U.S. Department
of Transportation

National Highway
Traffic Safety
Administration

DOT HS 806 890
NHTSA Technical Report

February 1986

An Evaluation of Child Passenger Safety: The Effectiveness and Benefits of Safety Seats

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 806 890		

4. Title and Subtitle

AN EVALUATION OF CHILD PASSENGER SAFETY
The Effectiveness and Benefits of Safety Seats

5. Report Date

February 1986

6. Performing Organization Code

7. Author(s)

Charles J. Kahane, Ph.D.

8. Performing Organization Report No.

9. Performing Organization Name and Address

Office of Standards Evaluation
National Highway Traffic Safety Administration
Washington, D.C. 20590

10. Work Unit No. (TRAIS)

11. Contract or Grant No.

12. Sponsoring Agency Name and Address

Department of Transportation
National Highway Traffic Safety Administration
Washington, D.C. 20590

13. Type of Report and Period Covered

NHTSA Technical Report

14. Sponsoring Agency Code

15. Supplementary Notes

An agency staff review of an existing Federal regulation performed in response to Executive Order 12291.

16. Abstract

The purpose of child safety seats is to reduce the number of child passengers killed or injured in motor vehicle crashes. The seats function by absorbing and safely distributing crash impact loads over the child's body while holding the child in place and preventing contacts with vehicle interior components or ejection from the vehicle. Seats have to be convenient and easy to use. Federal Motor Vehicle Safety Standard 213 specifies performance and labeling requirements for child safety seats. The objectives of this agency staff evaluation are to measure the effectiveness, benefits and usage of safety seats and other safety measures for child passengers aged 0-4. The study is based on statistical analyses of National Accident Sampling System, Fatal Accident Reporting System and State accident data, analyses of sled test and compliance test results, and observational surveys of restraint system usage and misuse. It was found that:

- o Child safety seats saved the lives of 158 children aged 0-4 during 1984. Lap belts saved an additional 34 lives. In all, 192 children were saved by child passenger safety measures in 1984.
- o 46 percent of child passengers aged 0-4 were in a safety seat in 1984. An additional 14 percent used the lap belt only.
- o 39 percent of safety seats were correctly used in 1984.
- o A correctly used safety seat reduces fatality risk by 71 percent and serious injury risk by 67 percent. But misuse can partially or completely nullify this effect. In 1984, the average overall effectiveness of safety seats (correct users plus misusers) was 46 percent.

17. Key Words	18. Distribution Statement
child passenger; child restraint; child safety seat; infant; toddler; crashworthiness; evaluation; sled test; tether; booster; biomechanics; accident analysis; statistical analysis; misuse	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	468	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ABC	three-level injury scale used by police
accomp.	accompanied
AIS	Abbreviated Injury Scale
AP	Anterior-Posterior
approx.	approximately
avg.	average
BMDP4F	Biomedical Programs (p-series): contingency table analysis
CDC	Collision Deformation Classification
CRASH	Computer Reconstruction of Accident Speeds on the Highway
Delta t	duration of the impact
Delta V	vehicle's velocity change during the impact
df	degrees of freedom
DMV	Division of Motor Vehicles
DOT	Department of Transportation
DV	see Delta V
EFU	Equivalent Fatality Unit
exc.	excursion
FARS	Fatal Accident Reporting System
fats.	fatalities
FMVSS	Federal Motor Vehicle Safety Standard
g, G	unit of acceleration approximately equal to 32.2 ft/sec/sec
GM	General Motors

HIC	Head Injury Criterion
hosp.	hospitalized, hospitalizations
HSRC	Highway Safety Research Center
HYGE	trade name for an accelerator sled
in.	inches
inj.	injured, injuries
IS	Inferior-Superior
K	killed
KA, K + A	police-reported serious or fatal injuries
KAB, K + A + B	police-reported moderate, serious or fatal injuries
KABC, K + A + B + C	police-reported injuries of all severities
MCR	MCR Technology, Inc. (NHTSA contractor for the sled tests of Chapter 7)
MD	Maryland
MDAI	Multidisciplinary Accident Investigation
mph	miles per hour
MPV	Multipurpose Vehicle
N/A, n.a.	not applicable
NC	North Carolina
NASS	National Accident Sampling System
NCSS	National Crash Severity Study
NCSS-NASS	NASS data elements collected by NCSS investigators
NHTSA	National Highway Traffic Safety Administration
nonfat.	nonfatal
nonhosp.	nonhospitalizing
occ.	occupants
Penna	Pennsylvania

psgr.	passenger
red.	reduction
rel.	relative
RL	Right-Left
RMS	Root-Mean-Square
RSEP	Restraint Systems Evaluation Project
SAE	Society of Automotive Engineers
SAS	Statistical Analysis System
Tenn.	Tennessee
TLI	Total Laceration Index
UMTRI	University of Michigan Transportation Research Institute
unk.	unknown
unr.	unrestrained
unspec.	unspecified
w.	with

ACKNOWLEDGMENTS

Above all, I am grateful to Pete Ziegler and Val Radovich of NHTSA for their long-term support of the evaluation of child passenger safety. Mr. Ziegler invited me to review his work statements for observational surveys and adapted his data collection to meet evaluation needs. He kept me informed of any new literature and discussions on usage or effectiveness. Mr. Radovich on many occasions discussed with me the functions and characteristics of the various types of safety seats, sled test technology, dummy design and regulatory history. He encouraged and assisted in the sled testing project and the statistical analyses of accident data; his comments motivated me to undertake the analysis of compliance test results. On the occasions when I did not follow his advice (e.g., in the choice of dummies), I learned the hard way that he was right.

In addition to Messrs. Ziegler and Radovich, six other NHTSA employees reviewed the report in detail: Carl Clark, Elizabeth Harrison, Dick Jasinski, Sue Partyka, Nancy Rubenson and Jim Simons. Moreover, Mr. Jasinski lent me compliance test reports from his own files when they had been lost from the public files; Ms. Partyka often advised me about details in FARS, NASS and NCSS-NASS data; and Ms. Rubenson guided me through her collection of promotional and educational literature. Two major contracts in support of the evaluation were managed by staff from other NHTSA offices. Jerry Kossar and Carl Clark shared in developing and managing the sled testing project (Mr. Kossar also co-authored an SAE paper on child passenger safety with me). Angie Sebastian, Allan Berkowitz, Steve Benson, Pam Anikeeff and Noel Bleich guided Contract DOT-HS-9-02259 through its five-year history, ending with the successful North Carolina accident investigation project. Jenny Tynan, Mike Beebe, Howard Pritz, Ken Welty and Gregg Wills of NHTSA's Test Center prepared and calibrated the dummies used in the sled test study. Day Waterman supported the accident investigation project by providing safety seats and explaining their designs to the contractor and me; she helped me establish contacts with child passenger safety leaders. After Ms. Waterman left NHTSA, Theresa Siani continued this support. The staff at the Technical Reference library and Docket room fulfilled my eclectic information requirements, as they have on earlier evaluations. Alleyne Monkman typed the report, with assistance from Blanche Walker.

Since I made extensive use of the survey data collected at Hardee's restaurants and the accident data collected by telephone interviews in North Carolina, I wish to express my appreciation to Hardee's Food Systems and the North Carolina Division of Motor Vehicles, who helped make these studies possible.

B. J. Campbell, Nguyen Minh Chau, George Chi, Mark Edwards, Mike Goryl, Bill Hall, Anil Khadilkar, Mei-Mei Ma, Julia Perpich and Benjamin Phillips responded to my inquiries about the data files which I analyzed in this evaluation. Elaine Weinstein, Executive Director, National Child Passenger Safety Association had some valuable suggestions for the report. Lt. Dan Raper, Tennessee Highway Patrol, provided documentation for their study of fatal accidents. Bud Mertz (General Motors) provided information on the GM child dummy. E. C. Hughes (then with the National Safety Council) and Drs. Robert S. Sanders, Robert G. Scherz and Robert S. Vinetz encouraged me to pursue the evaluation and suggested issues which they felt were important.

SUMMARY

Safety seats for infants and small children riding in motor vehicles are one of the most successful auto safety innovations of the 1960's. They are designed to hold children in place during a crash and prevent them from being thrown into the instrument panel or other parts of the vehicle or from being ejected from the passenger compartment. Moreover, they are specifically tailored to a child's anatomy and designed to restrain a child without applying dangerous forces to vulnerable body regions. By contrast, the lap and shoulder belts that come with the vehicle are designed for adults and are in several ways inappropriate for small children.

At first, the seats were purchased only by a minority consisting of the most safety-conscious parents. During the 1970's, a massive educational campaign by the medical community, consumer groups, safety seat manufacturers and insurance companies, among others, made a much wider public aware that children needed safety seats. Between 1978 and 1985 every State, beginning with Tennessee, passed laws requiring safety seats for young child passengers. The public has supported the laws and generally understands why they are needed. By 1984, close to half of the child passenger population aged 0-4 was riding in safety seats.

The National Highway Traffic Safety Administration has long had a critical role in child passenger safety. Federal Motor Vehicle Safety Standard 213, which took effect on April 1, 1971, required that any child seat marketed for use in a vehicle be designed to restrain and protect children in a crash: it had to be attachable within a car by the car's belt

system and it would have to distribute rather than concentrate crash forces over the child's torso. A new version of Standard 213 took effect on January 1, 1981, with a 30 mph dynamic test requirement. In the dynamic test, dummies' excursion beyond the confines of the seat had to be within specified limits. So did head and chest forces. The NHTSA standards helped eliminate nonsafety or inadequate seat designs from the market.

In addition to promulgating the standards, NHTSA held conferences and workshops on child passenger protection throughout the United States, provided information and resources to the State and local groups seeking to increase usage of safety seats and encouraged States to fund child passenger safety programs under Section 402 of the Highway Safety Act of 1966.

Executive Order 12291 (February 1981) requires agencies to evaluate their existing major programs, including any program whose annual effect on the economy is $100 million or more. The objectives of an evaluation are to determine the actual benefits--lives saved, injuries prevented, damage avoided--and costs of safety devices produced and sold in response to agency standards or programs and to assess cost-effectiveness.

This report is an evaluation of what has been accomplished to enhance the safety of children aged 0-4 who are passengers in motor vehicles. The report provides estimates of the number of children actually being saved by safety seats each year. The growth in that number measures the success of the child passenger safety program. The most important parameter for calculating benefits is an estimate of the effectiveness of safety seats in actual use: the average reduction of casualty risk for children in safety seats (including correctly used and misused seats) relative to unrestrained children.

The exact effectiveness of safety seats (in actual use) is still not agreed upon by the safety community and a wide variety of estimates ranging as high as 90 percent is quoted in the literature. The evaluation's primary objective was to pin down an in-use effectiveness estimate, but in the process it was found that the goal is a moving target. Effectiveness is not constant, but has increased year by year as an ever greater percentage of the safety seats in use are being used correctly.

That brings up the second goal of the evaluation: a more complete understanding of the problem of improperly used seats. It is well known that an alarming percentage of safety seats (65 percent in one study) are not being used according to manufacturers' instructions; it is generally believed that misuse of seats is the major factor holding down effectiveness and benefits. But it has to be recognized that some types of misuse are far more detrimental than others. The evaluation identifies the more common use modes for each major type of safety seat and then groups them into three categories:

> Correct use - exactly as recommended by the manufacturer or close enough that there would not be a significant loss of safety benefits.

> Partial misuse - significantly lower effectiveness than correct use, but there should still be substantial benefits if the crash

is not too severe. Something is holding the child within the seat and something is anchoring the seat within the vehicle. But the child will experience more excursion or crash forces and/or the seat will be more likely to fail, because of the way it is misused (e.g., not using the required tether, misrouting the lap belt).

<u>Gross misuse</u> - situations where children would be thrown from the seats or the seats (with children in them) would become projectiles in a crash--basically like an unrestrained condition. (Also included in this category were children riding in feeder seats, infant carriers, or other devices intended for use in the home, not the car. By 1984, only 0.3 percent of child passengers were in such devices, although they were much more common in the 1970's. They could not be separated from grossly misused safety seats because the accident data, as well as many of the observational surveys, likewise do not identify them as a distinct category but merely include them among "safety seat users.")

The evaluation estimates the frequencies of the three categories, year-by-year, and the average effectiveness of each category. That makes it possible to estimate overall effectiveness (the weighted average of the three categories) and lives saved, year-by-year. The difference in benefits between 100 percent correct usage and the actual mix of correct use and misuse is the bottom-line effect of the problem of misused seats.

In addition, the evaluation tracks the overall usage of safety seats, year-by-year. It gives a preliminary comparison of the effectiveness of the major types of seats--when correctly used and, more importantly, when their frequency of misuse is taken into consideration. It estimates the effectiveness of two other child passenger safety measures that should be employed only when a certified safety seat is not available: restraining a child with an adult lap belt only or having the child ride unrestrained in the back seat. It also estimates the benefits of moving a restrained child from the front to the back seat.

The evaluation is based on analyses of accident data, observational surveys of restraint system usage and sled tests with restrained and unrestrained dummies.

Accident analyses have been performed in anticipation of this study since 1978. But the most recent data have been the most meaningful because they contain much larger samples of safety seat users. NHTSA's Fatal Accident Reporting System provided a good estimate of overall fatality reduction. The agency's in-depth accident data based on probability sampling--the National Accident Sampling System (NASS), National Crash Severity Study (NCSS) and Restraint Systems Evaluation Project (RSEP)--were combined to obtain an estimate of serious injury reduction. Pennsylvania data for 1981-83 were used for calculating injury-reducing effectiveness, overall and by injury type. State data from New York, Maryland, New Jersey and Idaho were analyzed for this evaluation, while published studies of Tennessee, Michigan and Washington data were reviewed. The accident data analyses, even though they are the basis for this study's overall effectiveness estimate, nevertheless have three shortcomings. They do not distinguish between correctly used and misused seats; the estimate derived from any data file is valid, at best, only for the year in which the data were collected--in later years, when a larger percentage of the seats would have been used correctly, effectiveness would have risen; the data are themselves biased because the investigators (police, NHTSA contractors) tended to report certain safety seat users, especially the gross misusers, as "unrestrained." A unique study performed in North Carolina during 1983-1984, however, compared police-reported safety seat use to actual use, by misuse mode (based on detailed interviews in which parents explained how they used each component of the safety seat)--thereby making it possible to correct for the biases in the other studies.

The comparison of correctly used and misused seats was based primarily on a sled test project conducted especially for this evaluation. The project differed from earlier sled test studies with child dummies in that:

- o The sled buck was the actual passenger compartment of a mid-sized car and the injury-producing contacts of the dummies were similar to those that would occur in real crashes.

- o Unrestrained dummies were included in the tests; the results for the restraint systems were always compared to the baseline, unrestrained case.

- o Tests were carried out with four distinct types of toddler seats, correctly used and in each common misuse mode, over a wide range of speeds, in frontal and oblique frontal impacts.

In combination with statistics on safety seat usage, the test results provided all information needed for an overall effectiveness estimate (in frontals). Side impact tests, however, could not be carried out nor was it possible to test infant seats or to include all of the less common types of toddler seats.

- Real world accident data (from NASS-NCSS-RSEP) were used to calibrate a relationship between the front-seat unrestrained dummies' Head Injury Criterion/torso deceleration and children's risk of serious head/torso injury in frontal crashes (through the mutual association of dummy results and injury risk with crash velocity). Thus, the sled tests results could be used to predict realistic injury rates.

The data from this special study were complemented by a statistical analysis of 1981-84 compliance test results for Standard 213--frontal sled tests of correctly used and partially misused safety seats. The compliance tests provided data on a variety of safety seat models which were not included in the special study. They employed a more severe deceleration pulse than the tests in the special study; as a result, the seat types which performed best in the compliance tests were not the same as the best performers in the special study--although, in both test series, all correctly used seats performed very well relative to misused seats or unrestrained dummies.

The sled test results were used to obtain effectiveness estimates for safety seats, correctly used and in each of the misuse modes that commonly occur in actual practice. Next, observational surveys of safety seat usage indicated the relative frequency of occurrence of each seat type/misuse mode combination. The effectiveness estimates were then averaged (weighted by frequency of occurrence) to obtain an overall estimate of serious injury reduction for the mix of correctly used and misused seats that was actually found in the traffic population. Since that mix changed from year to year, so did the overall estimate.

The most detailed observational survey of safety seat usage was conducted at Hardee's restaurants during 1984. The make/model of safety seat and the exact way in which it was used was recorded for over 1000 children; based on the taxonomy of this evaluation, the data were grouped to estimate the frequency of occurrence of each seat type/misuse mode in 1984. Five other observational surveys gave accurate estimates of overall usage during 1974-84 and (with some interpretation) a split between correct use/partial misuse, on the one hand, and gross misuse, on the other. The Hardee's data, sales trends for safety seats and three parking lot surveys of unoccupied seats made possible a further split between correct users vs. partial misusers. Thus, the frequency of correct users, partial misusers and gross misusers could be estimated year-by-year from 1979 to 1984 and employed for weighting the sled test results to obtain year-by-year estimates of overall effectiveness and benefits.

Finally, these year-by-year effectiveness estimates from the sled tests/usage surveys were compared to the police-reported accident data analyses (which were corrected for the usage reporting biases found in the

North Carolina study). The agreement was almost perfect: effectiveness (in actual practice) was just below 30 percent in the studies based on pre-1979 accident data and just over 45 percent by 1984. Moreover, the sled tests accurately estimated safety seat effectiveness in NASS (57 percent, since gross misusers are counted as "unrestrained") and the injury reductions in the various accident studies for lap belt only and for moving an unrestrained child to the back seat. The excellent correlation of the sled test predictions with the results of the accident analyses and the consistent trend among the accident studies themselves (after the year of the data collection and the source of the reporting biases are taken into account) provide an especially high degree of confidence in the overall effectiveness estimates of this evaluation and the year-to-year trend of rising effectiveness. Each of the data sources used in the evaluation had some shortcomings (documented in the text); nevertheless they fit together exceptionally well and the whole picture became clear after assembling the parts.

The sled test data analyzed in this evaluation showed that each of the major types of approved safety seats currently on the market is highly effective when correctly used. They do not support a conclusion that any particular type of seat (correctly used) is significantly more effective than the other types (correctly used) over the full range of frontal crash types that occur on the highway--although the tests did show that certain types of seats may excel in some specific crash situations.

Some topics were not addressed in this evaluation and remain to be resolved in follow-up studies: the effectiveness of correctly used and misused toddler seats in side impacts, by seat position--to be studied using

...aled tests supported by accident data; the effectiveness of correctly used vs. misused infant seats; booster seats vs. adult belts for children age 5 or older; the compatibility of safety seat designs with the various types of safety belt systems that are installed in passenger vehicles; a State-by-State analysis of safety seat usage vs. the type of buckle-up law, the level of enforcement, and the States' educational and promotional activities in child passenger safety--to identify the combinations of factors that best increase usage of safety seats.

The principal findings and conclusions of this evaluation are the following:

Principal Findings

BENEFITS

o The number of child passengers, aged 0-4, in cars, light trucks and vans who were saved by a safety seat or by the vehicle's lap belt steadily increased from 38 in 1979 to 192 in 1984:

Lives Saved in:	1979	1980	1981	1982	1983	1984
By safety seats	30	47	60	88	135	158
By lap belts	8	9	10	15	24	34
TOTAL	38	56	70	103	159	192

o The actual number of child passenger fatalities dropped steadily from 694 in 1979 to 551 in 1984. If restraints had been unavailable for children, the number of fatalities would have remained almost constant:

	1979	1980	1981	1982	1983	1984
Actual fatalities	694	688	632	632	617	551
Lives saved by restraints	38	56	70	103	159	192
Fatalities if restraint usage had been zero	732	744	702	735	776	743

o In 1984, safety seats and lap belts saved 26 percent (192 out of 743) of the fatalities that would have occurred to child passengers aged 0-4.

o The injury saving benefits of safety seats and lap belts in 1984 were:

	Hospitalizations Prevented	Children Avoiding any Injury
By safety seats	1,020	17,000
By lap belts	330	4,000
TOTAL	1,350	21,000

USAGE

o The percentage of child passengers aged 0-4 who used a child seat or lap belt tripled between 1974 (20 percent) and 1984 (60 percent). Most of the increase came after 1981, with the widespread introduction of State buckle-up laws:

Percent of Children in	1974	1979	1980	1981	1982	1983	1984
Child seats	16	15	20	24	32	42	46
Lap belt only	4	3	4	4	6	9	14
Child seats or lap belts	20	18	24	28	38	51	60
Number of States with buckle-up laws in effect at the end of the year	0	1	2	3	13	31	46

o Among child seat users, the percentage of seats that were used correctly increased from 18 percent in 1979 to 39 percent in 1984. The percent of seats that were grossly misused or not intended for automotive use (such as feeder seats or infant carriers for home use) decreased from 50 percent in 1979 to 21 percent in 1984:

<table>
<tr><th>Percent of Child Seats in Use</th><th>1974 ....</th><th>1979</th><th>1980</th><th>1981</th><th>1982</th><th>1983</th><th>1984</th></tr>
<tr><td>Correctly used</td><td rowspan="2">39</td><td>18</td><td>20</td><td>22</td><td>25</td><td>30</td><td>39</td></tr>
<tr><td>Partially misused</td><td>32</td><td>38</td><td>41</td><td>45</td><td>46</td><td>40</td></tr>
<tr><td>Grossly misused safety seats/home child carriers used as car seats</td><td>61</td><td>50</td><td>42</td><td>37</td><td>30</td><td>24</td><td>21</td></tr>
</table>

o Since overall usage of safety seats tripled (from 15 to 46 percent of all child passengers) while the proportion of seats used correctly doubled (from 18 to 39 percent of seats in use), the percent of all child passengers who were in a correctly used safety seat increased (from 3 to 18 percent) between 1979 and 1984:

Percent of All Child Passengers in	1979	1980	1981	1982	1983	1984
Correctly used safety seats	3	4	5	8	13	18
Partially misused seats	5	8	10	14	19	18
Grossly misused safety seats/ home child carriers used as car seats	7	8	9	10	10	10
(Not in a child seat)	85	80	76	68	58	54

o Safety seat usage drops off sharply as children get older. According to 1984 nationwide observational and accident data, 68 percent of infants under age 1 were in safety seats but only 17 percent of 4-year-olds. One likely factor is that most of the State buckle-up laws currently do not require safety seats to be used through age 4.

Age of Child	Percent Using Safety Seats	Number of States in 1985 Requiring Safety Seat at that Age
0	68	All 50
1	62	47
2	51	40
3	27	30
4	17	10

o While safety seat usage keeps dropping as children get older, lap belt usage first increases but then levels off beyond age 2 - as evidenced by 1983-84 North Carolina accident data. Thus, the proportion of children using either restraint system falls as age increases:

Restraint System Usage in North Carolina (%)

Age of Child	Safety Seats	Lap Belt Only	Safety Seat or Lap Belt
0	76	1	77
1	55	11	66
2	25	19	44
3	10	20	30

(The North Carolina buckle-up law applies to children under 2, requiring a safety seat for infants under 1 and a choice of seat or belt for 1 year olds.)

OVERALL EFFECTIVENESS

o In 1984, the overall average effectiveness of safety seats (based on the mix of correct users and misusers that actually occurred on the road) and other safety measures for child passengers aged 0-4 were:

Percentage Reduction of:	Fatalities	Hospitalizations	Nonserious Injuries
Safety seats	46	46	37
Lap belt only	33	50	30
Unrestrained: back seat vs. front seat	27	27	25
Safety seat users: back seat vs. front seat	20	20	20

o Before 1984, the overall average effectiveness of safety seats was lower because a larger percentage of the seats were misused. Effectiveness increased steadily from 27 percent in 1979 to 46 percent in 1984:

Reduction in Fatalities/Hospitalizations	1979	1980	1981	1982	1983	1984
Safety seats	27	32	35	38	42	46
Lap belt only (fatality reduction)	33	33	33	33	33	33
Unrestrained: back seat vs. front seat	27	27	27	27	27	27
Safety seat users: back seat vs. front seat	23	23	22	22	21	20

o The benefits of moving a restrained child from the front seat to the back seat were slightly higher before 1984 because a greater proportion of the seats were misused. When safety seats are used correctly, there is relatively less difference between the front and rear seat of a car, because the child is less likely to contact vehicle interior surfaces (which are more hazardous in the front seat than in the back seat).

o Lap belts are quite effective for small children at moderate speeds, but casualty reduction in frontal crashes dwindles beyond crash velocities (Delta V) of 30 mph.

o An unrestrained child (age 0-4) in the back seat has 55 percent lower risk of a hospitalizing head or torso injury in frontal crashes than an unrestrained child in the front seat. But unrestrained front and back seat passengers have about equal risk of serious injuries in nonfrontal crashes. They also have about equal risk of arm or leg injuries, even in frontal crashes.

EFFECTIVENESS - CORRECTLY USED VS. MISUSED SEATS

o Correctly used safety seats are estimated to reduce fatalities by 71 percent and hospitalizations by 67 percent. These are averages for all types of seats in correct use during 1984--but the estimates would have been about the same in other years.

o Partially misused seats are estimated to reduce fatalities by about 44 percent and hospitalizations by 48 percent. These are the averages for all the partial misuse modes of the various types of seats in use during 1984--the estimate would have been about the same in other years. Effectiveness of partially misused seats decreased rapidly after crash velocity (Delta V) exceeded 30 mph in frontal crashes.

o Grossly misused safety seats are of little or no value in preventing fatalities or serious injuries.

EFFECTIVENESS OF SAFETY SEATS - IN THE BACK SEAT VS. THE FRONT SEAT

o The serious injury reductions for safety seats, when used in the front seat of a car, were:

	Reduction (%) of Hospitalizations Relative to Front-Seat Unrestrained
Correctly used seat	69
Partially misused	49
Grossly misused	0
OVERALL (1984 mix of correct/misused)	48

o The serious injury reductions for safety seats, when used in the back seat of a car, were:

	Reduction (%) of Hospitalizations Relative to		
	Front-Seat Unrestrained	Back-Seat Unrestrained	Front-Seat Restrained*
Correctly used seat	73	63	11
Partially misused	59	45	20
Grossly misused	26	0	26
OVERALL (1984 mix of correct/misused)	58	43	20

*I.e., correctly used: back vs. front; partially misused: back vs. front; etc.

o A child in a correctly used safety seat in the back seat of a car is 73 percent less likely to be hospitalized than an unrestrained child in the front seat.

o In 1984, the overall effectiveness of safety seats (based on the mix of correct and incorrect usage) was 48 percent in the front seat and 43 percent in the back seat - relative to unrestrained children in the same seat position.

EFFECTIVENESS OF SAFETY SEATS - INFANTS VS. TODDLERS

o Safety seats are about equally effective in reducing the fatalities of infants and toddlers, as evidenced by statistics based on the 1980-84 mix of correctly used and misused seats:

	Fatality Reduction, 1980-84 (%)
Infants (age less than 1)	43
Toddlers (age 1-3)	44
Average of both groups	43

Each of these numbers would be about 3 percent higher for 1984, alone, since a larger proportion of the seats was used correctly than in 1980-83.

EFFECTIVENESS OF SAFETY SEATS - BY BODY REGION

o Safety seats are quite effective in preventing injuries to every body region, even when misuse of seats is taken into account:

Percent Reduction by Body Region	Pennsylvania 1981-83 Moderate Injuries* All Crashes	Sled Tests, 1984 Mix Hospitalizations Frontal Crashes
Head, face	48	41
Torso	44	44
Neck, back	25	
Arms	74	
Legs	87	

*Police-reported levels K, A or B.

CORRECT USAGE AND MISUSE - BY TYPE OF SAFETY SEAT

o Ten types of safety seats were identified in this evaluation. Correct usage varied from 9 to 90 percent among the different types, gross misuse from zero to 33 percent. The tethered seat (belt through frame) was the least often correctly used and most often grossly misused type. Seats with full shields were least often misused. A partial shield (harness pad--not armrest) significantly reduced gross misuse of tetherless seats.

Type of Seat	Example of a Best-Selling Make/Model	Share of 1984 On-the-Road Mix	Correct Use	Partial Misuse	Gross Misuse
Tethered (belt thru frame)	Strolee Wee Care 597, 599	17	9	58	33
Tethered belt-around	GM/Century Child Love Seat	3	18	79	3
Tetherless belt-around	Bobby Mac Champion	9	12	74	14
Tetherless, harness only	Century 100	18	53	21	26
Tetherless, partial shield	Questor One-Step	20	56	29	15
Tetherless, full shield	Cosco/Peterson Safe-T-Shield	2	76	24	0
Shield-booster	Collier-Keyworth Co-Pilot	4	90	0	10
Booster (using car's shoulder belt or tether-harness)	Kolcraft Tot Rider XL	12	40	45	15
Infant belt-around	GM/Century Infant Love Seat	10	41	48	11
Infant (belt thru frame)	Most convertible seats, when used by infants	5	45	45	10
	TOTAL OR AVERAGE	100	39	40	21

EFFECTIVENESS - BY TYPE OF SAFETY SEAT - WHEN CORRECTLY USED

o The sled test studies that were conducted or reviewed for this evaluation showed that all types of approved toddler seats are highly effective when correctly used. They did not consistently support a conclusion that any one type is significantly more effective than the others. Therefore, the preliminary conclusion is that all types of correctly used seats reduce fatalities by close to 71 percent and hospitalizations by close to 67 percent. The detailed findings of the studies were:

o In the sled tests which used the passenger compartment of a mid-sized car, "soft" crash pulses, and 15-35 mph frontal and oblique-frontal impact speeds: dummies in boosters and seats with full shields had less severe head injury predictions than dummies in toddler seats with harnesses (tethered or tetherless-harness only types).

o But in 1981-84 NHTSA compliance tests, with substantially "harder" crash pulses at a 27.5 mph impact speed: booster, shield-booster, tetherless full-shield and tetherless belt-around seats had more severe head injury predictions than tetherless (harness only or partial shield) or tethered (belt-around or belt through frame) types.

o In both series of tests, there were no significant differences among chest injury predictions for the various types, although tetherless-full shield seats performed slightly worse than the other types.

o In the compliance tests, boosters (with tether-harness or shoulder belt), tethered belt-around and tethered (belt through frame) seats allowed significantly less excursion of the dummies' heads in frontal impacts than did the other types.

o Very limited side impact data suggested that the tethered belt-around seat allowed less head excursion than the other types. Little else is known about performance in side impacts, especially for seats with a full shield and no harness.

o Sled tests conducted to date do not offer predictions of neck or abdominal injuries for children in toddler seats and not even for head and chest injuries in infant seats.

o The data base on boosters and shield-boosters is still scanty. Specifically, researchers are concerned about the potential for abdominal injury when users of booster seats make direct contact with a car's lap belts or with the shield. For shield-booster seats, there are also unanswered questions about the kinematics of subjects that are larger or smaller than a 3-year-old dummy.

EFFECTIVENESS - BY TYPE OF SEAT - WHEN MISUSERS ARE INCLUDED

o In 1984, the overall average serious injury reduction for each type of safety seat (based on the mix of correct users and misusers that actually occurred on the road) was:

Type of Seat	Reduction (%) of Hospitalizations Based on Frontal Sled Tests
Tethered (belt thru frame)	34
Tethered belt-around	49
Tetherless belt-around	41
Tetherless, harness only	45
Tetherless, partial shield	51
Tetherless, full shield	62
Shield-booster	60
Booster (using shoulder belt or tether-harness)	54
Infant seats (both types)	43*

*Fatality reduction based on 1980-84 accident data

o Since all types of seats are estimated to reduce hospitalizations by 67 percent when correctly used, the differences between seat types in the preceding table are due only to the fact that some types are misused more often and/or more severely than others.

o All of the preceding estimates are preliminary and subject to change when more sled test or accident data become available (especially on side impacts).

THE MOST COMMON MISUSE MODES

o The most common forms of partial misuse of safety seats in 1984 were:

Misuse Mode	Percent of All Partial Misusers
Lap belt misrouted thru frame	23
Tether not used	21
Harness not used (lap belt correctly routed around child)	20
Booster seat--no shoulder belt/tether harness	13
Infant seat--facing wrong way	7
Bobby Mac--shield not used, else correct	5
Tether not used and belt misrouted	4

o The most common forms of gross misuse in 1984 were:

Misuse Mode	Percent of All Gross Misusers
Child not secured in seat	37
Child not secured and seat not anchored in car	33
Seat not anchored in car	27

MISUSE OF INDIVIDUAL HARDWARE ITEMS

o Tethers were more often not used than any other hardware item during 1984. Full shields and integral harness/partial shields were much less frequently misused than plain harnesses. Seats with lap belt routing around the child had no more lap belt non-use than seats with routing through the frame--and virtually no incorrect use.

Types of Seats	Individual Item Misused		Percent of Seats of those Types
All seats with tethers	Tether not used		85
Booster seats	Shoulder belt/tether harness not used		60
All seats with plain harness	Harness not used		36
Lap belt through frame	Lap belt routed too low	24	35
	Lap belt not used at all	11	
Infant seats	Seat facing wrong way		33
Lap belt around child	Lap belt not used		11
Seats with full shields	Shield not used		9
Seats with integral harness/ partial shield	Harness not used		8

NOTE: The identification of partial vs. gross misuse takes into account simultaneously the status of each of the seat's hardware items and the design of the seat. It cannot be derived from the percentages shown in the above table.

EFFECTIVENESS OF SPECIFIC PARTIAL MISUSE MODES

o The serious injury reductions in four specific partial misuse modes, as estimated in the frontal and oblique-frontal sled tests which used the passenger compartment of a mid-sized car, were:

Type of Seat	Partial Misuse Mode	Effectiveness (Percent)
Tethered	Tether not used-otherwise OK	49
Tethered	Tether not used and lap belt too low	44
Tetherless - harness only	Lap belt too low	46
Booster	No shoulder belt/tether harness	59*

*However, in the 1981-84 NHTSA compliance tests, which used a "harder" crash pulse, the booster seat with no shoulder belt/tether harness had significantly <u>more severe</u> head injury predictions than the tethered seat with the tether not used. (The other two misuse modes were not tested.)

POTENTIAL BENEFITS OF SAFETY SEATS

o In 1984, safety seats spared an estimated 158 lives. That number could have been as high as 527 if every child age 0-4 had been in a correctly used seat:

Overall Usage	Actual Effectiveness (1984 Correct/Misuse Mix)	Potential Effectiveness (All Seats Used Correctly)
1984 level	158	244
1984 level for infants (no dropoff for older children	233	360
100 percent usage	341	527

Conclusions

o All of the safety seats tested in this evaluation were highly effective in frontal crashes when they were correctly used. The study does not conclude that any specific type of safety seat is more effective than the others, when correctly used.

o Even partially misused safety seats are quite effective at the *lower crash speeds. Thus, certain seat types which are rarely used* correctly still have benefits because their misuse is, in most cases, just a partial misuse.

o Lap belts significantly reduce fatalities and injuries of children aged 1-4 who ride in passenger cars. Moving an unrestrained child aged 0-4 from the front seat to the back seat has similar benefits. But neither measure is nearly as effective as a correctly used safety seat.

o The fatality and injury risk for a safety seat user in the back seat of a car is significantly lower than in the front seat. Thus, the best protection is obtained by correctly using a safety seat in the back seat of a car.

o Overall usage and correct use of safety seats increased dramatically from 1979 to 1984. State buckle-up laws, more convenient safety seat designs and educational programs by the safety/medical community have all contributed significantly to this vital safety improvement.

- In general, the types of seats that intuitively seem more convenient are the ones that are most often used correctly. An exception is the seats that require the lap belt to be routed around the child each time the seat is used. Despite that apparent inconvenience, they had just as low a rate of belt nonuse as the seats with one-time belt-through-frame routing and they had virtually no problem of misrouted belts.

- Designs in which the harness is integral with a partial shield have greatly reduced failures by parents to buckle the harnesses. They have remedied the form of misuse responsible for the largest loss of benefits for safety seats.

- Nonuse of tethers and misrouting of lap belts through the frame are two other problems that occur frequently and significantly reduce the overall benefits of safety seats.

- Safety seat usage drops off rapidly after a child reaches age 2, resulting in a serious loss of potential benefits for the seats. Many of the current State buckle-up laws do not require a safety seat to be used beyond age 2 or 3.

- Safety seats are one of the most effective and beneficial auto safety devices currently in use, but there is still much room for increased benefits since fewer than half of child passengers are using the seats and fewer than half of the seats are being correctly used.

