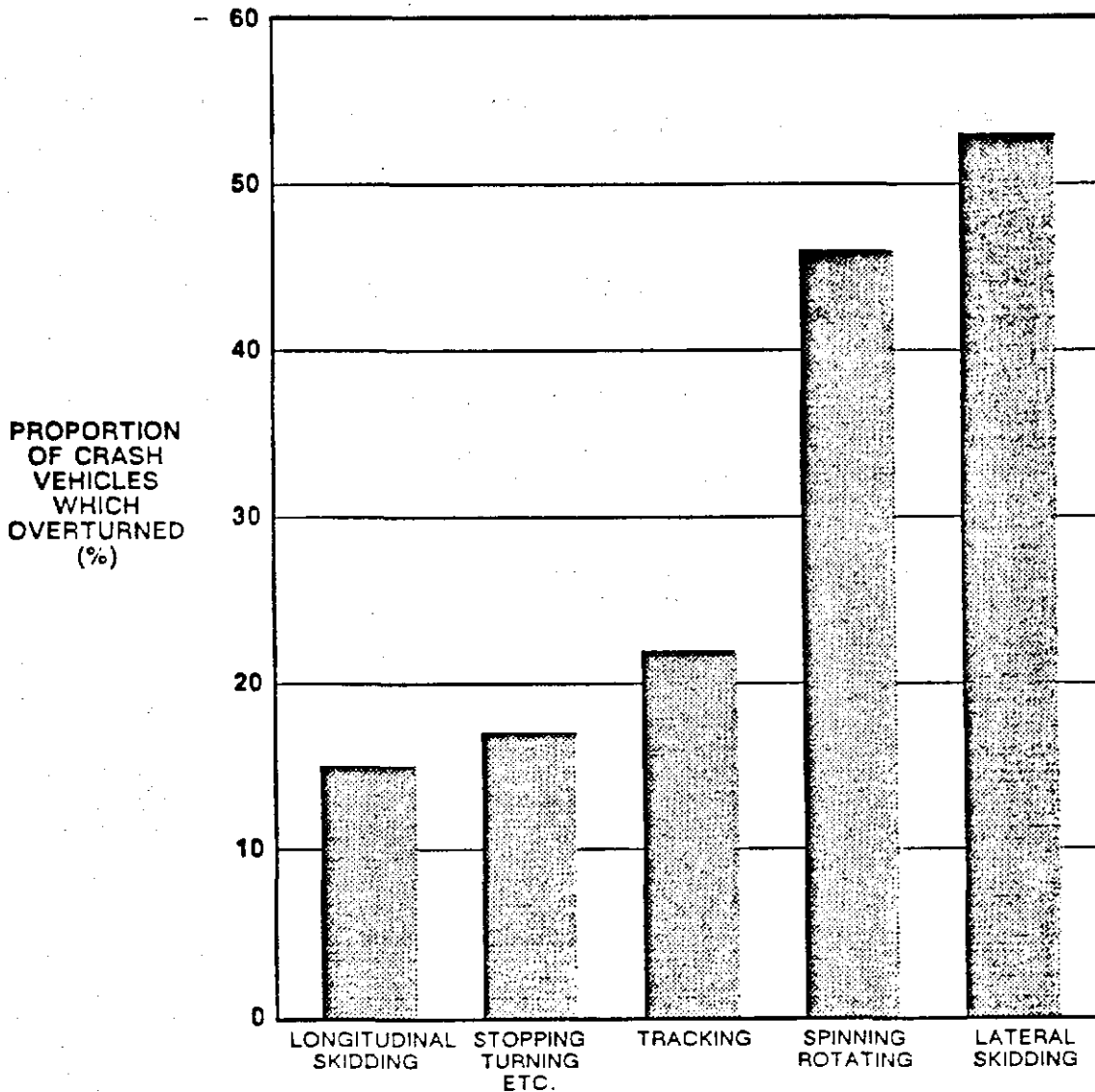
(c) Several other features previously indicated to play a role in overturns also seemed, in the judgment of the clinical analysts, to be mainly incidental. These include narrow fixed objects, curbs, guardrails, dividers, and fences.

Summarizing, this analysis of crash events began by showing that a large majority of overturns were initiated off

the road, though about a fifth of light truck rollovers began on the road. Considering the off-road rollovers, the data indicated that light trucks may overturn more frequently than cars because their crashes tend to occur more where the roadsides have rollover-conducive features, such as sideslopes and ditches. More distinctive, however, was evidence that, for most of the features, utility vehicles and pickups overturned at higher rates than passenger cars. Van rollover rates were pronouncedly higher than car rates with only a few of the features. As to which features were most likely to cause an overturn, statistical and clinical analyses gave somewhat different indications. Both indicated that fill slopes and ditches were very important rollover "triggers", but they disagreed as to whether cut slopes and fences were significant to rollover.

3.2.4 Vehicle Dynamics in Rollovers

As a final approach to understanding why light truck overturn rates are higher than car rates, the vehicle dynamics in rollovers were compared. Examined first were the vehicle actions just prior to the crash. Figure 3.5 shows the overturn rates for each of the five categories of vehicle pre-crash orientation coded by the clinical analysts. Clearly, lateral (sideways) skidding and vehicle spinning or rotating were the actions most likely to be followed by overturn. If light trucks were more subject to loss of control involving lateral skidding



Pre-Crash Vehicle Orientation

Example: Of all vehicles which were tracking prior to the crash, approximately 22% overturned.

Figure 3.5. Pre-Crash Vehicle Orientation and Rollover
(Clinical data file, weighted to be representative of the RNASR3 file.)