FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN

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

Kenneth W. Terhune, Ph.D.

Accident Research Section

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.

VALLEY FORGE CORPORATE CENTER 2600 MONROE BOULEVARD NORRISTOWN, PA 19403 TEL. (215) 666-3000

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 <u>was</u> a research objective to study conditional probabilities--the likelihood of vehicle rollover <u>given that a single-vehicle crash has occurred</u>. 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)

* * *

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.

TABLE OF CONTENTS

		Page
	ABSTRACT	ii
	ACKNOWLEDGEMENTS	iv
	FOREWORD	v
	LIST OF TABLES	viii
	LIST OF FIGURES	x
1.0	INTRODUCTION	1
	1.1 Background	2
	1.2 Objectives	5
2.0	RESEARCH METHODS	7
	2.1 Why NASS Data Were Chosen	7
	2.2 Data Sets Created	12
	2.3 Weighted vs. Unweighted Data	18
3.0	RESULTS	22
	3.1 Replications of Analyses in Calspan's 1986 Report	22
	3.1.1 Injury Rates	23
	3.1.2 Rollover Rates	25
	3.1.3 Effects of Rollover on Injuries	26
	3.1.4 Summary	31
	3.2 Comparisons of Car and Light Truck Rollovers	32
	3.2.1 Effects of Driver and Environmental Variables	33
	3.2.2 Controlling for Environmental Roll Risk	42
	3.2.3 The Event Sequence of Rollovers	44
	3.2.4 Vehicle Dynamics in Rollovers	55
	3.2.5 Overall Summary: Light Truck vs. Car Rollovers	63
	3.3 Comparisons of Car and Light Truck Ejections	64
	3.3.1 Controlling for Crash Severity	66
	3.3.2 Ejection and Injury in Cars and Light Trucks	73
	3.3.3 Avenues of Occupant Ejection	78
	3.3.4 Summary of Section 3.3	87
4.0	DISCUSSION	90
	4.1 The Rollover-Injury Paradox	90
	4.2 The Elevated Light Truck Overturn Rates	92
	4.3 The Elevated Light Truck Ejection Rates	94
	4.4 Research Methodology Issues	95
5.0	CONCLUSIONS	99
6.0	RECOMMENDATIONS	101
7.0	REFERENCES	103
	APPENDICES	105

LIST OF TABLES

Table No.	Title	Page No.
2.1	Variables Needed for the Data Analyses	9
2.2	Composition of the Working Files Selected from the NASS Automated Data Base	13
2.3	Coding Rules for Light Truck Identification: NASS 1980-1985	15
2.4	Variables Extracted from the NASS Cases Through Clinical Case Examination	17
2.5	Composition of the Clinical File	19
3.1	Driver Injury Rates by Vehicle Type, With Controls for Gender, Restraint System Use and Environment: NASS 1980-1985	24
3.2	NASS Variables Examined for Their Relationship to Vehicle Overturn	34
3.3	Variables Distinguishing Rollovers from Other Single-Vehicle Crashes	36
3.4	Cars vs. Light Truck on Rollover-Related Variables	38
3.5	Generation of Rollover Rates Adjusted for Driver Age and Land Use	40
3.6	Environmental Categories and Single-Vehicle-Crash Rollover	43
3.7	Single-Vehicle Rollover Rates of Vehicle Types Within Environmental Rollover Risk Categories	45
3.8	Locations Where Rollovers Began	46
3.9	Causes of Rollovers as Judged in Clinical Analysis	53
3.10	Pre-Crash Vehicle Orientation and Vehicle Type	58
3.11	Types of Rollovers Experienced by the Vehicle Types in Clinical Analysis	62

LIST OF TABLES (CONTINUED)

Table No.	Title	Page No.
3.12	Ejection Rates of Drivers Not Using Restraint Systems	65
3.13	Single Vehicle Crash Severity Scale Derived from the Collision Deformation Classification (CDC) and Occupant Injury Rates of Cars	69
3.14	Vehicle Types and Rollover Crash Severity Derived from CDC and Injury Rates	71
3.15	Main Portals of Occupant Ejection	79
3.16	Door Openings and Occupant Ejection	81
3.17	Open Windows and Occupant Ejection	82
3.18	Ejection in Relation to Open Tops of Vehicles	83
3.19	Occupant Ejections in Relation to Vehicle Structural Failures	85
3.20	Ejections Due to Structural Failures in Pickups and Utility Vehicle Rollovers	86
B-1	Coding Body Type from NASS Vehicle Data Form	B-5

LIST OF FIGURES

Figure No.	Title	Page No.
3.1	Rural Rollovers and Driver Injury: NASS 1980-1985 Unrestrained Drivers in Single-Vehicle Crashes	27
3.2	Urban Rollovers and Driver Injury: NASS 1980-1985 Unrestrained Drivers in Single-Vehicle Crashes	29
3.3	Crash Exposure of Vehicles to Roadside Rollover Hazards	50
3.4	Estimated Probability of Rollover, Given Roadside Feature Contact	51
3.5	Pre-Crash Vehicle Orientation and Rollover	56
3.6	Rollover Rates for the Most Common Pre-Crash Vehicle Orientations	59
3.7	Coding Guide for Rollover Types	61
3.8	Unrestrained-Occupant Ejection Rates in Relation to Crash Severity in Rollovers: I	68
3.9	Unrestrained-Occupant Ejection Rates in Relation to Crash Severity in Rollovers: II	72
3.10	Occupant Injuries in Relation to Crash Severity, Ejections, and Restraint Use in Rollovers: I	74
3.11	Occupant Injuries in Relation to Crash Severity, Ejections, and Restraint Use in Rollovers: II	75
3.12	Attributed Sources of Injuries to Ejected Occupants in Single-Vehicle Crashes	77
B-1	CALAX Accident Type Codes	B-6

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 Safely 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:

- 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);
- 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);
- 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

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

B. Sample Sizes

RNASTRK3	RNASTRK4	RNASTRK5
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
4,565 total vehicles	7,056 total occupants	45 AIS6 injuries
		751 inj., AIS unknown
		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

Vehicle Type		NASS Classification	Numbers in RNASTRK3 Sample
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, Ramcharger, 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)

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

B. Light Truck Ejection Cases (Vehicles)

	Primary Sample	Supplementary Sample*
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: NASS 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

	Passenger Cars	Pickup Trucks	Light Vans	Utility Vehicles
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.

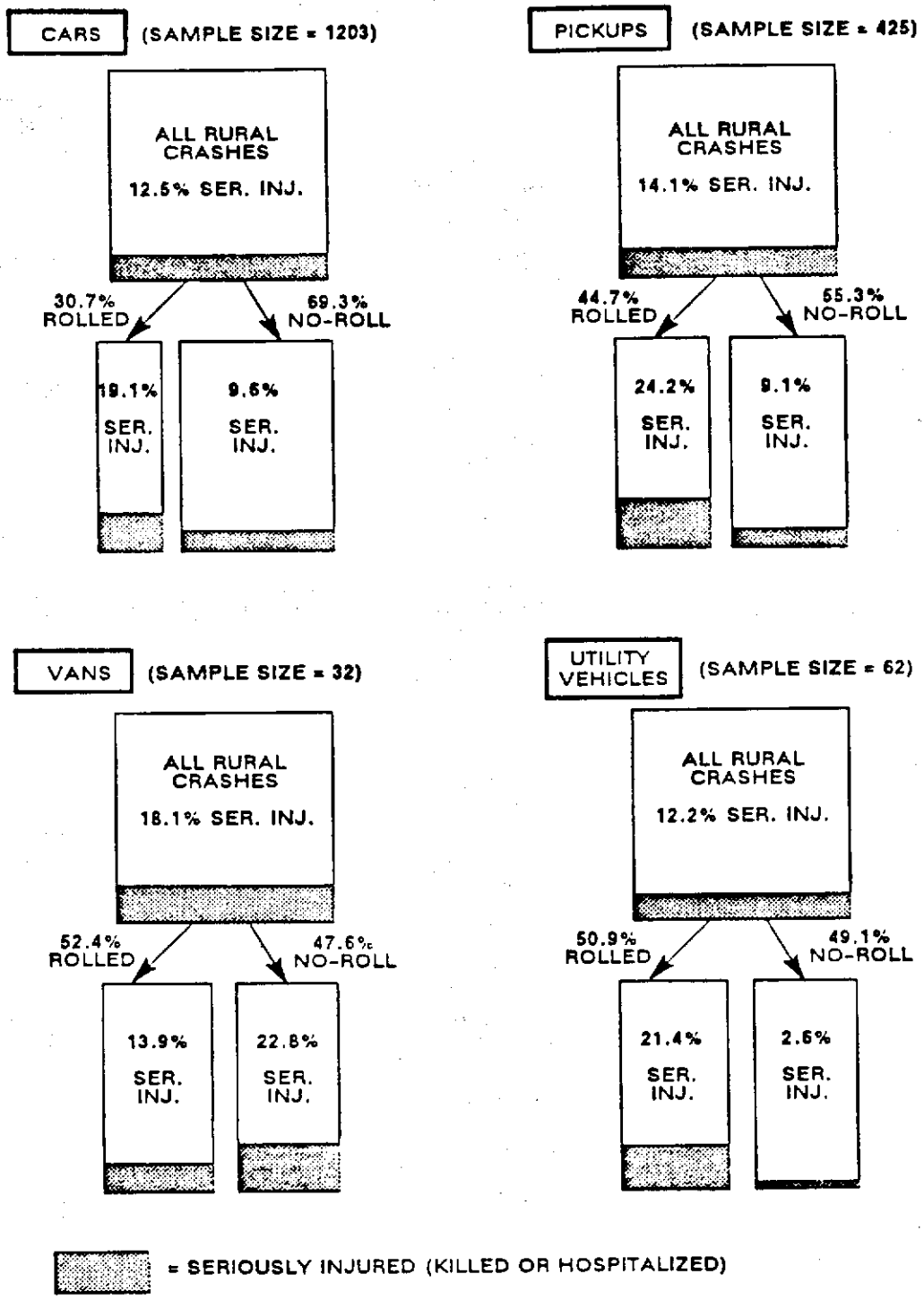


Figure 3.1. Rural Rollovers and Driver Injury: NASS 1980-1985 Unrestrained Drivers in Single - Vehicle Crashes (RNASTRK4 file; weighted data.)

(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.

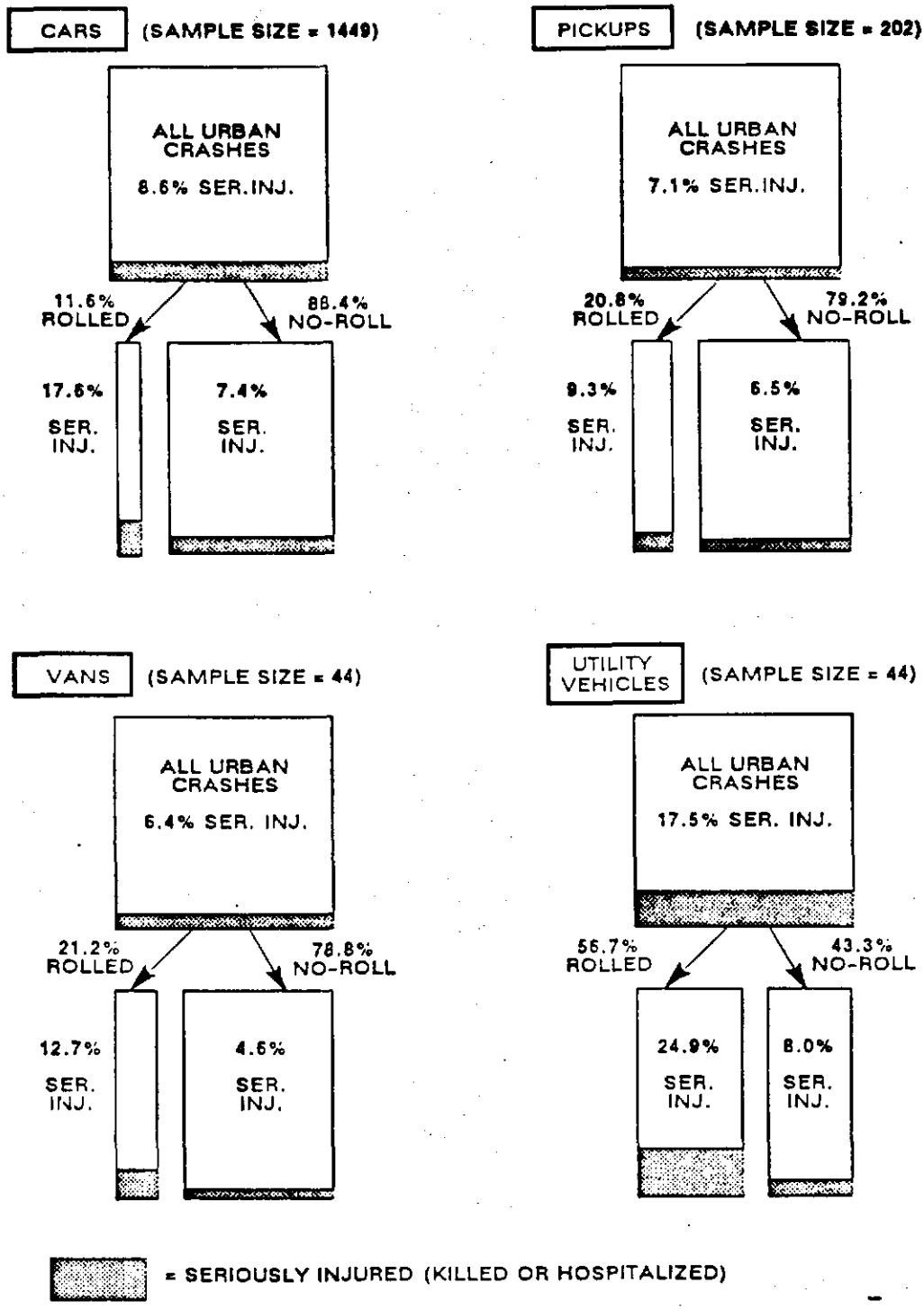


Figure 3.2. Urban Rollovers and Driver Injury: NASS 1980-1985 Unrestrained Drivers in Single - Vehicle Crashes (RNASTRK4 file; weighted data.)

(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 <u>not</u> 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

(RNASTRK3 data file; unweighted data)

		Cars		Light Trucks	
		No Roll	Roll	No Roll	Roll
Land Use					
	Urban	62.7%	32.1%	49.4%	25.0%
	Rural	37.3	67.9	50.6	75.0
		100.0%	100.0%	100.0%	100.0%
	Chi-Square*	263.1 (P=0)		64.4 (P=0)	
Light Condition					
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
		100.0%	100.0%	100.0%	100.0%
	Chi-Square*	123.4 (P=0)		139.6 (P=0)	
Number of Travel Lanes					
	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
		100.0%	100.0%	100.0%	100.0%
	Chi-Square*	55.1 (P=0)		32.0 (P=0)	
Horizontal Alignment					
	Straight	59.8%	49.9%	61.9%	54.5%
	Curved	40.3	50.1	38.1	45.5
		100.0%	100.0%	100.0%	100.0%
	Chi-Square*	25.9 (P=0)		5.3 (P=.0200)	

Table 3.3 (Continued)

		Cars		Light Trucks	
		No Roll	Roll	No Roll	Roll
Driver Age					
	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
		100.0%	100.0%	100.0%	100.0%
	Chi-Square*	15.8 (P=.0007)		10.4 (P=.0061)	
Frequency Driving Road					
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
		100.0%	100.0%	100.0%	100.0%
	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 NASS sample.