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Evaluation of NHTSA regulations and programs

Executive Order 12291, dated February 17, 1981, requires Federal agencies to perform evaluations of their existing regulations, including those rules which result in an annual effect on the economy of $100 million or more [22]. The evaluations should determine the actual costs and actual benefits of existing rules. More recently, Executive Order 12498, dated January 4, 1985, requires agencies to develop a regulatory planning process including publication of plans to review existing regulations pursuant to Executive Order 12291 [23].

The National Highway Traffic Safety Administration began to evaluate its existing Federal Motor Vehicle Safety Standards in 1975 [39]. Its goals have been to monitor the actual benefits and costs of safety equipment installed in production vehicles in response to standards and, more generally, to assess whether a standard has met the specifications of the National Traffic and Motor Vehicle Safety Act of 1966 [55]--i.e., to determine whether a standard is practicable, meets the need for motor vehicle safety, protects against "unreasonable" risk of accidents, deaths or injuries, and provides objective criteria. In 1985, the agency extended the scope of its evaluations beyond the safety standards and published reviews of some of its other programs that had to be evaluated under Executive Order 12291 or a Congressional requirement. The agency has published 11 comprehensive evaluations of safety standards or other programs to date.

1.2 Agency efforts in child passenger safety

The first car seats for children were introduced in 1933 [66]. They hooked over an automobile's seatback and their functions were to constrain a child to prevent him from interfering with the driver, raise him up so he could look out the window and to prevent injury if the driver applied the brakes suddenly. The first child seats designed primarily for preventing deaths and injuries in motor vehicle crashes were developed by Ford and General Motors during the mid-60's, coinciding with many other important developments in auto safety. The basis for child safety seats was that the occupant restraint system built into the vehicle (lap belts, at that time) was not suitable for small children.

Because hookover seats continued to be produced even after the development of crashworthy child seats, the agency issued Federal Motor Vehicle Safety Standard 213 setting minimum requirements for any device marketed as a "safety car seat" [20]. The effective date was April 1, 1971. The standard required manufacturers to provide information on how to use their seats correctly. It specified that seats be designed for attachment within a car by the car's belt system (outlawing the hookover type) and that the seats distribute frontal crash forces over a child's thorax and pelvis, rather than concentrating them on one body region. The seats had to have backsfrom 15 to 20 inches high (for whiplash protection in rear impacts) and were not allowed to have sharp edges. Under a static load of 1000 pounds (500 pounds for a rearward facing seat), they had to retain a torso block and were limited to 10 inches forward movement. This version of Standard 213 is sometimes called the "static test standard" because of the last requirement or "213-71" because of its effective date. The standard did not regulate infant seats, "car beds" or, of course, seating devices marketed for other than automotive use (e.g., feeder seats).

By 1972, it had become evident that some brands of seats meeting Standard 213-71 had unsatisfactory performance in frontal 30 mph sled tests. Interest in dynamic sled testing of safety seats increased considerably after 1972, when the Consumers Union began publishing comparative test results for the various designs then on the market [13]. The agency endorsed the concept of a dynamic test requirement and after several years of developing test dummies, performance criteria, etc., issued a new Standard 213 in December 1979 [21]. The standard took effect on January 1, 1981. Its principal innovations were that it covered infant as well as toddler seats and required a 30 mph frontal test, limiting the dummies' head and knee excursion to levels that would not allow contact with interior surfaces of an average sized passenger car (a maximum of 32 inches head excursion and 36 inches knee excursion from the seatback pivot point forward). During the test, no loadbearing or structural part of the device is allowed to separate so as to create jagged edges that could injure a child. For the 3 year old dummy, Head Injury Criterion must not exceed 1000 and peak chest acceleration, 60 g's. Rearward facing infant seats including car beds were also subjected to 30 mph tests, with limitations on the excursion and rotation of seat and dummy. In addition, the new standard recognized the problem of seats being frequently misused: tethered seats have to meet a 20 mph dynamic test with the tether unattached. Seats with a shield and harness have to meet the 20 mph test with the harness unattached.

All seats must have labels posted on them showing how they are to be used correctly. The new rule is often called the "dynamic test standard" or "213-81" (because of its effective date). Around 1980, many of the models previously shown to have difficulty meeting 30 mph tests were withdrawn from the market or redesigned.

The agency's efforts in child passenger safety, however, have not been confined to rulemaking. NHTSA has taken the lead in providing information and resources to State and local child transportation safety advocates: the agency held a National Conference on Child Passenger Protection [65] and 10 regional workshops in 1979 for those leaders. A second round of workshops was held in 1984. NHTSA declared September 1979 as Child Transportation Safety Month and spread the message on safety seats through newspapers, printed materials at auto dealerships, and announcements on television and radio; the messages have been followed up many times since 1979. States were urged to fund child passenger safety programs with moneys granted by NHTSA under Section 402 of the Highway Safety Act of 1966 [30]. States used 402 funds for safety seat loaner programs, education programs in hospitals for mothers of newborn babies, and public information and education. Finally, NHTSA worked with the medical community and local child passenger safety organizations to urge States to pass laws requiring small children to be in safety seats.

The biggest boost to child passenger protection came from State buckle-up laws. Tennessee was the first State to pass a safety seat usage requirement [84]. It took effect on January 1, 1978. State officials, private organizations and individuals worked hard to make the law a success in terms of casualty reduction and public acceptance. Encouraged by

Tennessee's experience, Rhode Island passed a law taking effect in 1980, West Virginia in 1981 and 10 States in 1982. As of June 1, 1985, every State and the District of Columbia have buckle-up laws for child passengers [80].

1.3 Evaluation of child passenger safety measures

The child passenger safety program has been exceptionally successful because the agency has not been alone in promoting it. The medical community has supported it enthusiastically, spearheaded by a small number of physicians who have made it their personal priority. State and local governments and citizens' groups have worked hard for it. Juvenile product manufacturers have been conscientious in improving their safety seats.

Because of the overall success of the program, the evaluation should focus less on the specific benefits of a particular NHTSA regulation or initiative and more on the overall net benefits achieved in child passenger safety during the past 10 years (1974-84) and especially on the critical issues dealing with child passenger protection.

The most basic issue is the overall effectiveness of safety seats. Everyone agrees they are beneficial, but a review of earlier studies reveals the extent of disagreement about their level of effectiveness. Two analyses had been published by 1978: the one suggested that safety seats reduce fatalities by 93 percent [74], the other, by 7 percent [32] (see Section 3.1). The lower estimate has long since been forgotten. The high number is still widely believed [5], [8], [34], [72] even though it is improbable in view of the extent to which the seats are misused, the number of fatal accidents that involve catastrophic circumstances that would not be mitigated by restraints, etc. Since 1978, quite a few other studies have been published, comprising a wide range of estimates (see Section 3.2). A 1983 paper by Kahane, Kossar and Chi offered "best guesses" on overall effectiveness based on the information available at that time: 40-50 percent fatality reduction and 30-35 percent serious injury reduction [42]. Thanks to the State buckle-up laws and changes in accident report forms and record systems, information on the performance of safety seats in accidents improved vastly during 1983-85. It has become possible to give a rigorous estimate rather than a "best guess" and, moreover, to gauge the year-to-year changes in effectiveness as the mix of correctly used and misused seats changed (Section 8.2). In the process, many of the discrepancies between the earlier studies are explained.

A second critical issue is the misuse of safety seats: how often they are misused and what the consequences are in crashes. Although Williams clearly indicated in his 1976 paper [85] that there was a serious misuse problem, the safety community did not give it their full attention until the 1983 SAE Child Injury and Restraint Conference highlighted by Shelness' presentation of survey results [76]. But there is more than one way to misuse a seat. Earlier studies concentrated on errors in anchoring seats with tethers and lap belts while not presenting data on errors in harnessing the child within the seat - or they focused on harnessing without data on anchoring. In fact, both sets of data elements need to be collected on each child in order to obtain accurate statistics on the frequency and extent of misuse. A 1984 survey conducted at Hardee's restaurants furnished those statistics [14]. This evaluation analyzes them and develops a taxonomy of the common misuse modes (Section 2.1). That sets the stage for the second half of the misuse issue: recognition that "misuse" is not a monolithic condition. Some modes of misuse are worse than others. It is necessary to calculate the injury risk associated with each common misuse mode and compare it to the risk for the correctly restrained and the unrestrained child. Only then will it be possible to know how much of the potential benefit of safety seats is lost because of various types of misuse - and that, it would seem, is what the safety community really wants to know about misused seats.

A third issue of wide interest is to compare the effectiveness of the major types of seats, when correctly used and, just as importantly, when their frequency of misuse is taken into consideration. It is important to know if any type of seat is failing to measure up to the others because its design is not crashworthy or because it is complicated or inconvenient to use correctly.

A fourth question is whether lap belts are effective crash protection in passenger cars for children under 5. It is especially relevant because most of the State buckle-up laws allow the use of lap belts in lieu of safety seats in some or all situations [84]. Yet there has been some doubt as to whether belts are effective at all, let alone how effective.

The fifth issue is the injury reduction obtained by moving an unrestrained child from the front seat to the back seat of a car. Earlier accident analyses showed substantially lower injury rates for back-seat occupants. But do the reductions reflect genuine differences in child protection or are they a consequence of extraneous factors? Also, what injury reduction is obtained by moving a restrained child from the front seat to the back seat of a car?

The goals of this evaluation are to examine the five preceding critical issues and, as a consequence, to estimate the number of lives saved by safety seats in each year from 1979 to 1984 (Section 8.4) and the number that could potentially be saved if seats were correctly used (Section 8.6).

Some other important questions are not addressed by the evaluation. The effectiveness of safety seats by crash mode (especially side impacts) will be covered in a follow-up study when appropriate accident data and laboratory test results become available. The evaluation does not study neck or abdominal injuries in detail, because appropriate instrumentation for child dummies had not been developed before 1984 to study these types of injuries. For the same reason, tests were not conducted with instrumented dummies larger or smaller than a three year old. These issues should be explored in the future because there is concern that certain types of safety seats, especially boosters with small shields, may have problems with abdominal loading and/or with larger and smaller dummies. (See, for example, the September 5, 1985 letter from W. L. Hall and other North Carolina researchers to NHTSA Docket 74-09-N17-018.) Although the study reviews the year-by-year increase in safety seat usage and compares usage in States with and without buckle-up laws (Section 2.2), it does not compare usage on a State by State basis or analyze what factors caused safety seat usage to be highest in certain States. Originally it was also intended to compare the effectiveness of safety seats meeting the dynamic test standard to those which were withdrawn from the market shortly before 1981, but samples of the latter could no longer be obtained during the sled testing described in Chapter 7. Finally, resources were not available for testing effectiveness of each current model of safety seats in each misuse mode; testing had to be limited to the most common models of the principal generic types of seats.

It is hoped that the evaluation, in addition to fulfilling review requirements of Executive Order 12291, will help the safety community by documenting the frequency and consequences of specific types of misuse and that it will encourage child passenger safety leaders by demonstrating the year-by-year gains in lives saved since 1979.

1.4 The child passenger safety problem: a statistical overview

A few statistics make it easier to understand the dimensions of the child passenger safety problem. In Section 8.4 it is estimated that nearly 750 child passengers aged 0-4 would have died each year in cars, light trucks or vans if restraint systems had not been available. In 1983, motor vehicle accidents were the number one killer of children in the 1-4 year age bracket [2], p.8. On the other hand, the motor vehicle occupant fatality rate per capita for children aged 0-4 was only one fourth as high as for persons older than 4 [42].

In addition to the fatalities, about 5000 children per year would have been hospitalized at least overnight and 100,000 would have had lesser injuries, had restraint systems not been available (see Section 8.5).

The nature of child passenger accident involvements and injuries is best seen by comparing distributions of child passengers with those of motor vehicle <u>passengers</u> older than 4. A principal difference between small children and older persons is that the children aged 0-4 are far more likely to use the back seat and/or the center positions of a car:

Percent Riding in	Age 0-4	Age 5+
Front right seat	28	75
Front center seat	9	2.5
Rear outboard seats	44	18
Rear center seat	19	4.5

The distributions are based on the 19 city restraint usage survey conducted in 1984 [26] and include restrained as well as unrestrained passengers in the traffic stream (not accident involved). Obviously, small children are more easily able to fit in the back seat and the center positions than adults. The increased use of the back seat enhances safety in frontal impacts; the center positions, in side impacts.

The remaining statistics deal with unrestrained, injured passengers. The percentage of fatally injured <u>passengers</u> who are ejected is close to 30 for both age groups:

	Age 0-4	Age 5+
Percent of psgr. fatals who were ejected	28	30

The statistics are based on 1975-84 FARS* (for the children) and 1984 FARS (for the older persons). Intuitively, small children should be more vulnerable to ejection because they are smaller projectiles; but that may

---

*All acronyms and abbreviations are spelled out in the "List of Abbreviations" near the beginning of this report.

have been mitigated by increased use of the back seat or because their smaller mass makes it harder for them to achieve the momentum needed to force open the door or break through a side window.

The distributions of unrestrained, hospitalized passengers with AIS 2 or greater injury [1], by vehicle impact site, are quite similar for small children and older persons:

Percent of AIS $\geq$ 2 Hospitalizations in	Age 0-4	Age 5+
Frontals	60	57
Side impacts	29	31
Rollovers	9	9
Rear impacts	2	2
Undercarriage impacts	--	1

The distribution for small children is based on NCSS, 1979-83 NASS, NCSS-NASS and RSEP data; for older persons, NCSS.

A clear difference, on the other hand, can be seen in the frequency at which various body regions are injured. Here are the distributions of individual AIS $\geq$ 2 injuries of hospitalized unrestrained passengers, based on the same data as the preceding table:

Percent of Serious Injuries	Age 0-4	Age 5+
Head, face, neck	56	36
Torso	17	39
Arms	7	9
Legs	20	16

The predominance of head injuries in small children is obviously associated with the large relative size of their heads. The high incidence of leg injuries, on the other hand, requires a different explanation, viz., that the interior geometry of motor vehicles is not designed for protecting the unrestrained legs of a toddler.

Finally, there are some noticeable differences in the injury sources of unrestrained small children and older persons. The distribution of injury sources, for the individual AIS $\geq$ 2 injuries of hospitalized passengers, is based on NCSS and 1981-83 NASS, for the small children, and NCSS alone, for the older persons:

Percent of Serious Injuries Due to Contact with	Age 0-4	Age 5+
Instrument panel	29	19
Front seatback	18	10
Glove compartment area	9	10
Side interior, armrests, etc.	9	16
Exterior to car	7	9
Windshield	5	10
Noncontact injury, other occs.	5	7
Broken glass	5	1
Console (transmission lever)	4	--
Other	9	18

The instrument panel is struck more often by small children than by adults because of children's small stature: they are liable to hit the panel with torso, head and legs. The front seatback is struck more often because small children are likelier to ride in the back seat than adults and contact the front seatback in frontal collisions. The instrument panel with glove compartment and the seatback account for 56 percent of serious injuries of children age 0-4, versus only 39 percent for older passengers.

Side interior surfaces are less likely injury sources for young children than for adults, probably because there is more room between a door and a child than between the door and an adult, especially if the child is in the center seat (which is rarely used by adults) - that makes it less likely that an intruding door structure will contact the child. Windshields are struck less often, of course, because they are too high up to be contacted by children in most cases. The relatively high number of child injuries involving the shift lever console is due to the large number of children in the center seating positions.

The primary function of child safety seats is to absorb impact loads and distribute them safely over the child's body while preventing the child from contacting the vehicle's interior components. The limits on HIC and chest deceleration prescribed in Standard 213 are aimed at assuring that safety seats will properly absorb impact energy and distribute the loads over the least vulnerable parts of a child's body. The limitations on head and knee excursion in the dynamic test of Standard 213 are aimed at preventing any serious injury-producing contact in a frontal crash up to 30 mph in an average sized car. (It is more difficult to avoid contacts in minicompact cars or in side impacts - see Section 3.3.) The misuse of a seat can increase the risk of noncontact injuries and at the same time reduce the range of crash situations where contact is avoided. Lap belts are capable of preventing contact with the vehicle if the child is small (age 2-3), but are associated with serious noncontact injuries in higher severity crashes. Moving an unrestrained child to the back seat does not prevent contact but at least shifts it from the instrument panel to the less hazardous front seatback.

A related function is to prevent ejection of the child from the vehicle. A correctly used safety seat and even many misused seats should achieve that goal. But if a seat is misused to the extent that a child becomes a projectile, it will not be useful for that purpose. A snugly worn lap belt ought to prevent ejection; moving an unrestrained child to the back seat, on the other hand, may be of no value in that regard.

A final safety function is to keep a small child away from the driver, limiting distractions from the driving task. Safety seats achieve that goal unless the child is able to climb out of them (e.g., if the harness is not fastened or if the child has learned to climb out of a shield type seat). Lap belts also accomplish it. An unrestrained child in the back seat, on the other hand, is not prevented from moving around to disturb the driver.

1.5 Evaluation data sources and their limitations

The evaluation has been seven years in the making. In 1978, a contract was awarded to analyze State accident data from New York, New Jersey and Idaho [47]. At that time, those were almost the only States which made a distinction between child seats and other restraint systems on their accident report forms [79] and which automated their files in a manner allowing statistical analysis. The contractor's report (1980) was the first statistical analysis of child seats per se based on State data and it showed significant injury reductions. Its limitations were: no confirmation of the validity of the safety seat usage reporting -- in fact, serious doubts about its validity; no distinction between correctly used and misused seats; no detailed injury data; and a mix of safety seat types and misuse modes that is different from today's. Furthermore, the New Jersey and Idaho sample sizes were too small for significant results on serious injuries. In short, the study produced effectiveness estimates that were lower "than expected" with no adequate explanation of why. A 1982 follow-up study by another contractor analyzed larger samples of New York and Maryland data and produced similar estimates, but with greater statistical precision [7]. These studies, reviewed in Chapter 3, accomplished as much as was possible with State data of the 1975-80 vintage.

The agency initiated a study in late 1979 that aimed for a validity check of safety seat usage reporting, distinction between correctly used and misused seats and more detailed injury information. Data were to be collected by personnel at medical facilities, but the original study design proved unworkable. The University of North Carolina took over the study in 1983-84 and found a way to collect similar data through telephone interviews [28]. Their data, as reviewed in Chapter 3, are especially useful for providing a comparison between police-reported and "actual" usage of restraint systems by children. They provided the "missing link" needed to explain the (larger) discrepancy between safety seat usage observed in surveys and reported in State accident data and the (much smaller) discrepancy between effectiveness estimates based on State data and actual effectiveness. On the other hand, the North Carolina data were not detailed enough on the misuse of seats and did not contain a large enough sample for meaningful effectiveness estimates by seat type or misuse mode.

In 1983, the agency contracted for 43 sled tests with 2-4 dummies per test in an effort to get at the heart of the problem: estimating the effectiveness of the major types of seats when correctly used and in their most common misuse modes [46]. These sled tests differed from earlier ones in that the sled buck was the entire passenger compartment of a mid-sized car, allowing the dummies to contact vehicle interior components as they would in real crashes; moreover, unrestrained dummies were included in the tests and the injuries with restraints were compared to the unrestrained; the tests were carried out over a wide range of speeds. Unrestrained injury data from the agency's accident files were used to calibrate the biomechanical model (dummy response vs. injury risk). The results for the various seat types/misuse modes were weighted by their frequency of occurrence in an observational survey to obtain average overall effectiveness. The effectiveness estimate obtained from the sled tests closely matched the estimates obtained from accident data. The sled tests, described in Chapter 7 and Appendices 1-4, were the basis for the evaluation's effectiveness estimates for correctly used seats and misused seats (although a Tennessee fatal accident study [24] provided a supplementary estimate for correctly used seats).

The sled tests of Chapter 7 used a sled buck which was the passenger compartment of a specific mid-sized car and relatively "soft" deceleration pulses simulating barrier impacts of that car. Only one popular brand of safety seat from each of four generic types was tested. It was desired to examine the possible effects of using a smaller car as the sled buck, or a more severe deceleration pulse, or a different choice of safety seat models. The agency's Standard 213 compliance tests for 1981-84 included 110 frontal tests at 27.5 mph with correctly used seats and a sled pulse substantially higher than the one used in Chapter 7. Virtually every model of safety seat on the market was tested at least once. They also included 30 tests at 18.5 mph in three specific misuse modes. These data (Section 3.4) complemented the sled tests of Chapter 7 in that they showed how various types of seats performed differently with a harsher deceleration pulse. They also showed that different make/models of seats of the same generic type had about the same performance.

The sled tests of Chapter 7 were limited to frontal and oblique-frontal impacts with 3-year-old dummies. The compliance tests were even further limited to frontal impacts at a single speed and they, of course, did not include tests with unrestrained dummies. When appropriate instrumentation is developed, the agency plans to conduct side impact tests (including a simulation of the intruding door structure)--a crash mode where considerably less is known about the performance of safety seats. Afterwards, the testing will be extended to 6 month old dummies in infant seats--correctly used and in the most common misuse modes. Finally, the agency may conduct similar tests with subteen dummies in booster seats and the vehicle's belt systems. Other limitations of the sled test approach of Chapter 7 were: only head and torso injuries were considered; the procedure generates estimates of serious injury reduction, but it does not generate estimates of fatality reduction. Additional caveats are noted in Appendix 1.

The designers of NHTSA's Fatal Accident Reporting System (FARS) included safety seats as a distinct category of restraint system usage from the start (1975). But FARS is only as good as the quality of the State data it is based on--and most States began distinguishing safety seats from belts circa 1980. Pre-1980 FARS data could not be used for evaluating safety seats. On the other hand, the 1980-84 FARS files were excellent for estimating overall fatality reduction (Chapter 4). Like other accident data, FARS makes no distinction between correctly used and misused seats.

The agency's National Accident Sampling System (NASS) for 1979-83, in combination with the earlier National Crash Severity Study and Restraint System Evaluation Project contained just enough cases of children in safety seats for a statistically meaningful estimate of serious injury reduction (Chapter 6). In earlier years, the sample size would have been too small. This evaluation, then, contains the first significant results on safety seats from the agency's files. Of course, the sample size is still far too small to classify effectiveness by crash mode, seat type, or misuse mode.

The agency has received and automated several States' accident data bases and, of those, Pennsylvania was exceptionally useful because of its sample size, data quality and injury coding system. It was possible to calculate effectiveness for some specific injury types as well as overall (Chapter 5). The principal limitation of the Pennsylvania data was the small number of serious injury cases.

The agency has also sponsored 5 observational surveys of restraint system usage since 1979 and these data are extensively analyzed in Chapter 2. A 1984 survey conducted at Hardee's restaurants provided, for each observed safety seat user, a full description of how the tether, harness, shield and the car's lap belt were used and the direction in which the seat was facing. That unique file made it possible to classify the frequency of misuse by seat type. The Hardee's survey, however, is only representative of 1984 and does not provide statistics on overall use vs. nonuse of seats. The other 4 NHTSA surveys provide statistics on overall use from 1979 through 1984 and, with some interpretation, the frequency of certain types of misuse. Interpretation is needed since the definition of misuse varied slightly from survey to survey. Chapter 2 includes a procedure for inferring, from the 5 surveys, the frequencies of the various types of misuse during 1979-84, on a year-to-year basis. The changes in the frequency of misuse are important, because they change overall average effectiveness.

Each of the many data sources used in this evaluation has its own shortcomings but the sources complement one another well and produce remarkably consistent results. Chapter 8 shows that the effectiveness estimates from the accident data are almost identical to those derived from the sled tests in combination with the usage surveys -- after the accident analyses are corrected for the safety seat usage reporting biases discovered in the North Carolina study.

1.6 Classification of safety seat types and misuse modes

One of the first analytic tasks of the evaluation is to classify the many safety seats on the market into a manageable number of generic "types." The various makes and models considered to be of the same type should resemble one another in:

- The way they are correctly used
- The ways in which they can potentially be misused
- The frequency of correct use and the various misuse modes, on the road
- The effectiveness/performance characteristics, with correct use
- The effectiveness/performance characteristics in the various misuse modes

Ten generic types of safety seats were defined. They are listed in Table 1-1, together with the list of make/models included with each type and the instruction for correct use of that type of seat. The list of make/models comprises those encountered in the 1984 "Child Safety Seat Identification Guide" [9]. It includes seats produced in 1984 or discontinued before 1984 but still widely seen on the road. Other seats, for the most part, would readily fit in one of the ten types since the taxonomy in Table 1-1 is really quite straightforward. The distinctions between types are based on differences in one or more of the following attributes:

- o Forward facing toddler seat vs. rearward facing infant seat vs. booster chair
- o Tether required vs. tether not required
- o Car's belt around child and seat vs. through the seat only
- o Upper body restraint by harness vs. shield vs. car's shoulder belt
- o Harness connects to partial shield vs. unconnected/no shield

Theoretically, those attributes allow 3x2x2x3x2=72 combinations but, in fact, only the 10 types listed in Table 1-1 are found in the marketplace.

Only a few words of explanation are in order. "Infant" seats are to be used facing backwards and "toddler" seats, forward. "Booster" seats also face forwards but are readily distinguished from "toddler" seats because the former, in almost all cases, have no seatback, no self-contained harness (their tether harness attaches to the vehicle) and a higher limit for the size of the child. Many seats are "convertible" infant/toddler types: throughout this evaluation, as well as in Table 1-1, they are

TABLE 1-1

TYPES OF CHILD SEATS

Seat Type	Brands Included	How to Use Correctly
A. SAFETY SEATS FOR TODDLERS (plus convertible infant/toddler seats, when used by children aged 1 or more)		
TETHERED	Strolee Wee Care 500 series (e.g., 597, 599) Bobby Mac Super 814	Tether to rear seat belt (if used in front seat); to anchorage point (if used in back seat). Car's lap belt through designated permanent route, high on the tubular frame. Harness around child. Armrest optional.
TETHERED BELT-AROUND	GM/Century Child Love Seat	Tether to rear seat belt (if used in front seat); to anchorage point (if used in back seat). Harness around child. Car's lap belt around child and seat, each time seat is used.
TETHERLESS BELT-AROUND	Most Bobby Mac seats* Welsh Travel Tot, 989, 7809 Kolcraft Hi-Rider 1903	Harness around child. Shield placed around child, each time seat is used. Car's lap belt around shield, child and seat, each time seat is used.

* Some of these seats come with optional tethers, which are rarely used and which are not required for meeting Standard 213.

TABLE 1-1 (continued)

Seat Type	Brands Included	How to Use Correctly
TETHERLESS-HARNESS ONLY	Century 100, 300 Cosco/Peterson Safe & Easy*, Safe-T-Seat* Questor Care Seat, Safe Guard* Strolee Wee Care 600 series *,** Kolcraft Hi-Rider 17330 Teddy Tot Astroseat 9100 Graco Little Trav'ler Welsh Travel Tot 368 Pride Ride 830*	Car's lap belt through designated permanent route, high on tubular frame or plastic shell. Harness around child. Armrest (which is sometimes called a "partial shield") optional.
TETHERLESS-PARTIAL SHIELD	Century 200, 400XL Cosco/Peterson Safe & Snug, Safe-T-Mate Questor One Step* Kolcraft Redi-Rider Collier-Keyworth Roundtripper, Safe & Sound Nissan Child Safety Seat Welsh Travel Tot 369 Pride Ride 820* Teddy Tot Astroseat 9300 Strolee Wee Care 618	Car's lap belt through designated permanent route high on tubular frame or plastic shell. Harness, partial shield form an integral unit which fastens around child in one step.

* Some of these seats come with optional tethers, which are rarely used and which are not required for meeting Standard 213

** A small proportion of these seats have a true partial shield (harness pad)

TABLE 1-1 (continued)

Seat Type	Brands Included	How to Use Correctly
TETHERLESS-FULL SHIELD	Cosco/Peterson Safe-T-Shield Kolcraft Quikstep	Car's lap belt through designated permanent route, high on tubular frame or plastic shell. Shield snaps into place around child. Harness not needed in forward-facing use. Seat has high back and side panels.
SHIELD-BOOSTER	Collier-Keyworth Co-Pilot*** Century Commander Cosco/Peterson Explorer I Kolcraft Tot-Rider Quikstep Bobby Mac Wings***	Small shield snaps or swings into place around child. Car's lap belt around shield, child and seat, each time seat is used.
	Ford Tot Guard Mopar Child Seat	Large shield permanently in place. Car's lap belt permanently routed around shield. Slide the child in behind the shield.
		Both kinds have no harness, low seatback: not for infants.
BOOSTER	Century Safe-T-Rider Cosco/Peterson Travel Hi-Lo Teddy Tot Astrorider Kolcraft Tot Rider XL Strolee Wee Care Booster Seat	Car's lap and shoulder belt around child and seat, through belt guides, each time seat is used. If no shoulder belt - car's lap belt around child and seat, tether harness snaps around lap belt and into anchorage point.

*** Not recommended for children weighing less than 30/35 pounds

TABLE 1-1 (concluded)

Seat Type	Brands Included	How to Use Correctly
B. SAFETY SEATS FOR INFANTS (plus convertible infant/toddler seats, when used by infants aged less than 1)		
INFANT BELT-AROUND	GM/Century Infant Love Seat Questor Dyn-O-Mite, Care Seat Bobby Mac Deluxe II, Champion, Baby Chair Kolcraft Hi-Rider XL, Redi-Rider Graco Little Trav'ler Collier-Keyworth Cuddle Shuttle Nissan Child Safety Seat	Seat faces <u>rearwards</u>. Harness around child. Car's lap belt <u>around</u> child and seat, each time seat is used.
INFANT (Belt thru Frame)	Century 100,200,300 Cosco/Peterson First Ride, Safe & Easy, Safe-T-Shield, Safe-T-Seat, Safe & Snug, Safety Shell, Safety-T-Mate Questor One-Step Strolee Wee Care 500, 600 series Kolcraft Quikstep Teddy Tot Astroseat Welsh Travel Tot Collier-Keyworth Safe & Sound Pride Ride	Seat faces <u>rearwards</u>. Car's lap belt through designated permanent route near front of tubular structure. Harness around child.
C. "HOME CHILD CARRIERS USED AS CAR SEATS"		
	Child carriers/chairs not intended for automotive use Feeder seats Car beds not designed to meet Standard 213 Pre-1971 hookover seats	

Note: The Rose Little Rider Harness is a distinct type of safety device meeting Standard 213-71; it has not been included in the preceding table because few if any are still in use.

classified as "toddler" seats when used by children age 1 or over and "infant" seats when used by children aged less then 1. Thus, each of these seats is listed twice in Table 1-1.

The first two types, comprising seats requiring a tether, does not include models which come with an "optional" tether which is, in fact, infrequently used and not strictly needed for meeting Standard 213.

The "tetherless-partial shield" type, as defined in Table 1-1, includes only those partial shields that are connected to the harness, forming an integral unit that fastens around the child in one step. Other "partial shields," where the harness must be independently buckled to fully protect the child, are considered as if they were merely armrests and the seat is included in the "tetherless-harness only" type. (In fact, a few of those partial shields may offer a fair amount of protection without the harness, but as long as the manufacturer defines "correct" use to include the harness, the seat is classified in the "harness only" type.)

Conversely, some of the "tetherless-full shield" seats include harnesses intended for use only in the rearward facing mode but occasionally used in the forward facing mode. Since the manufacturer states that "correct" forward-facing use is without the harness, they are considered to have full rather than partial shields.

The Ford Tot Guard and Mopar Child Seat are rarely seen on the road (less than 1 percent of seats in 1984). For that reason, they were grouped with some more common models to whom they bear greater resemblance than to any others. Together, they comprise the "shield booster" type.

The relative frequencies of the 10 types on the road during 1984 are shown in Table 2-2 and, with a more detailed classification of misuse modes, in Table 2-1.

In addition to safety seats, the evaluation frequently discusses "home child carriers used as car seats." They are not covered by and cannot meet Standard 213-71 (the static test standard). They included feeder seats or chairs which are not intended for automotive use but for propping up the baby or child at home, in public places, etc. "Car beds" or other bassinets not designed to meet Standard 213 are included. These devices are often counted as "child seats" in the evaluation for the simple reason that most of the accident and observational data likewise count them among the "safety seat users" and do not identify them as a separate category. Essentially, a "home child carrier" is a seat which is not intended to hold a child in place during a crash and/or cannot be safely anchored within the car by a lap belt. For that reason, pre-1971 "hookover" car seats (which must be extremely rare by now) are counted with the home child carriers. On the other hand, safety seats meeting Standard 213-71 but withdrawn from the market prior to the 1981 dynamic test requirement (these, too, had become extremely rare by 1984) are not counted here but would be classified among the preceding types of safety seats.

Chapter 2 describes the ways that each type of seat can be correctly used or misused. But all use modes can be classified into three basic categories, which are employed throughout this evaluation.

Correct users are children whose safety seat is being used exactly as recommended by the manufacturer or close enough to the recommended method that there would not appear to be a significant loss of safety benefits --e.g., using a "tetherless-harness only" seat without the partial shield/armrest. Table 2-1 lists, for each type of seat, the use modes that can still be called "correct" use.

Partial misusers are children whose safety seat is misused to the extent that a significant reduction of effectiveness is expected (relative to correct use) but can still expect substantial benefits from the seat if the crash is not too severe. In any partial misuse mode, there is something holding the child in the seat and something anchoring the seat within the vehicle. The dangers of partial misuse are that the child will have more excursion or loading than with correct use and/or the seat will fail in a severe crash because forces are transmitted to the "wrong" part of the seat. Typical causes of partial misuse are nonuse of the tether, misrouting of the lap belt and carrying an infant in the forward-facing mode. Table 2-1 lists the partial misuse modes associated with each type of seat.

Gross misusers are children who would certainly or at least very likely be thrown from their seats or remain attached to their seats but become projectiles because their seats are not anchored within the vehicle. There is an obvious, qualitative difference between partial and gross misuse --the latter is essentially an unrestrained condition while the former is not. For that reason, throughout this study, a distinction is made between partial and gross misusers--in the compilation of usage statistics, the estimation of effectiveness, and the examination of biases in accident data files. Monolithic statistics on "misuse" are meaningless without such a distinction. For example, the Hardee's survey showed that the GM Love Seat is "misused" an alarming 85 percent of the time [14], p.65--but it is still an effective seat because only 3 percent of the misusers are gross misusers (see Table 2-1). The proper taxonomy of misuse modes is at the heart of the evaluation of safety seats.

CHAPTER 2

USE AND MISUSE OF SAFETY SEATS IN THE UNITED STATES

During the summer of 1984, NHTSA sponsored a unique survey of child safety seat users, which was conducted in parking lots of Hardee's restaurants. Through a combination of observational and interview data, the investigators were able to determine accurately the make/model of the seat, the status of the tether, harness, lap belt, etc. With those detailed data, it became possible to determine that 40 percent of safety seats were correctly used in 1984; 40 percent were partially misused, providing children some restraint but significantly less than a correctly used seat; 20 percent were grossly misused, leaving a child essentially unprotected.

Other surveys never offered a comparable amount of detail but they did measure the overall use of safety seats. It has increased steadily, from 15 percent of child passengers in 1979 to 46 percent in 1984. From the Hardee's statistics, sales data on child seats, and the earlier surveys it is possible to piece together the extent to which seats were correctly used in previous years. Since 1979, the percentage of seats used correctly has increased from 20 to 40 while gross misuse decreased from 50 to 20 percent. Thus, the threefold increase in overall usage (from 15 to 46 percent of child passengers) has been accompanied by an even more gratifying sixfold increase in correct usage (from 3 to 18 percent of child passengers).

2.1 The Hardee's survey of safety seat users (1984)

Earlier surveys were of two types: (1) Occupied cars were briefly observed at a stop light, allowing time to record use/nonuse of the harness and, perhaps the car's lap belts, but not the make/model of seat, the use of the tether and the correctness of lap belt routing. (2) Unoccupied cars were observed in parking lots, allowing detailed observation of the tether, lap belt routing, and the make/model of seat but not, of course, the usage of the harness (or even the lap belt, if it was supposed to go around the child). Unfortunately, a conclusive verdict on the correctness of safety seat usage cannot be accomplished without simultaneous knowledge of the make/model of seat, the status of the harness, tether and lap belt, the age of the child and the direction in which the seat was facing. The Hardee's survey provides all of those items.