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

(RNASTRK3 data file; unweighted data)

Land Use	Cars	Pickups	Vans	U-Vehs	Chi-Square
Urban	54.5%	33.9%	55.6%	40.7%	111.6
Rural	45.5	66.1	44.4	59.3	(P=0)
	100.0%	100.0%	100.0%	100.0%	
Light Condition					
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	
	100.0%	100.0%	100.0%	100.0%	
Number of Travel Lanes					
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	
	100.0%	100.0%	100.0%	100.0%	
Driver Age					
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)
	100.0%	100.0%	100.0%	100.0%	
Frequency Driving Road					
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	
	100.0%	100.0%	100.0%	100.0%	
Horizontal Alignment					
Straight	57.1%	56.8%	64.1%	60.7%	2.7
Curved	42.9	43.2	35.9	39.3	(N.S.*)
	100.0%	100.0%	100.0%	100.0%	
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 NASS 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
pickups	-	30.5%	rollover rates
vans	-	36.4%	with weighted
utility vehicles	-	43.8%	NASS data

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 RNASTRK3 data file.)

A. Overall Rollover Rates Within Environmental Categories

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

B. Distribution of Crashes Among Environmental Categories

"Rollover Risk Level"	Cars	Pickups	Vans	U-Vehs
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	100.0%	100.0%	100.0%	100.0%
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)

"Rollover Risk Level"*	% Vehicles Overturning**			
	Cars	Pickups	Vans	U-Vehs
Low	14.9%	25.7%	18.4%	53.3%
(Vehicles represented in denominator)	(1501)	(242)	(53)	(58)
Moderate	29.5	54.5	65.9	23.9
(Vehicles represented in denominator)	(701)	(145)	(7)	(6)
High	35.0	65.6	54.2	82.5
(Vehicles represented in denominator)	(1079)	(253)	(42)	(54)
Very High	67.6	94.0	59.1	90.4
(Vehicles represented in denominator)	(254)	(94)	(5)	(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 RNASTRK3 file)

	Cars	Pickups	Vans	U-Vehs
On road	3.5%	19.2%	18.9	24.4
Off road	96.5	80.8	81.1	75.6
Total	100.0%	100.0%	100.0%	100.0%
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:

The % overturns involving contact with $feature_i$=

$pr(feature_i)$ X $pr(feature_i\ contact|feature_i)$ X

$pr(rollover|feature_i\ contact)$

where..

$pr(feature_i)$ = probability that the feature was present at the crash site

$pr(feature_i\ contact|feature_i)$ = probability that the feature is contacted, given its presence

$pr(rollover|feature_i\ contact)$ = 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(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(rollover|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

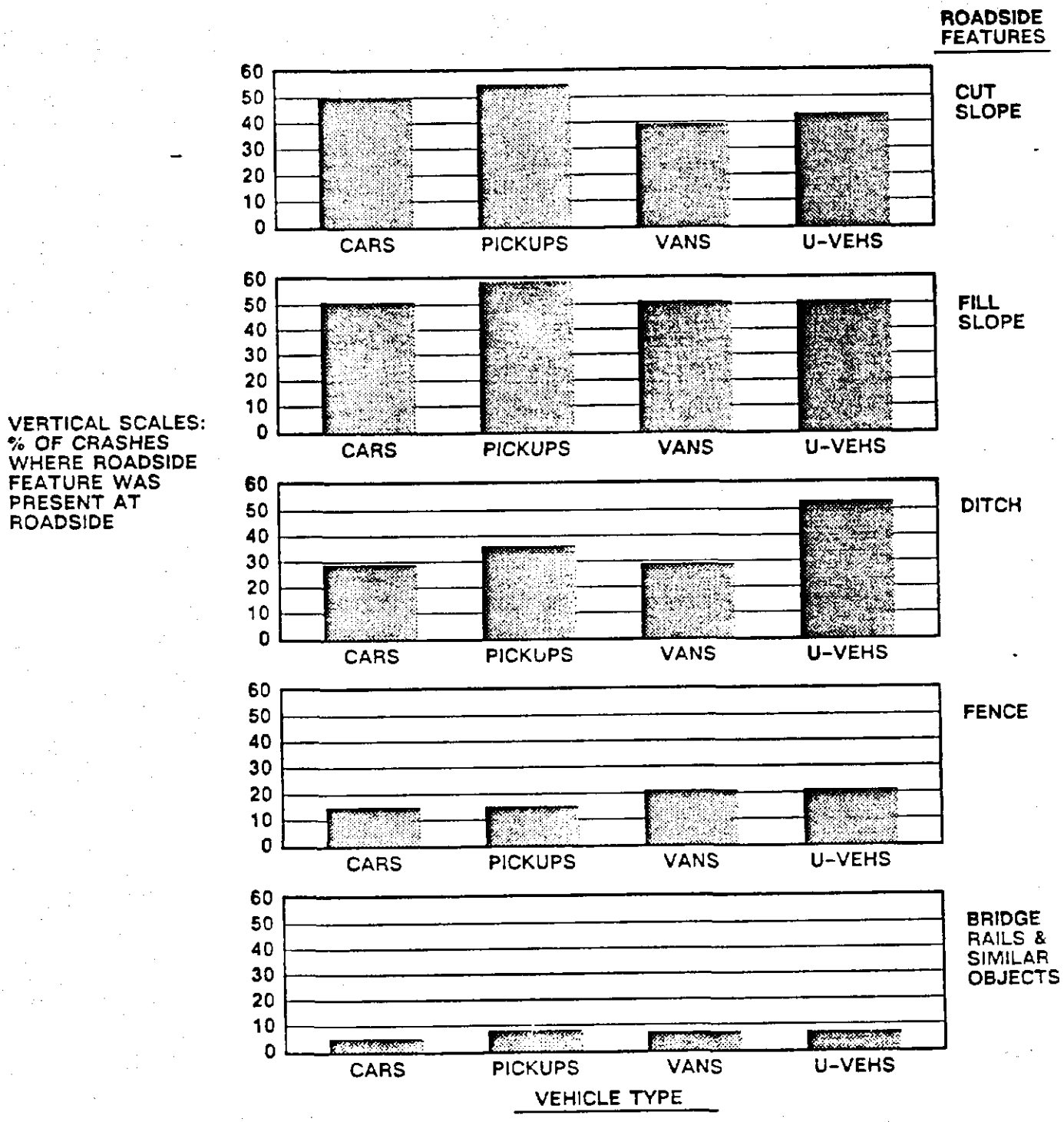


Figure 3.3. Crash Exposure of Vehicles to Roadside Rollover Hazards
(Clinical data file, weighted to be representative of the RNASTRK3 file.)

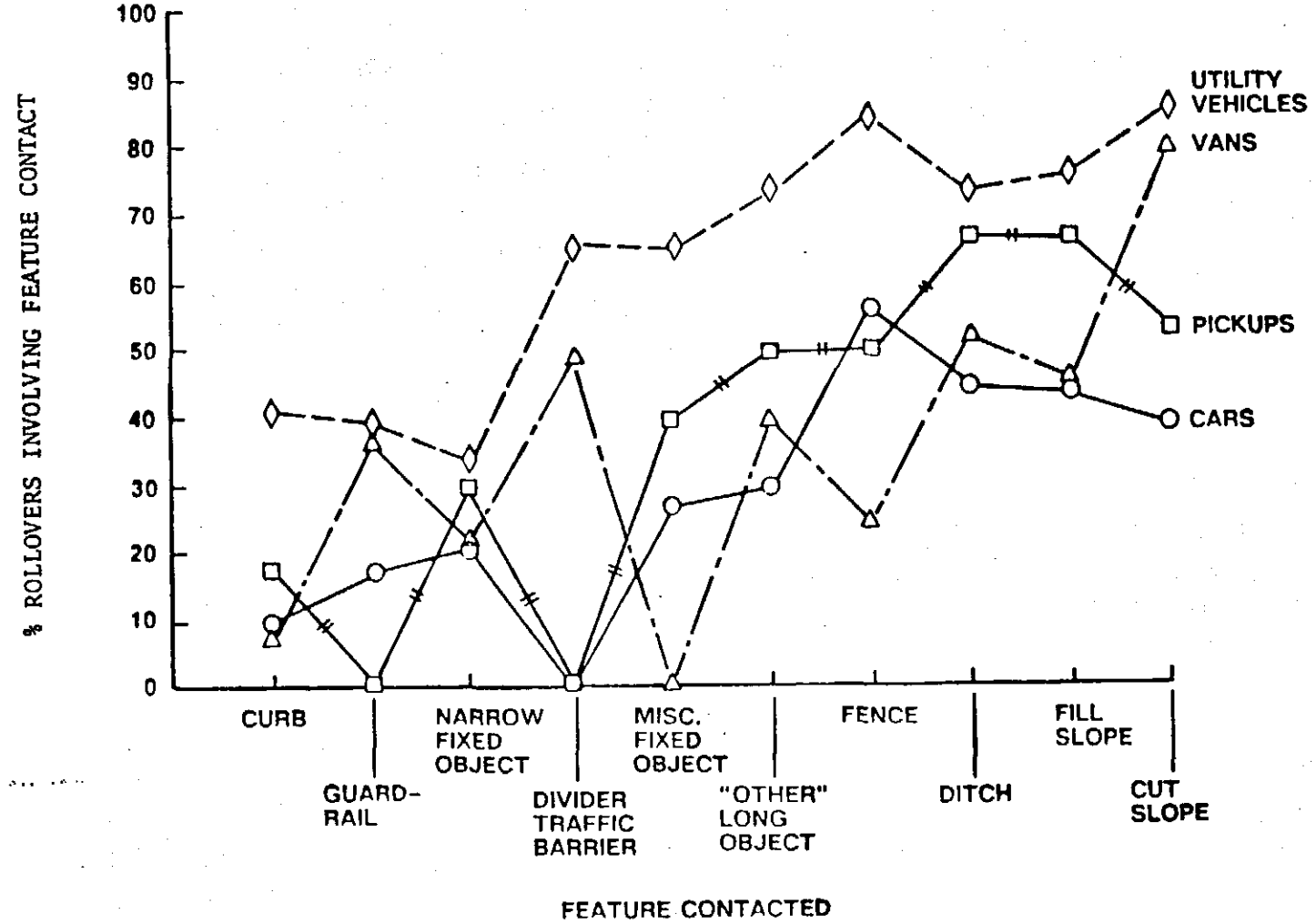


Figure 3.4. Estimated Probability of Rollover, Given Roadside Feature Contact (Clinical data file, weighted to be representative of the RNASTRK3 file.)

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 RNASTRK3 data file)

Attributed Rollover Cause	Cars	Pickups	Vans	U-Vehs
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	100.0%	100.0%	100.0%	100.0%
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.

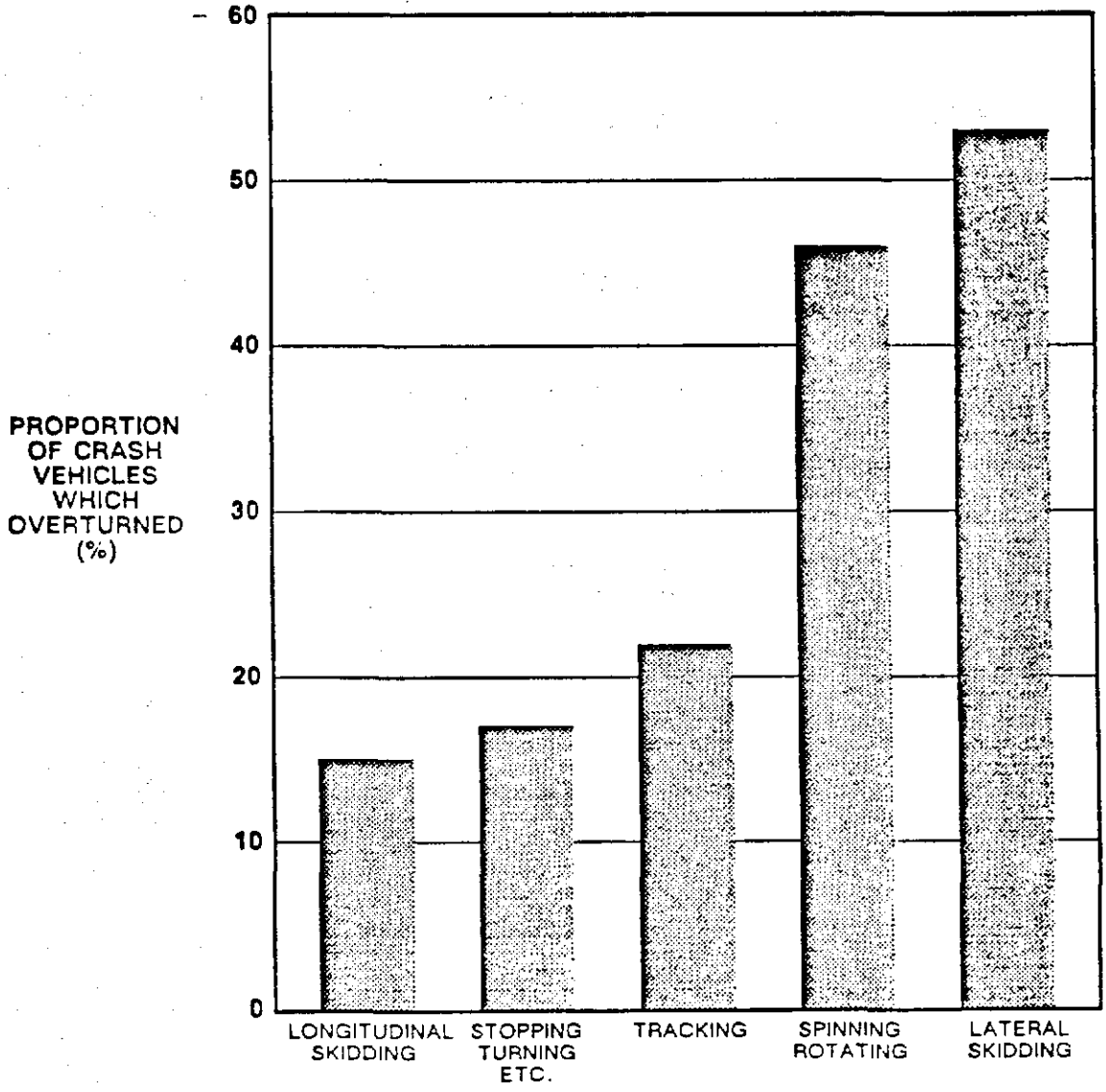
(c) Several other features previously indicated to play a role in overturns also seemed, in the judgment of the clinical analysts, to be mainly incidental. These include narrow fixed objects, curbs, guardrails, dividers, and fences.

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 RNASTRK3 file.)

or spinning, that could partially explain their elevated overturn rates. Table 3.10 compares the vehicle types on their orientations preceding rural and urban crashes. The table shows that spinning/rotation was an uncommon precrash event for all vehicle types, while lateral skidding patterns varied between rural and urban crashes. In rural crashes, the light trucks were almost uniformly higher than cars in their lateral skid rates, with utility vehicles leading the list. Note also that in rural crashes the utility vehicles were tracking prior to their crashes much less than any of the other vehicle types. In urban crashes, pickups and vans had the lowest lateral skid rates, but utility vehicles again had the highest. Taking any skidding or spinning as loss of control, the overall rates of control loss were as follows:

utility vehicles	- 73.6%
pickups	- 60.4%
cars	- 56.4%
vans	- 52.1%

Here, the utility vehicles exhibit rates distinctly higher than the other vehicles.

Our final analysis of vehicle precrash orientations compares the rollover rates of the vehicle types for the two most common orientations -- tracking and lateral skidding. Figure 3.6 shows that in crashes beginning in the tracking mode,

Table 3.10 Pre-Crash Vehicle Orientation and Vehicle Type

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

A. Rural Crashes

Vehicle Orientation	Cars	Pickups	Vans	U-Vehs
Tracking	39.2%	35.3%	29.0%	14.5%
Lateral skidding	33.6	51.3	52.5	58.7
Longitudinal skidding	15.7	11.9	12.3	12.1
Spinning, rotating	1.7	1.5	4.2	9.2
Stopping, turning, etc.	9.9	0	2.1	5.5
Total	100.0%	100.0%	100.0%	100.0%
No. of Vehicles Represented	2017	493	54	85

B. Urban Crashes

Tracking	29.7%	48.4%	60.6%	31.7%
Lateral skidding	36.6	24.2	26.9	44.4
Longitudinal skidding	20.4	24.4	6.2	19.8
Spinning, rotating	6.6	3.0	2.1	0
Stopping, turning, etc.	6.6	0	4.2	4.1
Total	100.0%	100.0%	100.0%	100.0%
No. of Vehicles Represented	1501	241	53	58

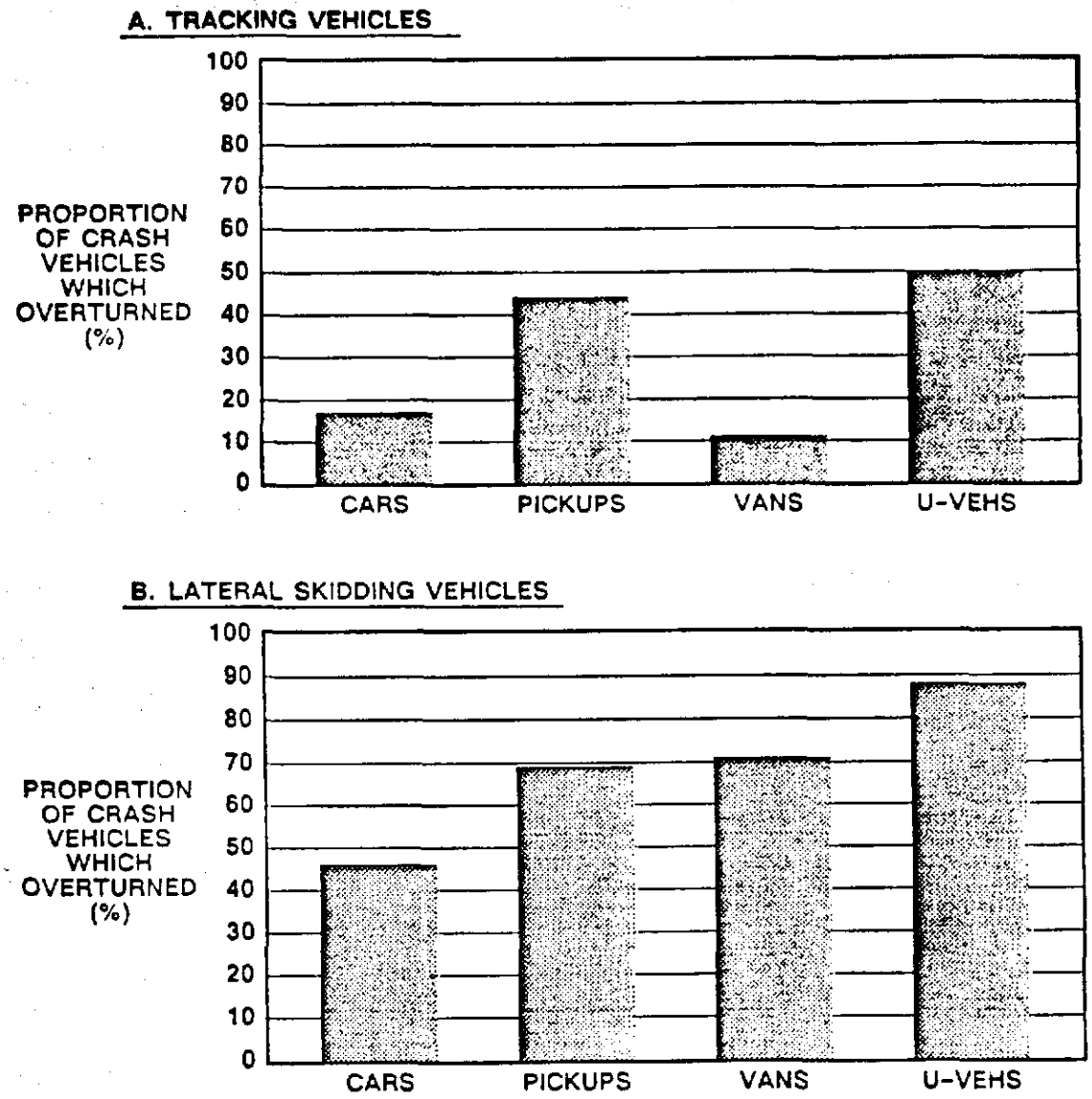


Figure 3.6. Rollover Rates for the Most Common
Pre-Crash Vehicle Orientations.
(Clinical data file, weighted to be representative of the RNASTRK3 file.)

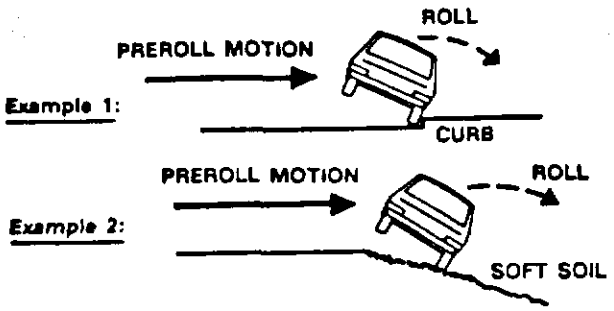
car and van rollover rates were very low. Approximately half the pickups and utility vehicles overturned, however. In crashes beginning from lateral skids, the rollover rates order the vehicles in a now-familiar pattern, with cars at the low end and utility vehicles at the high end. These results suggest two things:

(1) Pickups and utility vehicles seem more vulnerable to rollover than the other vehicle types, since their overturn rates were substantial in both the tracking and lateral-skidding precrash modes.

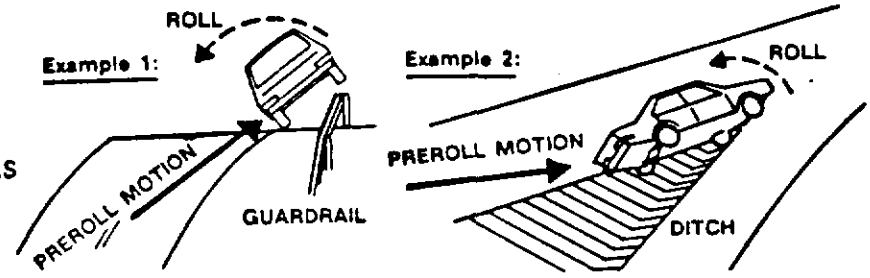
(2) Since the typical pattern of rollover rates appears when lateral skidding is "held constant," the elevated overturn rates of light trucks cannot be wholly attributed to lateral-skidding tendencies of the vehicles or their crash environments.

Another dynamic aspect of rollovers examined was the type of rollover, coded by the clinical analysts as per Figure 3.7. The results are shown in Table 3.11. (Breakdowns into urban and rural groups yielded a nearly identical pattern, so those data are not shown.) It can be seen that slightly more than half of the passenger car overturns were simple "trip-overs," whereas a large majority of the light truck rollovers were of that type. Note especially the vans. The results raise the possibility that light trucks are more vulnerable to simple tripping actions than cars.

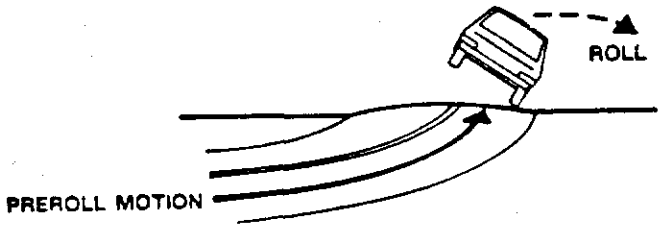
1. Trip-Over: Vehicle lateral motion is resisted by opposing force, inducing roll moment.



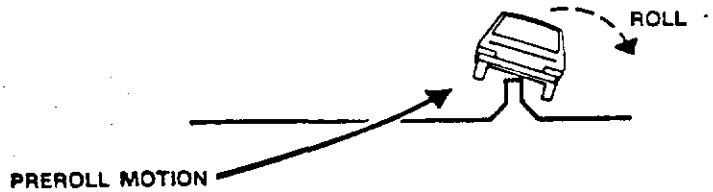
2. Flip-Over: Forward-moving vehicle is vigorously rotated about its longitudinal axis by ramp-like object such as a guardrail taper or ditch back slope.



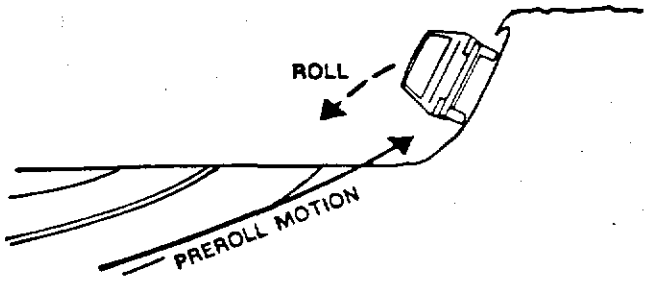
3. Turn-Over: Centrifugal forces from a sharply turning or rotating vehicle produce a rollover moment when resisted by surface friction.



4. Climb-Over: Vehicle climbs up and over fixed object such as barrier.



5. Fall-Over: Vehicle is tipped by slope or object so that its center of gravity is outboard of its wheels.



6. Bounce-Over: Any case where vehicle rebounds off fixed object (such as a guardrail), overturns as a consequence.

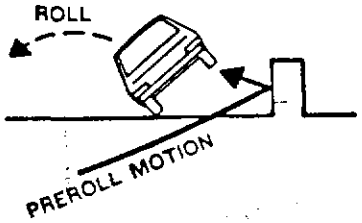


Figure 3.7 CODING GUIDE FOR ROLLOVER TYPES

Table 3.11 Types of Rollovers Experienced by the Vehicle Types in Clinical Analysis

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

Rollover Type	Cars	Pickups	Vans	U-Vehs
(1) Trip-over	57.1%	80.8%	91.9%	80.0%
(2) Flip-over	14.3	5.8	5.4	4.4
(3) Trip/flip combination	7.2	3.9	0	4.4
(4) Turn-over	0	1.9	0	2.2
(5) Trip/turn combination	5.4	5.8	0	2.2
(6) Flip/turn combination	1.8	0	0	0
(7) Fall-over	5.4	0	2.7	2.2
(8) Climb-over	3.6	0	0	0
(9) Other	5.4	1.9	0	4.4
Totals %	100.0%	100.0%	100.0%	100.0%
No. Vehicles	56	52	37	45
Aggregates				
Any trip-over (1,3,5)	69.7%	90.5%	91.9%	86.6%
Any flip-over (2,3,6)	23.3	9.7	5.4	8.8
Any turn-over (4,5,6)	7.2	7.7	0	8.8
All combinations (3,5,6)	14.4	9.7	0	6.6

Summarizing this section, lateral skidding was found to be a common precrash vehicle orientation associated with rollover. It was most prevalent among all light truck types in rural crashes, and among utility vehicles and cars in urban crashes. Once in lateral skids, all light truck types exhibited higher roll rates than cars. The clinical analysts categorized light truck rollovers primarily as simple "trip-overs," whereas car overturns seemed to involve more complex dynamics.

3.2.5 Overall Summary: Light Truck vs. Car Rollovers

Many aspects of overturns were examined in this study, mainly to determine whether driver and/or environmental variables can account for high light truck overturn rates. Analyses were also made to see if light truck rollover dynamics differed from the car dynamics. Environmental factors, pertaining to the urban-rural dimension and to roadsides, were found to be highly related to rollover. Driver factors were weakly related, though driver youth was associated with overturn. In controlling for these factors, light truck overturn rates remained higher than car rates. Utility vehicle rates were distinctly the highest. In regard to crash dynamics, light truck crashes exhibited lateral skidding somewhat more than cars, but when holding lateral skidding constant, previous overturn patterns were maintained, i.e., cars had the lowest rates and utility vehicles had the highest. On-road overturns were much more frequent among light trucks than cars. Light

truck rollovers nearly always involved simple "trip-overs," while car overturns tended to be more complex.

3.3 Comparisons of Car and Light Truck Ejections

A first question of interest is whether the expanded NASS sample in the this study supports previous indications of high occupant ejection rates in light trucks, especially in utility vehicles. Using weighted data to provide population estimates, Table 3.12 shows ejection rates of unrestrained drivers. The results generally confirm previous indications, except that ejection was found to be preeminently a utility vehicle problem, for the ejection rates in those vehicles were many times the car rates. The pickup ejections also exceeded the car rates, except in urban rollovers. Vans, however, gave little evidence of an ejection problem.

Notice in Table 3.12 that ejections occurred primarily in rollovers. To get a further perspective on the importance of overturns to ejections, the actual (unweighted) number of ejected occupants in the light truck samples were counted. There were 149 ejectees in rollover crashes, and only 16 in nonrollovers. Consequently, the overturn ejections will be given most attention in subsequent sections.

Table 3.12 Ejection Rates of Drivers Not Using Restraint Systems

(RNASTRK3 data file; Weighted data)

A. Rural Crashes

	Cars	Pickups	Vans	U-Vehs
Within Rollover Crashes	11.2%	12.5%	2.8%	42.7%
Within Nonroll Crashes	0.6	1.1	0	0
Within All Crashes	3.9%	6.4%	0.6%	22.0%

B. Urban Crashes

Within Rollover Crashes	5.8%	2.9%	5.4%	17.6%
Within Nonroll Crashes	0.4	0.9	0	4.6
Within all Crashes	1.0%	1.4%	2.8%	11.6%

3.3.1 Controlling for Crash Severity

It might be hypothesized that the risk of ejection increases with crash severity, a factor that should should be controlled in any comparisons among vehicle types. Unfortunately, it is difficult to fully control for severity in our comparisons, for two reasons:

(a) The most widely accepted index of severity -- velocity change during the crash -- is not applicable to overturns.

(b) Another index of crash severity -- amount of overall vehicle damage -- is not used in the NASS. Even if such an index were used, comparisons among vehicles differing in crashworthiness can be misleading, for under the same crash conditions, the vehicles would differ in the amount of overall damage.

While difficult, some attempt to control for severity was considered important, so use was made of the Collision Deformation Classification (CDC) damage extent estimates recorded in NASS cases. The units of these estimates differ across the lateral, longitudinal, and vertical dimensions of vehicles, and across vehicle types. Hence, CDC extents must be considered crude severity indicators. To minimize ambiguity,

vehicles with damage in one and only one dimension were compared initially. Figure 3.8 shows the relationships between CDC extent and ejection rates for overturned vehicles experiencing either (a) top damage only or (b) side damage only. For cars, ejection rates systematically increased with CDC extent. The light trucks exhibited similar tendencies, though not as clearly. (Because of their small samples, the light trucks were not divided into types; consequently, the results predominantly reflect pickups.) Generally, Figure 3.8 suggests a plausible relationship between crash severity and occupant ejection rates, approximating the relationship found by Tourin (1958).