2.1.1 Procedure

As described by Cynecki and Goryl, the contractor (Goodell-Grivas, Inc.) selected 10 metropolitan areas in the East, South, Midwest and Southwest, each of which had at least 5 Hardee's restaurants [14], pp. 10-12. Data were collected at 4 to 7 restaurants in each city. With the cooperation of Hardee's, Inc., and permission of restaurant managers and customers, the investigators Kavanaugh and Brunett observed the safety seat usage and interviewed the drivers, usually while they were waiting in the drive-through lane. The observation portion of the survey included a detailed description of harness, lap belt and tether status and the direction in which the seat was facing. The interview portion included questions about the make/model of the seat (this information undoubtedly had to be supplemented in many cases by the investigator's observation), the age of the child, the adult's reasons for choosing the seat, knowledge of how it should be used correctly, etc. [14], pp. 59-64. Data were collected at lunch and suppertime on Tuesday through Saturday. There were 1006 cases of safety seats occupied by children [14], pp. 13-15.

The contractor's report did not use the categorization of safety seats established in Table 1-1 nor the terminology of "partial" versus "gross" misuse as defined in Section 1.6. Therefore, the raw data were acquired and reanalyzed in preparing this evaluation.

2.1.2 Results

The occupied seats were classified by make, model and general type (toddler, booster or infant) into the 10 categories defined in Table 1-1. Within each of the categories the children were classified, where applicable, by the status of the lap belt, harness, shield, tether and the direction in which the seat was facing. The various combinations were then grouped, as shown in Table 2-1, among "correct" users, partial misusers and gross misusers of safety seats. A total of 957 cases are used in Table 2-1; 49 of the 1006 cases in the contractor's report were discarded because the seat make/model was unknown or the lap belt/harness usage was unknown or ambiguously coded.

For example, the tethered type seat was observed, with all variables appropriately documented, 161 times in the survey. In 10 of those 161 cases, the seat was used exactly as recommended by the manufacturer: the tether attached to the rear lap belt/tether anchorage, correctly routed and tight, the harness fully attached and snug over the child's shoulders and the lap belt through the proper route on the tubular frame. There were 4

TABLE 2-1

1984 MIX OF SAFETY SEAT USE MODES
BY SAFETY SEAT TYPE (ACTUAL COUNTS FROM
HARDEE'S SURVEY)

	U S A G E O F			
	Tether	Harness	Lap Belt	N of Observations
T E T H E R E D S E A T S (belt through frame)				
	Correct	Correct	Correct	10
	Correct	Correct	Too low	3
	Correct	Not over shoulders*	Too low	1
				--
			"CORRECT" USERS	14
	Not used	Correct	Correct	57
	Not used	Not over shoulders*	Correct	12
	Not used	Harness but no armrest	Correct	4
	Not used	Correct	Too low	10
	Not used	Correct	Around child	1
	Not used	Not over shoulders*	Too low	3
	Not used	Harness but no armrest	Too low	1
	Correct	Correct	Around base	3
	Not used	Not used	Around child	2
				--
			PARTIAL MISUSERS	93
	Correct	Not used	Correct	2
	Correct	Not used	Not used	2
	Not used	Correct/not over shoulders	Not used	12
	Not used	Not used/armrest only	Correct/too low	20
	Not used	Not used/armrest only	Not used	17
	Not used	Unknown	Not used	1
				--
			GROSS MISUSERS	54

*Around torso but too loose to stay on shoulders

TABLE 2-1 (continued)

Tether	Harness	Lap Belt	N of Observations
TETHERED BELT-AROUND SEATS			
Correct	Correct	Correct	5
Correct	Not over shoulders*	Correct	1
			--
		"CORRECT" USERS	6
Not used	Correct	Correct	8
Not used	Not over shoulders*	Correct	3
Correct	Not used	Correct	2
Not used	Not used	Correct	13
			--
		PARTIAL MISUSERS	26
Not used	Not used	Not used	1
			--
		GROSS MISUSERS	1

Harness	Shield	Lap Belt	N of Observations
TETHERLESS BELT-AROUND SEATS			
Correct	Correct	Correct	9
Not over shoulders*	Correct	Correct	1
			--
		"CORRECT" USERS	10
Correct	Not used	Around child	19
Not over shoulders*	Not used	Around child	1
Not used	Correct	Correct	1
Not used	Not used	Around child	42

		PARTIAL MISUSERS	63
Correct	Not used	Not used	6
Not used	Not used	Not used/around base	6
			--
		GROSS MISUSERS	12

*Around torso but too loose to stay over shoulders

TABLE 2-1 (continued)

USAGE OF Harness	Lap Belt	N of Observations
TETHERLESS SEATS (HARNESS ONLY)		
Correct	Correct	71
Harness but no armrest	Correct	13
Not over shoulders*	Correct	9
		--
	"CORRECT USERS"	93
Correct	Too low	15
Harness but no armrest	Too low	6
Not over shoulders*	Too low	9
Correct	Around child	2
Not used/armrest only	Around child	5
		--
	PARTIAL MISUSERS	37
Correct/not over shoulders	Not used/around base	10
Not used/armrest only	Correct/too low	29
Not used	Not used	6
		--
	GROSS MISUSERS	45
TETHERLESS SEATS (PARTIAL SHIELD)		
Correct	Correct	100
Not over shoulders*	Correct	6

	"CORRECT" USERS	106
Correct	Too low	47
Not over shoulders*	Too low	4
Harness but no "shield"	Too low	1
"Shield" but no harness	Around child	1
Not used	Around child	3
		--
	PARTIAL MISUSERS	56

*Around torso but too loose to stay over shoulders

TABLE 2-1 (continued)

USAGE OF Harness	Lap Belt	N of Observations
Correct	Not used/around base	14
"Shield" but no harness	Correct/too low	3
Not used	Correct/too low	10
Not used	Not used	1
		--
	GROSS MISUSERS	28

USAGE OF Shield	Optional Harness	Lap Belt	N of Observations
TETHERLESS SEATS (FULL SHIELD)			
Correct	Not used	Correct	11
Not used	Correct	Correct	2
			--
		"CORRECT" USERS	13
Correct	Not used	Too low	2
Not used	Correct	Too low	1
Not used	Not used	Around child	1
			--
		PARTIAL MISUSERS	4

USAGE OF Shield	Lap Belt		N of Observations
SHIELD-BOOSTER SEATS			
Correct	Correct		35
			--
		CORRECT USERS	35
Not used	Around child (above the seat)		4
			--
		GROSS MISUSERS	4

TABLE 2-1 (continued)

	USAGE OF			
	Tether Harness	Shoulder Belt	Lap Belt	N of Observations
BOOSTER SEATS				
	Correct	Not available	Correct	10
	Not applicable	Correct	Correct	36
				--
			CORRECT USERS	46
	Not used	Not available	Correct	40
	Not applicable	Behind child	Correct	13
				--
			PARTIAL MISUSERS	53
	Not used/n.a.	Not used/n.a.	Not used	17
				--
			GROSS MISUSERS	17

	USAGE OF			
	Harness	Lap Belt	Seat Facing	N of Observations
INFANT BELT-AROUND SEATS				
	Correct	Correct	Rearward	39
				--
			CORRECT USERS	39
	Not used	Around child	Rearward	22
	Correct	Around child	Forward	15
	Not over shoulders*	Around child	Forward	1
	Not used	Around child	Forward	7
				--
			PARTIAL MISUSERS	45
	Correct	Not used	Rearward	1
	Not used	Not used	Rearward	6
	Not used	Not used	Forward	3
				--
			GROSS MISUSERS	10

*Around torso but too loose to stay over shoulders

TABLE 2-1 (Concluded)

U S A G E O F

Harness	Lap Belt	Seat Facing	N of Observations
I N F A N T S E A T S (Belt Through Frame)			
Correct	Correct	Rearward	19
Not over shoulders*	Correct	Rearward	2
			--
		"CORRECT" USERS	21
Correct	Too low	Rearward	3
Not over shoulders*	Too low	Rearward	1
Correct	Correct (for toddler)	Forward	11
Correct	Too low (for toddler)	Forward	5
Not over shoulders*	Too low (for toddler)	Forward	1
			--
		PARTIAL MISUSERS	21
Correct	Not used	Rearward	1
Correct	Not used	Forward	2
Not used	Correct	Rearward	1
Not used	Not used	Forward	1
			--
		GROSS MISUSERS	5

*Around torso but too loose to stay over shoulders

more cases where the manufacturer's instructions were not correctly followed but they were still considered "correct" usage because the loss of effectiveness was believed to be small. The lap belt was routed too low on the tubular frame; however, when the tether is correctly attached, the incorrect routing would not be expected to have the adverse consequences (seen in the sled tests of Chapter 7) that would occur without a tether. Also, in one case, the harness was over the child's chest rather that the shoulders. But since it was otherwise correctly attached, it was still felt to provide satisfactory upper-body restraint. Thus, 14 of the 161 users of tethered seats (as defined in Section 1.6.) could be considered correct users.

There were 93 partial misusers of tethered seats. The 10 tether-harness-lap belt combinations included in Table 2-1 among the partial misusers were further classified into 4 subgroups, as indicated by the blank lines. In the first subgroup, everything was correct or almost correct except the tether, which was not used (73 children). That is considerably less protective than correct use, but probably the best of the misuse modes. The second subgroup left off the tether and additionally misrouted the lap belt - too low through the tubular structure or around the child and the seat (15 children). That would tend to allow the seat to tip over even further than would occur in the preceding subgroup. In the third subgroup, the tether and harness were on but the lap belt was routed around the base of the seat (3 children). Without the tether, the lap belt would have difficulty holding the seat (i.e., gross misuse) but with the tether, the seat should stay in place. In the fourth subgroup, the tether and harness were not used and the lap belt was routed around the child and the seat (2 children). That is not a gross misuse because the lap belt should hold the child and seat in place. But it is an inferior partial misuse mode since it provides no upper body restraint.

There were 54 gross misusers of tethered seats. Essentially, there were 13 children who used the harness but not the lap belt, 22 who used the lap belt (through the tubular frame) but not the harness, and 19 who used neither.

The categorization of the 33 children in tethered belt-around seats was simpler. There were 6 children who used the tether, harness and lap belt correctly or almost correctly. The 26 partial misusers included two subgroups: 11 who used everything except the tether; 15 who did not use the harness but were at least partially protected because the lap belt was around them and the seat (the correct routing). The main advantage of belt-around seats, in fact, is that children derive some protection as long the lap belt is properly attached. Only 1 child was in a grossly misused seat.

The categorization of tetherless belt-around seats depends on the use of the harness, the lap belt and the detachable shield. There were 85 children in those seats. Ten of them used all three items correctly or almost correctly. The 63 partial misusers comprised two subgroups. The first consisted of 20 cases where the harness was used correctly and the lap belt was routed around the child without using the detachable shield. That is probably a quite protective use mode which could even be contemplated for inclusion with the "correct" users; however, it was classified as a partial misuse because the seat is designed to rely on the shield for working with the lap belt to keep the seat firmly in place. (It has no lap belt guides in the absence of the shield.) The second subgroup, clearly less well protected, consists of 43 children who were not harnessed but had the lap belt around them (almost always without the shield). There were 12 gross misusers.

The tetherless seats with only a harness (and perhaps a separate armrest or "partial shield," primarily for comfort - see Table 1-1, "tetherless harness only" types) and lap belt routing through the tubular structure just had two critical safety items for parents to adjust: the harness and the lap belt. Among the 175 children in those seats, 93 were "correctly" restrained because both items were used properly or almost so. The 37 partial misusers had two subgroups: The vast majority (32) had the harness on correctly but the lap belt misrouted, almost always too low on the tubular structure. It would allow the seat to tip over further than a properly used one. The other subgroup (5 children) were not harnessed but had the lap belt around themselves and the seat. It is not a gross misuse but it is not a desirable way to use this type of seat, which has no guides for the lap belt in the front. The 45 gross misusers included 10 with a harness but no lap belt, 29 with a lap belt but no harness and 6 with neither.

The tetherless seats with an integral partial shield/harness (as defined in Table 1-1), whose purpose is to make it easier for parents to use the harness, had the same groupings as the preceding type, but with a lower rate of gross misuse. Among 190 children, 106 used the seat properly. There were 52 partial misusers who were correctly harnessed but their lap belt was routed too low; 4 partial misusers had no harness but the belt was around them and the seat. Among the 28 gross misusers, 14 had the harness but no lap belt, 13 the lap belt but no harness and 1, neither; the last two numbers (i.e., those without a harness) are much lower than the preceding case, showing that the integral partial shield accomplished its purpose. In Table 2-1 it is assumed throughout that the partial shield, without the harness, cannot be counted on to keep the child in the seat and should be considered equivalent to "harness not used." That may be a pessimistic assumption.

There were 17 children in seats with full shields (as defined in Section 1.6, not in the Goodell-Grivas report [14]). None of those easy-to-use seats was grossly misused. The category is unique in that there are two distinct subgroups of "correct" users. That is because some of the seats came with an optional harness. If parents used the harness instead of the shield, they did something distinctly different from the recommended procedure but they were protecting their child well. Thus, out of 13 "correct" users, there were 11 who correctly used the shield and the lap belt and 2 who used harness and lap belt. The 4 partial misusers belonged to 3 subgroups: shield correctly used, but lap belt too low on the tubular structure; harness correctly used, but lap belt too low; no shield or harness, but belt around the child and seat.

The shield-booster seat (as defined in Section 1.6) was also easy to use. Out of 39 cases, 35 parents properly attached the shield and routed the lap belt around child and seat, beneath the shield. In the remaining 4 cases, the shield was not attached to the booster cushion. The child sat on the cushion and the lap belt was routed around the child. The cases were classified as gross misuse, even though the child would be held in place by the belt. The belt, however, would not hold the booster cushion in place (it has no guides for the lap belt) and could ride up on the child's body, with undesirable effects. There was not a single case of outright nonuse of the lap belt.

The conventional booster seat requires proper usage of the vehicle's lap belt; also the vehicle's shoulder belt or the tether harness that comes with the seat. The last two items are mutually exclusive and are believed to provide approximately equivalent protection. Among 116 children, 46 were using the booster seat correctly: 10 with the tether harness (in the back seat) and 36 with the lap and shoulder belt (in the front seat, or in the back seat of a Honda Accord or Volvo). There were 53 partial misusers who had the lap belt on properly but the shoulder belt routed behind them/unavailable and no tether harness. Unlike the shield-booster type, this is not a gross misuse: the conventional booster seat has guides for the lap belt and will stay in place, restraining, at least, the lower part of the child's body. There were 17 cases of gross misuse, where neither the vehicles' belts nor the tether harness were used to keep child and seat in place.

Cynecki and Goryl classified as "infant seats" any device that is recommended only for use by infants under age 1 plus any convertible (infant/toddler) seat that was being used by a child under age 1. The correct use of an infant seat requires 3 items: the seat must be installed facing rearward, the lap belt must be routed correctly and the harness used.

There were 94 children in belt-around infant seats; 39 were correctly restrained. The 45 partial misusers included three distinct subgroups. There were 22 babies in rearward facing seats, correctly belted but not harnessed. Since the belt goes around the child and the seat, it may keep the child in place during lower-level crashes even without a harness. So this is not a gross misuse even though it is certainly an undesirable way to use the seat. There were 16 cases in which the seat was installed facing forward and the harness and lap belt were used: another partial misuse, since the baby will stay in the seat but be exposed to undesirable harness and belt forces in a frontal crash. Even moderate frontal accelerations can be dangerous for small babies. The worst subgroup of partial misusers had the seat facing forward, the belt around child and seat, and no harness (7 children). There were 10 gross misusers, all without the lap belt, most also omitting the harness and/or facing in the wrong direction.

Infants seats requiring the lap belt to be routed through the tubular frame occurred 47 times. Almost all of them were convertible infant/toddler seats being used by infants. In 21 cases, all three items were correct, or nearly so. The 21 partial misusers split into 3 subgroups: 4 infants faced rearward and were correctly harnessed, but the lap belt was routed incorrectly on the tubular frame; 11 cases where the occupant was a baby but the seat was being used in the forward-facing toddler position, albeit correctly; 6 cases where the seat was used in the toddler position and, moreover, the lap belt routed too low. The 5 gross misusers included cases where the harness was not used, or the lap belt, or both.

2.1.3 Summary and discussion

Table 2-2 shows that about 40 percent of child safety seats (i.e., 383 out of 957) were used "correctly" in 1984 - i.e. exactly according to manufacturers' specifications or close enough that the child got most of the protection afforded by the seat. Another 40 percent were partially misused (398 out of 957), giving children some restraint and protection but significantly less than in a correct use mode. The remaining 20 percent (176 out of 957) were grossly misused: the child would be thrown from the seat in a crash or the child and seat would become projectiles in the car.

There were large differences among seat types as to the extent of correct usage. The tethered and tethered belt-around seats as well as the tetherless belt-around seat with detachable shield had the lowest rates of correct usage by far -- barely over 10 percent according to the top section of Table 2-2. The tetherless seats with lap belt routing through the frame all had over 50 percent correct usage (second section of Table 2-2). Moreover, gross misuse declined sharply in response to convenience features such as the integral partial shield/harness and the full shield.

The two types of booster seats had quite different usage patterns. The shield-booster type was almost always correctly used, but the conventional booster less than half of the time. Still, the conventional, tether-equipped booster seat was far more often correctly used than the tether-equipped toddler seats (because the booster seat offers a choice of using the car's three-point belt or the tether harness). Gross misuse was relatively uncommon for both types. The two kinds of infant seats had similar distributions of correct use (close to 40 percent), partial misuse and gross misuse.

TABLE 2-2

1984 MIX OF SAFETY SEAT USE MODES BY SAFETY SEAT TYPE - SUMMARY TABLE (ACTUAL COUNTS FROM HARDEE'S SURVEY)

Seat Type	Correct Users	Partial Misusers	Gross Misusers	Total
Tethered (belt through frame)	14	93	54	161
Tethered belt-around	6	26	1	33
Tetherless belt-around	10	63	12	85
SUBTOTAL	30	182	67	279
Tetherless-harness only	93	37	45	175
Tetherless-partial shield	106	56	28	190
Tetherless-full shield	13	4	0	17
SUBTOTAL	212	97	73	382
Shield-booster	35	0	4	39
Booster	46	53	17	116
SUBTOTAL	81	53	21	155
TOTAL: Children aged 1-4	323	332	161	816
Infant belt-around	39	45	10	94
Infant (belt through frame)	21	21	5	47
SUBTOTAL: Infants aged < 1	60	66	15	141
TOTAL: Children aged 0-4	383	398	176	957

Some other observations may be made about safety seat usage. One is that gross misuse was highest for seats with relatively cumbersome harnesses and with the belt routed through the tubular frame: the tethered type (34% gross misuse) and tetherless-harness only (26%).

Seats that required the lap belt to be reattached each time they are used (the three "belt-around" types and both types of booster seats) paradoxically had lower rates of misuse than the ones with one-time lap belt attachment. Parents seem to be willing to attach a lap belt repeatedly, as long as it is simple. Furthermore, the belt around the child has the advantage of partly compensating for a failure to use the harness, making that only a partial misuse. Also, it is generally difficult for parents to find the correct route through tubular structure, resulting in many partial misuses of the seats with one-time lap belt attachment.

The number of items that must be attached or adjusted seems to be as influential as the complexity of the items. Misuse was especially prevalent on the seats which required three items to be attached. On the tetherless belt-around seats, for example, half of the parents made their lives simple by dispensing with the harness and detachable shield.

Finally, two observations from the contractor's report should be reemphasized here. One is that the most frequent reason for nonuse of the harness (according to the parents) is that the children themselves disconnected it [14], p. 41. Perhaps buckle release pressures have been set too low in some cases. Another is that 78 percent of the booster seats were used by children age 4 or younger [14], p. 33. De facto, the booster seat is a device for protecting the young child even more so than the 5-12 year old child. Booster seats need to be designed to protect young as well as older children.

2.2 Overall safety seat usage in the traffic population, 1974-84

Between 1979 and 1984, the agency sponsored 4 surveys of restraint system usage by the child passenger population. They were based on observations of cars stopped at shopping mall exits in 19 metropolitan areas. Three shopping malls per area were selected in 1979, representing a range of socioeconomic environments. The same malls were used in each subsequent survey. Together with a 1974 survey by the Insurance Institute for Highway Safety, they provide a record of safety seat use during 1974-84.

What the five surveys do most accurately is measure the percentage of child passengers age 0-4 that are in some kind of seat. The brief time available for the observations limits the amount of additional detail. Nevertheless, the more recent surveys distinguish between automotive child safety seats meeting Standard 213 and home child carriers used as car seats (e.g., feeder seats or infant carriers); between seats which have the harness and lap belt attached (not necessarily correctly) and those which don't; between infant and toddler seats. They also provide estimates of how many children used the lap belt only: they may be underestimates because of the difficulty of seeing the lap belt in use.

The surveys are reviewed in reverse chronological order since the latest ones have the best data, which can be used to explain gaps in the earlier ones.

2.2.1 Goryl and Cynecki (1984)

The 18,366 observations of child passengers aged 0-4 were distributed as follows [26], Tables 37, 39, 41, 43, and 44:

	Infants	Toddlers	Toddlers in Booster Seats
Correctly used	565	----	152
Correctly harnessed	---	5518	---
Forward facing	147	----	---
Harness used-belt not used	150	----	---
Harness not used - belt used	24	----	196
Harness not used - belt unspec.	---	1455	---
No harness and no belt	79	----	51
Seat used - no details	26	87	10
Home child carrier	30	33	---
Lap belt only	7	1251	---
Unrestrained	465	8120	---

There were subtotals of 1493 infants and 16,873 toddlers. Counting only the children in safety seats or home child carriers, there were 1021 infants and 7502 toddlers. Over 99 percent of them were in automotive safety seats and under 1 percent in home child carriers.

The modes of safety seat usage in the preceding table do not correspond directly to the ones in Section 2.1, but there are some rough equivalences. If the observations above the first line are treated as a surrogate for "correct use or partial misuse" while the cases between the two lines are counted as "gross misuse," the percentages are very close to what was actually seen in the Hardee's survey (Table 2-1 and 2-2).

For example, the 5518 children in toddler seats described as "correctly harnessed" should include all cases of correct usage plus those partial misuses which involve not tethering and/or routing the belt too low. On the other hand, it includes some gross misusers (viz., the ones who used the harness but not the lap belt) while excluding some partial misusers (viz., those who did not use the harness but routed the lap belt around child and seat). Those two groups are fairly small and of similar size, cancelling each other out. Thus, the 1542 toddler cases between the first and second lines account for 22 percent of the 7060 users of toddler seats. That is very close to the 21 percent gross misuse of toddler seats in the Hardee's survey (first 7 seat types in Table 2-2, i.e. 144 out of 700 cases - the "shield-booster" type was considered a toddler seat, not a booster seat, by Goodell-Grivas).

The reporting of infant seat usage in the preceding table, at first glance, seems to have few ambiguities, since it spells out the use of the harness, the lap belt and the direction the seat was facing. On closer inspection, the 150 cases (15% of total) of "harness used - belt not used" are unrealistic, as only 3 percent of the Hardee's cases were in that mode (see Table 2-1). It is suspected that most of the 150 involved a convertible seat where the belt was (correctly) routed through the tubular structure and that the observers were not aware of that type of infant seat. Conversely, the 147 forward-facing seats may have been an underestimate, probably because the observers had no opportunity to determine the exact age of a child and tended to classify some of the infants in forward-facing seats as toddlers. The best strategy is to include "forward facing" and "harness used - belt not used" as surrogates for correct use/partial misuse and assume that the small number of cases where the belt really was not used are cancelled out by those in which the harness was not used and the belt routed around the child and seat. Indeed, the cases between the 2 lines accounted for 13 percent of the infant seat users, corresponding to the 11 percent gross misusage actually observed in the Hardee's survey (last section of Table 2-2).

The observations of booster seats seem to be thorough and valid. The 61 cases between the lines are 15 percent of the total, corresponding exactly to the 15 percent gross misuse of conventional booster seats in Table 2-2.

In summary, the 6728 cases above the first line account for 80 percent of the safety seat users and 36.6 percent of all passengers aged 0-4. They are equivalent to the proportion of children in correctly used or partially misused safety seats (which was 82 percent in the Hardee's survey, where there was a higher number of easy-to-use booster seats). The cases between the two lines account for 9.4 percent of all children and are equivalent to the proportion of grossly misused seats. Since 0.3 percent (66 cases) of children were in home child carriers used as car seats 46.3 percent of all child passengers were in some kind of child seat during 1984, as shown in Table 2-3 (49.3 percent during the last quarter of 1984). An additional 6.9 percent used the lap belt only and 46.8 percent were unrestrained.

TABLE 2-3

RESTRAINT SYSTEM USAGE IN THE TRAFFIC POPULATION
CHILDREN AGED 0-4, 1974-84

<table>
<tr><th></th><th colspan="5">Calendar Year (Data Source)</th></tr>
<tr><th></th><th>1974 (Williams)</th><th>1979 (Phillips)</th><th>1981-82 (Phillips)</th><th>1983 (Perkins, Cynecki & Goryl)</th><th>1984 (Goryl & Cynecki)</th></tr>
<tr><th></th><th colspan="5">Percent of Children Aged 0-4 Using:</th></tr>
<tr><td>Safety seat, correct use or partial misuse</td><td>6.1</td><td>7.6</td><td>17.4</td><td>31.5</td><td>36.6</td></tr>
<tr><td>Safety seat, grossly misused</td><td rowspan="2">9.4</td><td rowspan="2">7.6</td><td>5.4</td><td>9.0</td><td>9.4</td></tr>
<tr><td>Home child carrier used as car seat</td><td>3.8</td><td>1.1</td><td>0.3</td></tr>
<tr><td>SUBTOTAL: safety seats and home child carriers</td><td>15.5</td><td>15.2</td><td>26.7</td><td>41.6</td><td>46.3*</td></tr>
<tr><td>Lap belt only</td><td>3.9</td><td>1.6</td><td>2.3</td><td>4.6</td><td>6.9</td></tr>
<tr><td>Unrestrained</td><td>80.6</td><td>83.2</td><td>71.0</td><td>53.8</td><td>46.8</td></tr>
<tr><td>N of observations</td><td>3,917</td><td>3,924</td><td>14,695</td><td>15,847</td><td>18,366</td></tr>
</table>

* 49.3 percent in the last quarter of 1984.

2.2.2 Perkins, Cynecki and Goryl (1983)

The same contractor (Goodell-Grivas, Inc.) performed essentially the same survey in 1983. The 15,847 observations were distributed as follows [61], pp. 43-47 and Tables 42, 44, 46 and 47:

	Infants	Toddlers	Toddlers in Booster Seats
Correctly used	767	----	105
Correctly harnessed	---	3732	---
Forward facing	119	----	---
Harness used-belt not used	110	----	---
Harness not used-belt used	38	----	---
Belt not used-harness unspec.	---	----	149
Harness not used-belt unspec.	---	502	34
No harness and no belt	46	----	---
Seat used-no details	50	743	23
Home child carrier	77	100	---
Lap belt only	---	735	---
Unrestrained	662	7855	---

The estimates for home child carriers are based on statements in the text, viz., that they were used by 4.1 percent of the infants [61], p.43 and "less than 1 percent" of the toddlers [61], p.45.

For infant seats, this survey resembles the 1984 results in that there are too few "forward facing" cases and too many "harness used - belt not used." As in 1984, the first line is drawn below both of those modes. Among toddlers, there was a very large number of "seat used - unsure of details." The data make sense only if all of those cases are counted with the gross misusers, putting the ratio of gross misusers to correct users right in line with the 1981-82 and 1984 surveys (see Table 2-3).

The booster seat data are also confusing. The large number (149 out of 311) of "belt not used" undoubtedly includes primarily cases where the lap belt was used without the shoulder belt. "Harness not used - belt not specified" is not a useful categorization. Instead of relying on those results, the 311 observed booster seat cases will be assumed to have the 85 to 15 split of correct-use/partial-misuse to gross misuse observed in both 1984 surveys (Hardee's and 19 cities).

The 4728 infant and toddler cases above the first line, when added to 85 percent of the 311 booster seat users, account for 78 percent of all safety seat users - equivalent to the percentage in correctly used or partially misused safety seats. In 1983, 22 percent of safety seats were grossly misused, while in 1984, only 20 percent.

Table 2-3 shows that 41.6 percent of all child passengers were in safety seats or home child carriers during 1983, as opposed to 46.3 percent in 1984. Correct use/partial misuse changed slightly more (31.5% in 1983, 36.6% in 1984). Lap belt usage was higher in 1984, home child carriers declined sharply and gross misuse of safety seats about the same in absolute terms.

2.2.3 <u>Phillips (1981-82)</u>

A different contractor (Opinion Research Corp.) performed the survey at the same 19 metropolitan areas during 1981-82 [64], pp. 23-41. During 1981 the observations were made at traffic intersections and in 1982, at shopping center exits as well as intersections (the results were comparable). The 14,695 cases of children aged 0-4 were distributed as follows [64] pp. 33, 35, 38 and 40:

	Infants	Toddlers
Safety seat - appears correct	763	1745
Harness used - lap belt not used	24	25
Lap belt used - harness not used	118	516
Harness and lap belt not used	67	98
Home child carrier	291	270
Lap belt only	---	344
Unrestrained	1142	9304

Booster seats were rare in 1981-82 and were not treated as a separate category. The results appear reasonable except that the "harness used - lap belt not used" category has too few cases; most likely, some cases where the lap belt was not used (hard to detect given the brief observation time allowed) appeared correct to the observers. If the strategy of drawing the first line below "harness used - lap belt not used" is repeated here, the cases of lap belt nonuse (gross misuse) should be more or less cancelled out by those where the harness was not used but the belt was around the child (partial misuse). When the cases between the two lines are employed as a surrogate for gross misuse, they account for 24 percent of the safety seat users, a result consistent with the 22 percent in 1983 and 20 percent in 1984.

Table 2-3 shows that 26.7 percent of child passengers were in safety seats or home child carriers during 1981-82. The proportion of children in home child carriers (3.8%) was considerably higher than in later years and was of the same order of magnitude as the percentage in approved, but grossly misused seats (5.4%).

2.2.4 Phillips (1979)

The first survey of child restraint usage sponsored by NHTSA [62], pp. 31-42 did not contain detailed information on misuse modes or make a clear distinction between approved safety seats and home child carriers. (While the text states that "not proper" seats were not to be recorded as child restraints, [62], p. 32, Phillips himself confirmed that home child carriers were usually included among the child restraints [63].) The 3924 cases of child passengers were distributed as follows [62], pp. 38 and 42:

	Infants	Toddlers
Child seat secured by lap belt	156	144
Child seat not secured by lap belt	164	136
Lap belt only	---	64
Unrestrained	386	2874

Half of the child seats were not secured by lap belts. There are two possible explanations for that inordinately high number, which does not even take into account the harness. One possibility is that home child carriers account for a large proportion of the total. The other is that the observer often failed to notice the lap belt when it was routed through the tubular structure. The first theory seems reasonable in view of the high proportion of home child carriers in the 1981-82 survey. Likewise, a survey conducted in Traverse City, Michigan during 1979 found that 36 percent (100 out of 274) of "child seats" were actually home child carriers [56]. Thus, the lines are drawn under "child seat secured by lap belt" and "child seat not secured" but the cases between the two lines (i.e., child seats not secured) are used as a surrogate for grossly misused safety seats plus home child carriers. With those assumptions, Table 2-3 shows that the 1979 results are fully in line with the subsequent surveys. Overall usage of safety seats plus home child carriers was 15.2 percent, of which exactly half were correctly used or partially misused safety seats (as compared to two-thirds in 1981-82, three-quarters in 1983 and four-fifths is 1984).

It can be seen that "infants" comprised 18 percent of the 0-4 year olds in this survey but only 12 percent, for example, in the 1984 survey (see Section 2.2.1). Phillips gave assurances, however, that this was not the result of any attempt to oversample infants (relative to toddlers) but rather due to inaccurate age classification by observers, etc. [63]. Since infants were not over or undersampled (relative to toddlers) in any of the surveys, it is valid to merge the infant and toddler cases, without any weight factors, as has been done here.

2.2.5 Williams (1974)

The survey was conducted by the Insurance Institute for Highway Safety in 14 amusement areas and shopping centers in Maryland, Massachusetts and Virginia [85]. Cars were stopped at exits from those sites; restraint usage was observed and the drivers interviewed. Children were classified into age groups 0, 1, 2, 3 and 4-9. Under the assumption that 1/6 of the unrestrained and lap belted children in the 4-9 age group were 4 years old and all of the (very few) child restraint users, there were 3917 children aged 0-4 in the study, distributed as follows:

	Tether Required	Tether Not Required
Child seat, harness & lap belt used	42	128
Harness used, lap belt not used	8	62
Lap belt used, harness not used	10	122
No harness and no lap belt	6	179
"Inadequate protective devices"	--	53
Lap belt only	--	152
Unrestrained	--	3155

It is suspected that not only Williams' "inadequate protective devices" but also a large proportion of his "misused child seats" were actually home child carriers. The best evidence for this is that tethered seats, which accounted for a large proportion of genuine safety seats and are well represented in the "harness and lap belt used" mode, are greatly under-represented among the 3 misuse modes, especially "no harness and no lap belt" - not because the presence of the tether encourages use of the lap belt and/or harness, but more likely, because many of the latter cases are home child carriers. (An alternative possibility, suggested by Radovich, is that tethered seats were indeed used correctly more often in those days, before State use laws, because they were purchased by parents most strongly motivated to protect their child passengers.)

The first line, as in the first three surveys, is drawn under the "lap belt not used" group to compensate for cases of "harness not used" which were not actual gross misuse. With that approach, Table 2-3 shows that 15.5 percent of children were in safety seats or home child carriers (about the same as in 1979) but only 6.1 percent of all children were in a correctly used or partially misused safety seat while 9.4 percent were in a home child carrier or grossly misused safety seat (even worse than 1979).

2.2.6 Restraint system usage and the law

State laws requiring small children to use safety seats or lap belts took effect in Tennessee on January 1, 1978, in Rhode Island in mid 1980 and in every other State between mid 1981 and mid 1985 [80] [84]. Obviously, they are a primary reason that safety seat usage tripled between

1979 and 1984. The 19 city surveys of restraint system usage, since 1981, have included some cities covered by State laws during most or all of the survey and some which were not covered at any time or just briefly covered during the survey. Restraint system usage (safety seats or lap belts) for cities with and without the laws was:

	Restraint System Usage (%)	
	State Use Law	No State Use Law
1979	----	16.8
1981-82	34.2	27.1
1983	51.5	39.4
1984	56.4	32.0

The results are not directly comparable from year to year because more and more cities were moving from the "No Law" column to the "Law" column. Nevertheless, several trends are apparent from the data:

- o Restraint use was higher in cities with a use law than in cities without one.

- o Restraint usage continued to rise after the laws took effect, presumably due to stronger enforcement, better public education and awareness, and more convenient safety seats.

- o Even in cities that were not yet covered by use laws, restraint usage was much higher in the 1980's than in 1979, presumably due to anticipation of laws to take effect in the near future, spillover effect of laws in nearby States, better public education and awareness, and more convenient safety seats.

A detailed analysis of how much of the increase is due to State laws versus public education, more convenient seats, etc., will not be attempted here, but it is fairly clear that all of those factors helped increase usage.

2.3 Correct use vs. partial misuse, 1979-84

The five surveys described in Section 2.2 gave fairly accurate estimates of the percentage of child passengers using any type of child seat. They gave reasonable estimates of how that percentage can be broken down into correct use/partial misuse, gross misuse and home child carriers (see Table 2-3). But they were not useful for separating correct use from partial misuse, since they did not include information on the tether, the routing of the lap belt, etc.

So far, the identification of correct use vs. partial misuse has been accomplished for 1984, thanks to the Hardee's survey (Table 2-2). The Hardee's results will be used to estimate correct use vs. partial misuse, year by year, as far back as 1979, by the following technique:

- o The Hardee's data are used to estimate the correct use/partial misuse split in 1984 for 4 groups of generic seat types (Section 2.3.1).

- o Previous observation surveys of seats in unoccupied cars suggest that the 1984 split was about the same as in earlier years (Section 2.3.2).

- Sales data and the results of Section 2.2 are used to estimate the relative prevalence of the 4 groups of seat types, year-by-year (Section 2.3.3).

- The correct use/partial misuse split for the entire safety seat population is obtained by averaging the 4 groups of seat types, weighted by their prevalence (Section 2.3.4).

2.3.1 Correct use vs. partial misuse in the Hardee's survey

Table 2-2 listed the numbers of correct users, partial misusers and gross misusers of each type of seat. If the gross misusers are excluded, the percentage of correct users among the remaining mix of correct users/partial misusers is:

Tethered (belt thru frame)	13	14
Tethered belt-around	19	
Tetherless belt-around	14	
Tetherless - harness only	72	69
Tetherless - partial shield	65	
Tetherless - full shield	76	
Shield booster	100	100
Conventional booster	46	47
Infant belt-around	46	
Infant (belt through frame)	50	

It is evident that the 10 seat types can be grouped into four clusters with respect to extent of correct use. The tethered, tethered belt-around, and tetherless belt-around seats have close to 14 correct users per 100 correct users/partial misusers. The other 3 types of tetherless toddler seats are much easier to use correctly, with close to 69 percent correct use among the correct users/partial misusers. In other words, the partial or full shields reduce gross misuse but have little effect on partial misuse. The shield booster seat was either correctly used or grossly misused, so 100 percent of correct users/partial misusers were correct. Conventional booster seats and infant seats (including convertible seats used by infants under one year), although totally different seat types, had similar levels of correct use. They were between the first two groups, with close to 47 percent correct usage among the correct users/partial misusers.

2.3.2 Other surveys of tether attachment and lap belt routing

In 1984, Goodell-Grivas observed over 3,000 unoccupied toddler seats in cars parked at shopping malls in 19 metropolitan areas [26], pp. 51-53. The tether was correctly attached in 15 percent of the tethered seats and tethered belt-around seats (and incorrectly installed in another 2 percent). That figure is identical to what was seen in the Hardee's survey (Table 2-1). Since non-use of a tether is the primary cause of partial misuse of a tethered seat, this survey validates the Hardee's results that misusers greatly outnumber correct users of tethered seats. The Goodell-Grivas survey showed that 52 percent of children were correctly belted in tetherless seats where the belt is designed to pass through the frame (Table 53 of [26] less Bobby Mac seats). That is a bit lower than the 62 percent correct belt use for those seat types in the Hardee's survey. Surveys of unoccupied cars are not useful for investigating tetherless belt-around seats because the belt and detachable shield are used only when the child is in the seat.

Goodell-Grivas conducted an identical survey of 2,932 unoccupied toddler seats in 1983, with quite similar results: 18 percent of the tethers were correctly installed on seats where tethers were standard equipment (Strolee and Century in Table 57 of [61]) and another 4 percent were incorrectly installed. On tetherless seats other than Bobby Mac, 52 percent of belts were correctly routed [61], Table 56.

In 1982, Shelness and Jewett designed and managed a survey of unoccupied cars at shopping malls in 12 States; 2,323 toddler seats were examined in detail [76]. They found that 16 percent of tethers were correctly installed and another 15 percent were "incorrectly" installed. However, the two most common forms of incorrect installation were anchoring the tether to the front seatback or the floor. While not according to manufacturers' instructions, those misuse modes, in many crashes, might provide adequate protection. On tetherless seats with belt routing through the frame, 53 percent of lap belts were correctly routed.

Williams' 1974 survey [85] found that 35 of 66--i.e., 53 percent of tethers were anchored. But this statistic may be anomalous because he reported that only 66 of 490 car seats--i.e., 13 percent of car seats were equipped with tethers. The actual percentage was undoubtedly higher (see Section 2.3.3). Perhaps, many tether-equipped seats with unanchored tethers were reported as untethered seats.

In summary, the two Goodell-Grivas surveys and, possibly, the study by Shelness and Jewett confirm the 15 percent correct use of tethers in the Hardee's survey and suggest it has changed little over time. As a result, they support the use of the 14:86 ratio of correct use to partial misuse established in the Hardee's survey. But it is also possible that tether use was somewhat higher in earlier years, when tethered seats were purchased by exceptionally motivated parents.

The studies suggest that the 62 percent correct use of lap belts on tetherless seats, as observed in the Hardee's survey, may be on the high side in comparison with earlier years, where it was 52-53 percent. By inference, the 69:31 ratio of correct use to partial misuse in the Hardee's survey is too high and 60:40 may be more appropriate for earlier years, when some seats had even more inconvenient belt routings than the ones currently produced [76].

The 1984 Goodell-Grivas survey of safety seat usage on the road (Section 2.2.1) is the only one that examined conventional booster seats at virtually the same level of detail and accuracy as the Hardee's survey. There were 152 correctly used booster seats and 196 secured by a lap belt but with no upper body restraint. That is a 44:66 ratio of correct use to partial misuse and virtually identical to the 46:64 ratio in the Hardee's survey.

The shield booster type was rare before 1984 and need not be considered in estimating correct usage vs. partial misuse for the pre-1984 mix of seats. The other types were sold in substantial quantities. Based on the Hardee's survey and the earlier data, the rounded numbers that best express correct use vs. partial misuse are:

	Ratio of Correct Use:Partial Misuse
Tethered, tethered belt-around & tetherless belt-around seats	15:85
Tetherless seats (belt thru frame)	60:40
Conventional booster seats	45:55
Infant seats	45:55

2.3.3 The mix of safety seats in use, 1979-84

The Hardee's survey plus three surveys of overall safety seat usage (Sections 2.2.2-2.2.4) give accurate estimates of the proportion of safety seat users who were infants (as opposed to 1-4 year old toddlers):

Survey Year	Percentage of Safety Seat Users Who Were Infants
1984 (Hardee's)	16
1983	20
1981-82	31
1979	52

These percentages are based on the correct users and partial misusers only, i.e., the cases above the first line in the tables accompanying Sections 2.2.2-2.2.4. The proportion of users who were infants has declined steadily because safety seat usage by toddlers has increased dramatically while usage by infants was relatively high even in 1979. Based on linear interpolation, the percentage of infants by calendar year, was

Calendar Year	Percentage of Safety Seat Users Who Were Infants
1979	52
1980	44
1981	35
1982	27
1983	20
1984	16

The apportionment of other-than-infant seat users in 1979-83 is based on sales data. (For 1984, the Hardee's data can be used directly.) Annual sales of toddler and booster seats are believed to have been approximately [17], [67]:

Sales by Seat Type (Thousands)

Calendar Year	Tethered	Tetherless	Booster
1983	650	1550	1200
1982	740	1200	660
1981	700	900	300
1980	650	400	--
1979	650	400	--
1976-78	400	200	--

The average working life of a safety seat is 4 years [67]. In other words, the seats in use during mid-1983 would include half the 1983 sales (since the other half would not have been sold before the middle of the year) and all of the 1980, 1981 and 1982 sales. The seats in use at the middle of each calendar year were distributed as follows:

Seats in Use, by Seat Type (Thousands)

Calendar Year	Tethered	Tetherless	Booster
1983	2415	3275	1560
1982	2370	2300	630
1981	2050	1450	150
1980	1775	1000	--
1979	1525	800	--

The figures for tethered vs. tetherless seats agree with what was observed in unoccupied cars in shopping centers: e.g., in 1983, Perkins, Cynecki and Goryl reported 1302 tethered and 1630 tetherless seats [61] pp. 54-55, which is close to the 2415:3275 ratio estimated above. In 1982, Shelness and Jewett reported 1648 tethered and 1585 tetherless seats [76] Figure 2, duplicating the 2370:2300 ratio in the above table. On the other hand, the proportions of booster seats in the preceding table, while consistent with the Hardee's survey, are much higher than what was seen in any other survey by Goodell-Grivas [26], [61]. It is unknown why booster seats were so underrepresented in those surveys.

The figures in the preceding table need two modifications before they can be used for calculating the correct use/partial misuse split. One is that the totals for booster seats need to be reduced by 22 percent, because 22 percent of them are used by children older than 4 (see Section 2.1.2). The other is that the "tetherless" category includes the tetherless belt-around seats. They need to be pulled out of the tetherless group and added to the tethered group, which they resemble in the matter of misuse rates. They have accounted for about 10 percent of toddler seats, year after year [26],[29],[61]. With those changes, the table becomes:

Seats in Use, by 0-4 Year Olds (Thousands)

Calendar Year	Tethered + Tetherless Belt-Around	Tetherless - Tetherless Belt-Around	Booster
1983	3106	2584	1217
1982	2886	1784	491
1981	2412	1088	117
1980	2053	722	--
1979	1758	567	--

The relative shares of infant and toddler seats were estimated at the beginning of this section. The share for toddler seats must be further split according to the distributions in the preceding table. The results, which are shown in Table 2-4, indicate the overall mix of safety seats in use during 1979-84.

TABLE 2-4

SAFETY SEATS IN USE BY INFANTS AND TODDLERS,
BY SEAT TYPE AND CALENDAR YEAR, 1979-84

	Percent of Safety Seats			
Calendar Year	Infant	Tethered Plus Tetherless Belt-Around	Tetherless Minus Tetherless Belt-Around	Booster
1979	52	36	12	---
1980	44	41	15	---
1981	35	43	20	2
1982	27	41	25	7
1983	20	36	30	14
1984*	16	27	40	17

* Based directly on Hardee's survey (correct users and partial misusers in Table 2-2)

Infant seats, as discussed above, accounted for a steadily declining share of safety seat users--from 52 percent in 1979 to 16 percent in 1984. Tethered seats gained from 36 to 43 percent in 1979-81, partly on the strength of a 1977 Consumer Reports article praising a specific tethered seat and partly because of the overall gain of toddler relative to infant seats [76]. They began losing ground after 1981, slowly at first and then rapidly, to 27 percent in 1984. A 1982 Consumer Reports article favoring tetherless seats for their convenience may have been a factor [76]. Tetherless toddler seats have gained rapidly from 12 percent of seats in use during 1979 to 40 percent in 1984. So have booster seats: from almost nothing in 1979-80 to 17 percent in 1984.

2.3.4 The correct use/partial misuse split, 1979-84

The ratios of correct users to partial misusers for each seat type (developed at the end of Section 2.3.2) are multiplied by the shares that each seat type had in a given calendar year, as shown in Table 2-4, yielding the correct use/partial misuse split for the entire safety seat population in that year:

Calendar Year	Ratio of Correct Use:Partial Misuse
1979	36:64
1980	35:65
1981	35:65
1982	36:64
1983	39:61
1984	49:51

The split for 1984 is based directly on the Hardee's survey (Table 2-2). Correct use was close to 35 percent during 1979-82, dipping slightly in the years that tethered seats reached their peak. It climbed in 1983 and even more in 1984, as tethered seats lost market share, tetherless seats were replaced by even easier-to-use models, and convenient new types (shield-booster) were introduced. It is safe to say that the alarming results of observation surveys on misuse helped spur the change for the better: participants in those surveys can take pride in this achievement.

2.4 Use and misuse of safety seats, 1979-84

Table 2-3 showed overall safety seat use in 4 surveys, which were conducted during 1979, 1981-82, 1983 and 1984. The surveys made a distinction between gross misuse/home child carriers and correct use/partial misuse but they did not separate correct use from partial misuse.

Table 2-5, the principal result of this chapter, shows restraint usage for each calendar year and separates correct use from partial misuse. It is derived from Table 2-3 in two steps. First, the 1979 and 1981-82 results are linearly interpolated to obtain estimates for 1980 and 1981 and the 1981-82 and 1983 results are interpolated to obtain estimates for 1982. Then, the correct users and partial misusers are subdivided according to the ratios developed in Section 2.3.4, by calendar year.

Table 2-5 shows that the situation for child passengers aged 0-4 improved in every possible way during 1979-84 and it improved steadily from year to year. The percentage of unrestrained children dropped from 83.2 to 46.8, while use of child seats (safety seats or home child carriers) increased from 15.2 to 46.3 percent; lap belts from 1.6 to 6.9 percent. Among child seat users, half were in grossly misused safety seats or home child carriers in 1979, one-fifth in 1984. And among correct users/partial

TABLE 2-5

USE AND MISUSE OF SAFETY SEATS, 1979-84,
CHILD PASSENGERS AGED 0-4

<table>
<tr><th></th><th colspan="6">Restraint System Usage By Calendar Year (%)</th></tr>
<tr><th></th><th>1979</th><th>1980</th><th>1981</th><th>1982</th><th>1983</th><th>1984</th></tr>
<tr><td>Correctly used safety seat</td><td>2.7</td><td>4.0</td><td>5.4</td><td>8.0</td><td>12.3</td><td>17.9</td></tr>
<tr><td>Partially misused safety seat</td><td>4.9</td><td>7.5</td><td>10.0</td><td>14.1</td><td>19.2</td><td>18.7</td></tr>
<tr><td>Grossly misused safety seat</td><td rowspan="2">7.6</td><td rowspan="2">8.2</td><td rowspan="2">8.9</td><td>6.6</td><td>9.0</td><td>9.4</td></tr>
<tr><td>Home child carrier used as car seat</td><td>2.9</td><td>1.1</td><td>0.3</td></tr>
<tr><td>SUBTOTAL: Safety seats and home child carriers</td><td>15.2</td><td>19.7</td><td>24.3</td><td>31.6</td><td>41.6</td><td>46.3</td></tr>
<tr><td>Lap belt only</td><td>1.6</td><td>1.9</td><td>2.2</td><td>3.1</td><td>4.6</td><td>6.9</td></tr>
<tr><td>Unrestrained</td><td>83.2</td><td>78.4</td><td>73.5</td><td>65.3</td><td>53.8</td><td>46.8</td></tr>
</table>

misusers, correct usage rose from one-third to nearly one-half. Taken together, these gains mean that the percentage of child passengers in a correctly used safety seat increased from 2.7 percent in 1979 to 17.9 percent in 1984--more than a sixfold increase.

Child passenger protection laws, which took effect in most States during 1982-84, are responsible for much of the increase in overall usage. But improved design of safety seats and programs to educate parents must be credited for the even faster increase in correct usage. The improvement in Table 2-5 is steady rather than abrupt because States enacted their laws at different times, usage increased gradually during the periods before and after a law's effective date, and it takes years for improved seats to replace completely the earlier stock.

CHAPTER 3

EARLIER STUDIES OF SAFETY SEAT EFFECTIVENESS

The literature on child safety seats exceeds that for any auto safety device except, probably, safety belts and air bags. The review here is limited to statistical analyses of effectiveness based on accident data and sled test studies comprising various types of correctly used and misused seats, including a new analysis of NHTSA compliance test results for 1981-84 safety seats. It is further limited, for the most part, to American data since even Canadian seats and usage patterns differ from those of the United States. Despite the restrictions, there are a lot of studies to review.

All of the statistical analyses suggested that the seats are effective, but the estimates of casualty reduction ranged from 7 to 91 percent. The statistically reliable and unbiased studies, however, indicated that safety seats reduced injuries by 30-40 percent in the 1970's and 40-50 percent in the 1980's. A unique study by the Highway Safety Research Center, reviewed in this chapter, sheds light on the tendency of police to underreport grossly misused safety seats.

The laboratory studies and compliance test data showed that all current designs of safety seats are effective for 3 year olds in frontal crashes. They clearly illustrated the dangers of misusing the seats. The compliance tests complemented the sled test results of Chapter 7: while all correctly used seats were effective in both sets of tests, the ones which resulted in relatively higher HIC values on the compliance tests had the lowest HIC values in Chapter 7, where the sled was decelerated more gradually than in the compliance tests.

3.1 Two pioneers

Two studies with widely divergent views on effectiveness could be found in 1978.

3.1.1 Scherz - Washington State data (1970-77)

Scherz used Washington State accident files (police-reported data) for 1970-77 [74]. At that time, the accident report did not have a distinct code for child safety seats, so the study compares "restrained" children (safety seat or lap belt) to unrestrained. The statistics for children aged 0-5 were:

	Unrestrained	Restrained	Reduction for Restrained (%)
N of children	26,550	5,052	
Fatalities	123	2	
Fatality rate (%)	0.46	0.04	91
Serious (level A) or fatal injuries	801	40	
Serious injury rate (%)	3.02	0.79	74

The observed 91 percent fatality reduction is clearly statistically significant, as is the 74 percent reduction of serious injuries. The levels of effectiveness cannot be considered realistic, however, in view of the fact that the "restrained" category includes misused seats and lap-belt-only. Tables 2-3 and 2-5 showed that correct users of safety seats were always outnumbered by misusers during 1970-77 and sometimes even by lap belt users. Thus, the effectiveness of correctly used seats would have to be well over 100 percent in order for the average effectiveness of correctly used seats, misused seats and lap belts to be 91 percent! Even without the misusers and lap belt users, effectiveness could not be 91 percent since well over 10 percent of fatalities involve catastrophic compartment invasion at the victim's seat position, fire, immersion or a foreign object entering the compartment [25], p. IV-58 - IV-64.

Evidence of bias may be found within Scherz's study. It computed casualty rates for 6-15 year old children and adults. In both of those age groups the "restrained" population during calendar years 1970-77 consisted primarily of lap belt users, with only a few lap-and-shoulder belt users. The true fatality reduction for lap belts is probably 30-40 percent and the serious injury reduction, 25-35 percent [25], p. IV-2. But in Washington State, the observed fatality risk was 84 percent lower for restrained 6-15 year olds than for unrestrained; 78 percent lower for restrained adults than for unrestrained. The serious injury rate for restrained 6-15 year olds was 69 percent lower than for unrestrained. In other words the observed effectiveness of lap belts for older children and adults is almost as high as that of safety seats for small children. Since the former is exaggerated by a factor of 2 or more, so, in all likelihood is the latter.

Two sources of bias seem most probable. One is that the restrained persons, on the average, were involved in less severe crashes than the unrestrained, thereby resulting in lower injury rates. That bias is often present in studies of restraint users [25], pp. IV-3 - IV-11, but it is usually not too large (i.e., no more than 20 percent). The primary source of bias would appear to be that injured restraint users were misreported as unrestrained and/or uninjured unrestrained occupants were misreported as having been restrained. The phenomenon of incorrectly reporting restraint usage in a manner that biases effectiveness has been documented elsewhere in the literature [6], [58]. It is probably strongest in locations where police (or the public) are most firmly convinced that restraints are effective and injured persons, a priori, must have been unrestrained--and certainly Washington State was such a place (Seattle consistently had the highest voluntary belt usage of 19 major metropolitan areas [26], [61], [62], [64]).

Scherz's study has been widely quoted, especially in brochures urging parents to protect their children in safety seats [5], [19], [31], [34]. Its continuing popularity is due to the fact that it was the first on that subject, had highly favorable results and above all it is due to Dr. Scherz's own enthusiastic efforts to convince the public and, especially, the medical community of the need for child passenger protection. Its results became a leitmotif in the medical literature [8], [72]. Dr. Scherz's efforts were successful because the American Medical Association's, the American Academy of Pediatrics' and individual doctors' overwhelming support for child passenger protection played a major role in enacting usage laws in every State. Thus, it is possible that Scherz's study has been more directly responsible for saving lives than any other statistical analysis of automobile accident data.

3.1.2 NHTSA Regulatory Impact Assessment (1978)

The agency's regulatory analysis supporting the proposed inclusion of dynamic testing in Standard 213 [32] included effectiveness estimates for

- correctly used safety seats meeting the proposed dynamic test: 25 percent fatality reduction and 50 percent injury reduction

- correctly used seats meeting only the 1971 static requirements: 5 percent fatality reduction and 20 percent injury reduction

- a safety seat with the tether unattached, meeting the proposed less stringent (20 mph) dynamic test: 8 percent fatality reduction and 30 percent injury reduction.

The estimates were not based on evaluation of accident data or systematic laboratory tests with restrained vs. unrestrained dummies; rather, the cumulative distributions of fatalities and injuries were taken from adult occupant accident data and it was assumed that the restraints would save all casualties at Delta V's below the proposed test speeds (or 15 mph in the case of the pre-dynamic seat) and none above.

The first of the 3 estimates corresponds to what is defined as a "correctly used" seat in this report and the third, more or less, to a "partially misused" seat. In 1984, when 40 percent of seats were correctly used, 40 percent partially misused (and 20 percent grossly misused--see Table 2-5), the above estimates add up to an overall 13 percent fatality reduction for safety seats (i.e., .4 x 25 percent plus .4 x 8 percent) and 32 percent injury reduction. In 1979, when only 18 percent of seats were correctly used and 32 percent partially misused, these estimates add up to just 7 percent overall fatality reduction and 19 percent injury reduction--they are an order of magnitude smaller than Scherz's estimates! (It should be noted that NHTSA superseded some of the estimates with higher ones in a 1980 regulatory analysis [78].)

3.2 Statistical analyses of accident data

3.2.1 Knoop et al. - New York, New Jersey and Idaho data (1974-78)

This was the first of three statistical studies sponsored by NHTSA's Office of Program Evaluation and managed by Kahane [47]. It was the first step in an effort to narrow down the range of effectiveness values suggested by the two pioneering studies. Three States were located--New York, New Jersey and Idaho--whose police accident report included a distinct category for child safety seats in their restraint usage variable, who obtained data on uninjured as well as injured passengers involved in crashes and who agreed to furnish accident tapes for analysis. Records of car passengers aged 0-4 were extracted and analyzed by techniques similar to the ones used for more recent Pennsylvania data in Section 5.2 of this report: the children were grouped into 3 categories of restraint usage (child seat, lap belt, unrestrained). Injury rates were computed for each of 3 levels of injury: fatal (level K) or serious (level A); K, A or B level; any type of injury (K, A, B or C). The injury rates were then adjusted using control variables such as age of child, seat position, vehicle damage, vehicle weight, etc. Finally, effectiveness was computed as the reduction of the restrained injury rates relative to the unrestrained.

New York - Data from calendar year 1974 and 1977 were available for analysis. Available sample sizes and restraint system usage for the two years combined was:

	N of Cases	Percent of Cases
Unrestrained	17,310	79
Child seat	1,721	8
Lap belt	2,738	13

Reported lap belt usage was much higher and child seat usage lower than in on-the-road surveys of child passenger protection (Table 2-3), suggesting that some type of classification errors occurred. Table 12 on p. A-9 of [47] shows that reported child seat usage is appropriately 3 times higher for 0-1 year olds than for 2 year olds and 3 times higher for 2 year olds than for 3 year olds. On the other hand, reported lap belt usage is implausibly as high or higher for 0-1 year olds as for older children. That is the pattern not only for New York but for New Jersey, Idaho, Maryland and Pennsylvania. The subject of restraint usage misclassification is discussed in more detail in Sections 3.2.4, 5.1 and 8.1. The conclusion of those discussions is that, in fact, most of the police-reported safety seat users were really in safety seats and most of the reported lap belt users were belted--the exceptions being that most of the infants reported to have used lap belts were really in safety seats and that many grossly misused seats are reported as unrestrained.

The effectiveness estimates and their confidence bounds (one-sided α = .05) were:

	Child Seats	Lap Belts
K or A injury reduction		
Best estimate	28	54
Confidence bounds	6-49	39-67
K, A or B injury reduction		
Best estimate	26	36
Confidence bounds	18-34	30-42
Overall injury reduction		
Best estimate	30	30
Confidence bounds	24-36	25-34

The effectiveness of child seats in mid-1970's New York data appears to be in the 25-30 percent range. That estimate, as will be shown in Section 8.2.1, is quite appropriate considering that the majority of child seats in circulation at that time were misused or were home child carriers used as car seats (see Tables 2-3 and 2-5, also).

New Jersey - Data were only available from calendar year 1975 because it was the single year (prior to 1978) that police reported child seats as a distinct restraint category. The available sample sizes and restraint system usage were:

	N of Cases	Percent of Cases
Unrestrained	5,175	77
Child seat	633	9
Lap belt	930	14

The sample size was about 1/3 as large as for New York, precluding a meaningful analysis of serious (K or A level) injury rates. The effectiveness estimates for the lower levels of injury and their confidence bounds were:

	Child Seats	Lap Belts
K, A or B injury reduction		
Best estimate	19	61
Confidence bounds	3-36	51-70
Overall injury reduction		
Best estimate	20	48
Confidence bounds	11-29	42-55

The results are not materially different from New York.

Idaho - Files from 1976-78 could be used; nevertheless, the combined sample had few child seat users:

	N of Cases	Percent of Cases
Unrestrained	3,287	87
Child seat	143	4
Lap belt	331	9

With 143 cases, an effectiveness analysis could only be carried out for the overall injury rate and even that was of limited statistical value:

	Child Seats	Lap Belts
Overall injury reduction		
Best estimate	13	38
Confidence bounds	-17 - +42	21-54

Again, the results resemble those from New York.

3.2.2 Chi - New York and Maryland data (1975-80)

The preceding study, relying primarily on 2 calendar years of New York data, had wide confidence bounds. When additional years of New York data became available, plus Maryland files, the Office of Program Evaluation awarded a second contract for statistical analyses. Chi used basically the same analysis techniques, with several refinements [7].

New York - Files were available from 1975 through 1978, containing a sample of child seat users twice as large as Knoop's:

	N of Cases	Percent of Cases
Unrestrained	29,883	79
Child seat	3,212	9
Lap belt	4,565	12

Overall restraint usage was the same as in Knoop's study but the "reporting gap" between child seats and lap belts narrowed.

The raw, unadjusted injury rates were:

	N of Children	% Inj.	% K, A or B	% K or A
Unrestrained	29,883	29.0	18.2	2.6
Child seat	3,212	20.3	12.6	1.6
Lap belt	4,565	21.2	12.1	1.4

After using control variables to adjust the injury rates, Chi obtained the following effectiveness estimates:

	Child Seats	Lap Belts
K or A injury reduction		
Best estimate	34	46
Confidence bounds	20-48	38-54
K, A or B injury reduction		
Best estimate	24	29
Confidence bounds	18-30	24-33
Overall injury reduction		
Best estimate	25	24
Confidence bounds	19-31	20-28

Chi also found that unrestrained children in the back seat had a 40 percent lower rate of serious injuries than unrestrained front-seat child passengers; a 39 percent lower moderate (K, A or B) injury rate and a 27 percent lower overall injury rate.

Maryland - Accident files from 1977-80 contained about half as large a sample as the one from New York:

	N of Cases	Percent of Cases
Unrestrained	21,225	82
Child seat	1,672	6
Lap belt	3,047	12

The raw, unadjusted injury rates were:

	N of Children	% Inj.	% K, A or B	% K or A
Unrestrained	21,225	19.9	6.0	1.4
Child seat	1,672	17.2	5.1	1.0
Lap belt	3,047	15.0	3.4	0.6

After the rates were adjusted, the effectiveness estimates were:

	Child Seats	Lap Belts
K or A injury reduction		
Best estimate	36	59
Confidence bounds	11-51	43-75
K, A or B injury reduction		
Best estimate	33	46
Confidence bounds	19-48	36-56
Overall injury reduction		
Best estimate	17	22
Confidence bounds	9-24	16-27

As in New York, the unrestrained child was substantially safer in the back seat than in the front: 28 percent fewer serious injuries, 32 percent fewer moderate injuries and a 22 percent lower overall injury rate.

Discussion - The pattern of these State data analyses is becoming relatively clear. Serious and moderate injury reduction for child seats appears to have crept upwards as time passed: from 25-30 percent in the mid-1970's to about 35 percent near the end of that decade. That trend is consistent with the increasingly more correct usage of the restraints and the declining number of flimsy seats (which in many cases may have been coded as "child restraints" by police) relative to safety seats--see Table 2-3 and Section 8.2.1.

Lap belts had a consistently high effectiveness (40-60 percent observed) in reducing serious injuries of children. Lap belt usage on State accident files was consistently higher than in the observational surveys, raising a possibility that some of the reported lap belt users were actually in child seats or, conversely, that the observational surveys underestimated actual lap belt usage.

3.2.3 Hall et al. - North Carolina accident and interview data (1983-84)

In 1979, the Office of Program Evaluation issued its third contract to analyze accident data [18]. The two preceding studies and the first observation survey of safety seat usage in 19 metropolitan areas (Section 2.2.4) had shown that safety seat effectiveness was being seriously degraded because many seats were being misused. The contract's objective was to compute injury rates for correctly used vs. misused seats and for various types of seats. The original plan was to obtain the cooperation of emergency rooms and physicians' offices in providing injury data and interviewing parents about how safety seats were installed and used. A pilot test in Montgomery County, Maryland, despite full cooperation by the hospitals and doctors involved, showed that this plan would not achieve an adequate sample of restrained children within available funds and time. Further work was stopped until a feasible data collection method could be found.

North Carolina's Child Passenger Protection Law, which took effect in July 1982, required the Highway Safety Research Center (HSRC) to evaluate the law in cooperation with the State Department of Motor Vehicles. The original NHTSA contract (now under Traffic Safety Programs management) was modified to co-sponsor HSRC's evaluation [28] and have them provide the accident data specified in its original objectives.

From May 1983 to March 1984, the State DMV furnished HSRC with reports of all accidents involving child passengers aged 0-3. HSRC interviewed parents (or other accompanying adults) by telephone on a probability sample of cases [28], pp. 8-16. The interview included detailed questions on the type of injuries, restraint system usage and, if a safety seat was used, the disposition of the harness, lap belt and tether and the direction in which the seat was facing [28], pp. 17-37.

The North Carolina data are unique in that they are the only large accident data file (2105 unweighted child cases) which includes information on whether safety seats were correctly used. Moreover, they specify the interview-based and the police-reported restraint system usage in each case, making it possible to examine the police-reported usage for classification errors (if one assumes that interview-reported usage is valid). They can be used to check on some of the patterns observed in the State data analyses (e.g., possible overreporting of lap belt usage, underreporting of safety seat usage). On the other hand, two possible shortcomings of the HSRC data, as compared to the original plan for the contract, are that parent-reported injury information is not as authoritative as data provided by medical facilities and restraint use and misuse information given over the phone several days after the accident might not be as fresh or candid as what would be stated at the treatment facility soon after the crash.

The analytic report by Hall et al [28] classified safety seat usage into two categories: "proper" and "improper," based on the parent interview. A seat was "improperly" used if it was not belted to the car/failed to stay in place or the child was not harnessed in the seat/was ejected from the seat or if the seat faced in the wrong direction. Otherwise, it was "properly" used [28], p. 37. The rationale for this simple dichotomy was that telephone interviews precluded an accurate determination of seat make/model, tether use or appropriateness of the lap belt routing. Thus, the "improper" uses include most of the "gross misusers" and some "partial misusers" in the nomenclature of Section 1.6, while the "proper" uses include the "correct users" and many or most of the "partial misusers." Hall's report relied almost entirely on the interview-based injury data, rather than the police-reported injury data.

In addition to Hall's formal report, HSRC provided certain tables to NHTSA with a more detailed treatment of misuse modes, police-reported vs. interview-reported restraint use, and police-reported vs. interview-reported injury scales.

The principal finding of the formal report was that safety seats are highly effective, especially if they are "properly" used. The sample consisted of 7197 weighted (2105 unweighted) child passenger cases, with parent-reported restraint use distributed as follows [28], Table 35:

	N of Cases	Percent of Cases
Unrestrained	3,537	49
Safety seat - "proper"	1,722	24
Safety seat - "improper"	913	13
Lap belt	1,025	14

Note that lap belt usage is 3 times as high as what was observed in the 1983 survey in 19 cities (Table 2-3). Thus, parent-reported lap belt use is consistent with the trend seen in the State data files.

The parent-reported injury descriptions were grouped into 5 categories [28], pp. 26-35, of which the two most severe ones were "fatal or severe head injury" and "fractures or severe bleeding--other than head." Injury rates were computed for the top level of injury and for the top two. Then they were adjusted, with vehicle damage severity as the control variable. After adjustment, the effectiveness estimates were [28], Table 37:

Reduction of	Safety Seat "Proper"	Safety Seat "Improper"	Lap Belt
Fatality, serious head injury	76	45	32
Fatality, serious head injury, fracture, severe bleeding	57	42	39

The estimates for safety seats are higher than in the two preceding studies although, to be sure, the combined effectiveness for all restrained children (seats plus belts) is nowhere near the 74-91 percent of Scherz's study. It is perplexing, however, that the effectiveness of "improperly" used seats should be so high when, according to the description on p. 37 of [28], most of those seats were grossly misused.

A more detailed tabulation of the "improperly" used seats revealed that, in fact, only half of them were grossly misused--i.e., the harness was not used or the lap belt was not used. (That amounts to 18 percent of all safety seat users--identical to the Hardee's survey, as shown in Table 2-2.) The other half were partial misusers--i.e., the seat faced the wrong way or the seat moved a short distance forward or sidewise (possibly indicating a misrouted lap belt). Injury reduction was calculated separately for the partial misusers and the gross misusers (without controlling for vehicle damage severity, in this case):

Reduction of	All Safety Seat Users	Safety Seat "Proper"	Safety Seat "Improper" Partial Misusers	Safety Seat "Improper" Gross Misusers
Fatality, serious head injury	70	77	55	70
Fatality, serious head injury, fracture, severe bleeding	57	62	41	58

The 70 and 58 percent injury reductions for the gross misusers are almost as high as the 77 and 62 percent reductions for "properly" used safety seats, indicating a strong bias in the data. The principal source of bias appears to be the parent-reported injury scale used by HSRC. One obvious problem is that the scale puts any facial laceration requiring stitches in the "serious head injury" category while placing serious internal injuries, rib fractures, etc, in the next lower category. In addition, it seems that parents who claimed their children were in safety seats underreported the severity of the injuries and/or parents who claimed that their children were unrestrained overreported it. At first glance, that would seem hard to believe, especially considering the objective, detailed and straightforward interview protocol used by HSRC [28], pp. 26-35 and Appendix B. But the proof of the matter is that a far more credible set of estimates is obtained when the police-reported injury severity is used in combination with the parent-reported restraint system usage:

Reduction of	All Safety Seat Users	Safety Seat "Proper"	Safety Seat "Improper" Partial Misusers	Safety Seat "Improper" Gross Misusers	Lap Belt Users
K or A level injury	56	77	46	1	61
K, A or B level injury	40	60	23	-10	34
Any injury	45	56	41	11	41

Note that these reductions are based on simple injury rates and have not been adjusted for differences in vehicle damage severity or seat position. If they had been adjusted, they might have been 5-10 points lower [28], pp. 71-80. The unadjusted estimates for all safety seat users (56, 40 and 45 percent reductions of serious, moderate and minor injuries in the preceding table) are essentially the same, within sampling error, as the unadjusted estimates in Pennsylvania data shown in Table 5-2 of this report (43, 52 and 44 percent reductions).

The estimates for "properly" used seats (77, 60 and 56) seem high, although not inordinately so, considering that at least 1/3 of the "properly" used seats were, in fact, partially misused. Conversely, the estimates for gross misuses (1, -10, and 11) might all have been less than zero if they had been adjusted for seat position and vehicle damage severity--i.e., too low. To some extent, this may be due to HSRC's method of determining if a seat was misused--i.e., if something bad happened (child thrown from seat, etc.) then the seat was misused. It also seems possible that parents whose children were injured, especially at the higher levels of injury, may have been more likely to report a misuse of the seat than if the child was uninjured, thereby distorting the results even more in favor of the "properly" used seats. But this last effect, if it occurred at all, could not have been excessive: the 60-77 percent unadjusted injury reduction for "properly" used seats, corresponding to an adjusted reduction of 50-75 percent, is very much in line with the other findings of this report.

When the <u>police-reported</u> restraint usage data are used in combination with the police-reported injury data, the injury reduction for safety seats is 52 percent for K + A level, 37 percent for K + A + B and 36 percent for all injuries. Those estimates are just 4, 3 and 9 percent lower than with parent-reported restraint usage. In North Carolina, in the case of small children, the source of the restraint usage information does not appear to bias the effectiveness too much (see also Table 33 of [28]).

3.2.4 Police reporting of restraint system usage in North Carolina

A major advantage of the North Carolina data is that they allow a comparison of police-reported and parent-reported restraint system usage. As Hall argues in [28], pp. 65-66, the parent-reported usage was probably a lot more accurate because of HSRC's in-depth systematic interviewing approach, the rapport established between interviewer and parent, and the opportunity that parents had to decline the interview if they did not desire to discuss the accident (and fewer than 5% of parents declined to be interviewed [28], pp. 22-23). So, in the discussion that follows, discrepancies between the two sources will be termed "errors" in police reporting.

Table 30 of the HSRC report contains the basic data:

Police-Reported	Parent-Reported			
	Unrestrained	Safety Seat	Belts	Total
Unrestrained	3644	688	467	4799
Safety seat	22	1823	47	1892
Belts	22	233	559	814
Total	3688	2744	1073	7505

Police and parents agreed in 6026 cases, or 80 percent of all cases. Police had a clear tendency to underreport usage of both types of restraints: there were only 44 unrestrained children whom the police reported to have been restrained, but 1155 cases for which the opposite happened. Safety seat usage, in particular, was underreported by 31 percent (2744 vs. 1892).