In comparing light truck and car ejection rates while controlling for crash severity, Figure 3.8 gives inconsistent results. For top-damage-only vehicles, light truck ejection rates were higher than car rates at every severity level. The opposite was generally the case in the side-damage-only crashes. A possible interpretation is that light trucks (mainly pickups) are more likely than cars to eject their occupants only in rollovers of at least 180 degrees.

In an attempt to control for severity in overturns that may include both top and side damage, the pattern of injuries in cars was examined in relation to combinations of top and side damage in rollovers. Based on the injury rates, severity scale categories were identified as in Table 3.13. The

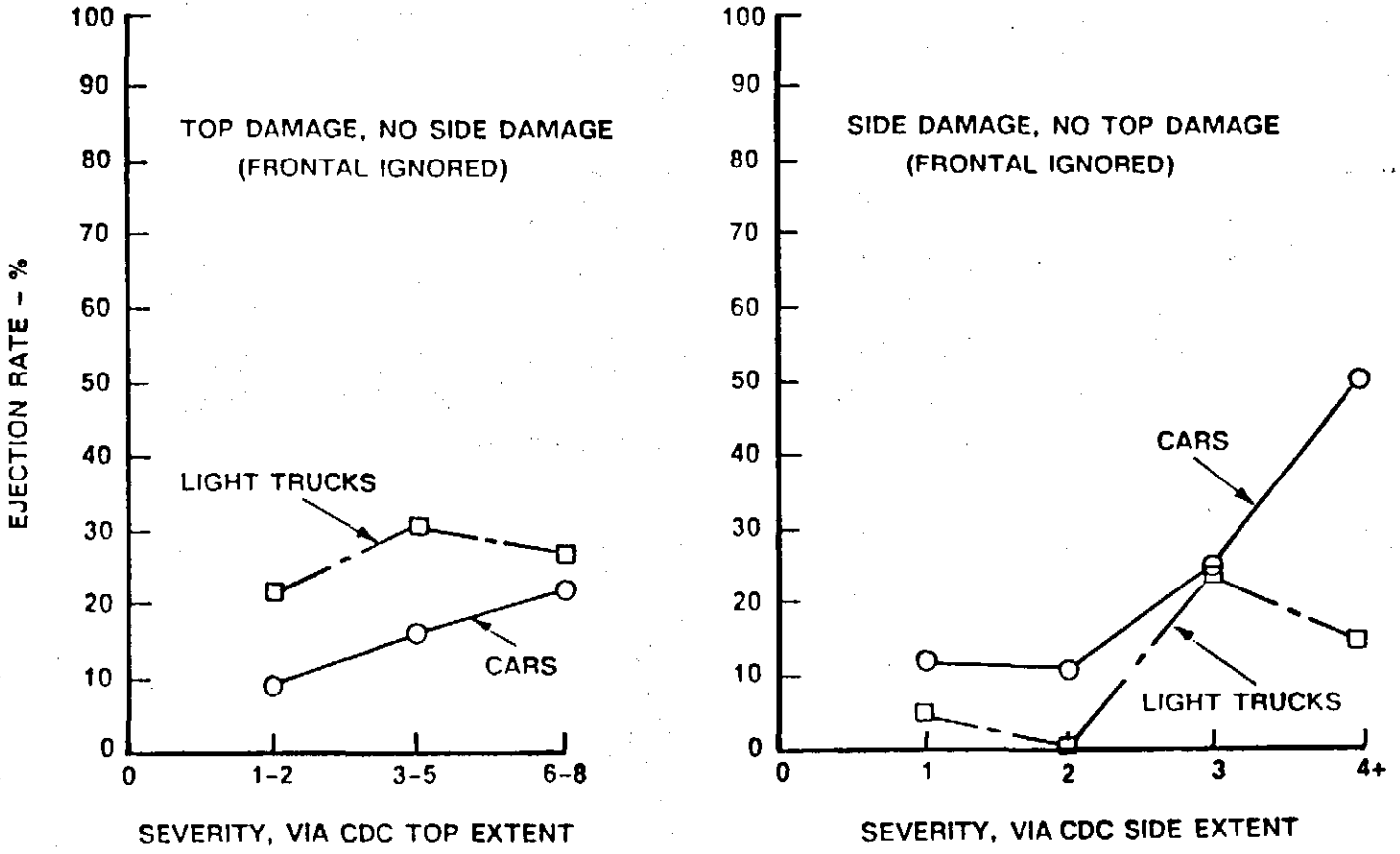
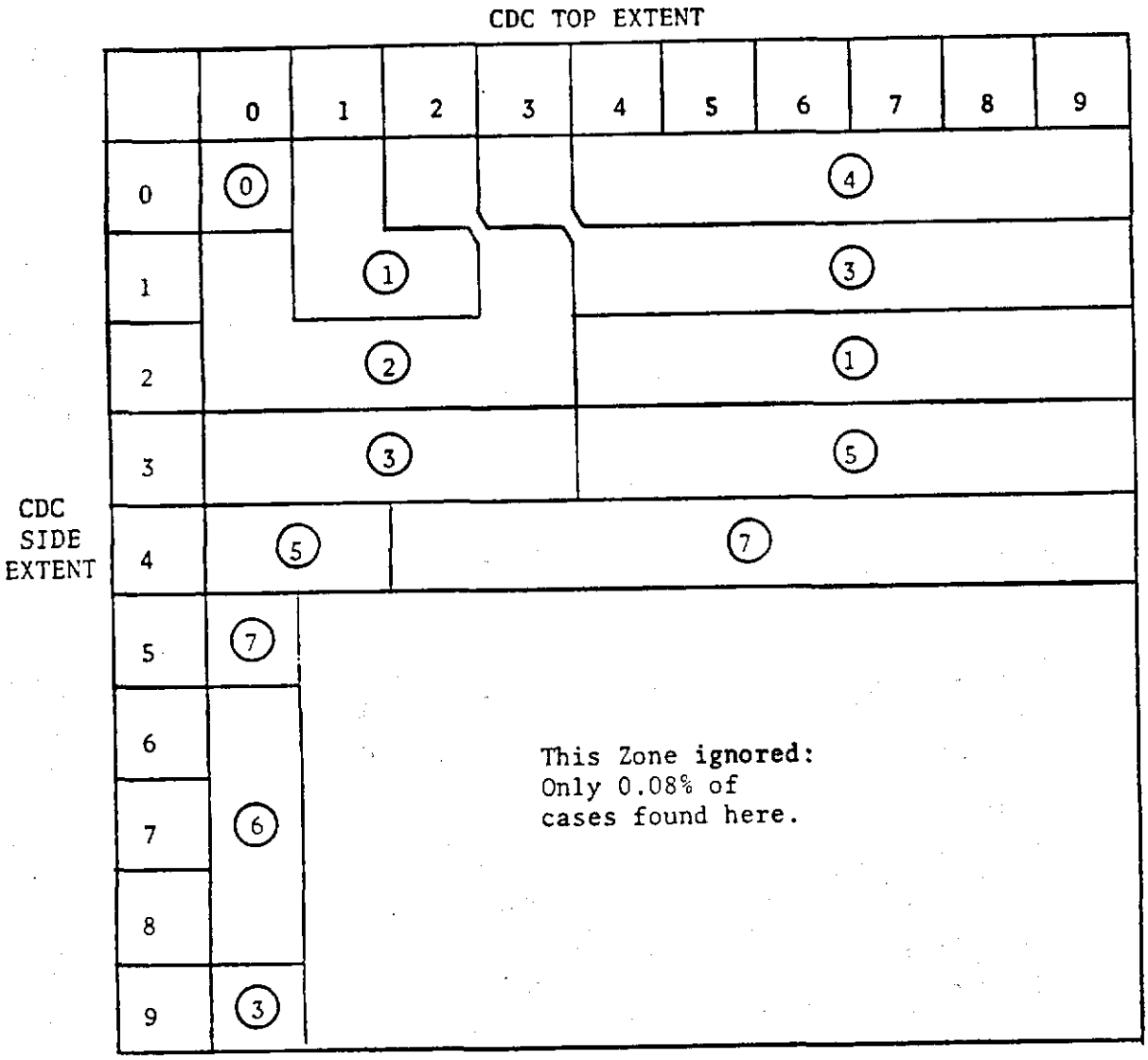


Figure 3.8. Unrestrained-Occupant Ejection Rates in Relation to Crash Severity in Rollovers: I. (RNASTRK4 data - unweighted.)

Table 3.13 Single Vehicle Crash Severity Scale Derived from the Collision Deformation Classification (CDC) and Occupant Injury Rates of Cars



Scale Level	% Car Occupants Killed/Hospitalized
1	0-9%
2	10-19
3	20-29
4	30-39
5	40-49
6	50-59
7	60 or more

categories are not entirely systematic in relation to the CDC extents, reflecting in part some of the peculiarities of the CDC. For example, high CDC extent values tend to reflect shallow, surface-swiping damage, not indicative of high crash severity. Notice particularly how injury rates were related to side extent when top extent was zero.

Using the scale shown in Table 3.13, the vehicle types were compared to see whether they differed in crash severity. The results (Table 3.14) suggested that all light truck types had higher severity (level 3+) rollovers than cars in rural crashes, while only pickups had a higher frequency of such rollovers in urban crashes. This supports the necessity of controlling for severity in comparing ejection rates. Using the severity levels of Table 3.13, the ejection rates of cars and light trucks were plotted (Figure 3.9). Here, the light truck ejection rates exceeded the car rates in five out of the seven levels. It thus seems that, while high ejection rates of light trucks may be partially attributable to higher crash severities, that may not be the entire explanation for their ejection rates. Any inferences must be regarded cautiously, however, because of limitations of our crude severity measure. One problem is that it is tautological, as it is based on injury outcomes. (A relationship between the severity measure and injury is "built in".) Another problem was implied previously. That is, if light trucks are more crashworthy than cars, comparing cars and light trucks which have suffered equal

Table 3.14 Vehicle Types and Rollover Crash Severity
Derived from CDC and Injury Rates

(RNASTRK4 data - unweighted)

A. Rural Rollover

Severity Levels*	Cars	Pickups	Vans	U-Vehs
0 (frontal damage only)	1.5%	3.5%	0%	2.3%
1-2 (low)	36.9	20.8	30.0	29.5
3-4 (intermediate)	58.9	69.5	70.0	63.6
5+ (high)	2.7	6.2	0	4.6
	100.0%	100.0%	100.0%	100.0%
Total no. vehicles	528	226	20	44

B. Urban Rollovers

Severity Levels*	Cars	Pickups	Vans	U-Vehs
0 (frontal damage only)	2.4%	1.8%	11.1%	0%
1-2 (low)	33.8	28.6	44.4	41.4
3-4 (intermediate)	58.7	67.9	44.4	55.2
5+ (high)	6.1	1.8	0	3.4
	100.0%	100.0%	100.0%	100.0%
Total no. vehicles	247	56	9	29

*See Table 3.13 for definitions of levels

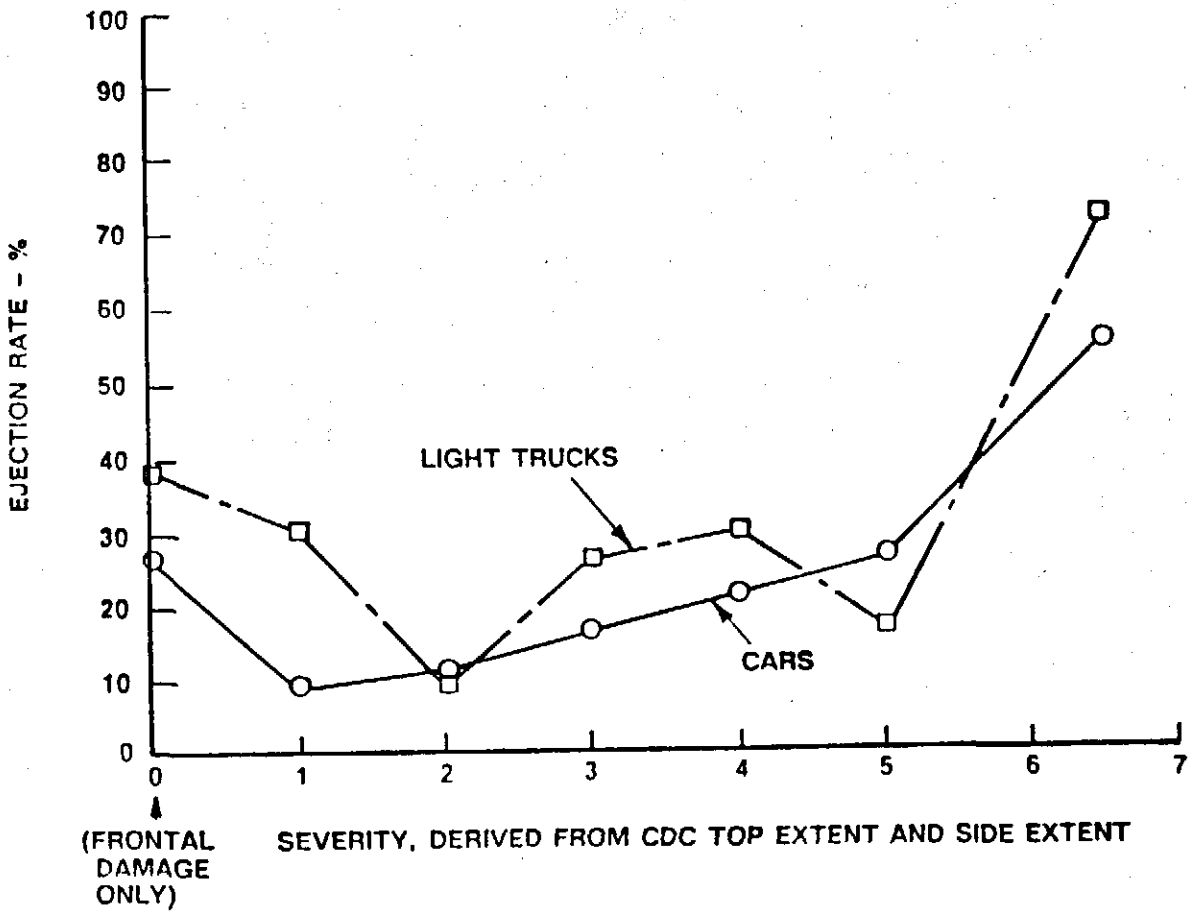


Figure 3.9. Unrestrained - Occupant Ejection Rates in Relation to Crash Severity in Rollovers: II. (RNASTRK4 data - unweighted.)

damage in single-vehicle crashes does not control for severity. Some evidence on the latter possibility is provided in the next section.

3.3.2 Ejection and Injury in Cars and Light Trucks

Since the ejection rates of pickups and utility vehicles were found to be higher than car rates, ejection may be posited as a significant injury source for occupants of those light trucks. On the other hand, since ejection is correlated with crash severity, one might hypothesize that most light truck ejections result from high-severity crashes, in which the occupants would have been seriously injured even had they not been ejected. If supported, that hypothesis would argue against ejection per se as a significant problem of pickups and utility vehicles. To shed light on this issue, occupant injury rates were plotted in relation to ejection status and crash severity (Figures 3.10 and 3.11). (The injury-based severity measure was not used, for that would have "built in" relationships, as noted in section 3.3.1.) The results revealed substantially higher injury rates among ejected occupants than among the nonejected, even if the latter were not using restraint systems. The only exception was the highest-severity light truck crashes in Figure 3.10; those results are suspect, for the injury rate of ejected occupants was lower than in the less-severe crashes. In general, however, the data indicate that ejection is very dangerous for occupants, even in low-severity rollovers.

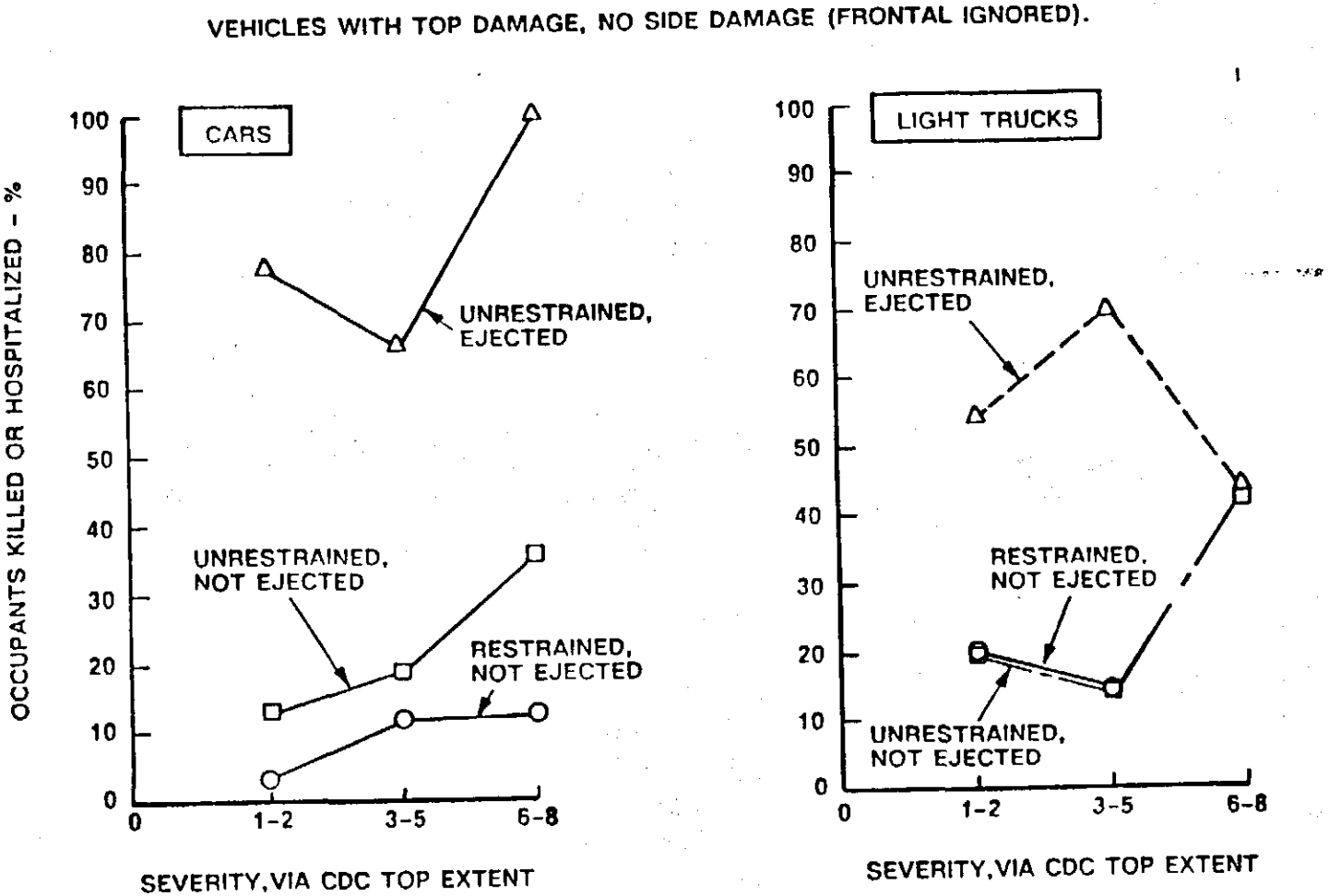


Figure 3.10. Occupant Injuries in Relation to Crash Severity, Ejections, and Restraint Use in Rollovers: I. (RNASTRK4 data, unweighted.)

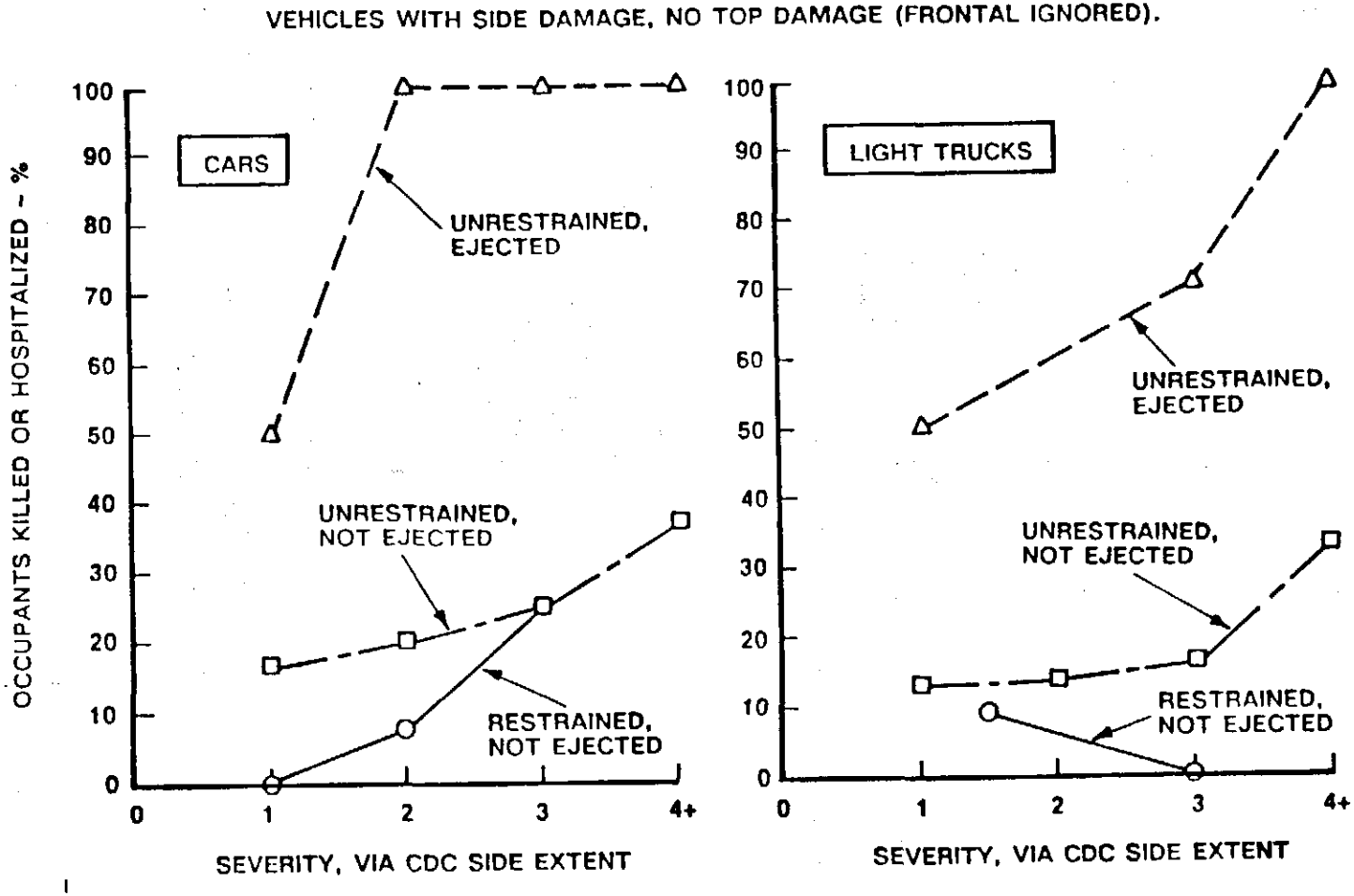


Figure 3.11. Occupant Injuries in Relation to Crash Severity, Ejections, and Restraint Use in Rollovers: II.
(RNASTRK4 data, unweighted.)

Comparing light trucks with cars in Figures 3.10 and 3.11, the injury rates were not very different under similar crash conditions. There is a tendency for light truck rates to be slightly lower; note the ejected occupants and the unrestrained-nonejected occupants in Figure 3.10, and the nonejected occupants in Figure 3.11. While of minor significance perhaps, these differences suggest that the injury effects of overturns may be slightly attenuated in some light trucks.

At the end of section 3.3.1, it was suggested that when cars and light trucks have the same damage levels, crash severity may actually have been higher in the light trucks. Judging by the injury rates, Figures 3.10 and 3.11 do not support that interpretation, hence it seems reasonable to consider damage levels as approximately equivalent severity indicators for cars and light trucks.

Another way to determine the importance of ejection to injury is to examine the reported sources of injury to ejected occupants, similar to the approach of Huelke, Compton, and Studer (1985). For our analysis, the NASS-reported injury sources were dichotomized into (a) the vehicle interior surfaces and components, and (b) the vehicle exterior and/or the environment. Figure 3.12 shows that, for light trucks at least, most injuries of ejected occupants were from sources

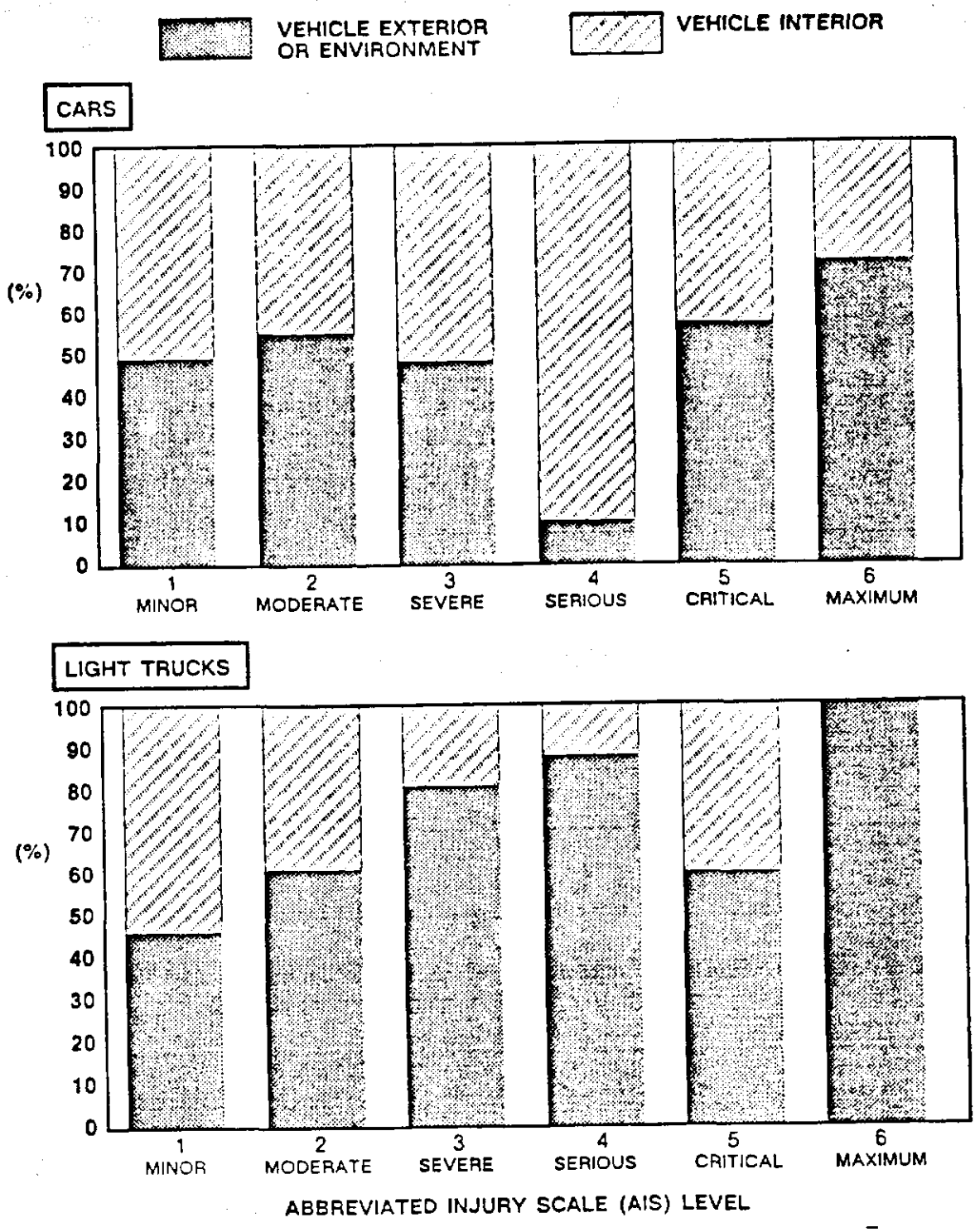


Figure 3.12. Attributed Sources of Injuries to Ejected Occupants in Single - Vehicle Crashes (RNASTRK5 file, unweighted data.)

external to the occupant compartments. The worst injuries were due predominantly to exterior sources. This gives further support to the idea that ejection is a highly dangerous event.

Having shown that occupant ejections are more frequent in pickups and utility vehicles than in passenger cars and vans, and having shown that ejection is highly injurious, next we consider how occupants are ejected.

3.3.3 Avenues of Occupant Ejection

This section addresses the question: What allows occupants to be ejected from vehicles? We have shown already that rollover promotes ejection (Table 3.12), so here we shall concentrate on effects of occupant compartments that permit the discharge of their human cargos.

The portals of occupant ejection are shown in Table 3.15. For pickups, the main portals were closed doors, roll-down windows, and the windshield. Of these, the windshield was much more prominent in the pickups than in the other vehicles. With utility vehicles, doors and roof structures were the primary egress portals; roofs stood out far more than in the other vehicle types. Notice also that the utility vehicles had open door and roof areas as prominent portals.

Table 3.15 Main Portals of Occupant Ejection*

(RNASTRK4 data - unweighted)

Portal	Cars	Pickups	U-Vehs
Roll-down windows	33.3%	20.2%	5.8%
Open	11.7	9.2	1.4
Closed	21.6	11.0	4.3
Doors	22.2	25.2	24.6
Open	3.6	2.5	10.1
Closed	18.6	22.7	14.5
Roof	13.8	4.2	24.6
Openable: open	4.1	0.8	10.1
Openable: closed	6.1	1.7	4.3
Other	3.6	1.7	10.1
Windshield	8.9	19.3	5.8
Other Windows	10.2	6.7	8.7
Other/Unknown portal	11.6	24.4	30.4
Total %*	100.0%	100.0%	100.0%
Total ejectees	225	119	69

*Vans had only 2 ejectees with portal information

Since doors were a major ejection avenue, the clinical case examinations identified vehicles where one or more doors opened during the crash. Part A of Table 3.16 shows that occupants were ejected in 41% of these vehicles, compared with only 6% of the vehicles in which the doors did not open. Clearly, door openings greatly raise the risk of ejection. Part B of Table 3.16 shows that this was mostly a problem of the utility vehicles.

Next examined were open windows as an ejection portal. Part A of Table 3.17 shows that ejections were much more likely in vehicles with their windows open. Part B of the table shows, however, that open windows were infrequent in the light truck crashes. Consistent with the data in Table 3.15, open windows were primarily a car problem.