The North Carolina data especially shed light on the reporting of lap belt usage. The clear majority (559 out of 814, or 69%) of children reported as "belted" by the police were, in fact, lap-belted. It is true that 233 of the 814 reported lap belt users (29%) were actually in safety seats, but that number is overshadowed by the 467 who really wore lap belts but were reported unrestrained. In total, the police somewhat underestimate actual lap belt usage (814 reported vs. 1073 actual). It seems likely, then, that the observational surveys described in Chapter 2, which consistently showed less than half the lap belt usage of accident data, gave substantial underestimates--presumably because it is harder to see a lap belt on a small child than a safety seat (or a lap/shoulder belt on an adult). The estimates of lap belt usage in accident statistics, on the other hand are reasonably accurate and the reported "lap-belted" populations are indeed, for the most part, lap-belted and not in safety seats.

One exception to this rule in North Carolina however, is the infant population [28], Table 31. Out of 70 police-reported "lap belt users" aged less than 1, 64 were actually in safety seats. (That means that for the 744 reported lap belt users aged 1 or more, 553, or 74% were really lap belted and only 169, or 23% were actually in safety seats.)

The North Carolina data make it possible to focus on the police's underreporting of safety seat usage as a function of how the seats were actually used/misused. Table 3-1 shows that there were 251 (110 + 141) children who used a safety seat, according to parents, but "improperly," with the harness unattached (parents said that the child was thrown from the seat or the harness was unused or unknown if used); 110 of these, or 44 percent were reported as "unrestrained" by the police. Out of 206 children

TABLE 3-1

POLICE UNDERREPORTING OF SAFETY SEAT USAGE, BY SAFETY SEAT USE MODE (NORTH CAROLINA)

Parent-Reported Safety Seat Use Mode	Police-Reported Restraint Usage		
	Unrestrained	Safety Seat	Percent Underreporting
Harness not used	110	141	44
Lap belt not used, harness used	84	122	41
GROSS MISUSERS	194	263	42
"Improper": partial misuse	107	349	23
"Proper"	383	1212	24
CORRECT USERS AND PARTIAL MISUSERS	490	1561	24

who used a safety seat "improperly," unsecured by a lap belt (parents said the seat tipped over completely, or a lap belt was unused or unknown if used) 84, or 41 percent were reported as "unrestrained" by police. The two preceding groups constitute the gross misusers of safety seats: 42 percent were reported as unrestrained by police.

There were 456 children whose safety seat usage was described as "improper" by HSRC but who would mostly be called partial misusers in this report: the seat was facing in the wrong direction for a child that size, or the seat moved a short distance forward or sideways probably due to a misrouted lap belt, etc. Only 23 percent of those children were reported unrestrained by the police. A nearly identical 24 percent of the "properly" restrained children (by HSRC's definition, which includes correct users and some partial misusers) were reported unrestrained. Those two groups constitute the correct users/partial misusers of safety seats: 24 percent were reported as unrestrained by police.

It is intuitively reasonable that underreporting was more prevalent for the grossly misused seats--i.e., if the child was thrown from the seat or the device was lying on the floor of the car, police would more readily conclude that the seat was not used. The different rates of underreporting have two important implications, however, for accident analyses based on police-reported restraint system usage:

- Effectiveness will be biased upwards, because the police-reported sample of users will contain proportionately fewer gross misusers (who get little benefit) than the population of actual users. The amount of bias is explored in Section 8.2.1.

o Usage is always underreported, but more so in earlier years when there were proportionately more gross misusers. For example, in 1984, when 18 percent of seats were grossly misused (Table 2-5), police underreported usage by 27 percent (.18 x .42 + .82 x .24). But in 1979, when 50 percent of seats were grossly misused safety seats or home child carriers used as car seats, police underreported it by 33 percent.

3.2.5 Tennessee's case-by-case fatality analysis (1979-82)

Two accident studies were performed in Tennessee, whose safety seat usage law took effect on 1-1-78, 2 1/2 years before any other State.

The Tennessee Highway Patrol performed a case-by-case analysis of the 51 child passengers age 0-3 who were killed in Tennessee accidents during 1979-82 [24]. Only 2 of the 51 fatalities were restrained, whereas safety seat usage by the general traffic population was 25 percent during 1979-82 in Tennessee. In each case they asked, "Would this child have died if a safety seat had been correctly used?" They concluded that 35 of the 49 unrestrained children would have survived: an effectiveness of 71 percent.

The study differs from all the other analyses of accident data in two important respects:

o It attempts to estimate the fatality reduction for correctly used safety seats, only.

o It is based on case-by-case judgmental analysis of what would have happened if a child had been restrained, not on real injury rates of children who actually were restrained.

There have been other case-by-case analyses of children in accidents but this one is unique in that it is based on a substantial number of truly severe crashes--a census of fatalities. Its major shortcoming is that it is based primarily on State accident data, which generally do not contain a detailed biomechanical reconstruction of the accident.

Although the rules for judging whether a correctly restrained child would have survived are not explicitly stated by the Tennessee Highway Patrol, a review of their paper suggests that the 49 unrestrained fatalities can be assigned to various groups. First, here are the groups of children who would not have survived, even if correctly restrained. The groups are listed in descending order of how confident this reviewer feels about Tennessee's decision that the child would have died:

a. Catastrophic fire or complete submersion in water (6 children)

b. Severe passenger compartment invasion at the child's seat position (6 children)

c. Insufficient information on report--assume conservatively that restraint would not have saved child (2 children)

Total: 14 children (29 percent)

Here are the groups of children that Tennessee feels would have survived if correctly restrained, again listed in descending order of this reviewer's confidence in the decision.

A. Child fell from a moving vehicle--no crash (2 children)

B. Ejected in an otherwise easily survivable crash (5 children)

C. Low speed collision in which all other occupants escaped significant injury (11 children)

D. Crash in which all other occupants escaped significant injury--no compartment invasion at child's position (7 children)

E. Another child in same car was correctly restrained and survived (1 child)

F. Died only as a result of head injury from being thrown into windshield or dashboard (4 children)

G. Collision in which other (unrestrained) persons were killed, but investigator felt was intrinsically survivable if child had been restrained (5 children)

Total: 35 children (71 percent)

From these categories it would not appear that Tennessee has overestimated the potential benefits of correctly used safety seats. Among the potential survivors, only group G would appear to raise significant doubts and it only contains 5 children. (Note that more than half of the children belong to group A, B and C and would almost certainly have been saved by correctly used seats or even partially misused ones.) If all children in groups G and c would not have been saved, effectiveness could have been as low as 61 percent. But if all children in groups G and c would have been saved, fatality reduction would have been as high as 76 percent.

Thus, the Tennessee case-by-case analysis is quite compatible with the sled test results of Chapter 7, which suggest a 67 percent serious injury reduction for correctly used safety seats (Table 7-8)--especially so in view of the hypothesis that fatality reduction for correctly used seats ought to be a few percent higher than serious injury reduction.

Of course, if fatality reduction for correctly used safety seats is 71 percent, the aggregate fatality reduction for all safety seat users was much lower during 1979-82, since fewer than 1/4 of safety seats were correctly used (see Table 2-5).

3.2.6 Decker et al. - Tennessee data (1982-1983)

The United States Center for Disease Control, in cooperation with the Tennessee Department of Health and Environment and the Vanderbilt University School of Medicine analyzed data from a "bi-level" study conducted by Tennessee police agencies [15]. In other words, police were requested to supplement their usual accident report with a short additional form on child passengers' restraint use, seat position, injury severity, etc., in any accident where there was a child passenger younger than 4. In fact, the bi-level form was filled out for only 991 child passengers during 1982-83 and the study was based on those cases - that would appear to be about 10 percent of all police-reported accidents involving child passengers (based on per capita involvement rates in North Carolina [28], Maryland [7], New York [7] and New Jersey [47]). The accidents in which the bi-level form was filled out were disproportionately the ones investigated by State police or in which someone was injured.

Restraint system usage in the 991 case sample was:

	N of Cases	Percent of Cases
Unrestrained	498	50
Child seat	433	44
Lap belt	60	6

"The rates of child restraint device use presented herein are higher than those found in the [Tennessee] observational studies, which may be due to greater propensity to use child restraint devices during interurban trips [15]." But in all the other studies based on State accident data, police-reported safety seat usage was well below actual usage, as discussed in the preceding section. The anomaly here could be indicative of an unusual bias in the accident data.

The raw, unadjusted injury rates were:

	N of Children	% Inj.	% K,A, or B	% K or A
Unrestrained	498	56.4	47.2	18.9
Child seat	433	29.1	19.2	3.7
Lap belt	60	40.1	35.0	10.0

The observed injury reductions, based on the preceding injury rates, were:

	Child Seats	Lap Belts
K or A injury reduction	80	47
K, A or B injury reduction	59	26
Overall injury reduction	48	29

The effectiveness values are higher than those found in other studies, except Scherz's; actually the 80 percent reduction of K + A injuries is higher than Scherz's 74 percent. Furthermore, mirabile dictu, the 80 percent reduction here, which applies to the mix of correctly used and misused safety seats, is higher than the 71 percent fatality reduction estimated for correctly used seats alone in the other Tennessee study.

The circumstantial evidence suggests that the effectiveness results may have been biased upwards much as they were in Washington State. Tennessee was the pioneer of safety seat use laws; for years, the safety and medical community watched it closely, hoping for success. All police agencies had been requested to fill out the bi-level forms but only a small percentage of officers actually did: they may well have been the ones most motivated by enthusiasm for the new law. That enthusiasm, plus parents' fear of admitting a child was unrestrained when the law requires safety seats could have led to the overreporting of safety seat usage (mentioned above) by uninjured children. Conversely, if a child had been in a seat and injured, the enthusiastic officer who subsequently arrived at the scene might disbelieve the parents' claim that the seat was used (for then the child should not have been injured) or believed the claim but played down the injury severity and code it as B rather than A (since the distinction between A and B is a judgment call). Evidence for the latter possibility is found in the large discrepancy between the K + A injury reduction (80%) and the K + A + B reduction (59%); in Pennsylvania (Table 5-2) the reductions were 43 percent and 52 percent, respectively.

3.2.7 Wagenaar and Webster - Michigan injury data (1978-83)

Michigan's safety seat usage law for children aged 0-3 took effect on April 1, 1982. Wagenaar and Webster analyzed the benefits of the law, using State accident data [81]. They were handicapped because the data did not specify the restraint system usage of uninjured children, thereby making it impossible to calculate injury rates. Instead, they based their study on the raw month-by-month counts during 1978-83 of injured children aged 0-3, using time-series analysis to determine the effect of the use law on the counts. They determined that

o Child passenger injuries decreased by 25 percent as a consequence of the law.

o Before the law took effect, 12 percent of injured children were restrained by safety seats or lap belts.

o After the law was implemented, 51 percent of injured children were restrained.

Obviously, the law greatly increased usage of restraints and it reduced casualties. Moreover, the findings can be used to calculate the overall usage u_1 of restraints before the law (injured plus uninjured children), the overall usage u_2 after the law and the injury-reducing effectiveness e of restraints (when used)--by solving the 3 equations

$$\frac{(1-e)u_1}{.12} = \frac{1-u_1}{.88}$$

$$\frac{(1-e)u_2}{.51} = \frac{1-u_2}{.49}$$

$$(1-e)u_2 + (1-u_2) = (1-.25)\,[(1-e)\,u_1 + (1-u_1)]$$

The solutions are:

- The injury risk of a restrained child is 49 percent lower than for an unrestrained child

- 21 percent of children age 0-3 were restrained before the law

- 67 percent were restrained after the law

The 49 percent overall injury reduction for restrained children, which has not been adjusted for seat position, vehicle damage, etc., agrees closely with the 44 percent reduction for safety seats in Pennsylvania (based on unadjusted data--see Table 5-2).

Wagenaar also determined that fatal or incapacitating (K + A) injuries decreased by 22 percent as a consequence of the law. Again it is possible to determine the effectiveness E of restraints when used.

$$(1 - E)u_2 + (1 - u_2) = (1 - .22)\,[(1 - E)u_1 + (1 - u_1)]$$

where $u_1 = .21$ and $u_2 = .67$, as explained above. Thus

E = 43 percent reduction of K + A injuries, which is identical to the reduction for safety seats in Pennsylvania.

3.3 Sled testing of safety seats--earlier comparative studies

The traditional sled test for a safety seat, which is also used in compliance tests for Standard 213, involves a sled buck which is a "Standard Seat Assembly," resembling a bench seat of a passenger car. One or two safety seats are belted to the bench seat and Part 572 dummies are buckled into the safety seats. The sled buck does not contain other components of the passenger compartment such as the instrument panel, side doors, etc., so it is not possible to measure the forces on the dummy resulting from contacts with vehicle components. It is only possible to measure the forces resulting from the dummy's contact with itself or the restraint system and from noncontact phenomena. Specifically, the values of Head Injury Criterion (HIC) and chest g's measured in these tests are representative of what would have happened in real crashes if the dummy is correctly restrained and would not have contacted the vehicle interior. But the values of HIC and chest g's are not meaningful for an unrestrained dummy or for one that would have contacted the vehicle interior during a crash, since such contacts are not simulated by this sled buck. Instead, the measures used as surrogates for likelihood of contact with the vehicle interior are head excursion and, to a lesser extent, knee excursion: the maximum distances those parts of the dummy achieve relative to a fixed reference plane (the Seat Back Pivot Axis in a frontal test and the restraint's centerline in a lateral test). For example, a frontal head excursion of 35 inches or more means that the child's head would contact the instrument panel even in a large car while 27 inches or less would avoid such contact in small cars [45].

Head excursion cannot be measured for an unrestrained dummy or a grossly misused seat where the dummy becomes a projectile or a seat that fails during the test and allows the dummy to escape. Such cases are simply categorized as "dummy ejected."

Only the sled tests described in Chapter 7 of this report, based on a sled buck simulating an entire passenger compartment, allow estimation of injury risk for both restrained and unrestrained dummies. But the earlier sled tests described in this section and the NHTSA compliance tests described in Section 3.4 provide extensive information to check and complement the results of Chapter 7. They measure HIC and chest g's accurately for correctly used seats, under test conditions that are significantly different from those of Chapter 7 (above all, higher sled g's than in Chapter 7). They measure head excursion and describe the mechanical performance of partially misused seats.

3.3.1 Bayer, Peterson and Naab (1977-78)

The tests were performed at NHTSA's Engineering Test Facility [3] or Calspan [68] during 1977-78 before the dynamic test requirement of Standard 213 took effect. Radovich et al summarized and analyzed the test results [68]. Frontal tests were performed at 30 mph with 23-24 peak sled g's. The average values of head excursion and HIC, by seat type, were:

Seat Type	N of Tests w. Known Head Exc.	Avg. Head Excursion (In.)	N of Tests w. Known HIC	Avg. HIC
CORRECT USES				
Tethered belt-around	1	21.7	25	392
Tethered (belt thru frame)	5	26.6*	3	451
Tetherless harness-only	3	27.8	3	340
Shield booster**	4	29.4	28	819
Infant (belt thru frame)	3	36.5	--	---
PARTIAL MISUSES				
Tethered (belt thru frame) - tether not used	5	31.5***	--	---
Tethered belt-around - tether not used	1	37.8	--	---

*24.5 in the 3 tests where the tether did not break
**Ford Tot Guard or Mopar Child Seat, only
***36.0 for Strolee

Four generic types of toddler seats were tested in the correct use mode. They were 1977-78 models, predating Standard 213's dynamic test requirements by 3-4 years. Nevertheless, average head excursion was well below 32 inches (the subsequent test criterion) for each type and HIC's averaged well under 1000. There were some clear differences between seat types. The tethered belt-around (GM Love Seat) had substantially lower head excursion than other tethered types, which in turn had lower excursion than the two tetherless types. The three types that rely on a harness to restrain the child had about half the HIC of the shield-equipped type.

In the partial misuse modes, however, the tethered belt-around type allowed the greatest head excursion at 30 mph. The performance of the other tethered seats without the tether was not as bad as might be expected, in part, because some of them were, essentially, "tetherless" seats with "optional" tethers. The Strolee, which had a high platform and was definitely intended for use with a tether, had a lot of head excursion without it.

Fifteen dummies were subjected to 20 mph frontal impacts, including 9 in tether-equipped seats with the tether not in use and 5 in tetherless seats which are currently (1985) not on the market. The latter 5 all had head excursions of greater than 33 inches at 20 mph, which is probably why they are no longer on the market (the 1981 version of Standard 213 allows at most 32 inches at 30 mph).

The Test Facility also ran 8 dummies through 60 degree lateral impacts at 20 mph. The seat types that were tested, all in the correct use mode, were the tethered, tethered belt-around, tetherless belt-around, tetherless harness-only, tetherless full-shield, infant belt-around and infant (belt through frame). Only the tethered belt-around seat (which Radovich considers the standard by which all other seats are judged [66]) prevented the dummy from hitting the door panel adjacent to the dummy's seated position on the impacted side.

Dummies were not ejected from the seats on any test. On the other hand, many of the seats were damaged, even when correctly used: especially those tetherless seats which were subsequently withdrawn from the market. But, also, there were 4 cases of buckles opening on the lateral tests and 2 in frontal tests, 2 tethers that separated and one seat whose rivets pulled out.

3.3.2 Kelleher and Walsh (1978 and 1982)

Calspan performed two studies under contract to Transport Canada [44], [43]. The second one is summarized in a paper co-authored with the sponsors [45]. Canadian Standard 213 allows only 28 inches head excursion in the 30 mph frontal test, as opposed to 32 inches in the United States. The result is that tetherless seats, which have difficulty meeting a 28-inch standard, are rare in Canada. These studies emphasize tether-equipped seats; the 1978 report almost excludes other types. The amounts of head excursion (measured relative to the seat back pivot axis) in the 30 mph (22-23 sled g's) frontal crashes of the 1978 study were:

Seat Type	N of Tests	Avg. Head Excursion (In.)	
CORRECT USES			
Tethered belt-around	1	23.5	
Tethered (belt thru frame)	17	25.4	
Shield booster*	1	26.9	
Tetherless Pre-Std. 213-81	2	33.8	
Tetherless belt-around	1	34.4	
PARTIAL MISUSES			
Tethered belt-around - tether not used	1	33.8	
Tethered (belt thru frame) - tether not used	6	34.4	(1 apparent dummy ejection excluded)

*Ford Tot Guard

(Ten inches were added to the head excursions listed in [44], which were measured from the "seat reference plane" rather than the seat back pivot axis. The Canadian regulation allows 18 inches excursion beyond the seat reference plane [44] and 28 inches beyond the seat back pivot axis [45], a 10 inch difference. HIC was not included in these tests.) The frontal test results are quite similar to Bayer and Peterson's.

In the 1978 study's 90 degree lateral tests at 20 mph, the tethered belt-around seat again demonstrated its superiority, allowing 11.5 inches of lateral head excursion, while ten tethered seats had an average of 18.3 inches excursion and a tetherless full-shield type, 28.2 inches.

In the 1978 study's 45 degree sled runs at 30 mph, the 5 tethered seats (belt thru frame) allowed an average of 19.3 inches of head excursion in the direction of the sled acceleration vector, a tetherless belt-around type, 21.3 inches and the 2 pre-Standard 213-81 tetherless seats, an average of 23.3 inches.

The 1982 study contained a larger number of tetherless seats and, for the first time, booster seats; also, a wider variety of partial misuse modes and even some gross misuse modes. Of course, there were no measurements of head excursion in the gross misuse modes, only a description of the dummy's trajectory out of the seat. HIC was not reported for the tests with 3-year-old dummies. The head excursions in the frontal impacts were:

Seat Type	N of Tests	Avg. Head Excursion (In.)	
CORRECT USES - 27.5 mph			
Booster (with tether harness)	4	20	
Tethered (belt thru frame or around child)	unknown	24	
Tetherless belt-around or partial shield	5	28	
Tetherless harness-only	12	30	
Tetherless full-shield	2	30	
PARTIAL MISUSE - 27.5 mph			
Tethered: tether not used	2	34	
PARTIAL MISUSE - 18.2 mph			
Tethered: tether not used	4	29	
Tetherless belt-around or partial shield: harness not used, shield used	4	29	
Booster: no upper body restraint	4	32	
Tetherless: belt too low on frame	6	33	2 dummies ejected inches on the other 4

Head excursion with correctly used booster seats was clearly lower than with any other type of toddler seat. On the other hand, the study hints that booster seats might be associated with higher HIC's in 30 mph, 22 g crashes than are other seat types. A 6-year-old dummy had HIC of 977. No HIC's were reported, however, for the 3-year-old dummies. The results for tethered and tetherless seats were similar to the preceding studies. The tests clearly showed the hazard of routing the lap belt too low on the frame, with serious damage to some seats at 18.2 mph. The partially misused booster seat also had a lot of head excursion at that speed.

The contractor also performed ten 60 degree lateral sled tests at 20 mph using a variety of restraints, including correctly used booster seats. None of the devices would have prevented a nearside dummy from contacting the door with its head. (The tethered belt-around seat was not included among the tests.) But all of the devices prevented a center-seat occupant from contacting the door.

3.3.3 Weber and Melvin (1983)

The Highway Safety Research Institute performed 30 mph tests with partially misused seats as part of a NHTSA contract managed by Clark [82]. The tethered belt-around seat, with tether unattached, had 35.4 inches of head excursion--but the films suggested the seat might have worked its way loose from the lap belt if the speed had been higher and the dummy smaller. A tethered seat (belt through frame) with the tether unattached allowed 34.9 inches of head excursion. When, in addition, the lap belt was routed too low on this type of seat, the rivets in the frame tore apart and the seat/dummy became a projectile. A recently designed tetherless seat, by contrast, did not fare too badly with a misrouted lap belt; head excursion was 31.5 inches and the seat remained intact.

An infant belt-around seat in the forward facing position allowed the infant dummy to slide forward until its neck was caught on the vehicle's lap belt.

3.3.4 Comparison with results of Chapter 7

In general, the results of the published sled test studies are similar to those of Chapter 7 of this report. In the preceding studies, correctly used safety seats generally did not allow head excursions in excess of 32 inches in 30 mph frontal tests. Likewise, in Chapter 7, all of the correctly used seats were able to prevent a dummy's head from contacting interior components of an average sized vehicle (Chevrolet Citation).

In the earlier studies, partially misused seats consistently allowed more than 32 inches of head excursion at 30 mph and sometimes permitted it even at 20 mph. Similarly, in Chapter 7, partially misused seats allowed dummies' heads to contact the vehicle interior in most 35 mph tests, some 25 mph tests, but none of the 15 mph sled runs.

Another strong similarity between the earlier studies and the MCR results is that seats were damaged as a result of the tests, especially partially misused seats. The types of seat damage experienced in the HSRI tests were quite similar to those of Chapter 7. Some of the seats with the belt routed too low were damaged in the Calspan tests (Section 3.3.2) at 18.2 mph and in the Chapter 7 tests at 25 mph (but not at 15 mph). The work at the Engineering Test Facility revealed numerous damages even to correctly used seats. Although it is possible that the MCR tests had an increased number of damages as a result of seats being reused (see Step 8 in Appendix 1), the studies reviewed here show that similar damages occurred even when fresh seats were used on each test.

In one area there appears to be a difference between Chapter 7 and earlier sled tests: the dummies' HIC values. Bayer, Peterson and Naab's tests with early shield booster seats (Tot Guard and Mopar) had a higher HIC (819 @ 30 mph) than Khadilkar's tests with full-shield seats (383 @ 25 mph and 796 @ 35 mph - see Table 7-2). On the other hand, results for tethered and tetherless-harness only seats were about the same in the two studies. The earlier studies do not provide enough HIC data on recent safety seat designs for any further analysis. The review of NHTSA compliance test results for 1981-84, presented in the next section, is much more useful for that purpose.

3.4 Analysis of NHTSA compliance test data (1981-84)

The agency's compliance test files for 1981-84 include records of 110 frontal sled tests performed at close to 27.5 mph with correctly used forward-facing toddler seats occupied by 3-year-old Part 572 dummies. They comprise most of the makes and models of seats produced during those years. More than one seat was tested in many of the make/models if, for example, there was more than one "correct" use mode (e.g., upright and reclined) or if the model was produced for two or more years, or if any of the parameters measured on the first test was beyond the allowed limits.

An additional 30 seats were tested at 18.5 mph in one of three partial misuse modes: (1) tether not used on a tethered seat, (2) harness not used on a seat that has a separate shield and a harness, (3) no upper body support (tether harness or shoulder strap) on a booster seat.

All compliance tests were conducted according to exacting specifications [11] at the Calspan HYGE sled. (The results were compiled from about 90 documents on file at the NHTSA Technical Reference Library.) In the correct use modes, sled velocity was always within ± 0.4 mph of 27.5 and the sled's acceleration-time history had to be inside a band that was nowhere more than 3 g's wide. Specifically, peak g's were always close to 22. Likewise, in the partial misuse tests, speeds were equally close to 18.5 mph and peak g's, 15. Note that these are much more abrupt accelerations than the sled tests of Chapter 7 (8 g's @ 15 mph, 14 g's @ 25 mph and 20 g's @ 35 mph). In the compliance tests, fresh seats and fresh lap belt webbing (always from the same roll, to assure repeatability) were used on each run, but not in Chapter 7. Tethers and tether-harnesses were anchored behind the seatback, assuring that these devices would perform efficiently.

The objectives of the analysis of compliance test results were to check the findings and assumptions of Chapter 7 and, more generally, to compare the variety of seat types and models that were on the market during 1981-84. Specifically, the objectives were:

o A comparison of HIC, chest g's and head excursion for the 8 generic typs of toddler seats (correctly used at 27.5 mph). How do the results compare with Chapter 7, where sled g's were much lower and several other conditions were different?

o A comparison, within seat types, of the various brands on the market. Chapter 7 only tested one brand for each generic type and assumed other brands would have yielded similar results. Is that a valid assumption?

o Tests of other hypotheses in Chapter 7, such as: tetherless harness-only, tetherless partial-shield and tetherless beltaround are about equally effective when correctly used; shield booster is about as effective as tetherless full-shield.

o A closer look at the performance of booster and shield-booster seats, where few data have been available in the past.

Appendix 5 of this report lists all of the compliance test results, starting with the correct-use tests at 27.5 mph, followed by the misuse tests at 18.5 mph. The data are classified by generic seat type. The document number, seat make/model, HIC, chest g's and head excursion are listed for each record. Ten of the cases, however, were excluded from the analyses: the Nissan safety seat because the emergency locking retractors on its harness seem to be responsible for test results which are not directly comparable to the other types (viz., unreasonably large head excursions) and the pre-1983 Cosco-Peterson Safe-T-Shield because it was apparently modified circa 1983, resulting in substantially better performance (the pre-1983 test results would not be characteristic of the current seat).

Table 3-2 presents the average values of HIC, chest g's and head excursion by seat type and, within seat types, by manufacturer. Part A of the table deals with the 100 remaining tests of correctly used seats (27.5 mph) while Part B tabulates the partial misuse tests (18.5 mph).

There were visible differences in HIC among the various types of correctly used seats. For example, HIC averaged 330 in the 37 tests of tetherless-harness only seats and 539 in the 12 runs with booster seats. The variations in chest g's were not as large but for head excursion, the differences between seat types were again clear-cut (e.g., 20.9 inches for boosters and 29.1 for tetherless-harness only).

Within seat types, the differences between manufacturers do not have a clear pattern. For example, among tetherless-harness only seats, the International Astroseats had an average HIC of 241. Only one Strolee seat of this type was tested and HIC was 602. That apparently large difference was offset by the fact that the other 8 manufacturers' HICs were all within the fairly narrow band of 287 to 393. The remainder of Section 3.4 is devoted to a statistical assessment of the significance of differences between seat types and manufacturers.

One important fact is obvious, however, from the data: all of the safety seats listed in Table 3-2, when correctly used, achieved Standard 213's targets of 1000 HIC, 60 chest g's and 32 inches head excursion, usually with a considerable safety margin on each parameter. Among the seat type/manufacturer combinations which were subjected to more than one test, the worst average HIC was 708, chest g's 47.7 and head excursion 30.2

TABLE 3-2

HIC, CHEST G's AND HEAD EXCURSION IN NHTSA COMPLIANCE TESTS, BY SEAT TYPE AND MANUFACTURER (1981-84)

A. CORRECTLY USED SEATS: SLED SPEED APPROXIMATELY 27.5 mph AND APPROXIMATELY 22 PEAK g's

Seat Type	Manufacturer	N of Cases	AVERAGE HIC	AVERAGE Chest g's	AVERAGE Head Excursion (Inches)
TETHERED	Questor (Bobby Mac)	1	289	36.5	23.3
	Strolee	4	406	39.7	27.3
		5	382	39.1	26.5
TETHERED BELTAROUND					
	Century	2	334	38.5	23.1
TETHERLESS BELTAROUND					
	Kolcraft	2	470	47.7	27.8
	Questor (Bobby Mac)	8	508	37.4	28.4
	Welsh	3	698	41.5	28.8
		13	546	39.8	28.4
TETHERLESS - HARNESS ONLY					
	International	3	241	35.7	29.7
	Questor	3	287	38.5	29.6
	Cosco/Peterson	4	309	42.4	29.4
	Century	7	316	40.0	30.1
	Kolcraft	4	321	32.5	28.8
	Graco	2	329	37.4	28.5
	Babyhood	8	340	42.0	28.6
	Welsh	2	360	34.0	29.5
	Pride Trimble	3	393	38.9	28.1
	Strolee	1	602	47.6	26.7
		37	330	39.1	29.1

TABLE 3-2 (Continued)

Seat Type	Manufacturer	N of Cases	AVERAGE HIC	AVERAGE Chest g's	AVERAGE Head Excursion (Inches)
TETHERLESS - PARTIAL SHIELD*					
	International	3	273	32.8	29.0
	Collier-Keyworth	5	309	34.4	29.1
	Century	4	331	38.3	30.2
	Kolcraft	2	371	30.2	27.5
	Questor	2	380	36.0	28.7
	Strolee	1	485	42.4	28.4
	Cosco/Peterson	4	492	40.2	28.8
	Graco	1	749	35.4	31.3
		22	382	36.1	29.1
TETHERLESS - FULL SHIELD					
	Cosco/Peterson**	4	585	40.3	28.8
SHIELD BOOSTER					
	Kolcraft	1	297	26.0	29.8
	Ford	1	410	35.4	26.0
	Questor (Bobby Mac)	1	633	36.8	27.3
	Collier-Keyworth	2	677	34.4	28.9
		5	539	33.4	28.2
BOOSTER (with tether harness)					
	Kolcraft	2	407	36.8	22.0
	Cosco/Peterson	2	440	40.5	21.3
	International	1	460	44.0	19.9
	Strolee	3	493	38.0	20.8
	Century	4	708	41.1	20.4
		12	539	39.7	20.9

*Excludes Nissan child seat, whose harness is equipped with an emergency locking retractor, resulting in test values that are not directly comparable to the others.

**1983-84 models only. They incorporate certain improvements made after the 1982 model run.

TABLE 3-2 (Concluded)

B. PARTIALLY MISUSED SEATS: SLED SPEED APPROXIMATELY 18.5 mph AND APPROXIMATELY 15 PEAK G's

Seat Type/ Misuse Mode	Manufacturer	N of Cases	AVERAGE HIC	AVERAGE Chest g's	AVERAGE Head Excursion (Inches)
TETHERED/tether not used					
	Questor (Bobby Mac)	1	134	22.3	29.0
	Strolee	2	136	20.1	29.3
		3	135	20.8	29.2
TETHERLESS BELTAROUND/shield used, harness not used					
	Questor (Bobby Mac)	4	159	25.0	27.7
	Welsh	3	161	23.5	28.1
		7	160	24.3	27.9
TETHERLESS - "HARNESS ONLY"/harness not used, separate partial shield used					
	Pride Trimble	2	139	23.6	28.6
BOOSTER/tether harness not used (no upper body support)					
	Cosco/Peterson	4	194	14.9	31.5
	Century	3	287	14.7	31.1
	Kolcraft	5	378	17.9	31.9
	International	1	535	15.0	30.0
	Strolee	5	571	15.8	29.9
		18	384	16.0	31.0

inches. The average for all correctly used seats was 418 HIC, 38.4 chest g's and 27.7 inches of head excursion. By comparison, an unrestrained front-seat dummy, allowed to contact the vehicle interior freely, would have experienced close to 1100 HIC and 90 chest g's in 27.5 mph barrier impacts of the type conducted in Chapter 7 (linear interpolation for use mode 1F in Table 7-2).

3.4.1 Differences among seat types

One-way analyses of variance (actually, the SAS General Linear Models procedure since cell sizes were unbalanced [73], pp. 237-263) were performed for HIC, chest g's and head excursion by seat type (correctly used). The analysis for HIC showed a significant effect ($F = 9.57$; $df = 7, 92$; $p < .05$), i.e., the differences between seat types were significantly greater than the test-to-test variations among seats of the same type. The head excursion effect was also significant ($F = 66.97$; $df = 7, 92$; $p < .05$) but the chest g's effect was not ($F = 1.86$; $df = 7, 92$; $p \geq .05$).

Table 3-3 shows the average HIC for each type of seat, ranked from lowest (tetherless-harness only @ 330) to highest (tetherless-full shield @ 585). A statistical procedure - Duncan Grouping - corroborates what is apparent to the naked eye: the eight seat types fall into two groups with respect to HIC. The better group, with average HIC ranging from 330 to 382 (not a significant difference, considering the test-to-test variations within that group - see Appendix 5) consisted of tetherless-harness only, tethered beltaround, tetherless-partial shield and tethered (belt through frame). They are all "traditional" safety seats which use the same fundamental design to restrain a child in a frontal crash: the car's lap belt and/or tether decelerate the seat and do not directly contact the

TABLE 3-3

SEAT TYPES RANKED BY HIC IN NHTSA
COMPLIANCE TESTS* (1981-84)

Seat Type	N of Tests	Average HIC	Duncan Groupings**
Tetherless - harness only	37	330	A
			A
Tethered beltaround	2	334	A
			A
Tetherless - partial shield	22	382	A
			A
Tethered	5	382	A
Shield booster	5	539	B
			B
Booster	12	539	B
			B
Tetherless beltaround	13	546	B
			B
Tetherless - full shield	4	585	B

*Sled speed approx. 27.5 mph and approx. 22 peak g's.

**Seat types with the same letter are not significantly different from one another (α = .05) child. The indirect linkage between the child and the car helps to limit peak forces and keep HIC low in the compliance tests, despite the relatively high sled g's in those tests. The second group, with HIC ranging from 539 to 585, consisted of booster seats (where the dummy directly contacts the car's lap belt and the tether harness, anchored to the car), shield booster and tetherless full shield (where the dummy is decelerated by a shield, not a harness) and tetherless beltaround (paradoxically, one of the "traditional" types). It is clear why the booster and the two shield types would have higher HIC when sled g's are high; as for the tetherless beltaround, perhaps the combination of no tether and the belt around the seat causes the seat to rotate forwards, with resultant head accelerations. Although significantly worse than the preceding group, the 539-585 HIC is still far below the standard's 1000 requirement.

Table 3-4 shows average chest g's for each type. Shield boosters had the lowest chest g's, 33.4, while the other shield type (tetherless full-shield) had the highest, 40.3. The other 6 types were all in the narrow range of 36.1 to 39.8. As noted above, the analysis of variance did not show significant differences between seat types; the Duncan grouping procedure suggests only, perhaps, that shield boosters were significantly better than tetherless full-shield. There were no significant differences between any other pair of types. All seats averaged well below the standard's 60 g requirement.

Since head excursion was a highly repeatable parameter, it was easier to detect significant differences. Table 3-5 shows that there were four distinct groups with respect to head excursion. Booster seats with tethered harnesses were in a class by themselves at 20.9 inches. Next came

TABLE 3-4

SEAT TYPES RANKED BY CHEST g's IN NHTSA COMPLIANCE TESTS* (1981-84)

Seat Type	N of Tests	Average Chest g's	Duncan Groupings**	
Shield booster	5	33.4	A	
			A	
Tetherless - partial shield	22	36.1	A	B
			A	B
Tethered beltaround	2	38.5	A	B
			A	B
Tethered	5	39.1	A	B
			A	B
Tetherless - harness only	37	39.1	A	B
			A	B
Booster	12	39.7	A	B
			A	B
Tetherless beltaround	13	39.8	A	B
				B
Tetherless - full shield	4	40.3		B

*Sled speed approx. 27.5 mph and approx. 22 peak g's.