As noted previously, open roof areas were prominent among the portals of utility vehicles. Using the clinical data, it was possible to compare vehicles with and without open tops. Only utility vehicles had open tops, as there were no convertibles in the passenger car sample. Table 3.18 shows that in rollovers, the ejection rate was higher in open-topped than in non-open-topped utility vehicles, though the difference is merely suggestive since there were only seven open-topped vehicles. Among all rollover vehicles without open tops, the utility vehicle ejection rate was substantially higher than the rest. It should be recognized that the non-open-topped utility

Table 3.16 Door Openings and Occupant Ejection

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

A. The General Relation of Ejection to Doors Opening

	Doors Opened in Vehicle	
	No	Yes
Vehicles with ejections	6.3%	41.2%
Vehicles without ejections	93.7	58.8
	100.0%	100.0%

B. Door Openings and Vehicle Type

	Cars	Pickups	Vans	U-Vehs
Vehicles with doors opening	7.2%	9.5%	5.2%	25.2%
Vehicles without doors opening	92.8	90.5	94.8	75.8
	100.0%	100.0%	100.0%	100.0%

Table 3.17 Open Windows and Occupant Ejection

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

A. The General Relation of Ejection to Open Windows

	Windows Open Prior to Crash	
	No	Yes
Vehicles with ejections	5.1%	31.8%
Vehicles without ejections	94.9	68.2
	100.0%	100.0%

B. Open Windows and Vehicle Type

	Cars	Pickups	Vans	U-Vehs
Vehicles with windows open	9.3%	3.8%	5.1%	4.9%
Vehicles without open windows	90.7	96.2	94.9	95.1

Table 3.18 Ejection in Relation to Open Tops of Vehicles

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

A. Vehicles With Open Tops, in Rollovers
(All in sample were utility vehicles)

U-Vehs with ejections	57.1%
U-Vehs without ejections	42.9
	100.0%
Total vehicles in sample	7

(Note: Only one utility vehicle with an open top was not in a rollover; the rollover rate of open-topped utility vehicles was 93.7%.)

B. Vehicles Without Open Tops, in Rollovers

	Cars	Pickups	Vans	U-Vehs
Vehicles with ejections	19.3%	21.6%	11.8%	40.5%
Vehicles without ejections	80.7	78.4	88.2	59.5
	100.0%	100.0%	100.0%	100.0%
Total vehicles in sample	57	51	34	37

C. Vehicles Without Open Tops, Not in Rollovers

	Cars	Pickups	Vans	U-Vehs
Vehicles with ejections	1.7%	4.4%	1.9%	5.6%
Vehicles without ejections	98.3	95.6	98.1	94.4
	100.0%	100.0%	100.0%	100.0%
Total vehicles in sample	60	45	52	36

vehicles may include some with only cloth tops. Unfortunately, the clinical coding did not specify the roof material in all vehicles, so this inquiry was not pursued further.

Finally, the role of vehicle structural damage or failure in light truck ejections was studied. Table 3.19 shows that most ejections were attributed to such events. Because ejections were found primarily in rollovers, subsequent analysis concentrated on overturn crashes. A special, supplementary file was compiled by clinically examining pickup and utility vehicle rollovers involving ejection. (Van ejections were infrequent and were ignored.) The analysts identified the structural losses, if any, that were involved in each ejection. Table 3.20 shows that door openings were a leading contributor, consistent with Table 3.15. For utility vehicles, the second leading damage/failure was the loss or destruction of the roof, which was unique to utility vehicles. Nearly all of these involved a cloth or fiberglass top. Side window damage, in which the windows were often completely broken out during the overturn, provided the third most frequent damage/failure permitting ejection. Windshield losses and rear window destruction were also significant to the pickup ejections, less so for the utility vehicles. Counting side and rear windows and windshields, glass destruction provided major portals for pickup ejections. The significance of this was further reinforced by the clinical analysts' observation that, among all the rollover-ejection vehicles, window loss was experienced by 77% of the

Table 3.19 Occupant Ejections in Relation to Attributed Vehicle Structural Damage or Failure

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

	Cars	Pickups	Vans	U-Vehs
Ejections attributed to structural damage/failure	91.9%	76.8%	100.0%	62.7%
Ejections not attributed to structural damage/failure	8.1	23.2	0	37.4
Totals	100.0%	100.0%	100.0%	100.0%
Number of RNASTRK3 ejection vehicles represented	213	94	5	36
Actual no. of ejection vehicles in clinical file	11	13	5	17

Table 3.20 Ejections Attributed to Structural Damage/Failures in Pickups and Utility Vehicle Rollovers*

(Clinical File: All ejections in primary sample and supplementary ejection sample)

Damage or Failure	% of All Vehicles With Ejections** Pickups	U-Vehs
Door opened during rollover	26.0%	23.7%
Roof lost/destroyed	0	23.7
Side window destroyed	19.5	18.4
Windshield damage/failure	16.9	7.9
Rear window destroyed	10.4	2.6
Cargo area failure (occupants in cargo area)	3.9	0
Roof separation at B pillar	2.6	0
Sunroof damage/failure	1.3	0
Total no. damage/failures identified	62	29
Total no. vehicles	77	38

*Vans were omitted because of infrequent ejections.

**Percents do not add to 100 because some vehicles had more than one failure; others had no failures, or ejection route was unknown.

pickups and 37% of the utility vehicles. (Some of the latter didn't have glass windows, because of open or cloth tops.)

Summarizing, occupant ejections were found frequently to occur through the provision of egress portals in the vehicle occupant compartments. The portals were sometimes provided by open windows, but these were an infrequent source of light truck ejections. Much more commonly, loss of structural integrity during the crashes opened new avenues for ejection; these included door openings and the destruction of roofs, windshields, and windows. With the utility vehicles, open roofs or sides provided additional portals.

3.3.4 Summary of Section 3.3

We began this section by considering whether occupant ejection was an event especially prominent in light truck single-vehicle crashes. The evidence indicated that ejections were fairly infrequent in vans, somewhat more frequent in pickups than in cars, and 5 to 10 times more frequent in utility vehicles than in cars. Some of these differences were attributable to the higher rollover rates of light trucks, for ejections were found 3 to 10 times more frequent in rollovers than in nonoverturn crashes.

Our analyses next examined whether the elevated ejection rates of pickups and utility vehicles could result from their

being in more severe crashes than passenger cars. Using extent of vehicle damage as an indicator of crash severity, ejections were indeed shown to increase with severity, and in rural crashes at least, light trucks appeared to have experienced more high-severity crashes than cars. Controlling for severity, however, light trucks still evidenced higher ejection rates than cars. All such indications must be regarded cautiously, however, for the severity measures used were damage-based and comparisons among vehicle types may not be valid.

Since ejections were found to increase with crash severity, the analyses addressed the issue as to whether an ejection is an event dangerous in itself, or merely an incidental by-product of inherently injurious, severe crashes. Analyses using vehicle damage as severity indexes left little doubt that, with severity controlled for, ejection was highly injurious to occupants, much more serious than remaining within the crash vehicle. Furthermore, the injuries of ejected occupants were received mainly outside the occupant compartment, and this was especially true of the worst injuries.

The last analyses of the section focused on the mechanisms that allow occupants to be ejected in crashes, particularly in pickups and utility vehicles, the light trucks which have ejection rates significantly higher than cars.

Open windows presented a relatively minor portal for ejections, while dooring openings were a more significant route, especially for utility vehicles. For pickups, the main ejection portals were the windows, doors, and windshield, while doors and the roof structure were primary ejection media for utility vehicles. In clinical analysis of ejection cases, a majority of the pickup and utility vehicle ejections were attributed to loss of vehicle structural integrity. Focusing on overturns, the most prominent ejection-permitting damage/failures of pickups were door openings, destruction of the side or rear windows, and windshield losses. Loss or destruction of the roof structure was the ejection-permitting event unique to the utility vehicles, for which door openings and side window breakage also provided major ejection portals.

4.0 DISCUSSION

The data analyses began with a partial replication of Calspan's previous study of light truck occupant protection in single-vehicle crashes, to see if results of the earlier study would be upheld when using a NASS sample comprising twice the number of years included in the earlier study. Subsequent analyses addressed in depth the main questions of whether light trucks have rollover and occupant ejection problems. In the sections below, we shall consider what was learned on these substantive matters, and we shall also address some methodological issues.

4.1 The Rollover-Injury Paradox

In our previous study, three years of NASS data provided insufficient numbers of light trucks to show why, despite overturn rates substantially higher than passenger car rates, the injury rates of cars and light trucks were approximately equal. Ambiguity was greatest regarding the utility vehicles, for which small sample sizes rendered inconclusive the results of analyses controlling for confounding variables. In this study, using sample sizes about double those of the previous study, have we explained why elevated rollover rates did not inflate injury rates? For that matter, does it still seem that light truck injury rates are no worse than car rates? Considering the second question first, the answer is

affirmative, but some ambiguity remains because of small-sample instability of the van and utility vehicle data. Among unrestrained male drivers (Table 3.1), the rates of serious injuries were very similar among light trucks and cars, except for a substantially elevated injury rate of vans in rural crashes. Since there were only 21 vans in the subsample, and considering the vagaries of NASS weighting factors, we doubt that the van injury rate would be supported in further replication. Indeed, vans have repeatedly demonstrated low injury rates in other studies using other data bases (e.g., see Highway Loss Data Institute, 1986, and Partyka, et al., 1987).

Turning now to the light truck rollover-injury paradox, have we at last found a satisfactory explanation for how light trucks avoid high injury rates, given their high rollover rates? Perhaps. The evidence did indicate that occupant protection in nonoverturn single-vehicle crashes was somewhat better in light trucks than in cars. In rural crashes of utility vehicles, in fact, the nonrollover injury rate was much lower than the car rate. Exceptions, on the other hand, add a note of uncertainty to our explanation of the paradox. Nonrollovers did not have an offsetting effect among van rural crashes, nor among utility vehicle urban crashes. The ultimate resolution of the paradox may have to await a future study with substantially larger samples.

The fact that light truck injury rates tended to be lower than car rates in nonrollover crashes suggests an alternative theory. If light trucks, particularly utility vehicles, overturn more easily than cars, then single-vehicle crashes in which they don't overturn would tend to be mild, i.e., they may have lower impact speeds and therefore lower injury rates than the nonrollovers of cars. If correct, the theory also suggests that light truck rollovers would be less severe than car rollovers. Our rollover-injury analyses suggested the theory may have some credence in urban crashes.

4.2 The Elevated Light Truck Overturn Rates

The main thrust of our analyses of rollovers was to try to find driver and environmental factors that could explain why light truck overturn rates were consistently higher than car rates in single-vehicle crashes. The issue was exposure: that is, are light trucks driven more frequently by drivers with high rollover risks, or are light trucks used more frequently in environments where overturn is more likely in single-vehicle crashes? To be sure, these questions cannot be answered conclusively when we lack data on the exposure of vehicles not in accidents. Our analyses were confined to accidents, hence we learned mainly about factors that differentiated single-vehicle crashes involving rollovers from those involving fixed-object collisions. This limits our ability to generalize, but nevertheless, the study identified significant

driver and environmental variables that distinguish rollovers from nonrollovers. Overturns appeared more likely with younger drivers and those less familiar with the roads on which the crashes occurred, but environmental factors appeared more important to rollover. Rollovers appeared more likely in rural, nonresidential environments and where roadsides have sideslopes and ditches. While results indicated that pickups and utility vehicles are somewhat more exposed to environments with high overturn risk, controlling for confounding variables repeatly left light trucks with rollover rates substantially higher than cars.

The rollover rates of vans presented a challenging problem, for the estimate of their overall rollover rate in the crash population was the lowest of the three light trucks, differing from results in our previous study, in which vans had the second highest rate. Besides the possible contribution of small-sample statistical reliability, environmental factors cause confusion here. Vans benefit from high representation in urban crashes, which generally have much fewer overturns than rural crashes. When controlling for confounding variables, however, van rollover rates were the second highest of the vehicle types.

Utility vehicles presented consistently high rollover rates, regardless of which variables were controlled in the analysis. While effect of vehicle size was not an objective of

this study, a limited examination distinguishing truck-based utility vehicles from the shorter, non-truck-based ones indicated that it is primarily the latter whose high overturn rates stand out from the other light truck types.

Coming to "the bottom line," it is hard to defend the proposition that the elevated rollover rates of light trucks, particularly the utility vehicles, are basically due to their drivers or to their use in "high-risk environments." Certainly, those factors play a role in explaining the light truck rates, but the evidence now suggests that vehicle factors must make a major contribution. The only possibility we see for negating that inference would be a discovery that light truck drivers have some unusual tendencies not captured by age and sex. Circumstantial evidence to that point is the finding that light trucks tended to have more severe rollovers than cars in the rural crashes. Could that have been due to excessive speeds by their drivers? Perhaps. But considering the crudeness of our severity measure, and considering that researchers have had little success in finding driver factors to predict accidents, we doubt that such factors will ever explain much of the light truck rollover story.

4.3 The Elevated Light Truck Ejection Rates

Occupant ejection was shown to be a serious by-product of rollover: a moderate problem of pickups, and a significant

problem of utility vehicles. Indications that light truck rollovers were more severe than car overturns suggest an exacerbating factor, but controlling for crash severity still indicated light truck ejection to be a problem meriting concern. Various analyses indicated that anything that renders an occupant compartment less than a completely closed envelope increases the chances of ejection during rollover. Among pickups, occupant ejection was due mainly to doors opening and loss of window or windshield glass. Ejection from utility vehicles was due mainly to doors opening and to open or damaged roof structures, many of which were of cloth or fiberglass. While clinical analysis of the overturns attributed most ejections to losses of vehicle structural integrity, about 20 to 40 percent did not involve such losses. The utility vehicles were most prominent in this regard, for a number of their ejections were possible because the vehicle had no doors or roof. These findings indicate directions for possible improvements in reducing light truck ejections.

4.4 Research Methodology Issues

To conclude this discussion section, research issues of the study deserve comment. The first has to do with the percentage of rollovers in single-vehicle crashes as the dependent variable in the rollover analyses. The second concerns the relevance of driver variables in studying that dependent variable.

Assessing rollover risk. This study used the percentage of rollovers among single-vehicle crashes as the dependent variable indicating rollover risk. Others may prefer to use different rollover rates, such as single-vehicle rollovers per million vehicle miles. Aside from the considerable difficulty in obtaining the required exposure data, we prefer not to use such a rate because it would tend to obscure the factors determining rollover. The rate would be a complex combination of (1) factors determining the risk of getting into a crash in the first place, (2) factors affecting overturn, and (3) factors affecting crash reporting. From the data it would be very difficult to sort out vehicle overturn tendencies. Hence, we used as our rollover rate the percentage of single-vehicle crashes that involved rollover. This raises the question: What is the meaning of an above-average single-vehicle rollover percentage when exhibited by a vehicle type? Such a rate reflects a high ratio of overturns to fixed-objects no-overturn crashes. There are two possible interpretations for this:

(a) There are factors (vehicle, driver, and/or environmental) that create an above-average risk of rollover in single vehicle crashes of that vehicle type;

or (b) There is no elevated risk of rollover, but there are factors (vehicle, driver or environment) that create

a below-average risk of nonoverturn (fixed-object) crashes in single-vehicle crashes of that vehicle type.

Now, if the elevated rollover rates persist despite the controlling of relevant driver and environmental factors, then the evidence points to vehicle factors at work. In that case, which interpretation is valid? Interpretation (a) suggests a vehicle propensity to overturn. Interpretation (b) just doesn't seem plausible, leading us to conclude that with controls for relevant driver and environmental factors, high single-vehicle rollover percentages indicate above-average vehicle rollover tendencies.