**Seat types with the same letter are not significantly different from one another (α = .05)

TABLE 3-5

SEAT TYPES RANKED BY HEAD EXCURSION IN NHTSA COMPLIANCE TESTS* (1981-84)

Seat Type	N of Tests	Average Head Excursion	Duncan Groupings**
Booster	12	20.9	A
Tethered beltaround	2	23.1	B
Tethered	5	26.5	C
Shield booster	5	28.2	D
Tetherless beltaround	13	28.4	D
Tetherless - full shield	4	28.8	D
Tetherless - harness only	37	29.1	D
Tetherless - partial shield	22	29.1	D

*Sled speed approx. 27.5 mph and approx. 22 peak g's.

**Seat types with the same letter are not significantly different from one another (α = .05) the tethered beltaround seat (23.1), which was significantly better than other tethered seats (26.5). The (tetherless) shield booster and the other four tetherless seat types had nearly the same head excursions (28.2-29.1) and formed the worst group, still well below the standard's 32 inch requirement. The compliance test results are nearly identical to the research findings summarized in Section 3.3.

The results for partially misused seats were summarized in Part B of Table 3-2. At the relatively low speed of 18.5 mph, tethered seats with the tether unattached had low HIC (135) and chest g's (20.8) with passable head excursions (29.2). Similar results were achieved by tetherless seats with separate shields and harnesses in which the harnesses were not used. (The tests were limited, however, to seats with a crashworthy partial shield, not merely an armrest.) On the other hand, booster seats which required a tether harness/shoulder belt but were used without either did not meet the head excursion requirement in some tests (see Appendix 5) or had HICs over 500 when the dummy's head contacted the legs.

3.4.2 Differences among manufacturers

Two-way nested analyses of variance (using the SAS General Linear Models procedure [73], pp. 237-263) were performed for HIC, chest g's and head excursion by seat type (correctly used) and manufacturer. The analyses showed that, even within a particular seat type, there were significant differences between manufacturers in regard to HIC ($F = 4.41$; $df = 26, 66$; $p < .05$), chest g's ($F = 1.99$; $df = 26, 66$; $p < .05$) and head excursion ($F = 2.12$; $df = 26, 66$; $p < .05$). In other words, the differences between manufacturers within a given seat type were significantly greater than the test-to-test variations among seats of the same manufacturer and type.

The root mean square (RMS) errors for repeated tests of a single seat type and manufacturer, but possibly using different models (e.g., the Bobby Mac Champion, Deluxe II, 411 and 412 are all Questor tetherless beltaround seats) or positional variations (viz., reclined and upright, if both are deemed correct uses) were:

	RMS error
HIC	83.2
Chest g's	4.37
Head excursion	1.09 inches

The RMS errors were the basis for testing the differences between manufacturers of a given seat type. Let x be the average value of a parameter (say, HIC) for seats of a particular manufacturer and type, based on n tests. Let a be the average for all seats of that type and s be the RMS error for that parameter, as shown above. Then

$$z = \sqrt{n}\ (x - a)/s$$

is a measure of divergence from the average for that seat type. For example, there were 8 tests of Century tetherless-harness only seats with average HIC 316. The average for all tetherless-harness only seats was 330. Here

$$z = \sqrt{8}\ (316 - 330)/83.2 = -0.48$$

If:

$z < -2.58$ then the manufacturer is substantially better than average <u>for that type of seat</u> ($\alpha = .005$)

$-2.58 \leq z < -1.65$: better than average ($\alpha = .05$)

$-1.65 \leq z \leq 1.65$: close to average

$1.65 < z \leq 2.58$: worse than average ($\alpha = .05$)

$z > 2.58$: substantially worse than average ($\alpha = .005$)

Table 3-6 lists the performance of each manufacturer's seats, by seat type, according to the preceding criteria. Since tethered beltaround and tetherless-full shield seats were each produced by just one manufacturer, they were not included in the table. Table 3-6 contains 96 cells (32 manufacturer/seat types x 3 parameters); 8 were substantially better or worse than average, 19 were different from average but not substantially, while 69 were close to average. The distribution is consistent with the analysis of variance, which showed significant differences between manufacturers (if all manufacturers were the same, one could expect 1 cell substantially "different" from average, 9 different but not substantially different and 86 close to average--by chance alone). At the same time, the differences between manufacturers are not too extreme, since the vast majority of cells show average performance. None of the manufacturers show a consistent pattern of b's (better than average performance) or w's (worse) in Table 3-6.

Next, the results for the various types of seats were combined to produce single scores for each manufacturer. The main difficulty here is

TABLE 3-6

RELATIVE PERFORMANCE OF SAFETY SEATS IN NHTSA
COMPLIANCE TESTS, BY MANUFACTURER (1981-84 MODELS)

B = Substantially better than average <u>for that type of seat</u> (α = .005)
b = Better than average (α = .05)
w = Worse than average (α = .05)
W = Substantially worse than average (α = .005)
blank = Close to average

	Strolee Wee Care				Century			Cosco Peterson		
	Tethered	Harness Only	Partial Shield	Booster	Harness Only	Partial Shield	Booster	Harness Only	Partial Shield	Booster
HIC		W					W		W	b
Chest g's		w							w	
Head excursion		b			w	w				

TABLE 3-6 (Continued)

	Questor					Kolcraft					Collier-Keyworth	
	Tethered	Tetherless Beltaround	Harness Only	Partial Shield	Shield Booster	Tetherless Beltaround	Harness Only	Partial Shield	Shield Booster	Booster	Partial Shield	Shield Booster
HIC									B		b	w
Chest g's						w	B	b	b			
Head excursion	B							b	w			

	International			Welsh		Graco		Ford	Pride-Trimble	Babyhood
	Harness Only	Partial Shield	Booster	Tetherless Beltaround	Harness Only	Harness Only	Partial Shield	Shield Booster	Harness Only	Harness Only
HIC	b	b		W			W			
Chest g's					b					w
Head excursion							w	b		

that different manufacturers produce different mixes of seat types--which could bias the results if raw data are used. For example, a company that produces only boosters and tethered seats would have lower average head excursion than other companies--even if it ranked at the bottom among booster and tethered seats. Instead of raw data, the scores were adjusted to reflect differences among seat types. Since the average HIC for all compliance tests was 418 and for tethered seats 382, a raw HIC of 500 for a tethered seat was adjusted up to 500 + 418 - 382 = 536. But among tetherless beltaround seats, where 546 was the average, a HIC of 500 would be adjusted down to 500 + 418 - 546 = 372. Again, tethered beltaround and tetherless-full shield seats were excluded from the calculations, since they were produced by only one company.

Table 3-7 presents the adjusted HIC scores for the 12 manufacturers whose seats were tested. They ranged from 289 to 540 and the best 2 or 3 were significantly better than the worst 2 or 3, based on the Duncan test. However, the 6 larger manufacturers (Questor, Strolee, Century, Kolcraft, Cosco-Peterson and Collier-Keyworth, based on the Hardee's survey [14], pp. 22 and 28) were in the narrow band of 353 to 455 and did not differ significantly from one another. Ford's place at the top of the list is readily explained: Ford Tot Guard was lumped with other shield boosters, even though it was a somewhat different type of seat. Relative to shield boosters, Tot Guard had a lower HIC.

Table 3-8 compares the adjusted chest g's for the various manufacturers. Even though the scores varied from 34.9 to 41.5, there was no

TABLE 3-7

SEAT MANUFACTURERS RANKED BY HIC* IN NHTSA
COMPLIANCE TESTS** (1981-84 MODELS)

Manufacturer	N of Tests	Average Standardized HIC*	Duncan Grouping***			
Ford	1	289	A			
			A			
International	7	322	A	B		
			A	B		
Kolcraft	11	353	A	B	C	
			A	B	C	
Questor	15	389	A	B	C	D
			A	B	C	D
Collier-Keyworth	7	406	A	B	C	D
			A	B	C	D
Babyhood	8	428	A	B	C	D
			A	B	C	D
Cosco-Peterson	10	434	A	B	C	D
			A	B	C	D
Century	15	443	A	B	C	D
			A	B	C	D
Strolee	9	455	A	B	C	D
				B	C	D
Pride Trimble	3	482		B	C	D
					C	D
Welsh	5	521			C	D
						D
Graco	3	540				D

*Standardized across seat types--i.e., standardized HIC = Actual HIC -Average for seat type + 418.

**Sled speed approx. 27.5 mph and approx. 22 peak g's.

***Brands with the same letter are not significantly different from one another (α = .05).

statistically significant difference between any two manufacturers, according to the Duncan grouping. In other words, superior performance by a manufacturer on one seat type was cancelled out by average or below-average performance on other seat types (see Table 3-6).

Finally, Table 3-9 analyses head excursion based on adjusted scores. The 6 large manufacturers had nearly identical adjusted scores ranging from 27.5 to 28.4 inches, and were not significantly different from one another. Only Ford was substantially different (better) from the other manufacturers--again, because the Tot Guard was lumped with current shield boosters that allow greater head excursions.

The obvious conclusion from Tables 3-7 to 3-9 is that none of the major manufacturers produces a line of seats that performs consistently better (or worse) than any of the other manufacturers on NHTSA compliance tests.

All of the comparisons between manufacturers that were discussed in this section were based on 27.5 mph frontal impacts, at 22 g's, with three year old dummies in correctly used seats. Neck and abdominal injury parameters were not measured. The results would, of course, not necessarily have been the same under other crash conditions, with dummies of other sizes, or if abdominal injuries had been taken into account (e.g., see NHTSA Docket letter 74-09-N17-018, by W. L. Hall and other North Carolina researchers, dated 9/5/85, expressing concerns about shield booster seats). Therefore, the information presented in Tables 3-6 to 3-9 should not be treated as a comprehensive "rating" of seats.

TABLE 3-8

SEAT MANUFACTURERS RANKED BY CHEST g's* IN NHTSA COMPLIANCE TESTS** (1981-84 MODELS)

Manufacturer	N of Tests	Average Standardized Chest g's	Duncan Grouping***
Kolcraft	11	34.9	A
			A
International	7	36.1	A
			A
Graco	3	37.0	A
			A
Questor	15	37.0	A
			A
Welsh	5	37.3	A
			A
Collier-Keyworth	7	37.4	A
			A
Pride Trimble	3	38.2	A
			A
Strolee	9	39.7	A
			A
Century	15	39.7	A
			A
Ford	1	40.4	A
			A
Babyhood	8	41.3	A
			A
Cosco-Peterson	10	41.5	A

*Standardized across seat types--i.e., standardized chest g's = Actual g's -Average for seat type + 38.4.

**Sled speed approx. 27.5 mph and approx. 22 peak g's.

***Brands with the same letter are not significantly different from one another (α = .05).

TABLE 3-9

SEAT MANUFACTURERS RANKED BY HEAD EXCURSION* IN NHTSA COMPLIANCE TESTS** (1981-84 MODELS)

Manufacturer	N of Tests	Average Standardized Head Excursion (inches)*	Duncan Grouping***	
Ford	1	25.5	A	
			A	
Pride Trimble	3	26.7	A	B
			A	B
Babyhood	8	27.2	A	B
				B
Questor	15	27.5		B
				B
Kolcraft	11	27.5		B
				B
Strolee	9	27.7		B
				B
Cosco-Peterson	10	27.8		B
				B
International	7	27.8		B
				B
Collier-Keyworth	7	27.9		B
				B
Graco	3	28.0		B
				B
Welsh	5	28.1		B
				B
Century	15	28.4		B

*Standardized across seat types--i.e., standardized excursion = Actual excursion -Average for seat type + 27.7.

**Sled speed approx. 27.5 mph and approx. 22 peak g's.

***Brands with the same letter are not significantly different from one another (α = .05).

3.4.3 Comparison with Chapter 7

The only important difference between the compliance tests and the results of Chapter 7 is that the seat types which produced the lowest HICs in Chapter 7 had the highest ones here. Indeed, almost everything else--average HIC for all seats together, chest g's by seat type, head excursion--was remarkably similar considering the differences in crash pulses, sled bucks, dummies, choices of seats and test techniques (e.g., reuse of some seats and all lap belt webbing in Chapter 7).

The specific average HIC values at 27.5 mph of the four seat types which were tested in both studies were:

	Compliance Tests	Chapter 7 (Estimated)
Tetherless - harness only	330	526
Tethered	382	562
Booster	539	289
Tetherless - full shield	584	486
AVERAGE OF 4 TYPES	459	466

The Chapter 7 estimates are based on linear interpolation of the 25 mph and 35 mph results shown in Table 7-2. The booster seat, which was the best performer in Chapter 7, was worse than average on the compliance tests, while "traditional" seats with harnesses had the reverse scoring. The average of all 4 types, however, was nearly identical (459 vs. 466).

The difference is almost surely due to the higher sled g's in the compliance tests (22, as compared to 15.5 in Chapter 7). Possible additional factors are the "looser" restraint installations of Chapter 7 (reuse of the car's lap belts; use of a real vehicle interior as the sled buck, where tethers were not ideally anchored, lap belts not always tight and seats slid or dug into the car's seat cushion) and the differences of the dummies' heads and necks.

Specifically, sled g's are critically important in determining the efficacy of booster seats, where dummies come into direct contact with the car's belts and there is no additional buffer between the dummy and the sled buck's deceleration pulse. Since HIC is based on the formula

$$\int a^{2.5}\, dt \Big/ \Delta t$$

a 50 percent increase in sled g's, even when accompanied by a proportionate reduction in stopping time, can readily result in an 80 percent increase in HIC like the one experienced in the compliance tests vs. Chapter 7.

By contrast, in the "traditional" safety seats, the car's lap belt does not contact the dummy but applies its force to the safety seat structure, which acts as a force-limiting buffer. So higher sled g's do not directly translate into higher HIC. On the contrary, the looser installation procedures of Chapter 7--especially the tendency of the high platform seats to dig into the seat cushion (see Section 7.3)--allowed the seats to tip forward partially and caused the dummies' heads to rotate forward and downward in a whiplike action (perhaps aggravated by the GM dummy's more flexible neck and larger head--see Appendix 1, Step 3). As a result, HIC's were actually higher than in the compliance tests.

Which set of results is "right"? The best answer is: both. The tests of Chapter 7 use the sled pulse of a Chevrolet Citation's barrier impact, which is quite soft relative to most barrier impacts but probably representative of the average highway accident (which tends to have more gradual decelerations than barrier crashes). Similarly, the relatively "loose" installation of seats in Chapter 7 may be representative of actual practice on the highway. But the compliance tests used sled pulses of typical barrier impacts and are representative of an especially severe set of highway crashes. Another advantage is that they used a larger and varied sample of safety seats. Both sets of results should be considered in drawing conclusions about effectiveness.

Aside from the individual HIC results, there were few differences between the compliance tests and Chapter 7. Average HIC for all seats, as noted above, was nearly identical, suggesting that Chapter 7 may produce an accurate estimate for average effectiveness of all currently used seats, if not for individual seat types. Chest g's were quite similar in the two studies:

	Compliance Tests Chest g's	Chapter 7 (Estimated) Half of Torso g's
Tethered	39.1	34.6
Tetherless - harness only	39.1	40.1
Booster	39.7	39.8
Tetherless - full shield	40.3	51.5
AVERAGE OF 4 TYPES	39.6	41.5

The only difference of any magnitude was for tetherless-full shield. The Chapter 7 results were higher mainly because "torso g's" were the sum of chest and lower spine g's and the latter was especially high for the shield type seat.

Head excursions were not explicitly measured in Chapter 7, but the dummies in the correctly used seats avoided contact with the vehicle interior--consistent with the satisfactory head excursion results in the compliance tests.

Chapter 7 assumes that tetherless-harness only and tetherless-partial shield seats, when correctly used, are equally effective. The compliance tests fully support that assumption for HIC, chest g's and head excursion (see Tables 3-3, 3-4 and 3-5). Chapter 7 assumes that shield boosters are equivalent to tetherless-full shield. The compliance tests strongly support the assumption for HIC and head excursion, although not for the relatively less influential chest g parameter.

The compliance tests, together with the earlier studies reviewed in Section 3.3, showed tethered beltaround seats to perform very well on HIC and chest g's and outstandingly on head excursion and in lateral impacts. This type was not tested in Chapter 7. Therefore, it would be appropriate, in the effectiveness analyses of Section 7.7, to set its protection equal to the best seat type actually tested in that chapter. Likewise, tetherless beltaround seats, which were not tested in Chapter 7 but finished in the worst group on every parameter in the compliance tests, ought to have their effectiveness set equal to the least effective seat type tested in that chapter (which turns out to be the tetherless-harness only type).

Chapter 7's tests were limited to the Strolee 597A tethered seat, the Century 100 tetherless-harness only, the Cosco-Peterson Safe-T-Shield and the Century Safe-T-Rider booster seat, which were assumed to be "typical" of their generic types. The compliance tests confirm (Table 3-6) that the Strolee tethered seat is "average" in every parameter relative to other tethered seats. Century tetherless-harness only seats were average on HIC and chest g's and somewhat worse than average on head excursion--the latter is irrelevant, however, because none of the dummies in the Century 100 contacted the vehicle interior in Chapter 7, even at 35 mph. The Safe-T-Shield is the only one of its type and thus, automatically, typical. Finally, the Century booster seat, while average on chest g's and head excursion, was substantially worse than the average booster seat on HIC in the compliance tests. Despite that, the Century booster had very low HICs in Chapter 7, lower than any other seat types. So it is unlikely that the Chapter 7 results for booster seats were biased upward because the Century seat was used--they could hardly have been lower. In short, the compliance tests support Chapter 7's assumption that the tested brands were representative of their generic types and, more generally, that seat type is more important than brand as a factor influencing effectiveness.

The most important conclusion of the comparison between the compliance tests and Chapter 7 is that the latter study's overall estimate of the average effectiveness of <u>all</u> types of correctly used seats (i.e., 67 percent reduction of serious injuries) is consistent with the compliance tests and can be accepted with confidence. But the individual estimates for various seat types (correctly used) disagree with the compliance test results since the two studies encompass different parts of the crash environment. These individual results from Chapter 7 (e.g., 82% reduction for booster seats, 66% for tethered, etc.) cannot be accepted as valid at this time. Since the seats that performed relatively better in Chapter 7 were relatively worse in the compliance tests, the safest conclusion, at this time, is that all correctly used seats have effectiveness close to 67 percent.

CHAPTER 4

FATALITY REDUCTION: ANALYSES OF FARS DATA

The Fatal Accident Reporting System (FARS), a census of fatal accidents since 1975, provides the best estimates of overall fatality reduction for child passenger safety measures. As of December 1984, FARS contained records of over 4000 child passenger fatalities, including 200 safety seat users and 80 lap belted children--large enough numbers for statistically meaningful analyses.

Child safety seats, "when used" reduce both infants' and toddlers' fatalities by about 40-50 percent. Safety seat usage information in FARS is based primarily on police reports, where a substantial percentage of grossly misused seats are reported as "unrestrained" - thereby biasing the effectiveness estimate upward to some extent. Lap belts reduce the fatality risk of toddlers riding in passenger cars by roughly 30 percent. An unrestrained child in the rear seat has approximately 25-30 percent lower fatality risk than an unrestrained front-seat child passenger.

4.1 Analysis method and data preparation

The specific approach for analyzing FARS is to calculate the risks of child passenger fatalities relative to drivers. The latter act as a control group in the analyses. The approach was originally developed and used by Partyka in her 1984 study of "Restraint Use and Fatality Risk for Infants and Toddlers" [60].

First, the records of all child passengers (ages 0-5) are extracted from the FARS occupant files. (The five year olds were included only in the analyses of lap belt effectiveness and backseat vs. front seat.) Next the restraint use and injury information is located for the driver of any vehicle in which a child was a passenger. Throughout the analyses, driver's restraint usage is collapsed to 2 categories: "unrestrained" and "belted" (which includes the FARS codes for lap belt, shoulder belt, lap and shoulder and "used-type not specified"). Other FARS codes such as "unknown" are excluded from the analysis. The driver information is appended to the child's record. Three categories of child restraint usage are considered in the analyses: "unrestrained," "child safety seat" and "adult lap belt" (which includes the FARS codes for lap belt, shoulder belt and lap and shoulder). Other FARS codes such as "unknown" and "used-typed not specified" are excluded from the analysis. A total of 19 percent of the accident cases are excluded because the driver's or the child's restraint use was unknown or unspecified. Thus, for each child passenger on FARS, it is possible to compare the injury severity of the child and the driver. The individual comparisons can be summarized in tabular form as in the following example of unrestrained front-seat child passengers where the driver was also unrestrained:

	N of FARS Cases
Driver died, child survived	1694
Child died, driver survived	2218
Both died	738
Both survived	4594

Thus, there were a total of 2218 + 738 = 2956 children who died in those crashes; 1694 + 738 = 2432 drivers died in the crashes. The risk factor for unrestrained front-seat child passengers (relative to unrestrained drivers) is 2956/2432 = 1.215.

For unrestrained rear-seat child passengers accompanied by unrestrained drivers, the comparable tabulation is:

	N of FARS Cases
Driver died, child survived	1364
Child died, driver survived	994
Both died	422
Both survived	3877

Here, 994 + 422 = 1416 children and 1364 + 422 = 1786 adults died. The risk factor for unrestrained rear-seat child passengers (again, relative to a control group of unrestrained drivers) is 1416/1786 = 0.793. With the plausible assumption that the two control groups of restrained drivers are subject to about equal risk, the probablity of fatality is 1 -(0.793/1.215) = 35 percent lower for unrestrained children in the rear seat than in the front seat (in the aggregate FARS data which include all children age 0-5).

Risk factors, relative to unrestrained drivers, are likewise calculated for children who were in safety seats or adult lap belts and are shown in Table 4-1. The resulting "fatality reduction" estimates (for safety seats relative to unrestrained: 15% reduction in the front seat, 11%

TABLE 4-1

FARS YEARS 1975-84
CHILDREN AGED 0-5

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO THEIR ACCOMPANYING UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

(NOT USED FOR "BEST" EFFECTIVENESS ESTIMATES)

Child's Restraint Use and Seat Position	Child Fatalities	Unrestrained Driver Fatalities	Risk Factor	Red. (%) Rel. to Unr. Frt. Seat	Red. (%) Rel. to Unr. Rear Seat
Unrestrained - front	2956	2432	1.215	--	--
Unrestrained - rear	1416	1786	0.793	35	--
Safety seat - front	76	74	1.027	15	--
Safety seat - rear	82	116	0.707	42	11
Lap belt - front	22	27	0.815	33	--
Lap belt - rear	22	41	0.537	56	32

in the rear seat; for lap belt relative to unrestrained: 33% and 32%, respectively), however, cannot be considered meaningful since they have three obvious shortcomings:

- Reporting of safety seat usage on FARS before 1980 cannot be considered reliable because it was rare (prior to mandatory use laws) and not a reportable item in most State accident report forms [79]. Usage may often have been overlooked, except in the noteworthy situation when a child was killed in a safety seat [42]. That is a *serious* bias against safety seats. The bias and its remedy are studied in Section 4.2.

- Safety seat usage is much higher among infants than toddlers. Infants have about double the fatality risk of toddlers. When all age groups are lumped together as in Table 4-1, it creates a serious bias against safety seats. This bias is remedied in Sections 4.2 and 4.3.

- The fatality counts are small in the "safety seat" and, especially, the "lap belted" groups. The principal reason, of course, is that restraint usage by children was low before States passed mandatory use laws. Another reason is that Table 4-1 is limited to cars with unrestrained drivers. But adults who buckle up their child passengers are far likelier than average to buckle up themselves [28], [85].

The remedy for the last shortcoming is to include cases where the driver was belted and the child was in a safety seat or lap belt. The fatality-reducing effectiveness of lap-shoulder belts for adults is known to be close to 45 percent and, for lap belt only, 35 percent [25], p. IV-2. The mix of lap and lap-shoulder belts in 1975-84 FARS is approximately 20-80, so the average effectiveness of the mix is about 43 percent. (The statement about the belt usage mix is based on NHTSA's observational survey in the median year 1979 [64], p. 2, rather than the incomplete and possibly unreliable FARS reporting on the type of belt used.) Thus, if each belted driver fatality accompanying a restrained child is counted 1/(1 - 43%) = 1.754 times, it would give an estimate of how many drivers would have died if they had all been unrestrained.

Table 4-2 recapitulates the estimates of Table 4-1 (they are called "Estimate 1" in Table 4-2) but also shows what happens when the restrained child fatalities accompanied by belted drivers are added to those accompanied by unrestrained drivers while 1.754 times the belted driver fatalities are added to the unrestrained driver fatalities (Estimate 2).

Table 4-2 shows that the procedure doubles the sample of lap-belted children and increases by a quarter the sample of children in safety seats, while resulting in fatality reduction estimates that are, on the average, about the same as those based on unrestrained drivers only.

TABLE 4-2

FARS YEARS 1975-84
CHILDREN AGED 0-5

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

(NOT USED FOR "BEST" EFFECTIVENESS ESTIMATES)

Child's Restraint Use and Seat Position	Child Fatalities	Unrestrained Driver Fatalities	Risk Factor	Red. (%) Rel. to Unr. Frt.Seat	Red. (%) Rel. to Unr. Rear Seat
Unrestrained-front	2956	2432	1.215	--	--
Unrestrained-rear	1416	1786	0.793	35	--
Safety seat - front					
Estimate 1	76	74	1.027	15	--
Estimate 2	76+15=91	74+8/.57 = 88	1.034	15	--
Safety seat - rear					
Estimate 1	82	116	0.707	42	11
Estimate 2	82+26=108	116+30/.57 = 168.6	0.641	47	19
Lap belt - front					
Estimate 1	22	27	0.815	33	--
Estimate 2	22+20=42	27+22/.57 = 65.6	0.640	47	--
Lap belt - rear					
Estimate 1	22	41	0.537	56	32
Estimate 2	22+22=44	41+18/.57 = 72.6	0.606	50	24

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

$$\text{Estimate 2: Risk factor} = \frac{\text{Child fats. accomp. by unr. driver + Child fats accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$$

The remaining tables of this chapter will be structured like Table 4-2: in each case, two estimates are provided. First, the straightforward but smaller-sample estimate based on unrestrained drivers only; below it, the imputed larger-sample estimate including the belted drivers. That gives the reader the option of using either estimate.

4.2 Fatality reduction for safety seats

In the preceding section it was stated that FARS statistics prior to 1980 were biased against safety seats. Table 4-3 clearly shows how severe the bias is. In the table, safety seat effectiveness is calculated separately for each calendar year of FARS data, using the relative risk factor method of Table 4-1 (but with front and rear seat occupants lumped to maximize sample size). Effectiveness is strongly negative each year from 1975 through 1979; safety seats increased fatality risk by at least 71 percent in each year. Between 1980 and 1984, effectiveness is always positive, ranging between 16 and 48 percent, with no particular trend. (The fluctuations in those years are evidently due to the small numbers of cases on which each year's estimate is based.)

The 4 middle columns of Table 4-3 pinpoint the main causes of the bias. The risk factor for unrestrained children is nearly constant from 1975 through 1984, so it is not the cause. The risk factor for restrained children, on the other hand, is much higher before 1980 than after. That factor is the ratio of restrained child fatalities to unrestrained driver fatalities in cars where a child was restrained (2nd and 3rd columns). The counts of restrained child fatalities appear realistic, increasing gradually from year to year between 1975 and 1983, reflecting the steady increase of safety seat usage by the child passenger population at large. The counts of

TABLE 4-3

INTERACTION OF FARS CALENDAR YEAR WITH
THE OBSERVED "EFFECTIVENESS" OF SAFETY SEATS

FARS Calendar Year	Child Fatalities in Safety Seats*	Unrestrained Driver Fatalities*	Risk Factor	Risk Factor for Unrestrained Children	Reduction for Safety Seats (%)
1975	4	1	4.000	1.007	-297
1976	5	3	1.667	0.964	-73
1977	8	1	8.000	1.079	-642
1978	9	5	1.800	0.996	-81
1979	11	6	1.833	1.074	-71
1980	12	18	0.667	1.166	43
1981	15	23	0.652	0.895	27
1982	25	27	0.926	1.103	16
1983	36	64	0.563	1.088	48
1984**	33	42	0.786	1.013	22

*In vehicles where the driver was unrestrained and at least one child was reported to be in a safety seat.

**Incomplete data

unrestrained driver fatalities (accompanying restrained children) are unrealistic before 1980: there are far too few. They jump from 6 in 1979 to 18 in 1980. The most reasonable explanation is that safety seat usage went largely unreported on FARS before 1980, except in the startling case where a child was killed while in a seat. If the child lived and the driver died, the child would not be reported as having been in a safety seat and the driver would not have been counted in Table 4-3.

Why was 1980 the watershed year for safety seat reporting on FARS?

- o The move to make "child safety seat" a distinct restraint use category on State accident report forms began in the late 1970's. Without such a category, safety seat usage is likely to be mentioned in the police report only in unusual cases.

- o Many States began working on mandatory use legislation around 1980, further raising police officers' awareness of the seats. Workshops, magazine articles and the increase in safety seat usage had a similar effect.

The simple remedy for the pre-1980 bias is to use only the FARS data from calendar years 1980 to 1984. Since few safety seat users were reported before 1980, the loss of sample size is not worrisome.

Table 4-4 shows effectiveness estimates for all systems, based on 1980-84 FARS data. It is identical to Table 4-2, except for the restriction of the data set. Safety seat effectiveness is 27 percent in the front seat and 37 percent in the rear seat--already a big improvement over the 15 and

TABLE 4-4

FARS YEARS 1980-84
CHILDREN AGED 0-5

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO
UNRESTRAINED DRIVERS, BY CHILD'S SEAT
POSITION AND RESTRAINT USAGE

(NOT USED FOR "BEST" EFFECTIVENESS ESTIMATES)

Child's Restraint Use and Seat Position	Child Fatalities	Unrestrained Driver Fatalities	Risk Factor	Red. (%) Rel. to Unr. Frt.Seat	Red. (%) Rel. to Unr. Rear Seat
Unrestrained-front	1350	1117	1.209	--	--
Unrestrained-rear	702	834	0.842	30	--
Safety seat - front					
Estimate 1	56	63	0.889	26	--
Estimate 2	56+12=68	63+8/.57=77	0.883	27	--
Safety seat - rear					
Estimate 1	65	111	0.586	52	30
Estimate 2	65+19=84	111+27/.57=158.4	0.530	56	37
Lap belt - front					
Estimate 1	15	18	0.833	31	--
Estimate 2	15+15=30	18+12/.57=39.1	0.767	37	--
Lap belt - rear					
Estimate 1	16	33	0.485	60	42
Estimate 2	16+17=33	33+8/.57=47	0.702	42	17

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

$$\text{Estimate 2: Risk factor} = \frac{\text{Child fats. accomp. by unr. driver + Child fats. accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$$

19 percent calculated in 1975-84 FARS. Yet only 47 of 199 fatalities in safety seats were lost when the 1975-79 years of FARS were removed from the analysis.

Table 4-5 shows, in contrast, the effectiveness estimates based on 1975-79 FARS data only. Safety seats "increased" fatalities by 71 percent in the front seat and 211 percent in the back. On the other hand, the various effectiveness results for lap belts and for unrestrained children in the rear seat are about the same as Table 4-4, considering the sample size involved. Those systems were not subject to the reporting problems in 1975-79 that plagued safety seat statistics--lap belt usage and seat position were always items that had to be reported by police. Thus, while it is critical to exclude 1975-79 FARS data from the analysis of safety seat effectiveness, it is appropriate to include them when studying the effect of putting on a lap belt or moving an unrestrained child from the front seat to the back seat.

Table 4-4, however, still suffers from the shortcoming that children of all ages have been lumped together. Table 4-6 clearly shows how large a bias that creates. Safety seat usage is highest for infants under age 1 (19% in fatal accidents during 1980-84), who are the group most vulnerable to fatal injury (an unrestrained infant in the front seat is 2.163 times as likely to be killed as the accompanying driver). Safety seat usage declines rapidly as the child's age increases and so does vulnerability. At the other extreme, 5 year olds are biomechanical supermen (32 percent less likely to be killed than the driver, even when they are unrestrained, in the front seat) but only 0.5 percent of them are in safety seats. When children of

TABLE 4-5

FARS YEARS 1975-79
CHILDREN AGED 0-5

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

(NOT USED FOR "BEST" EFFECTIVENESS ESTIMATES)

Child's Restraint Use and Seat Position	Child Fatalities	Unrestrained Driver Fatalities	Risk Factor	Red. (%) Rel. to Unr. Frt.Seat	Red. (%) Rel. to Unr. Rear Seat
Unrestrained-front	1606	1315	1.221	--	--
Unrestrained-rear	714	952	0.750	39	--
Safety seat - front					
Estimate 1	20	11	1.818	-49	--
Estimate 2	20+3=23	11+0/.57=11	2.091	-71	--
Safety seat - rear					
Estimate 1	17	5	3.400	-178	-353
Estimate 2	17+7=24	5+3/.57=10.3	2.330	-92	-211
Lap belt - front					
Estimate 1	7	9	0.778	36	--
Estimate 2	7+5=12	9+10/.57=26.5	0.452	63	--
Lap belt - rear					
Estimate 1	6	8	0.750	39	no change
Estimate 2	6+5=11	8+10/.57=25.5	0.431	65	42

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

Estimate 2: $\text{Risk factor} = \dfrac{\text{Child fats. accomp. by unr. driver + Child fats. accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$

TABLE 4-6

INTERACTION OF CHILD'S AGE WITH RESTRAINT USAGE,
SEAT POSITION AND FATALITY RISK, FARS 1980-84

Child's Age	Restraint System Usage (%)			Percent of Children in Back Seat	Fatality Risk Factor for Unr. Child in Front Seat
	Safety Seat	Lap Belt	None		
0	19	2	79	25	2.163
1	16	4	80	34	1.377
2	8	4	88	42	1.121
3	5	4	91	49	0.977
4	3	6	91	52	0.935
5	0.5	4	95	58	0.679

all ages are lumped together, there is a preponderance of delicate infants among the safety seat users and hardy kindergartners among the unrestrained, making the comparison unfair.

The remedy, of course, is to perform separate effectiveness calculations for the various age groups. One estimate is obtained for infants under age 1, who are unique in terms of high vulnerability. The other estimate is for children aged 1 to 3, who form a relatively homogeneous group in regard to vulnerability. As for children aged 4 to 5, there are so few safety seat users on FARS that the group can be excluded from the analysis without undue loss of sample size.

Table 4-7 estimates the effectiveness of safety seats for infants less than 1 year old. The seats reduced fatality risk in the front seat by 40 percent (relative to an unrestrained infant in the front seat) and in the back seat by 49 percent (relative to an unrestrained infant in the back seat). Those are the calculations known as "Estimate 2," which include infants accompanied by belted drivers (see Section 4.1). By the simpler procedure known as "Estimate 1" (which is based only on vehicles with unrestrained drivers) the fatality reductions are 36 and 41 percent respectively. Estimates 1 and 2 are quite consistent; the small differences between them are not statistically meaningful in view of the small samples of restrained infants.

Estimates for children aged 1 to 3 are developed in Table 4-8. Safety seats reduced fatality risk for front-seat passengers by 41 percent, for back-seat passengers by 48 percent (based on Estimate 2; the results are nearly the same by Estimate 1: 42% and 42%).

TABLE 4-7

FARS YEARS: 1980-84
CHILDREN AGED: 0 (LESS THAN 1 YEAR)

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

Child Restraint Use and Seat Position	Child Fatalities	"Unrestrained" Driver Fatalities	Risk Factor	Reduction (%) Rel. to Unr. Front Seat	Reduction (%) Rel. to Unr. Rear Seat
Unrestrained - front	377	177	2.130	--	--
Unrestrained - rear	101	62	1.629	24	--
Safety seat - front					
Estimate 1	26	19	1.368	36	--
Estimate 2	26 + 5 = 31	19 + 3/.57 = 24.3	1.276	40	--
Safety seat - rear					
Estimate 1	23	24	0.958	55	41
Estimate 2	20 + 10 = 33	24 + 9/.57 = 39.8	0.829	61	49

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

Estimate 2: Risk factor = $\frac{\text{Child fats. accomp. by unr. driver + Child fats. accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$

TABLE 4-8

FARS YEARS: 1980-84
CHILDREN AGED: 1-3

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

Child Restraint Use and Seat Position	Child Fatalities	"Unrestrained" Driver Fatalities	Risk Factor	Reduction (%) Rel. to Unr. Front Seat	Reduction (%) Rel. to Unr. Rear Seat
Unrestrained - front	712	624	1.141	--	--
Unrestrained - rear	355	425	0.835	27	--
Safety seat - front					
Estimate 1	28	42	0.667	42	--
Estimate 2	28 + 6 = 34	42 + 5/.57 = 50.8	0.669	41	--
Safety seat - rear					
Estimate 1	38	79	0.481	58	42
Estimate 2	38 + 8 = 46	79 + 15/.57 = 105.3	0.437	62	48

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

$$\text{Estimate 2: Risk factor} = \frac{\text{Child fats. accomp. by unr. driver + Child fats. accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$$

Thus, observed effectiveness is close to 45 percent for both age groups and seating positions. The benefits of sitting in the back seat and using a safety seat are essentially additive, making a restrained child in the back seat 62 percent less vulnerable than an unrestrained child in the front seat.