A second issue concerns the study of driver factors in relation to the single-vehicle rollover percentage. One might reason that driver factors are irrelevant to such a rate, for once a single-vehicle crash begins, only the physical dynamics stemming from vehicle and environmental factors will determine whether rollover occurs. But that reasoning is incorrect, for driver factors can influence rollover occurrence during a crash. In the pre-crash mode, a driver's inputs can lead to control loss, which was associated with overturn during crashes (Figure 3.5). In the crash mode, a driver's attempts at corrective action could effect a rollover. Examples are often cited of drivers in road departures who trigger an overturn by trying to steer the vehicle back toward the road while it is

traversing down a fill slope. Such rollover-effecting behaviors may in turn be associated with driver age, gender, or even familiarity with the road (in the case of control loss). Hence, those factors were examined in this study.

5.0 CONCLUSIONS

Considering the various kinds of evidence brought to bear on the issues of this study, our conclusions are as follows.

(1) Overall, light trucks and cars continued to exhibit little differences in driver injury rates. While this study made only a limited replication of the analyses in our previous report (Terhune, 1986), the larger sample sizes in this study still resulted in driver injury rates which were very similar among the vehicle types. An exception was an elevated injury rate in vans in rural crashes, which was based on only 21 vehicles. Since both the vans and utility vehicles had relatively small samples in this study, further monitoring of their single-vehicle injury rates with larger samples is advisable.

(2) Light trucks have higher single-vehicle-crash overturn rates than cars; while driver and environmental factors play a role in elevating the overturn rates, vehicle factors appear to play a significant role. While this study did not examine vehicle factors per se, the elevated light truck rollover rates remaining after controlling for driver and environmental factors led us to this conclusion.

(3) Utility vehicles exhibit clearly the highest rollover tendencies. Virtually without exception, utility vehicles had the highest overturn rates when other factors were controlled.

(4) Ejection is preeminently a utility vehicle problem, and to a lesser extent, a pickup problem. Ejection was found to be a very dangerous event for occupants. While a by-product of high rollover rates and accident severity, light truck ejection rates tended to be higher than car rates when using limited controls for crash severity within rollovers. Particularly within rollovers, utility vehicle ejection rates were three to four times the car rates. Pickup ejection rates were only about half again as large as the car rates.

6.0 RECOMMENDATIONS

While light trucks generally protect their occupants as well as cars do in single-vehicle crashes, directions for further improvement of light trucks were indicated by this study. Our recommendations follow.

(1) It is recommended that vehicle factors promoting light truck rollover be studied. A limitation of this study is that, in suggesting the relevance of vehicle factors to light truck rollovers, it did not identify those factors. That was beyond the scope of the study, but future accident and engineering studies could address the vehicle factors in detail. For example, an accident study could examine the relationship of overturn to the center of gravity-track width ratio, which is often cited as a factor in utility vehicle overturns. Engineering studies, including laboratory tests, computer simulations, and full-scale rollover tests, could further investigate possible factors such as steering, suspension, and inertial properties in relation to rollover.

(2) It is recommended that the industry continue to support occupant restraint systems, encouraging their use in light trucks. This was not a study of restraint systems, of course, but restraint systems are an obvious

countermeasure to the occupant ejections found prominent in pickups and utility vehicles.

(3) It is recommended that pickup and utility vehicle design engineers consider ways to reduce the ejection-permitting structural losses that were identified in this study. The door-openings of pickups and utility vehicles, the window/windshield losses in pickups, and roof structural damage in utility vehicles were indicated as routes of occupant ejection. Since design engineers will undoubtedly need more detail on the structural losses than is provided in our summary statistics, it is recommended that they examine records of individual light truck crashes, as are available in the MVMA's light truck accident file.

(4) It is recommended that the effects of vehicle size be studied in relation to light truck occupant protection. This study provided limited evidence on the effects of vehicle size in finding that rollover rates were substantially higher in short utility vehicles than in the larger, truck-based ones. Since light trucks and cars include a wide range of weights and wheelbases, some of the differences in occupant protection among vehicle types may be due to vehicle size. Controlling for vehicle size in further research will clarify the comparative occupant protection afforded by vehicle type per se.

7.0 REFERENCES

Highway Loss Data Institute, Insurance Injury Report. Report HLDI 185-1, Washington, DC, 1986.

Huelke, Donald F., Compton, Charles, & Studer, Richard N. Injury severity, ejection, and occupant contacts in passenger car rollover crashes. Society of Automotive Engineers, Paper No. 850336, 1985.

Huelke, Donald F., Marsh, Joseph C., & Sherman, Harold W. Analysis of rollover factors and causation. Proceedings of the 16th Conference of the American Association for Automotive Medicine, 1972.

Joksch, H.C. Critical comments on the paper "Rollover and serious driver injury differences among various utility vehicles, pickup trucks, and passenger car groups." Paper presented at the 26th Conference of the American Association for Automotive Medicine, Ottawa, Oct. 1982.

McGuigan, R. & Bondy, N. A Descriptive Study of Rollover Crashes. Unpublished report, National Highway Traffic Safety Administration, Washington, D.C.: July, 1980.

National Highway Traffic Safety Administration. Light Truck and Van Safety: Report to the Committees on Appropriations, U.S. House of Representatives, U.S. Senate. May, 1987 (a).

National Highway Traffic Safety Administration. National Accident Sampling System - 1985. Report DOT HS 807 074, February, 1987 (b).

Partyka, S., Sikora, V., Surti, J., and Van Dyke, J. "Relative risk to car and light truck occupants." SAE paper 871093, May 1987.

Reinfurt, D.W., Stutts, J.C., and Hamilton, E.G. A Further Look at Utility Vehicle Rollovers (Revised). University of North Carolina, Chapel Hill, N.C., December, 1985.

Robertson, Leon S. and Kelley, A. Benjamin. The Role of Stability in Rollover-Initiated Fatal Motor-Vehicle Crashes Under On-Road Driving Conditions. Nanlee Research, Branford, CT and A.B. Kelley Corporation, Dunkirk, MD, May, 1986.

Terhune, K.W. Light Truck Safety: A Literature Review and Research Outline. Calspan Corporation Report No. 216. Buffalo, N.Y., 1985.

Terhune, K.W. A Comparison of Light Truck and Passenger Car Occupant Protection in Single-Vehicle Crashes. Calspan Corporation Report No. 7438-1, 1986.

Terhune, K.W., Ranney, T.A., Smist, T.E., and Woodill, R.A. A Study of Light Truck Aggressivity. Calspan Field Services, Inc. Report 7139-Y-1, Buffalo, N.Y.: 1984.

Tourin, Boris. "Ejection and Automobile Fatalities." Public Health Reports, 73 (5), 381-391, 1958.

APPENDIX A

Date coded: _____

Coded by: _____

Calspan Corporation
Rev. April, 1987

ROLLOVER-EJECTION CODING FORM

For Application to NASS Cases

Coding conventions: 8, 98 = inapplicable
9, 99 = unknown

Case Identification - Enter codes from Nass Accident Data form, page 1

1. Primary Sampling Unit Number — [1] [2]
2. Case Number - Stratification — [3] [4] [5] [6]
3. Accident year — 19 [7] [8]

(See "Date" on NASS Accident Data form)

Vehicle Identification - Enter codes from NASS Vehicle Data form, page 1

4. Vehicle model year — 19 [9] [10]
5. Vehicle make — [11] [12]

   Write make: _____

6. Vehicle model — [13] [14]

   Write model: _____

Determine from "Body Type" code on NASS Vehicle Data form, and definitions in Coding Manual.

7. Body Type — [15]

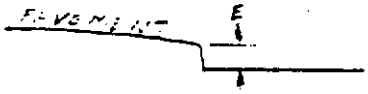
   1 - Passenger car
   2 - Pickup truck
   3 - Van
   4 - Utility vehicle

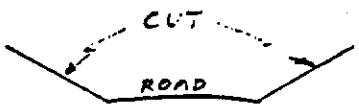
PSU __ __ Case No. __ __ __ __

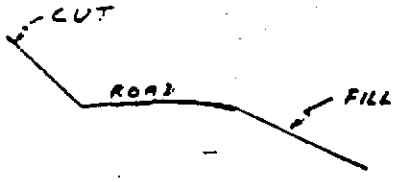
8.	**Vicinity of accident:** predominant land use	1 - Residential-urban 2 - Manufacturing or commercial 3 - Residential-rural (partly open land) 4 - Farming 5 - Undeveloped, open 6 - Undeveloped, treed or forested	16
9.	**Pre-crash travel surface**	1 - Paved road 2 - Unpaved road 3 - Off-road operation	17

IF OFF-ROAD OPERATION, GO TO VARIABLE 16

10-15: Roadside features within ± 100 ft. longitudinally along road
(Estimated from point of first harmful event.)

			Relation to Travel Direction	
			Left Side*	Right Side
10.	Depth(D) of longitudinal ditch. (Estimate to nearest foot.)	0 - No ditch 7 = 7 or more feet 8 = unknown	18	19
11.	Curb height(C)	0 - No curb 1 - C ≤ 8" 2 - C > 8"	20	21
12.	Edge dropoff extent(E) 	0 - No dropoff 1 - E ≤ 8" 2 - E > 8"	22	23
13.	Side slope type	0 - No side slope 1 - Cut 2 - Fill	24	25





*On divided highways, left side refers to median area

PSU ___ Case No. _____

		Relation to Travel Direction	
		Left Side*	Right Side
14. Side slope angle	0 - No slope	26	27
	1 - Flatter than 4:1		
	2 - 3 or 4:1		
	3 - 2:1		
	4 - 1:1 or steeper		

15. Fixed objects within 30 ft. of road edge and ± 100 ft. from F.H.E., longitudinally

15a. Narrow objects (light support, pole tree, signpost, hydrant)	0 = Not present 1 = 1-2 objects present 2 = 3-6 objects present 3 = > 6 objects present	28	29
15b. Longitudinal objects	0 = Not present 1 = Present		
	Guardrail	30	31
	Fence	32	33
	Divider/traffic barrier	34	35
	Wall (manmade or natural)	36	37
	Other, incl. bridge rail	38	39
15c. Miscellaneous: building, bridge pier, abutment, parapet, overpass structure		40	41

16. Vehicle preimpact travel orientation (If rollover, specify orientation just prior to rollover.)	1 - Tracking 2 - Skid sideways (2-5, 7-10 o'clock) 3 - Skid front (11 - 1 o'clock) 4 - Spin-rotate 7 - All other (turning, stopped, slowing, starting, lane changing, etc.)	42
17. CALAX code (See Coding Manual)		43 44
18. First harmful event (Use NASS '85 code)		45 46

*On divided highways, left side refers to median areas.

PSU __ __ Case No. __ __ __ __

19. Surface at location of 1st harm. event

1 - Pavement
2 - Sod
3 - Rock/hard packed soil or clay
4 - Soft soil/sand/gravel
7 - Other, including packed snow

47

20. Did vehicle traverse or contact (with body or tires) any of the following roadside features? (Include both harmful and nonharmful events.)

0 - No 1 - Yes

See variables 10-15 for definitions

Longitudinal ditch	48
Curb	49
Edge dropoff	50
Cut slope	51
Fill slope	52
Narrow fixed objects	53
Guardrail	54
Fence	55
Divider (traffic barrier)	56
Wall (manmade or natural)	57
Other, including bridge rail	58

21. Vehicle rollover (1/4 turn or more) 0 - No rollover 1 - Yes

59

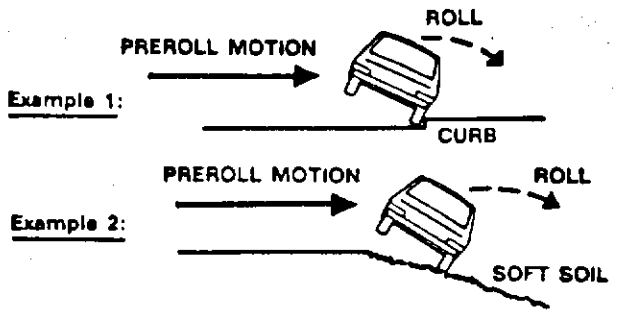
IF NO ROLLOVER OCCURRED, GO TO VARIABLE 25

22. Rollover type most closely fitting this accident. (Refer to Coding Guide for Rollover Types, next page)

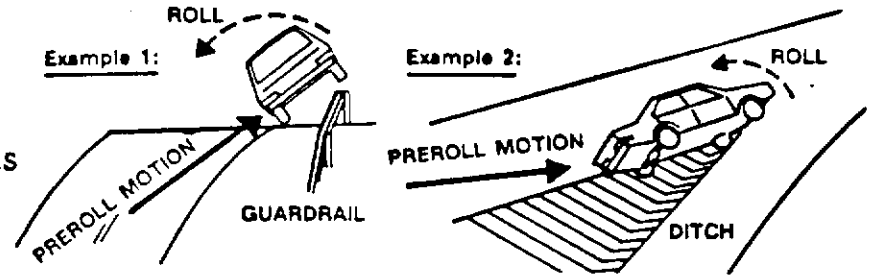
01 - Trip-over
02 - Flip-over
03 - Turn-over
04 - Climb-over
05 - Fall-over
06 - Bounce-over
For combinations of the above, see Coding Manual
97 - Other rollover (Describe: _____)

60 61

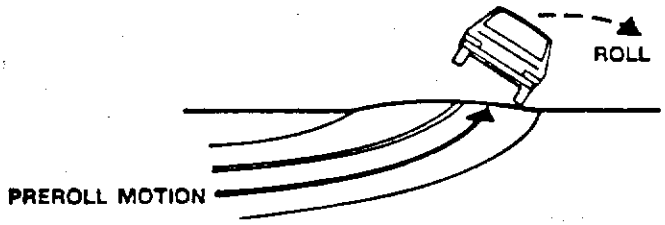
1. Trip-Over: Vehicle lateral motion is resisted by opposing force, inducing roll moment.



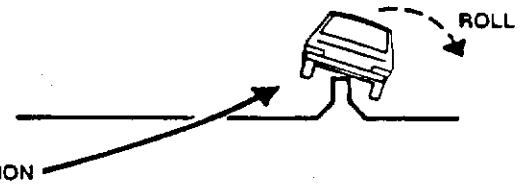
2. Flip-Over: Forward-moving vehicle is vigorously rotated about its longitudinal axis by ramp-like object such as a guardrail taper or ditch back slope.



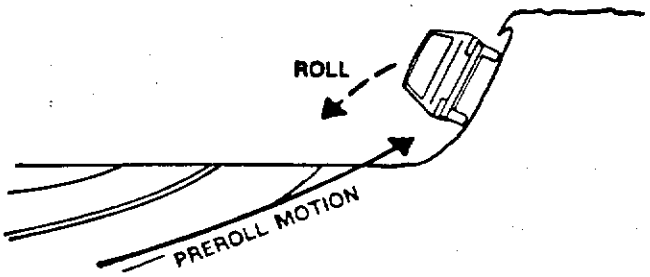
3. Turn-Over: Centrifugal forces from a sharply turning or rotating vehicle produce a rollover moment when resisted by surface friction.



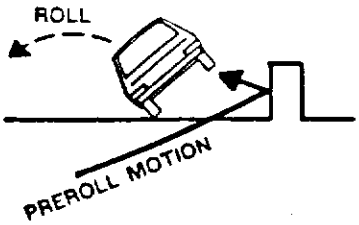
4. Climb-Over: Vehicle climbs up and over fixed object such as barrier.



5. Fall-Over: Vehicle is tipped by slope or object so that its center of gravity is outboard of its wheels.



6. Bounce-Over: Any case where vehicle rebounds off fixed object (such as a guardrail), overturns as a consequence.



PSU ___ Case No. ____

23. Which feature produced the rollover? ____ (62) ____ (63)

Roadside feature:
- 01 - Longitudinal ditch
- 02 - Curb
- 03 - Edge dropoff
- 04 - Cut slope
- 05 - Fill slope
- 06 - Narrow Fixed object (Name: _____)
- 07 - Guardrail
- 08 - Fence
- 09 - Divider/traffic barrier
- 10 - Wall (manmade or rock)
- 11 - Other, including bridge rail

On-road feature:
- 12 - Fixed object
- 13 - Nonfixed object
- 14 - Other, incl. pavement

24. Surface feature acting as rollover trigger (source of resistance to horizontal motion) ____ (64)
- 0 - None
- 1 - Pavement
- 2 - Pavement irregularity (e.g. pothole)
- 3 - Sod
- 4 - Rock or hard-packed soil or clay
- 5 - Soft soil/sand/gravel
- 7 - Other: _____

25. Number of doors opening during crash ____ (65)

26. Number of windows open before crash (Open-top vehicles: Code 8) ____ (66)

27. Were any occupants ejected? 0 - No 1 - Yes (includes partial ejections) ____ (67)

IF NO OCCUPANTS EJECTED, CODE NO FURTHER

28. Circle all ejected occupants below. Then, determine the code for the ejected occupant with the highest priority. Enter that code in the answer space at the right. ____ (68)

Code:
- 1 - Driver
- 3 - Right-front
- 6 - Second seat - right
- 4 - Second seat - left
- 2 - Front seat - middle
- 5 - Any other

Highest priority ↓ Lowest priority

CODE VARIABLE 29 FOR THE OCCUPANT WITH HIGHEST PRIORITY ABOVE.

29. Was occupant's ejection facilitated by damage to or failure at the ejection medium? 0 - No 1 - Yes ____ (69)

If yes, describe facilitating damage or failure. _____

_____

_____

APPENDIX B

CODING MANUAL

for

Rollover-Ejection Coding Form

by K.W. Terhune

Accident Research Section
Franklin Research Center
Division of Arvin/Calspan

March, 1987

This Coding Manual provides guidance on the coding of rollover and ejection information from accident cases in the National Accident Sampling System (NASS). The Coding Form is intended to capture information that is not already coded on the standard NASS forms. The only information you will take directly from the NASS forms is the identifying data required on page 1 of the Coding Form, and the First Harmful Event (Variable 18 on the Coding Form). All other information is to be derived from your examination of other sources in the NASS cases, specifically:

(a) the color slide photographs of the accident scene;

(b) the accident scene diagram;

(c) NASS descriptive information on how the accident occurred.

Much of the data you will code pertains to the crash environment, especially the road and the roadsides. You will have to make judgments on what you perceive in the photographs, and on the scene-diagram indications. In some cases the photographs and scene diagram will not provide as much clear information as you would like for making your judgments. Do the best you can with the available information. If the needed information is not available, or if it is too vague or ambiguous to code some variables, then use the codes for "unknown" on those variables. There is no rule of thumb for making your judgments, but it is better that you give a rough estimate than no estimate. Do not merely guess, however; there must be some evidence to support your estimate.

RECORDING ANSWER CODES

The data on all variables should be recorded in the answer columns at the right side of each page of the Coding Form. All answer codes will be numbers, corresponding to the codes given for each variable on the Coding Form.

Certain coding conventions are specified at the top of Page 1 of the Coding Form. If a variable is inapplicable to a particular accident, this will be indicated by instructions on the Coding Form, telling you to skip the variable for that case. All other variables require an answer coded by you. As noted previously, there may be insufficient information in a particular NASS case for you

to determine the correct answer code for some variables. In that case, use the conventional code for "unknown."

Each variable will require answers in either a one-digit or two-digit code, and answer spaces are provided accordingly. Consequently, "inapplicable" and "unknown" are to be coded as follows:

	1-digit answer	2-digit answer
inapplicable	8	98
unknown	9	99

Important points to remember in coding all answers are:

(1) Specify both digits in a 2-digit answer, even if the first digit is 0, such as 01, 02, 03 ...

(2) Mark your answer codes clearly, so there can be no confusion:

- Write 4 and not ✓ (latter may be misread as 9)
- 2 should be clearly distinct from 7
- 5 should be be written as 5 and not S

(3) Your answer in the answer columns should always be a number, and not a word or alphabet letter. For example, consider this code:

0 - No 1 - Yes

This is used in variables 20, 21, 27, and 29. Answers for these variables must be written as 0 or 1, never as Y or N, or yes or no.

REMARKS ON SPECIFIC VARIABLES

Body type (variable 7). Body types are listed on the NASS Vehicle Data Forms. Refer to these, and translate them into one of the four codes listed in variable 7. Refer to Table 1 to make the translation.

Roadside features (variables 10-15). Note that each of these requires separate answers for the left and right side of the road. Consider left and right to be from the point of view of the accident-vehicle driver as the vehicle was travelling prior to the accident.

CALAX code (variable 17.) Refer to Figure 1 to find the diagram that best describes the accident being coded. Note that if the vehicle was operating off the road at the time the accident occurred, codes 17 or 18 apply. Do not use codes 17 and 18 for vehicles off the road as a result of the accident sequence.

Rollover type (variable 22). Refer to the Coding Guide for Rollover Types. While many rollovers may not exactly fit the rollovers described in the Coding Guide, you should find the type that most closely fits the accident being coded.

Occasionally you may find a rollover that was a combination of two of the basic 6 rollover types, such that it would be misleading to consider the accident just one type or the other. In that case, we allow for coding the combination, by using each digit of the 2-digit code.

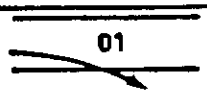
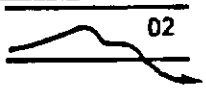
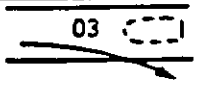
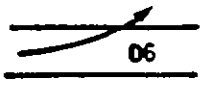
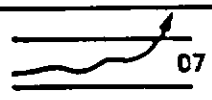
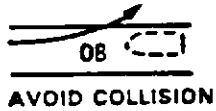
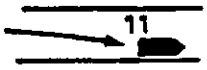
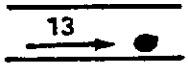
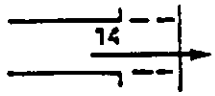
Example 1: The vehicle went off the road and down a fill-slope. The driver turned the steering wheel in an attempt to get the vehicle back onto the road. As the vehicle was turning on the slope, the wheels dug into the soil. This created a "trip-over" effect, but at the same time the centrifugal forces from the turning vehicle created a "turn-over" effect. This accident is coded 13 (1 for trip-over, 3 for turn-over).

Example 2. A vehicle bounces off a fixed object, causing the vehicle to rotate on as it rebounds onto the pavement. This is a combination of a "bounce-over" and a "turn-over," and is coded 63.

Table B-1. Coding Body Type from NASS Vehicle Data Form

	NASS 1980-81 Codes	NASS 1982-85 Codes
Passenger cars include . . .		
Convertible	01	Same as 1980-81
2-door sedan	02	
3-door/2 door hatchback	03	
4-door sedan	04	
5-door/4 door hatchback	05	
Station wagon (not van and truck based)	06	
Other automobile type	08	
Unknown automobile type	09	
Pickups include . . .		
Auto based pickup	Not identified	10
Pickup	50	50
Vans include . . .		
Van	51	40
Van-Commercial cutaway (not step van)	Not identified	41
Other van type	Not identified	48
Unknown van type	Not identified	49
Utility vehicles include . . .		
Short utility vehicle	Not identified	12
Truck-based station wagon	52	55
Truck-based utility; on/off road vehicle	43	56

Figure B-1. CALAX Accident Type Codes

A. Right Roadside Departure	 01 DRIVE OFF ROAD	 02 CONTROL/ TRACTION LOSS	 03 AVOID COLLISION WITH VEH., PED., ANIM.	04 SPECIFICS OTHER	05 SPECIFICS UNKNOWN
B. Left Roadside Departure	 06 DRIVE OFF ROAD	 07 CONTROL/ TRACTION LOSS	 08 AVOID COLLISION WITH VEH., PED., ANIM.	09 SPECIFICS OTHER	10 SPECIFICS UNKNOWN
C. Forward Impact	 11 PARKED VEH.	12 STA. OBJECT	 13 PEDESTRIAN/ ANIMAL	 14 END DEPARTURE	15 SPECIFICS OTHER	16 SPECIFICS UNKNOWN

17 = offroad operation, fixed object impact

18 = offroad operation, rollover

Surface feature triggering rollover (variable 24). In many cases, you will code "none" for this variable when a rollover occurred. You should code other than "none" only for those cases where a surface feature resisted the vehicle's horizontal motion so as to produce a rollover.

Sometimes a rollover will result from the combined action of a surface feature and another feature listed in variable 23. Perhaps the best example is Example 2 under "Trip-Over" on the Coding Guide for Rollover Types (page 5 of Coding Form). The fill slope produced the rollover, so code 05 would be the answer for variable 23. But soft soil acted as a rollover trigger, so code 5 would be the answer for variable 24.

Ejected occupant priority (variable 28). The occupants are listed in variable 28 in order from highest to lowest priority. Circle all occupants ejected. The circled occupant highest on the list has the highest priority: enter that occupant's code as the answer to variable 28.

Example: The right-front and second-seat-left occupants were ejected.

1 - Driver
3 - Right-front
6 - Second seat-right
4 - Second seat-left
2 - Front seat-middle
5 - Any other

Code 3, for the right-front occupant, is the answer for variable 28.

APPENDIX C

Driver and Environment Variables Having
Little or No Relation to Rollover

Variable	Cars		Light Trucks	
	No Roll	Roll	No Roll	Roll
Months Driving Experience				
1-11	6.4%	8.3%	8.2%	10.1%
12-23	5.0	5.3	4.2	6.1
24-35	6.1	5.6	5.4	6.1
36-47	5.5	6.0	4.5	5.1
48-60	6.6	7.9	6.2	7.2
>60	70.4	66.9	71.5	65.3
	100.0%	100.0%	100.0%	100.0%
Chi-Square	5.6 (N.S.)		3.7 (N.S.)	
Driver Alcohol Influence				
No	74.3%	70.8%	64.0%	66.2%
Yes	25.7	29.2	36.0	33.8
	100.0%	100.0%	100.0%	100.0%
Chi-Square	3.9 (P = .046)		0.5 (N.S.)	
Driver Gender				
Male	61.3%	60.0%	84.1%	80.6%
Female	38.7	40.0	15.9	19.4
	100.0%	100.0%	100.0%	100.0%
Chi-Square	0.5 (N.S.)		2.0 (N.S.)*	
Atmospheric Condition				
Clear	75.5%	82.2%	79.8%	81.2%
Rain	15.4	11.1	12.1	9.8
Other	9.1	6.7	8.1	9.0
	100.0%	100.0%	100.0%	100.0%
Chi-Square	18.1 (P=0)		1.5 (N.S.)*	

*N.S. = Not statistically significant

Variable	Cars		Light Truck	
	No Roll	Roll	No Roll	Roll
Road Division				
Not divided	75.4%	74.6%	80.1%	79.7%
Divided	24.6	25.4	19.9	20.3
	100.0%	100.0%	100.0%	100.0%
Chi-Square	0.7 (N.S.)		0.9 (N.S.)	
Vertical Alignment				
Level	60.7%	53.0%	61.8%	58.4%
Grade	25.5	28.8	27.9	27.3
Crest, sag, other	13.7	18.1	10.3	14.3
	100.0%	100.0%	100.0%	100.0%
Chi-Square	17.9 (P=0)		3.5 (N.S.)	
Road Surface Type				
Concrete	13.5%	11.0%	9.0%	10.5%
Bituminous	84.0	83.3	84.8	80.9
Slag, gravel, dirt, etc.	2.4	5.7	6.2	8.6
	100.0%	100.0%	100.0%	100.0%
Chi-Square	24.5 (P=0)		2.8 (N.S)	
Road Surface Condition				
Dry	64.1%	73.4%	68.4%	70.9%
Wet	22.2	16.3	18.7	14.7
Snow, ice, oil	13.5	10.3	12.9	14.5
	100.0%	100.0%	100.0%	100.0%
Chi-Square	28.0 (P=0)		3.1 (N.S.)	

*N.S. = Not statistically significant

APPENDIX D

Basic Data for Roadside Rollover Model

Roadside Feature	Vehicle Type	Exposure to Feature (1)	Probability of Contact,* Given Exposure (2)	Probability of Rollover, Given Contact* (3)	Net % Overturns Involving Feature Contact* (1) x (2) x (3)
Fence	Car	15.2%	35.5%	55.7%	3.0%
	Pickup	15.0	40.0	49.4	3.0
	Van	20.7	19.8	24.4	1.0
	U-Veh	20.8	51.4	84.7	9.1
Ditch	Car	28.6%	67.1%	44.0%	8.5%
	Pickup	35.8	75.1	66.2	17.8
	Van	28.9	70.2	51.7	10.5
	U-Veh	53.0	71.5	73.8	28.0
Fill slope	Car	51.2%	86.5%	43.1%	19.1%
	Pickup	58.5	81.9	66.3	31.7
	Van	51.0	65.1	45.2	15.1
	U-Veh	51.1	83.2	76.2	32.4
Cut slope	Car	50.3%	31.0%	38.6%	6.0%
	Pickup	55.0	39.5	52.8	11.5
	Van	39.4	36.8	79.6	11.5
	U-Veh	42.9	54.9	85.1	20.0
"Other" Longitudinal objects (bridge rails, etc.)	Car	5.0%	100.0%	29.5%	1.5%
	Pickup	8.0	100.0	49.5	4.0
	Van	7.2	71.7	39.3	2.0
	U-Veh	7.0	88.3	73.3	4.6
Miscellaneous fixed objects (building, bridge pier, abutment, etc.)	Car	26.3%	54.8%	27.1%	3.9%
	Pickup	16.9	58.6%	39.5	3.9
	Van	24.9	58.6	0	0
	U-Veh	15.8	29.7	64.7%	3.1
Narrow objects (pole, tree, light support, signpost, hydrant)	Car	87.3%	65.5%	20.4%	11.7%
	pickup	75.1	53.5	29.5	11.9
	Van	90.8	55.9	21.8	11.1
	U-Veh	83.9	36.8	34.4	10.7

*Contact = Vehicle contacted or traversed feature, with or without collision.

APPENDIX D (Continued)

Roadside Feature	Vehicle Type	Exposure to Feature (1)	Probability of Contacts,* Given Exposure (2)	Probability Rollover, Given Contact* (3)	Net % Overturns Involving Feature Contact* (1) x (2) x (3)
Guardrail	Car	10.3%	54.7%	17.3%	1.0%
	Pickup	15.9	50.3	0	0
	Van	16.5	50.0	36.4%	3.0
	U-Veh	14.6	27.1	38.6	1.5
Curb	Car	24.1%	64.3%	9.5%	1.5%
	Pickup	19.0	88.9	17.3	2.9
	Van	36.2	79.6	7.3	2.1
	U-Veh	15.8	94.9	40.6	6.1
Divider	Car	9.6%	24.3%	0%	0%
	Pickup	7.0	57.3	0	0
	Van	15.4	40.0	49.0	3.0
	U-Veh	9.3	50.1	65.2	3.0

*Contact = Vehicle contacted or traversed feature, with or without collision.