There appear to be 2 appropriate ways to combine the results by age group and seat position to obtain an overall effectiveness estimate for child safety seats. First, the actual average effectiveness of the seats, given the current age, seat position and correct/incorrect usage mix of the children who currently use safety seats. The weighted average of the risk factor for restrained children is calculated, where the weight factor is the number of unrestrained driver fatalities (based on Estimate 2 in Tables 4-7 and 4-8) in vehicles where a child used a safety seat. The weighted average of the risk factor for unrestrained children is likewise calculated, and the ratio of the averages is computed--i.e.

$$1 - \frac{24.3 \times 1.276 + 39.8 \times 0.829 + 50.8 \times 0.669 + 105.3 \times 0.437}{24.3 \times 2.130 + 39.8 \times 1.629 + 50.8 \times 1.141 + 105.3 \times 0.835}$$

= 45 percent fatality reduction

(where, for example, 24.3 is the number of "unrestrained" driver fatalities accompanying restrained front-seat infants in Table 4-7, Estimate 2; 1.276 is the risk factor for restrained front-seat infants; 2.130 is the risk factor for unrestrained front-seat infants, etc.).

It is also possible to compute average overall effectiveness for certain subpopulations, such as all infants less than one year old (front and back seats combined) or all front-seat passengers (infants plus age 1-3 combined) using formulas similar to the one above. The results are shown in Part A of Table 4-9. For every group, effectiveness is close to 45 percent. Moreover, the observed differences between groups are not statistically significant, in view of the moderately small samples on which they are based.

The second way to combine the results is to estimate what would have happened if all child passengers (age 0 - 3) had been in safety seats. How many fewer fatalities would there be than if all had been unrestrained? Here, the weight factors for the fatality risks are the numbers of unrestrained driver fatalities in vehicles where there was any child--unrestrained or in a safety seat. (The same mix of correctly/incorrectly used seats is assumed as the one that currently exists in the FARS data). Under those circumstances, the overall effectiveness would be

$$1 - \frac{201.3 \times 1.276 + 101.8 \times 0.829 + 674.8 \times 0.669 + 530.3 \times 0.437}{201.3 \times 2.130 + 101.8 \times 1.629 + 674.8 \times 1.141 + 530.3 \times 0.835}$$

= 43 percent fatality reduction

(where, for example, 201.3 = 177 + 24.3, is the sum of the unrestrained driver fatalities accompanying unrestrained front-seat infant passengers in Table 4-7 and the "unrestrained" driver fatalities accompanying restrained front-seat infant passengers, by Estimate 2, in the same table).

TABLE 4-9

OVERALL FATALITY REDUCTION FOR CHILD SAFETY SEATS (FARS RESULTS)

Age Group	Percent Reduction by Seat Position: Front Seat	Back Seat	Both Combined
A. GIVEN CURRENT MIX OF AGES, SEAT POSITIONS AND CORRECT/INCORRECT USAGE AMONG SAFETY SEAT USERS ON FARS			
Less than 1	40	49	45
1 - 3	41	48	45
Both combined	41	48	45
B. IF ALL CHILD PASSENGERS USED SAFETY SEATS, CORRECT/INCORRECT USE MIX SAME AS FOR CURRENT USERS			
Less than 1	40	49	43
1 - 3	41	48	44
Both combined	41	48	43

Effectiveness estimates for various subpopulations are shown in part B of Table 4-9. All estimates are close to 45 percent and only differ trivially from those in part A (effectiveness for current users only).

The FARS results are close indeed to the Pennsylvania findings (Chapter 5: 43 percent reduction of fatal and "serious" injuries; 45 percent reduction of fatal, serious and mid-level injuries). Police-reported accident data from the 1980's certainly point to an effectiveness for safety seats which is close to 45 percent. Chapter 8 describes in detail how this statistic relates to those obtained from other data sources and what the implications are for estimating the effectiveness of correctly and incorrectly used safety seats.

4.3 Fatality reduction for lap belts

Tables 4-4 and 4-5 showed that there was no particular bias for or against lap belts in pre-1980 FARS data (unlike the severe bias against safety seats). It is appropriate to use the full 1975-84 range of FARS data for lap belt effectiveness estimates. Table 4-6 shows that lap belt usage in fatal accidents is almost uniformly 4 percent for children aged 1 through 5. It is therefore statistically appropriate to lump children aged 1 through 5 and obtain a single effectiveness estimate for that group [69] pp.29-31. Reported lap belt usage was only half as large (2%) for infants aged less than 1 year. Frankly, it is unlikely that even so large a proportion of infants were truly restrained by lap belts alone (the analysis North Carolina data in Section 3.2.4 suggests that about 90% of police-reported "lap-belted" infants were actually in safety seats and incorrectly reported). The small number of "lap-belted" infants can be dropped from the analysis without fear of biasing the overall results.

Table 4-10 shows that lap belts reduced fatality risk of children aged 1 to 5 by 41 percent in the front seat (relative to unrestrained front-seat occupants) and 21 percent in the back seat (relative to unrestrained rear-seat occupants), based on Estimating Method 2. The results by Estimate 1, which are based on considerably smaller samples, are 31 and 33 percent, respectively. The results by Estimate 2, in addition to using a larger N, are more intuitively reasonable than those by Estimate 1: the sled tests of Chapter 7 likewise suggest that lap belts are relatively more effective for front-seat occupants. (See the discussion in that chapter.)

The current overall average effectiveness of lap belts, given the current front/back seat mix of lap belt users, is

$$1 - \frac{58.3 \times 0.617 + 71.6 \times 0.587}{58.3 \times 1.039 + 71.6 \times 0.742}$$

= 31 percent fatality reduction

(where 58.3 is the number of "unrestrained" driver fatalities accompanying lap-belted front-seat child passengers in Table 4-10, Estimate 2; 0.617 is the risk factor for lap belts, front seat; 1.039 is the unrestrained front-seat risk factor, etc.).

If all child passengers were to use lap belts there would be

$$1 - \frac{2115.3 \times 0.617 + 1734.6 \times 0.587}{2115.3 \times 1.039 + 1734.6 \times 0.742}$$

= 33 percent fatality reduction,

TABLE 4-10

FARS YEARS: 1975-84
CHILDREN AGED: 1-5

FATALITY RISK FOR CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND RESTRAINT USAGE

Child Restraint Use and Seat Position	Child Fatalities	"Unrestrained" Driver Fatalities	Risk Factor	Reduction (%) Rel. to Unr. Front Seat	Reduction (%) Rel. to Unr. Rear Seat
Unrestrained - front	2137	2057	1.039	--	--
Unrestrained - rear	1234	1663	0.742	29	--
Lap belt - front					
Estimate 1	18	25	0.720	31	--
Estimate 2	18 + 18 = 36	25 + 19/.57 = 58.3	0.617	41	--
Lap belt - rear					
Estimate 1	20	40	0.500	52	33
Estimate 2	20 + 22= 42	40 + 18/.57 = 71.6	0.587	44	21

Estimate 1: Risk factor = Child fats. accomp. by unr. driver/Unr. driver fats.

Estimate 2: $\text{Risk factor} = \dfrac{\text{Child fats. accomp. by unr. driver + Child fats. accomp. by belted driver}}{\text{Unr. driver fats. + (Belted driver fats./0.57)}}$

relative to the situation where all children are unrestrained (where 2115.3 = 2057 + 58.3 = unrestrained driver fatalities accompanying unrestrained front-seat child passengers plus "unrestrained" driver fatalities accompanying lap-belted front-seat child passengers). This estimate is marginally higher than the preceding one because unrestrained children are more likely to be in the front seat, where lap belts are more effective. When the data are weighted primarily by the unrestrained children, the results are more favorable for lap belts.

These fatality reductions for lap belts are substantially lower than the serious injury reductions observed in other chapters (e.g., 43 percent reduction of fatal, serious and mid-level injuries in Pennsylvania; 56 percent reduction of hospitalizations due to head or torso injuries in frontal crashes, according to the sled test results). The most reasonable conclusion is that lap belts are less effective in reducing fatalities than serious injuries. The conclusion is further supported by the detailed sled test results, which show high effectiveness for lap belts in moderate severity crashes, but declining effectiveness as crash severity increases. Further discussion of lap belt effectiveness is presented in Section 8.2.2.

4.4 Unrestrained children: back seat vs. front seat

Many of the tables so far (4-1, 4-2, 4-4, 4-5, 4-7, 4-8, 4-10) showed a lower fatality risk for unrestrained child passengers in the back seat than in the front seat. Aggregate data analyses, however, are biased in favor of the rear seat passenger. Table 4-6 shows that only 25 percent of infants under age 1 ride in the back seat. The older the child, the more likely to occupy the back seat: 58 percent of 5 year olds ride in the back.

But older children are less vulnerable to fatal injury. When unrestrained children of all ages are lumped together, there is a preponderance of robust pre-schoolers among the rear-seat occupants and delicate infants among the front-seat passengers, making the comparison unfair.

Again, it is necessary to disaggregate by age group. Table 4-11 shows that unrestrained infants in the back seat have 32 percent lower fatality risk than unrestrained infants in the front seat. Toddlers aged 1-3 have 26 percent lower fatality risk in the back seat than in the front. Pre-schoolers aged 4-5 likewise have 26 percent lower fatality risk in the back seat

The average overall fatality reduction for moving an unrestrained child from the front seat to the back seat is

$$1 - \frac{498 \times 1.480 + 2226 \times 0.840 + 1494 \times 0.632}{498 \times 2.184 + 2226 \times 1.139 + 1494 \times 0.849}$$

= 27 percent fatality reduction

(where 498 = 375 + 123 = driver fatalities accompanying unrestrained infants in either seat, from Table 4-11, 1.480 = rear-seat infant fatality risk, 2.184 = front-seat infant fatality risk, etc.)

This FARS analysis is exceptionally free of bias or data problems and it is based on large samples. The 27 percent fatality reduction estimate can be accepted with confidence.

TABLE 4-11

FARS YEARS: 1975-84

FATALITY RISK FOR UNRESTRAINED CHILD PASSENGERS RELATIVE TO UNRESTRAINED DRIVERS, BY CHILD'S SEAT POSITION AND AGE

Child Restraint Use and Seat Position	Child Fatalities	Unrestrained Driver Fatalities	Risk Factor	Reduction (%) Rel. to Front Seat
	CHILDREN AGED 0 (LESS THAN 1 YEAR)			
Unrestrained - front	819	375	2.184	
Unrestrained - rear	182	123	1.480	32
	CHILDREN AGED 1 - 3			
Unrestrained - front	1536	1349	1.139	
Unrestrained - rear	737	877	0.840	26
	CHILDREN AGED 4 - 5			
Unrestrained - front	601	708	0.849	
Unrestrained - rear	497	786	0.632	26

4.5 Safety seat users: back seat vs. front seat

According to Table 4-7, infants less than 1 year old had a risk factor of 1.176 when they rode in a safety seat in the front seat of a car (Estimate 2). Safety seat users in the back seat of a car had a risk factor of 0.829. That amounts to a 35 percent fatality reduction for moving a restrained infant from the front to the back seat.

Likewise, Table 4-8 showed that 1-3 year old safety seat users had a risk factor of 0.669 in the front seat and 0.437 in the back seat, again a 35 percent reduction.

These estimates have more than double the sample error of the overall effectiveness estimates for safety seats (Section 4.2) and should not be considered precise. Nevertheless, they suggest that restrained children, like unrestrained, obtain considerable benefits from using the back seat. The most desirable way to protect a small child is to use a safety seat, in the back seat of a car.

CHAPTER 5

INJURY REDUCTION: ANALYSES OF PENNSYLVANIA DATA

The Commonwealth of Pennsylvania's accident data for 1981-83 are exceptionally useful for studying the effectiveness of child passenger safety measures. They offer a large sample (over 3,000 safety seat users, nearly 600 of whom were injured). Police have been aware for many years of the importance of reporting restraint system usage accurately [41] and the police report has a distinct code for safety seats. Best of all, Pennsylvania uses an injury coding system that identifies the body region and type of injury, as well as the severity.

Child safety seats "when used" reduce infants' and toddlers' overall injury risk by 30 percent; they reduce the more serious injuries by about 45 percent. They are most effective against leg and arm injuries but do a good job on other types, too. Safety seat usage on the Pennsylvania file is based on police reports, where a substanial percentage of grossly misused seats are reported as "unrestrained" - thereby biasing the effectiveness estimates upward to some extent. Lap belts reduce small children's overall injury risk in passenger cars by 30 percent and they reduce the more serious injuries by 40-50 percent. At the low speeds characteristic of the accidents on this file, lap belts are effective against concussions and facial fractures but they are not effective against whiplash. An unrestrained child in the back seat has about 30-35 percent lower injury risk than an unrestrained front-seat child passenger. In these low-speed crashes, the back seat environment does a nice job protecting against fractures, concussions, and all types of head and torso injuries, but not against whiplash and minor blunt trauma to arms and legs.

5.1 Analysis method and data preparation

Pennsylvania accident files contain information on uninjured as well as injured occupants, making it possible to compute injury rates per 100 or 1,000 crash-involved children. Effectiveness is measured by comparing the injury rates of restrained to unrestrained children: either a simple comparison or after controlling for child's age and seat position.

It was decided to use only the data from 1981 and later years. The Pennsylvania accident report was apparently revised to include a distinct code for safety seats in mid 1977 [41], [79]. It is appropriate not to use the accident data from the first several years after that revision and to allow time for the police to become fully accustomed to using the new code. In addition, safety seat usage began to increase in the 1980's. Even though usage was not mandatory in Pennsylvania until 1984 [80], it was already common in 1981-83: at least 32 percent of children aged 0-1 were in seats. That should further reinforce officers' awareness that safety seat usage is a distinct reporting category. Since 1983 was the latest year of data available (in February 1985), the analysis is based on 1981-83 files.

The data files are available for access by NHTSA with the Statistical Analysis System [73]. Occupant records were selected for children aged 5 or less ($0 \leq AGE \leq 5$) who were passengers of motor vehicles (PER___TYPE = 2). There were 25,930 child passengers on the files for 1981-83.

A special problem was that the Pennsylvania automated files did not contain any records of children "0 years old." Were infants lumped in with 1-year olds or were they dropped entirely from the automated files? The large number of "1 year-olds" makes it clear that this category includes infants less than 1 year old and that infants have not been dropped from the file: the proportion of "1-year olds" in Pennsylvania is almost the same as infants and 1-year olds, combined, in FARS:

Child's Age	Percent of Child Passengers in Penna.	Percent of Driver Fatalities Accompanying Children, FARS 1979-84
0	--	13
1	25	15
2	21	20
3	19	19
4	18	18
5	17	15

Thus, the "1-year olds" in the Pennsylvania data will be referred to as "age 0 or 1" throughout this chapter.

Pennsylvania has two variables on restraint systems, with codes as follows:

Availability	Usage
0 = none	0 = none available
1-3 = belts	1 = in use
4 = safety seat	2 = not in use
9 = unknown	9 = unknown

In this chapter, the two variables are combined into a single code:

Unrestrained if Availability = "none" <u>or</u> Usage = "not in use"

Safety seat if Availability = "safety seat" <u>and</u> Usage = "in use"

Lap belts if Availability = belts <u>and</u> Usage = "in use"

Unknown - any remaining combinations

Table 5-1 shows restraint system usage in Pennsylvania accidents as a function of the child's age. Regrettably, the number of unknowns is high (20-31 percent) and there is no information about the unknowns to suggest whether or not they are representative of the rest of the population. They will have to be excluded from the analyses. Otherwise, police-reported restraint system usage looks almost exactly right for a place without mandatory use laws in the early 1980's.

The reported usage rate in the Pennsylvania accidents was 20 percent for 0-4 year olds (i.e., excluding the 5 year olds and the unknowns). This is exactly what would have been expected, based on the nationwide observed rate in States without usage laws (Section 2.2.6) and the levels of underreporting by police experienced in the North Carolina accident study (Section 3.2.4). Specifically:

	Observed Safety Seat Usage in States w/o Laws	Correct Use/Partial Misuse vs. Gross Misuse/Home Child Carrier	Reporting Rate for Police in N.C.	Expected 1981-83 (Weighted Average)
1981-82	25%	16% correct/partial	x .76	
		9% gross	x .58	
				20%
1983	35%	26.5% correct/partial	x .76	
		8.5% gross	x .58	

TABLE 5-1

INTERACTION OF CHILD'S AGE WITH RESTRAINT USAGE, SEAT POSITION AND INJURY RISK, PENNSYLVANIA 1981-83

Child's Age	Restraint System Usage (%) Safety Seat	Lap Belt	None	Unknown	Percent of Children in Back Seat	Percent of Unrestrained Front-Seat Passengers with K or A Injury	K, A or B Injury	Any Injury
0 or 1	32	11	37	20	42	1.2	5.4	29
2	14	13	47	26	49	1.0	5.9	37
3	6	12	52	30	53	1.0	7.0	39
4	3	12	54	31	59	1.5	7.8	43
5	1	10	58	30	59	0.8	8.0	44

Another indication of the validity of safety seat usage reporting in Pennsylvania is the trend shown in Table 5-1: usage declines from 40 percent of children aged 0-1 (unknowns excluded) to 1 percent of 5 year olds, matching the trend in all other surveys and data files.

Reported lap belt usage in Pennsylvania accidents is consistently 10-13 percent across all ages. That is much higher than the 3 percent observed during 1981-82 by Opinion Research Corporation in their 19 city survey (Section 2.2.3). It is also higher than the 5 percent observed by Goodell-Grivas, Inc., in their 1983 survey (Section 2.2.2). But it is close to the 9 percent lap belt usage observed by Goodell-Grivas in Pittsburgh, the only Pennsylvania location among the 19 cities surveyed [61], p. 46. It is also close to the 14 percent usage reported in the North Carolina study, which was based on interviews with parents (see Section 3.2.3).

Although the reported lap belt usage is consistent with the Pittsburgh survey and the North Carolina interviews, there is still cause for concern that belt usage is overreported. The most troublesome number in Table 5-1 is the 11 percent lap belt usage for children aged 0-1. It seems likely that many of these accident victims were, in fact, in safety seats (see Section 3.2.4). But the reported belt use for ages 2-5 is probably valid or, at least, contains few cases of children who actually used safety seats: lap belt usage remains constant as age increases while safety seat usage sharply declines; if reported lap belt users had actually been in safety seats, belt usage should also have declined. The Pennsyvlania trends are consistent with what was found in North Carolina (Section 3.2.4) where police reported lap belt usage correctly in most cases of children aged 1 or more. In addition, the injury patterns for reported lap belt users in Pennsylvania are distinctively different from children in safety seats (Section 5.4) and are consistent with what would actually be expected with lap belts. In short, while some of the infants' lap belt usage is probably misreported, there is reason to believe that the great majority of Pennsylvania's reported lap belt users were really in lap belts. (See also Section 3.2.4 and 8.1.2.)

Pennsylvania's unique injury coding system employs three variables: severity, injury type and body region. Only one injury is coded per person. The severity variable is the same ABC scale used in most other States, with the following descriptive terms:

0 - No injury
1 - Death
2 - Major injury (A)
3 - Moderate injury (B)
4 - Minor injury (C)

Only one out of every 30 injuries is coded level "A" by police (as compared to 1 in 5 in Texas [38], p. 211 or 1 in 6 in North Carolina [28], p. 70), suggesting that A injuries may be more serious, on the average, in Pennsylvania than in other locations.

The injury types were

1 - Amputation
2 - Bleeding [generally lacerations]
3 - Broken bone(s)
4 - Burns
5 - Concussion
6 - Shock
7 - Dizziness
8 - Abrasions/bruises
9 - Complaints of pain

"Shock" was nearly always a "minor" injury and evidently does not correspond to the clinical term "going into shock." In the analyses of this chapter, dizziness and "shock" of the head are classified as a sort of low-level concussion, while "shock" to other body regions is lumped with complaints of pain. During 1981-83, no children suffered amputations and only 22 had burns; these injury types could not be given separate statistical analyses.

The codes for body regions were

1 - face
2 - head
3 - neck
4 - back
5 - arms
6 - legs
7 - chest/stomach
8 - internal
9 - entire body

For more statistically meaningful results, "face" is lumped with "head," "back" with "neck," and "internal" with "chest/stomach" in the analyses that follow.

Missing data were rare (fewer than 1% of cases) on all of the injury variables.

The Pennsylvania codes for seat position are straightforward. Since about 2 percent of accident-involved child passengers were neither in the front or back seat (e.g., they were in the third seat of a station wagon), the counts for front and back seat passengers do not quite add up to the total count of children.

The analyses compute the injury reduction--for safety seats or lap belts relative to unrestrained children--by injury severity levels, by body region and severity and by body region and injury type. Similar computations are made for unrestrained children in the back seat relative to the front seat. Since the Pennsylvania coding scheme for the vehicle's point of initial impact is not too useful for discriminating between side impacts, frontals and rollovers, the analyses are not further subdivided by crash mode.

5.2 Injury reduction for safety seats and lap belts, by severity level

Table 5-2 shows that children in safety seats or lap belts had significantly lower injury rates than unrestrained children, at all severity levels. There were 12,799 unrestrained child passengers aged 5 or less in Pennsylvania accidents in 1981-83; 145 of them, or 1.13 percent had level "A" or fatal injury. Only 0.65 percent of the children in safety seats had such injuries, a 43 percent reduction of injury risk. Lap-belted children had 59 percent lower risk of serious injuries than unrestrained children. The serious injury rates for safety seats and lap belts are both significantly lower than the unrestrained rate ($\alpha = .05$) but they are not significantly different from one another. The numbers of seriously injured children in safety seats (21) and lap belts (14) are low and cause the injury rates to have high variances.

TABLE 5-2

INJURY RATES OF CHILD PASSENGERS AGED 0-5, BY RESTRAINT SYSTEM AND SEVERITY LEVEL (PENNSYLVANIA, 1981-83)

Restraint System	N of Children	n of Injuries	Injury Rate (%)	Reduction Rel. to Unrestrained (%)
		LEVEL "A" OR FATAL INJURIES		
Unrestrained	12,799	145	1.13	--
Safety seat	3,243	21	0.65	43*
Lap belt	2,989	14	0.47	59*
		LEVEL "A," "B", OR FATAL INJURIES		
Unrestrained	12,799	698	5.45	--
Safety seat	3,243	85	2.62	52*
Lap belt	2,989	91	3.04	44*
		ANY TYPE OF INJURY		
Unrestrained	12,799	4208	32.88	--
Safety seat	3,243	598	18.44	44*
Lap belt	2,989	631	21.11	36*

*Statistically significant reduction (α = .05)

The observed effectiveness of safety seats is highest at the "moderate" injury level: "A", "B" and fatal injuries are reduced by 52 percent. Lap belts also did well, reducing the injuries by 44 percent. Again, both restrained rates are significantly lower than the unrestrained, but not significantly different from one another.

For minor injuries, the reductions are not quite as great: 44 percent for safety seats and 36 percent for lap belts. Both reductions are, of course, significant and, in this case, the rate for safety seats is significantly lower than the one for lap belts.

The injury rates in Table 5-2 may be biased, however, because children of different ages have been lumped together. So have front and rear-seat passengers. Table 5-1 shows that safety seat usage is highest for infants age 0 or 1 (32%), who are the group least likely to have a reported moderate or minor injury (5.4% and 29%, respectively). Safety seat usage declines rapidly as age increases, whereas vulnerability to nonserious injuries increases. At the other extreme, 1 percent of 5 year-olds are in seats, but their unrestrained injury rates are 8 percent (moderate) and 44 percent (overall). When children of all ages are lumped together, the primarily infant safety seat users are unfairly compared to the mostly unrestrained older children (who are more vulnerable to minor injury). The bias is in favor of safety seats, which is the opposite direction of what took place in fatal accidents (Section 4.2): infants have a more tenuous hold on life, whereas older children, with their longer limbs, are more exposed to minor injuries and are also more likely to complain about them.

Likewise, safety seat users are more likely to be placed in the back seat than unrestrained children of the same age:

Age	Percent of Safety Seat Users in Back Seat	Percent of Unrestrained Children in Back Seat
0-1	62	27
2-5	73	53

Since the back seat is a safer place to ride, this is an additional bias <u>in favor of</u> safety seats. The trends for lap belts are in the same direction, although not nearly as strong.

For unbiased effectiveness estimates, it is necessary to control for the effects of age and seat positions. When counts of uninjured as well as injured persons are available, the BMDP4F program of multidimensional contingency table analysis is a satisfactory technique for removing the effects of control variables [16]. The data are tabulated across the 4 variables (restraint system, injury severity, age, seat position) and the 4-way table is analyzed to find statistically significant interactions among variables. Various models (lists of interaction terms) are tested and a model that adequately fits the data ($p > .05$) with maximal degrees of freedom is chosen. Table 5-3 shows the models that were selected for the three severity levels of injury. (A more detailed description of the analysis method may be found in [36], pp. 149-152 and, with some variations, in [35], pp. 164-183 and [37], pp. 225-252.)

TABLE 5-3

EFFECTIVENESS OF SAFETY SEATS AND LAP BELTS
4-WAY ANALYSIS OF 1981-83 PENNSYLVANIA ACCIDENTS

I = injury (dichotomized as shown below)
R = restraint (none, safety seat, lap belt)
S = seat position (front, back)
A = age of child (0-1, 2-5)

Type of Injury	Selected Model	Injury Reduction (%)	
		Safety Seat	Lap Belt
A or fatal (vs.B, C, O)	I does not interact with S or A: use aggregate injury rates	43	59
A, B or fatal (vs. C, O)	IR, IS, IA, RSA	45	42
Any injury (vs. uninjured)	IR, ISA, RSA	31	31

For serious injuries (K + A), the injury x restraint term was significant (restraints reduce injury) but the injury x seat position and injury x age terms were not (age and seat position had no significant effect on serious injury risk--indeed Tables 5-1 and 5-4 show few differences). Since injury risk does not interact with the control variables and the injury x restraint x control variable terms are also nonsignificant, it is possible to drop the modeling process entirely [69], p. 30. The "best" effectiveness estimate is still the one in Table 5-2, based on simple comparison of injury rates: 43 percent for safety seats, 59 percent for lap belts (subject to fairly large sampling errors).

For moderate injuries (K + A + B), the interactions of injury with seat position and age are significant and the modeling process must be carried through. The best model contains the terms injury x restraint, injury x seat position, injury x age and restraint x seat position x age. Let N_{irsa} be the cell entries predicted by that model (subscripts explained in Table 5-3). Then

$$N_{11} = \sum_{s=1}^{2} \sum_{a=1}^{2} (N_{11sa}/N_{.1sa}) \; N_{..sa}$$

is a prediction of the number of K + A + B injuries that would have occurred if all children in Pennsylvania had been unrestrained. Similarly

$$N_{12} = \sum_{s=1}^{2} \sum_{a=1}^{2} (N_{12sa}/N_{.2sa}) \; N_{..sa}$$

is a prediction of the number of injuries that would have occurred if all children had been in safety seats (with the same mix of correctly and incorrectly used seats as actually occurred among the police-reported seat users).

$$N_{13} = \sum_{s=1}^{2} \sum_{a=1}^{2} (N_{13sa}/N_{.3sa}) \; N_{..sa}$$

is a prediction of the number of injuries that would have happened if all children had been lap-belted.

The best estimate of the effectiveness of safety seats is

$$\frac{N_{11} - N_{12}}{N_{11}} = 45 \text{ percent}$$

(given the mix of correctly and incorrectly used seats which actually occurred in Pennsylvania). This is 7 percent lower than the simple injury rate comparison in Table 5-2, confirming that the simple comparison was biased in favor of the seats. The best estimate of lap belt effectiveness is

$$\frac{N_{11} - N_{13}}{N_{11}} = 42 \text{ percent}$$

which is 2 percent lower than the simple injury rate comparison, a small bias in the same direction.

For injuries of all severities (K + A + B + C), the best model included the terms injury x restraint, injury x seat position x age, restraint x seat position x age. The best estimate of safety seat effectiveness is 31 percent--considerably lower than the 44 percent reduction found in Table 5-2. The best estimate of lap belt effectiveness is likewise 31 percent, which is also lower than the simple injury rate comparison (36%) but to a lesser extent.

5.3 Injury reduction for sitting in the back seat

5.3.1 Unrestrained children

Table 5-4 shows that unrestrained children riding in the back seat had significantly lower moderate and minor injury rates than unrestrained child passengers in the front seat. For K, A or B level injuries, the reduction was 34 percent. Injuries or any severity were reduced by 31 percent. On the other hand, the serious (K + A) injury rate was 8 percent higher in the back than in the front seat; that is not a statistically significant increase, however ($z = 0.47$, $p > .05$). This anomalous result is examined in more detail in Sections 5.4 and 5.5.

The injury rates in Table 5-4 may be biased, however, because children of different ages have been lumped together. Table 5-1 shows that older children are more likely to ride in the back seat (59% of 4-5 year olds versus 42% of 0-1 year olds) and also have higher rates of minor and moderate injury. That is a bias <u>against</u> the back seat passenger.

Multidimensional contingency table analysis is a suitable procedure for controlling for the effect of age, just as in Section 5.2. The

TABLE 5-4

INJURY RATES OF UNRESTRAINED CHILD PASSENGERS AGED 0-5
BY SEAT POSITION AND SEVERITY LEVEL (PENNSYLVANIA, 1981-83)

Seat Position	N of Unrestrained Children	n of Injuries	Injury Rate (%)	Reduction Rel. to Front Seat (%)
		LEVEL "A" OR FATAL INJURIES		
Front seat	6502	72	1.11	--
Back seat	6097	73	1.20	-8*
		LEVEL "A," "B," OR FATAL INJURIES		
Front seat	6502	431	6.63	--
Back seat	6097	267	4.35	34**
		ANY TYPE OF INJURY		
Front seat	6502	2432	37.40	--
Back seat	6097	1576	25.85	31**

*Not a statistically significant increase ($\alpha = .05$)
**Statistically significant reduction ($\alpha = .05$)

variables are injury, seat position and age (which is divided into 3 class intervals: 0-1, 2-3 and 4-5) and the unrestrained children are tabulated across them. For serious (K + A) injuries, there were no significant interactions between seat position or age with the injury variable. In other words, the analysis did not show an unrestrained child in the rear seat to have significantly different serious injury risk than the front-seat child passenger. For moderate (K + A + B) and minor (K + A + B + C) injuries, the most appropriate models were the ones that contained all possible interaction terms--i.e., for effectiveness estimates, the actual, observed data are entered into formulas similar to the ones developed in Section 5.2. The best effectiveness estimates were:

- o 35 percent reduction of moderate (K + A + B) injuries
- o 34 percent overall (K + A + B + C) injury reduction

As expected, both estimates are slightly (1-3%) higher than the ones based on simple comparisons of injury rates.

5.3.2 Safety seat users

The injury rates for safety seat users (age 0-5), by seat position, were:

	N of Children	% Inj.	% K, A or B	% K or A
Front seat	1099	20.93	2.82	0.55
Back seat	2144	17.16	2.52	0.70
Reduction for back seat (%)		18	11	-28

Aside from the K + A injury rates, which are based on very few injuries (6 in the front seat), the Pennsylvania data suggest that moving a restrained child from the front to the back seat reduces injury risk by about 10-20 percent.

5.4 Injury reduction by body region and injury type

An important advantage of the Pennsylvania data is that the police report the body region and type of injury (only one injury per victim). The information is based on the statements of emergency medical service personnel, crash-involved persons and the investigating officer. On the average, the crashes are of much lower severity than those studied in NHTSA towaway files (Chapter 6) or simulated by sled tests (Chapter 7). They provide information on the performance of restraint systems at the low severities.

Table 5-5 shows injury rates (per 1,000 children) by body region and severity, for unrestrained child passengers, children in safety seats and lap-belted children. Table 5-6 further subdivides the cases by injury type. What is most noticeable is that about 75 percent of the minor and moderate injuries were to the head or face while only 3 to 5 percent were torso injuries. (The data should be contrasted with Table 32 of [53], showing body region distributions for 1982 National Accident Sampling System data. See also Section 1.4.) The following factors all contribute to the high percentage of head injuries.

- o Minor and moderate injuries in low-severity crashes typically occur to the head and extremities, not the torso.

TABLE 5-5

INJURY RATES OF CHILD PASSENGERS AGED 0-5, BY RESTRAINT SYSTEM, BODY REGION AND SEVERITY LEVEL (PENNSYLVANIA, 1981-83)

		Unrestrained (N = 12,799)	Safety Seats (N = 3243)		Lap Belts (N = 2989)	
Body Region	Severity	Injuries per 1000 children	Injuries per 1000 children	Red. Rel. to Unr.(%)	Injuries per 1000 children	Red. Rel. to Unr.(%)
Head, face	(any injuries)	215.17	115.63	46	129.14	40
	K, A or B	37.11	19.12	48	19.07	49
	K or A	6.72	4.32	36	3.01	55
Neck, back	(any injuries)	12.34	8.02	35	13.05	-6
	K, A or B	1.64	1.23	25	2.01	-22
Chest, stomach, internal	(any)	8.99	6.78	24	13.38	-49
	K, A or B	2.19	1.23	44	1.00	54
Arms	(any injuries)	12.81	4.32	66	7.03	45
	K, A or B	2.34	0.62	74	1.00	57
Legs	(any injuries)	20.70	4.93	76	10.04	51
	K, A or B	4.92	0.62	87	2.34	52

TABLE 5-6

INJURY RATES OF CHILD PASSENGERS AGED 0-5, BY RESTRAINT SYSTEM AND SPECIFIC INJURY TYPE (PENNSYLVANIA, 1981-83)

Body Region	Injury Type/ Severity	Unrestrained (N = 12,799) Injuries per 1000 children	Safety Seats (N = 3243) Injuries per 1000 children	Safety Seats Red. Rel. to Unr.(%)	Lap Belts (N = 2989) Injuries per 1000 children	Lap Belts Red. Rel. to Unr.(%)
Head, face	fractures	2.34	2.15	8	0.67	71
	concussions/dizziness	11.02	6.78	38	5.68	48
	concussions	8.13	4.93	39	2.34	71
	lacerations	63.13	34.23	46	35.80	43
	lacerations AB	17.74	8.63	51	9.03	49
	lacerations A	2.50	1.85	26	1.67	33
	contusions	91.57	54.88	40	58.21	36
	contusions AB	9.69	5.55	43	4.68	52
	pain	47.11	17.58	63	28.77	39
Neck, back	pain	8.75	3.39	61	11.38	-30
Arms	fractures	1.48	0.31	79	0.67	55
	contusions/pain	8.60	2.78	68	5.69	34
Legs	fractures	3.44	0.62	82	2.68	22
	contusions/pain	15.00	3.70	75	6.69	55
Entire body	contusions/pain	21.33	12.95	39	19.07	11

- o Children, with their relatively large heads and small limbs, are relatively more prone to head injury (see also Section 1.4).

- o Only one injury is reported per child. When multiple regions are injured, the head injury is usually the location of the most severe injury or, at least, the injury that is most apparent at the accident scene.

5.4.1 Safety seats

Table 5-5 shows that safety seats--even the mix of misused and correctly used seats--did a good job protecting every body region at all severity levels. Head injuries were reduced by 46 percent, overall; by 48 percent at the moderate (K + A + B) level; and 36* percent at the serious (K + A) level. Among head injuries, Table 5-6 shows that safety seats did best in reducing complaints of pain (by 63%) and lacerations (51% at the moderate level, 46% overall). They were somewhat less effective against blunt impact trauma such as concussions (39%; 38% when dizziness and "shock" are included) and fractures (8%*).

Safety seats were effective in protecting the neck and back, reducing overall injury risk by 35 percent and complaints of pain (e.g., whiplash) by 61 percent. Contusions and complaints of pain to the entire body ("sore all over") decreased by 39 percent.

---

*Statistics based on a small number of injuries and subject to more sampling errors than the others.

Although torso injuries were reduced by just 24 percent overall, the moderate and more serious ones declined by 44* percent. (The number of torso injuries was too small to allow a meaningful breakout by injury type.)

Safety seats protected arms and legs exceptionally well. Arm injuries were reduced by 66 percent, 74* percent at the moderate level, including a 79* percent reduction of fractures. For leg injuries, the results were even better: 76 percent fewer injuries, 87 percent fewer at the moderate level, 82* percent reduction of fractures. (The injury reductions for arms and legs as well as complaints of pain in other areas may be overstated because safety seat users were more likely to be infants--whose arms and legs are less vulnerable than toddlers' and who may be unable to communicate complaints of pain.)

All of the findings are consistent with intuition. Safety seats ought to be effective against head injuries since they prevent head contacts with the vehicle's interior surfaces: especially against lacerations which may involve contact with glazing, which is far from the seat. The relatively lower effectiveness against concussions and facial fractures could

---

*Statistics based on a small number of injuries and subject to more sampling errors than the others.

reflect the fact that partially misused seats or even correctly used tetherless seats sometimes allow head excursion as far as the instrument panel (if the child is in the front seat) or front seatback (for a rear-seat passenger). Since safety seats hold a child securely in position they should do a good job against flexion or tension injuries to the neck, back or other body regions. It goes without saying that safety seats can be expected to provide excellent protection against arm and leg fractures, since they can usually prevent contacts with interior surfaces of the vehicle.

5.4.2 Lap belts

Tables 5-5 and 5-6 show that lap belts did a good job protecting children from all types of injuries except those involving pain or contusions to the neck or torso. Head injuries were reduced by 40 percent, overall, by 49 percent at the moderate level and 55* percent at the serious level. They were especially effective against the most serious types of head injuries: fractures (71%*) and concussions (71%* reduction of concussions per se; 48% reduction of concussions, dizziness and "shock"). But they also did an adequate job against lacerations (43%; 49% at the moderate level), contusions (39%; 52% at the moderate level) and pain (39%). For all types of head injury except pain, lap belts did as good or better than the 1981-83 mix of correctly used and misused safety seats.

---

*Statistics based on a small number of injuries and subject to more sampling error than the others.

Lap belts did not reduce neck and back injuries. In fact, they increased by 6 percent and by 22* percent at the moderate level. Pain injuries to the neck or back (e.g., whiplash) increased by 30 percent. The increases however, may to some extent be an artifact of the data, since only one injury is reported per child. Since lap belts reduce head injuries, a neck injury which was only secondary in an unrestrained child might now become the primary injury. Lap belts were also not very effective against "soreness all over," reducing that type of injury by just 11 percent.

For torso injuries, there was a clear trade-off with lap belts: minor injuries increased by 49 percent while moderate casualties were reduced by 54* percent.

Lap belts did an adequate job protecting the arms and legs, although not as successfully as safety seats. Arm injuries were curtailed by 45 percent overall, 57* percent at the moderate level, and 55* percent for fractures. Leg injuries were reduced by 51 percent overall, 52* percent at the moderate level, and 22* percent for fractures.

The results on lap belts are intuitively reasonable and are suitable evidence for the validity of lap belt usage reporting by police in Pennsylvania. The high reductions of the more serious types of blunt impact

---

*Statistics based on a small number of injuries and subject to more sampling error than the others.

trauma to the head and torso and adequate reductions of other head, arm, and leg injuries are consistent with the sled test results which showed that, at the low speeds characteristic of the Pennsylvania file, lap belts can prevent injury-producing contacts with the vehicle's interior surfaces without inducing harmful head-to-leg contact or belt forces on the abdomen. The poor performance on neck and back injuries (mostly muscular) and "soreness all over" is attributable to the fact that the belts do not hold a child's upper body in place but, on the contrary, cause the upper body and legs to "jackknife" about the immobilized pelvis. The increase in minor torso injuries is probably attributable to belts' pressure on the abdomen.

5.4.3 Unrestrained children: back seat versus front seat

Tables 5-7 and 5-8 are devoted to unrestrained child passengers. Table 5-7 shows injury rates (per 1000 children) by body region and severity, for children in the back seat vs. the front seat. Table 5-8 further subdivides the cases by injury type.

Table 5-7 shows that unrestrained children in the back seat enjoyed a remarkable reduction of minor (42%) and moderate (33%) head

---

*Statistics based on a small number of injuries and subject to more sampling error than the others.

TABLE 5-7

INJURY RATES OF UNRESTRAINED CHILD PASSENGERS AGED 0-5, BY SEAT POSITION, BODY REGION AND SEVERITY LEVEL (PENNSYLVANIA 1981-83)

Body Region	Severity	Front Seat (N = 6502) Injuries per 1000 children	Back Seat (N = 6097) Injuries per 1000 children	Back Seat (N = 6097) Red. Rel. to Front Seat (%)
Head, face	(any injuries)	273.15	158.77	42
	K, A or B	45.83	30.67	33
	K or A	6.46	7.22	-12
Neck, back	(any injuries)	12.61	12.47	1
	K, A or B	2.15	1.15	47
Chest, stomach, internal	(any)	11.07	7.05	36
	K, A or B	2.92	1.48	49
Arms	(any injuries)	12.46	13.61	-9
	K, A or B	2.61	2.13	18
Legs	(any injuries)	19.22	22.96	-19
	K, A or B	6.00	3.94	34

TABLE 5-8

INJURY RATES OF UNRESTRAINED CHILD PASSENGERS AGED 0-5, BY SEAT POSITION AND SPECIFIC INJURY TYPE (PENNSYLVANIA, 1981-83)

Body Region	Injury Type/ Severity	Front Seat (N = 6502)	Back Seat (N = 6097)	
		Injuries per 1000 children	Injuries per 1000 children	Red. Rel. to Front Seat (%)
Head, face	fractures	3.08	1.64	47
	concussions/dizziness	12.46	9.84	21
	concussions	9.54	6.89	28
	lacerations	83.51	43.46	48
	lacerations AB	23.38	12.30	47
	lacerations A	1.85	3.28	-78
	contusions	117.19	67.25	43
	contusions AB	12.15	7.38	39
	pain	56.91	38.22	33
Neck, back	pain	8.46	9.35	-11
Arms	fractures	1.54	1.48	4
	contusions/pain	7.69	9.84	-28
Legs	fractures	4.31	2.62	39
	contusions/pain	12.46	18.04	-45
Entire body	contusions/pain	19.53	23.95	-23

injuries in comparison to unrestrained child passengers in the front seat. At the serious level, however, the rear-seat passengers had a 12* percent higher injury risk; that increase is attributable to a completely anomalous 78* percent increase in serious lacerations--all other types of serious injuries decreased. The observed increase in serious lacerations is unexplained because it was precisely facial lacerations where sitting in the back seat seemed to have the greatest benefit: 48 percent overall and 47 percent at the moderate level (K + A + B). How could "moderate" lacerations decrease so substantially while "serious" ones increased? The back seat provided excellent protection against other types of serious head injuries: fractures (47%*) and concussions (28%; 21% when dizziness and "shock" are included). It did well against contusions (43%; 39% at the moderate level) and pain injuries (33%) to the head and face.

The back seat was not effective against minor injuries of the neck and back (1% reduction), especially pain injuries such as whiplash (11% increase). There was also a 23 percent increase in "soreness all over." But moderate-level neck and back injuries declined by 47* percent.

---

*Statistics based on a small number of injuries and subject to more sampling errors than the others.

The back seat performed nicely against torso injuries at the minor (36%) and K + A + B (49%) levels.

For arm and leg injuries, there was a clear trade-off: minor injuries increased while more serious ones decreased. Thus arm injuries increased by 9 percent, including a 28 percent rise in contusions and pain, whereas moderate level arm injuries fell by 18* percent, including a 4* percent drop in fractures. Likewise, leg injuries increased by 19 percent (contusions/pain by 45%) but moderate-level leg injuries decreased by 34 percent (fractures by an impressive 39 percent).

Two possible artificial reasons for the increases in minor neck, arm, leg and whole-body injuries should be mentioned in connection with the preceding statistics:

o Since only one injury per child is reported, the big decrease in head injuries could unmask minor injuries to other body regions which would have been secondary if the child had been in the front seat.

o Rear-seat passengers are, on the average, somewhat older and more likely to report a pain-type injury.

---

*Statistics based on a small number of injuries and subject to more sampling errors than the others.

Except for the anomalous result on level A lacerations, the findings confirm intuitions about the advantages of the back seat. The biggest reductions of head injuries were found for lacerations and fractures. They are the type of injuries most dependent on the surface characteristics of vehicle interior components: a cracked/broken windshield, a header/pillar or instrument panel/hardware are much harsher than the padded front seatback encountered by the rear-seat passenger. Contusions and pain injuries were not quite as effectively reduced by sitting in the back seat--they are injury types that are well mitigated by padding but, unlike the preceding types, are not as dependent on the presence of hardware/rough surfaces/broken glass. Concussions were reduced relatively the least by sitting in the back seat. They are blunt impact traumata which are strongly affected by the force-deflection characteristics of materials beneath the surface of components, not just the superficial padding. Nevertheless, the front seatback has forgiving force-deflection characteristics underneath the padding and the 28 percent reduction of concussions is still impressive and consistent with the 27 percent fatality reduction found in Section 4.4.

The substantial reduction of torso injury is consistent with the relatively better force-deflection characteristics of the front seatback (as opposed to the instrument panel, which is contacted by front-seat passengers). Also, the geometry of the front seatback is such that a child's legs and arms will strongly engage it before chest contact. The instrument panel's geometry, by contrast allows chest contact before an unrestrained child's short legs have significantly engaged the firewall/lower instrument panel. Thus, also, minor arm/leg injuries increased because there were more arm and leg contacts. But fractures did not increase because the contacts were with a relatively more forgiving surface. (The small observed increases in whiplash and "soreness all over" are probably due to the artificial reasons previously cited.)

CHAPTER 6

SERIOUS INJURY REDUCTION: ANALYSES OF NHTSA ACCIDENT DATA

The agency's in-depth accident files--the National Accident Sampling System (NASS), the National Crash Severity Study (NCSS) and the Restraint Systems Evaluation Project (RSEP)--contain ideal data for evaluating child passenger safety measures. Assessment of safety seat usage is based on interviews with parents, vehicle inspection and the police report. The types and severities of injuries are coded in detail as are the crash mode and severity. Unfortunately, the number of children, especially restrained children, is small. Statistically meaningful results can only be achieved by pooling the data from all of the agency's files and, then, just barely.

Child safety seats "when used" reduced the risk of injuries resulting in hospitalization (overnight or longer) by 56 percent (confidence bonuds: 30-75 percent) and injuries resulting in transport to a treatment facility by 30 percent in towaway crashes of passenger cars. On most of the agency's files however, children in grossly misused seats are counted as "unrestrained"; as a result, high effectiveness would be expected for "users," since their seats were correctly used or, at worst, only partially misused. The small sample of toddlers who used lap belts in passenger cars had 71 percent lower risk of hospitalization than unrestrained children (confidence bounds: 35-90 percent) and 31 percent lower probability of being transported to a treatment facility. An unrestrained child in the back seat had 24 percent lower risk of hospitalization than an unrestrained front-seat child passenger (but 32 percent lower in frontal crashes) and a 14 percent lower likelihood of being transported to a treatment facility.

The number of hospitalized children in safety seats (11) is completely insufficient for any more detailed analysis by injury type, seat position, crash mode, seat type or misuse mode. On the other hand, the number of hospitalized unrestrained children (over 200) is sufficient for further classification by injury body region and crash severity. That breakdown, carried out in Section 6.4, provides the vitally needed real world baseline data which are used to "calibrate" the dummies in Chapter 7 and make it possible to obtain effectiveness estimates from the sled test results.

6.1 Analysis method and data preparation

The main difficulty in analyzing NHTSA data files is scraping together an adequate sample size of crash-involved children. The solution is to pool data from all available files. That necessitates a method for pooling the data in a manner that yields unbiased estimates.

Eight NHTSA files are currently (March 1984) suitable for the analysis:

o The NASS files for 1983, 1982, 1981, 1980 and 1979. Each consists of a probability sample of towaway accidents (which had previously been reported to police), plus some nontowaway accidents, from a collection of areas of the United States that have also been selected by probability sampling techniques [52], pp. 55-59.

o The NCSS file, which was collected from 1977 through early 1979 by 7 teams located in areas that, in combination, were heuristically representative of the United States. It is a probability sample of towaway crashes [59].

o The NCSS-NASS file of 1979, where the NCSS teams investigated a probability sample of towaway accidents (plus some nontowaways) using a procedure almost identical to 1979 NASS [54].

o The RSEP file of 1974-75, which is a probability sample of towaway crashes of 1973-75 model cars in 5 metropolitan areas (plus the rural hinterlands of 2 of those areas). Information was collected only for the front-seat passengers in those crashes [50].

A ninth file, Multidisciplinary Accident Investigation (MDAI) was not used because the data are not a probability sample of towaway accidents and could not be combined with the others in a way that would allow calculation of unbiased injury rates.

Table 6-1 provides statistics for the 8 files (raw, unweighted data). There are records of 3129 children aged 0-5 in passenger cars on the files. The largest number of cases come from NCSS (836) and the last two years of NASS (538 and 652). Unfortunately about 40 percent of the (unweighted) NASS cases are from cars that were not towed. Those cases could not be used in the analysis, as will be explained, below. Thus, the 836 NCSS cases represent an even higher proportion of the 2258 children who were in towed vehicles.

Table 6-1

STATISTICS FOR CHILD PASSENGERS ON NHTSA ACCIDENT FILES
(AGE 0-5, ACTUAL UNWEIGHTED COUNTS)

				NASS					
	RSEP	NCSS	NCSS-NASS	1979	1980	1981	1982	1983	ALL FILES
All Crashes									
N of Children	199	836	215	210	179	300	538	652	3129
Towaways Only									
N of Children	199	836	195	116	95	167	289	361	2258
N with known vehicle damage	168	747	159	107	85	137	223	272	1898
Percent with known vehicle damage	84	89	82	92	89	82	78	75	84
N in Safety Seats	10	32	7	8	10	18	47	81	213
N in Lap Belts	51	18	4	3	4	3	24	43	150
N unrestrained	138	786	184	105	81	146	218	237	1895

The percentage of towed vehicles for which the external damage was fully documented by the Collision Deformation Classification (CDC) [12] is a measure of data completeness or quality. That percentage was close to 85 for all files, although there was some deterioration in the last two years of NASS. The 8 files may be considered fairly similar with regard to data quality.

The last rows of Table 6-1 show the unweighted counts of restrained and unrestrained children. There were 213 actual cases of children in safety seats and 150 in lap belts on the 8 files combined: small numbers in comparison to the 3,243 and 2,989, respectively, in 1981-83 Pennsylvania data (Table 5-2). The last year of NASS contains 81 of the 213 children in safety seats; RSEP contains 51 of the 150 lap-belted cases, while NCSS accounts for 786 of the 1895 unrestrained children.

It is necessary to combine the data files in a way that produces unbiased injury rates, gives each file a "weight" in the overall results that is proportional to the amount of information it supplies and minimizes file to file differences. The best way to reduce file to file differences is to use only the towaway accidents. The nontowaways contain few serious injuries, so their exclusion will not materially increase the sampling error of serious injury rates. But the retention of nontowaways in NASS would make it impossible to combine the data with the other files, which only contain towaways.

By eliminating the nontowaways, all files become probability samples of towaway crashes. But they are not simple random samples; rather, they are stratified samples with unequal sampling proportions. RSEP, NCSS and NCSS-NASS are easy to combine. The case weight factors that are already on those files can also be used on the combined file since they correspond to the inverses of the actual probabilities of selecting an accident for investigation. In particular, almost all the hospitalizations in those files had a case weight of 1. So a weighted count of, say, 10 hospitalizations in NCSS is statistically equivalent to a count of 10 hospitalizations in NCSS-NASS, since both are based on 10 actual cases. By contrast, the case weight factors in NASS cannot be used in combination with the other files. Single NASS cases often have weights in the 100's or 1000's and would drown out the data from the other files. Instead, it is more appropriate to use the "Ockham weights" developed by Partyka for use with NASS [57]. These give the same weight to all the cases in a given stratum; the cases in the stratum containing most of the hospitalizations are given a weight of 1; the other strata are given weights equal to the ratio of the sampling interval for that stratum to the interval for the first stratum. The Ockham weights make the various years of NASS quite similar to NCSS and RSEP.

Table 6-2 provides weighted injury rates for the 8 files combined and each of the separate files, using the Ockham weights for NASS. It is amazing how consistent the rates are from file to file. The percent of towaway-involved unrestrained children who were hospitalized was always 4 or 5, except for RSEP where it was 2. That lower rate could partly be due to the primarily urban composition of RSEP (less severe crashes) or it could

Table 6-2

STATISTICS FOR CHILD PASSENGERS IN TOWAWAY ACCIDENTS ON NHTSA FILES (AGE 0-5, WEIGHTED DATA)

				NASS					
	RSEP	NCSS	NCSS-NASS	1979	1980	1981	1982	1983	ALL FILES
Weighted N of children	298	3413	980	332	243	550	641	840	7297
Percent in safety seats	6	4	7	7	11	13	17	24	9
Percent in lap belts	26	2	4	1	6	2	10	12	5
Percent unrestrained	68	94	89	92	83	85	73	64	86
Unrestrained injury rates %									
Hospitalization	2	4	4	4	5	4	4	5	4
Transported from scene	29	30	35	26	26	30	32	27	30

partly be due to sampling error (with only 200 unrestrained occupants, 8 hospitalizations are expected, so as few as 4 might sometimes be observed). The percent of children who were transported from the accident scene to a treatment facility was never lower than 26 or higher than 35 and there was no indication of a trend; here, RSEP was right in the middle at 29. These statistics provide a high degree of confidence that towaways from one probability sample can be pooled with towaways from another and that the Ockham weights make NASS data more or less comparable to NCSS.

Table 6-2 also shows restraint systems usage on the various data files. Safety seat usage was 9 percent, overall, but increased steadily from 4 percent in NCSS (1977-early 79) to 24 percent in NASS 1983, reflecting the trend in the general population. The rates are lower than the ones observed in the general traffic population (Chapter 2) for several reasons:

- <u>Grossly misused seats</u> (harness and/or belts not used) <u>are almost always classified as "unrestrained" in NHTSA data files</u>. On NASS and NCSS-NASS, which account for over 75 percent of the safety seat users on NHTSA files (see Tables 6-1 or 6-2), investigators were specifically instructed to code as "safety seats" only those cases where the seat was "installed so as to comply with manufacturer's directions" [51]. Those instructions seem to encompass only correctly used seats but in actual practice, partially misused seats were also included in most cases: the NASS investigators primarily checked that the seats were anchored to the vehicles and the children restrained in the seats, rather than conducting a detailed survey of lap belt routing, etc. On NCSS and RSEP, the instructions did not specify anything about coding misused seats as "unrestrained." Nevertheless, the extremely low usage rate on NCSS (4% according to Table 6-2 vs. 15% in the 1979 observational survey, according to Table 2-3) suggests that something has been excluded. As a minimum, home child carriers used as car seats, which were quite common in 1977-79, must have been counted as "unrestrained" by NCSS and RSEP investigators. Perhaps, many of the grossly misused safety seats were also coded as "unrestrained."

o The data in Table 6-2 include 5-year-olds, who rarely are in safety seats, while most observational data cut off at age 4.

o Restraint usage by persons involved in towaway crashes may be lower than for the general population. (Section 8.1.1, however, compares the usage rates in accident data and observational surveys and suggests that the first two reasons, above, are adequate to account for the differences.)

Lap belt usage was 5 percent, overall. It was 26 percent in RSEP, which was limited to new cars with starter interlocks or continuous buzzers. Elsewhere, belt usage was low in 1977-81, but returned to 10 percent or more in 1982-83. As in most other accident files, reported belt usage is higher than what was found in observational surveys.

Three injury severity levels were used:

o Hospitalized (at least overnight) or killed o Transported from the accident scene to a treatment facility (released on the same day)

o Not transported, including uninjured.

The same injury criteria have been employed with NHTSA data files in other evaluations because they minimize sampling error given the sample design of the files, are not subject to missing data and have the same meaning from year to year [35], pp. 147-149, [36], [37], [38].

The analyses compute the percent of towaway-involved children in safety seats/lap belts who were hospitalized/transported and compare the injury rates to those of unrestrained children. Similar computations are made for unrestrained children in the back seat relative to the front seat.

6.2 Injury reduction for safety seats and lap belts

Table 6-3 shows that children in safety seats or lap belts had substantially lower injury rates than unrestrained children, at all severity levels. There were 5906.45 (weighted) cases of unrestrained child passengers in towaway crashes on NHTSA files; 232.63 of them, or 3.94 percent were hospitalized or killed. Only 1.75 percent of children in safety seats were hospitalized, a 56 percent reduction of serious injury risk. Lap-belted children had 71 percent lower risk of being hospitalized.

Both of these reductions are based on small numbers of observed serious injuries. There were 11 unweighted (11.38 weighted) cases of hospitalized children in safety seats. If the number of unweighted

Table 6-3

INJURY RATES IN TOWAWAY CRASHES FOR CHILD PASSENGERS
AGED 0-5, BY RESTRAINT SYSTEM (NCSS - NASS - RSEP)

Restraint System	Weighted N of Children	Weighted N of Casualties	Casualty Rate (%)	Reduction Rel. to Unrestrained %
		H O S P I T A L I Z A T I O N S*		
Unrestrained	5906.45	232.63	3.94	----
Safety seat	649.85	11.38	1.75	56
Lap belt	367.04	4.13	1.13	71
	T R A N S P O R T T O T R E A T M E N T F A C I L I T Y**			
Unrestrained	5906.45	1783.29	30.2	----
Safety seat	649.85	138.17	21.3	30
Lap belt	367.04	76.38	20.8	31

*Includes overnight hospitalizations and fatalities.

**Includes treated-and-released, overnight hospitalizations and fatalities.

hospitalizations is a Poisson variable, an "observed" 11 cases is compatible with an "expected" ranging from 6.2 to 17 (two-sided α = .1) [75], Chart I. That corresponds to a range of approximately 6.2 to 18 weighted hospitalizations (since a few of the hospitalizations could be in the 87.5 percent or 80 percent sampling strata, but none, by definition, may appear in the lower strata)--i.e., confidence bounds of 30 to 75 percent. There were 4 unweighted (4.13 weighted) lap-belted children who were hospitalized. The Poisson bounds for 4 "observed" cases are 1.4 to 7.8 "expected" unweighted cases or as many as 1.4 to 9 weighted cases (if several come from the 80 or 87.5 percent sampling strata)--i.e., confidence bounds of 35 to 90 percent. Thus, even though both reductions are based on small numbers of cases, they are nevertheless statistically significant.

Table 6-3 shows that safety seats reduced nonserious injuries (transport to a treatment facility) by 30 percent in towaway crashes; lap belts reduced them by 31 percent.

The injury rates in Table 6-3 may be biased, however, if restrained and unrestrained children have different distributions of age, seating position, or crash severity. While the sample of restrained children is far too small to allow a detailed analysis of biases as in the Pennsylvania data (Section 5.2) it is at least possible to examine biases heuristically.

Table 6-4 shows that, as usual, most of the safety seat users are age 0 or 1. It also shows that unrestrained infants under age 1 are twice as vulnerable to hospitalizing injury as toddlers (age 2-4). That is a bias against safety seats. The bias is mitigated, however, because many 1-year-olds are in safety seats and that is one of the least vulnerable age groups. Furthermore, 5-year-olds are the second most vulnerable age group and they are mostly unrestrained. The pattern for nonfatal injuries diffrs from the fatality pattern (Table 4-6), as has already been discussed in Section 5.2. Table 6-4 also shows that children in safety seats were 25-39 percent more likely to ride in the back seat than unrestrained children <u>of the same age</u>. That is a bias in favor of the seats. Finally, the percentages of children whose vehicles suffered exterior damage in extent zone 3 or greater (an indication of crash severity) were:

Unrestrained	32
Safety seats	24
Lap belts	31

It is another bias in favor of safety seats. In short, the high safety seat usage among infants (bias against the seats) is more or less cancelled out by their low usage among 5-year-olds, their higher usage in the back seat and the lower average severity of the crashes they were involved in--leaving little net bias.

There also does not appear to be much bias in either direction for lap belt users. Belt usage is fairly constant across age groups (although lowest for the vulnerable infants). The severity of the crashes involving lap belt users, as shown above, was almost the same as for unrestrained children.

Table 6-4

INTERACTION OF CHILD'S AGE WITH RESTRAINT SYSTEM USAGE, SEAT POSITION AND INJURY RISK (NCSS - NASS - RSEP)

Child's Age	Restraint System Usage (%): Safety Seat	Restraint System Usage (%): Lap Belt	Restraint System Usage (%): None	Percent of Unr. Children in Back Seat	Percent of Safety Seat Users in Back Seat	Percent of Unrestrained Front-Seat Passengers: Hospitalized	Percent of Unrestrained Front-Seat Passengers: Transported
0	23	2	75	14	39	7.4	31.9
1	22	3	75	21	60	3.3	28.8
2	8	8	84	40	70	3.0	31.8
3	2	5	93	49	87	4.2	34.3
4	4	8	88	55	86	3.9	33.7
5	1	4	95	67	100	5.9	34.0

6.3 Injury reduction for sitting in the back seat

Table 6-5 shows that unrestrained children aged 0-5 riding in the back seat had lower injury rates than unrestrained child passengers in the front seat. Hospitalizations were reduced by 24 percent. Back seat passengers were 14 percent less likely to be transported from the accident scene to a treatment facility.

The injury rates in Table 6-5 may be biased, however, because children of different age groups have been lumped together, but Table 6-4 suggests the bias is unimportant. Unrestrained infants under age 1 are primarily carried in the front seat and are the group most vulnerable to hospitalizing injury--but the next most vulnerable group, the 5-year-olds, mostly sit in the back seat. In other words, the two biases more or less cancel. Table 6-4 also shows that the risk of less severe injuries (transport to a treatment facility) varies little with the child's age, minimizing the bias.

Since there were 145 hospitalized unrestrained children in the front seat and 88 in the back, it is possible to subdivide the injuries and still get statistically meaningful rates. Table 6-6 compares the hospitalization risks of front and back seat passengers by the body region where the injury is located. Table 6-6 is limited to children aged 1-5. Unrestrained infants under age 1 were excluded because 86 percent of them were in the front seat and their unusually large heads and short limbs might have distorted the front-seat statistics for those body regions.

Table 6-5

INJURY RATES IN TOWAWAY CRASHES FOR UNRESTRAINED CHILD PASSENGERS AGED 0-5, BY SEAT POSITION (NCSS - NASS - RSEP)

Seat Position	Weighted N of Unrestrained Children	Weighted n of Casualties	Casualty Rate (%)	Reduction Rel. to Front Seat (%)
		HOSPITALIZATIONS*		
Front seat	3274.42	144.67	4.42	----
Back seat	2632.04	87.96	3.34	24
	TRANSPORT TO TREATMENT FACILITY**			
Front seat	3274.42	1054.67	32.2	----
Back seat	2632.04	728.63	27.7	14

*Includes overnight hospitalizations and fatalities.

**Includes treated-and-released, overnight hospitalizations and fatalities.

Table 6-6

HOSPITALIZING INJURY RATES OF UNRESTRAINED CHILD PASSENGERS AGED 1-5, BY SEAT POSITION AND BODY REGION

Body Region	Front Seat (2721 Towaway-Involved Children)	Back Seat (2538 Towaway-Involved Children)	
	Hospitalizations per 1000 children	Hosp. per 1000 children	Red. Rel. to Front Seat (%)
Any	38.22	31.80	17
Head, face, neck	25.14	18.20	28
Chest, shoulders	4.77	4.43	7
Abdomen, pelvis, back	8.25	3.55	57
Torso	11.31	6.40	43
Head or torso	27.84	20.30	27
Arms	5.43	3.69	32
Legs	7.69	8.42	-10
Arms or legs	11.77	11.72	none

NASS, NCSS and RSEP code up to 6 injuries per child. A child is defined here to be "hospitalized by a head injury" if the child was hospitalized and any of the injuries was a head, facial or neck injury whose AIS $\geq$ 2 (or whose AIS = 1 if the child's overall AIS is also 1) [1]. Thus, the same child could be hospitalized by a head injury and also by a chest injury. As a result, in Table 6-6, the injury rate for combination of body regions (torso) is usually less than the sum of its constituent rates (chest and abdomen).

The back seat is a good place for an unrestrained child to avoid head injuries: the hospitalization rate is 28 percent lower than in the front seat. It is an even better place to avoid serious torso injuries: the reduction was 43 percent. These two statistics, by the way, are remarkably consistent with the Pennsylvania results in Tables 5-7 and 5-8 (33 percent fewer K, A, B head injuries, 28 percent fewer concussions, 49 percent reduction of K, A, B "chest, stomach and internal" injuries). The reduction of torso injuries was primarily achieved for the abdomen (57%), not the chest (7%), although the samples, for that level of subdivision, are getting too small for precise results. By contrast, the back seat does not enhance protection for a child's limbs, at least not the legs (10% increase observed).

Table 6-7 further limits the analysis to <u>frontal crashes</u>, which account for about 55 percent of the hospitalizations of unrestrained child passengers riding in the front seat. The back seat is especially effective in frontal crashes, reducing the overall risk of hospitalizations by 33 percent. Most of the benefit is for head injuries (57 percent reduction)

Table 6-7

HOSPITALIZING INJURY RATES OF UNRESTRAINED CHILD PASSENGERS AGED 1-5 IN FRONTAL CRASHES, BY SEAT POSITION AND BODY REGION

Body Region	Front Seat (1306 Towaway-Involved Children)	Back Seat (1310 Towaway-Involved Children)	
	Hospitalizations per 1000 children	Hosp. per 1000 children	Red. Rel. to Front Seat(%)
Any	43.95	29.48	33
Head, face, neck	30.59	13.07	57
Chest, shoulders	5.87	3.15	46
Abdomen, pelvis, back	11.32	3.05	73
Torso	15.40	5.44	65
Head or torso	34.67	15.45	55
Arms	5.96	3.24	46
Legs	12.85	10.11	21
Arms or legs	16.01	12.59	21

and torso injuries (65 percent reduction). Hospitalizations due to head and/or torso injuries dropped by 55 percent. By contrast, the reduction for arm or leg injuries was only 21 percent.

The implication of Tables 6-6 and 6-7 are that the back seat, while quite effective in frontal crashes, offers few if any benefits in nonfrontal crashes (which comprise side impacts, rear impacts and roll-overs).

All of the preceding results are intuitively reasonable. The "frontal surface" opposite the back seat passenger is the front seatback. It is a much "friendlier" surface than the instrument panel and windshield, which are in front of the front seat passenger. Thus a large effect would be expected in frontal crashes. By contrast, the adjacent side interior surfaces (doors) and rear interior surfaces (seat cushions) are of roughly the same composition for the front and rear passengers, suggesting little difference in injury risk.

In frontal crashes, the rear seat passenger will strike the seatback first with the legs, then the arms, head and torso. But in the front seat, a short-legged child will hit the instrument panel hard with its torso and head before the firewall/lower instrument panel has done a good job slowing down its legs. Thus, the back seat provides the most protection for the torso and head, the least for the legs.

6.4 Unrestrained injury risk in frontal crashes--by body region and Delta V

The sled tests of Chapter 7 establish a relationship between frontal Delta V (crash severity), on the one hand, and dummies' impact severity parameters such as HIC, chest g's, etc., on the other. What is really desired, however, is the relationship between injury severity and measures such as HIC. The vital link--the relationship between injury and Delta V in frontal crashes--is provided by the accident data from NASS, NCSS and RSEP. Since Delta V has been estimated for the accidents on those files by the CRASH program [48], it is possible to subdivide the data by intervals of Delta V and to compute the injury risk on each interval.

The limitation to this approach is the available sample size. When there are not enough cases of hospitalized children in each interval, the injury rates have meaningless fluctuations due to sampling error. Of course, the procedure yields meaningful results only for unrestrained children and, then, only if several precautions are taken to maximize the available sample size.

The first precaution is to solve the problem of missing data on Delta V. It would be an intolerable loss of data simply to exclude the 46 percent of NASS, NCSS and RSEP cases where Delta V was unknown, not only because of the loss of sample size but also because certain types of crashes would be virtually excluded (e.g., impacts with large trucks). Delta V, it should be recalled, is estimated by the CRASH program, which requires detailed damage measurements on all involved vehicles and cannot be applied at all in certain types of fixed object collisions. CRASH does contain a subroutine, however, which assigns approximate damage measurements to a vehicle based on its mass and its Collision Deformation Classification (CDC) [12], [48], pp. 5, 20-22. The subroutine can be taken one step further to provide a surrogate for Delta V, actually an approximate "barrier equivalent velocity" using only the mass and the CDC for the case vehicle--by running CRASH under the assumption that the case vehicle's damage (as approximated from the CDC) was caused by an impact with a rigid immobile fixed object. The surrogate variable has only 3 percent missing data on NASS, NCSS and RSEP frontal impacts.

The relationship between the surrogate variable and Delta V was tested on the 576 frontal impacts where both were known. The surrogate (henceforth abbreviated as DV_2) was an unbiased estimator of Delta V (abbreviated as DV_1) in the sense that both had an average of 15, over the 576 cases. But it was not a precise estimator to the extent that the correlation coefficient between the two variables was .66. Based on regression, the best relationship between the two variables is

$$DV_1 = 4.645 + .7082\ DV_2$$

Thus, in the remainder of this section "Delta V" is defined as

DV_1, if known

$4.645 + .7082\ DV_2$ otherwise

A second precaution is to combine chest and abdominal injuries into a single category: torso injuries. As Table 6-7 showed, there were only 12 children hospitalized by chest injuries in frontal crashes: too few to allow further subdivision by Delta V. But there were 27 children with hospitalizing torso injuries: just barely enough to allow subdividing.

A third precaution that may be necessary is to lump front and rear seat passengers. It would be desirable to avoid this, because the two groups might have different responses to Delta V. In Tables 6-8 through 6-11, injury rates are calculated for front and rear seats combined and for front seat only. The results are then compared as to statistical validity and Delta V trends.

On the other hand, the deletion of cases involving infants under age 1 is an unavoidable diminution of the available sample. The sled tests of Chapter 7 use 3-year-old dummies. The accident data should contain the broadest range of children whose injury responses could be said to resemble 3-year-olds': 1 to 5-year-old children satisfy that criterion; infants, with their much higher injury risk (Table 6-4) and very different body structures, do not.

The class intervals of Delta V that are used in Tables 6-8 through 6-11 are 0-10 (literally $0 < \text{Delta V} \leq 10$), 10-15, 15-20, 20-25, 25-30, 30-40 and 40-50 mph. They were selected to include roughly equal numbers of hospitalized children (except for the lowest, which hardly contains any) so as to enhance statistical stability of the injury rates.

Table 6-8 shows head injury risk as a function of Delta V for unrestrained child passengers aged 1-5 in frontal towaway crashes (front and back seats lumped together). The injury risk is the percentage of towaway-involved children who were hospitalized by a head injury. It is calculated in Table 6-8, as follows: The first column shows the (weighted) number of towaway-involved children in each interval of Delta V, e.g., 819.21 between 10 and 15 mph. The next three columns enumerate the hospitalized children in that interval (10-15 mph): 12.33 whose hospitalizing injuries (see Section 6.3) included a head injury, 5 whose hospitalizing injuries did not include a head injury and 2 hospitalized children whose specific injuries were unreported. It is assumed that the (typically small) number of hospitalizations with unknown injuries have the same distribution as the others; thus, it is estimated that a total of 13.75 children actually had hospitalizing head injuries (5th column of Table 6-8). The injury risk at 10-15 mph is 13.75/819.21, or 1.68 percent.

Table 6-8 shows that head injury risk escalates steadily and rapidly as Delta V increases: from 0.3 percent in towaways with Delta V $\leq$ 10 to 35.2 percent when 40 < Delta V $\leq$ 50. When injury risk is graphed against Delta V (i.e., the median value of Delta V in each interval) on <u>log log</u> paper, as in Figure 6-1, the data points come amazingly close to describing a straight line with slope 2.5 (the correlation of log DV and log Inj. Risk is .996). In other words, each 1 percent increase in Delta V is associated with a 2.5 percent increase in head injury risk.

TABLE 6-8

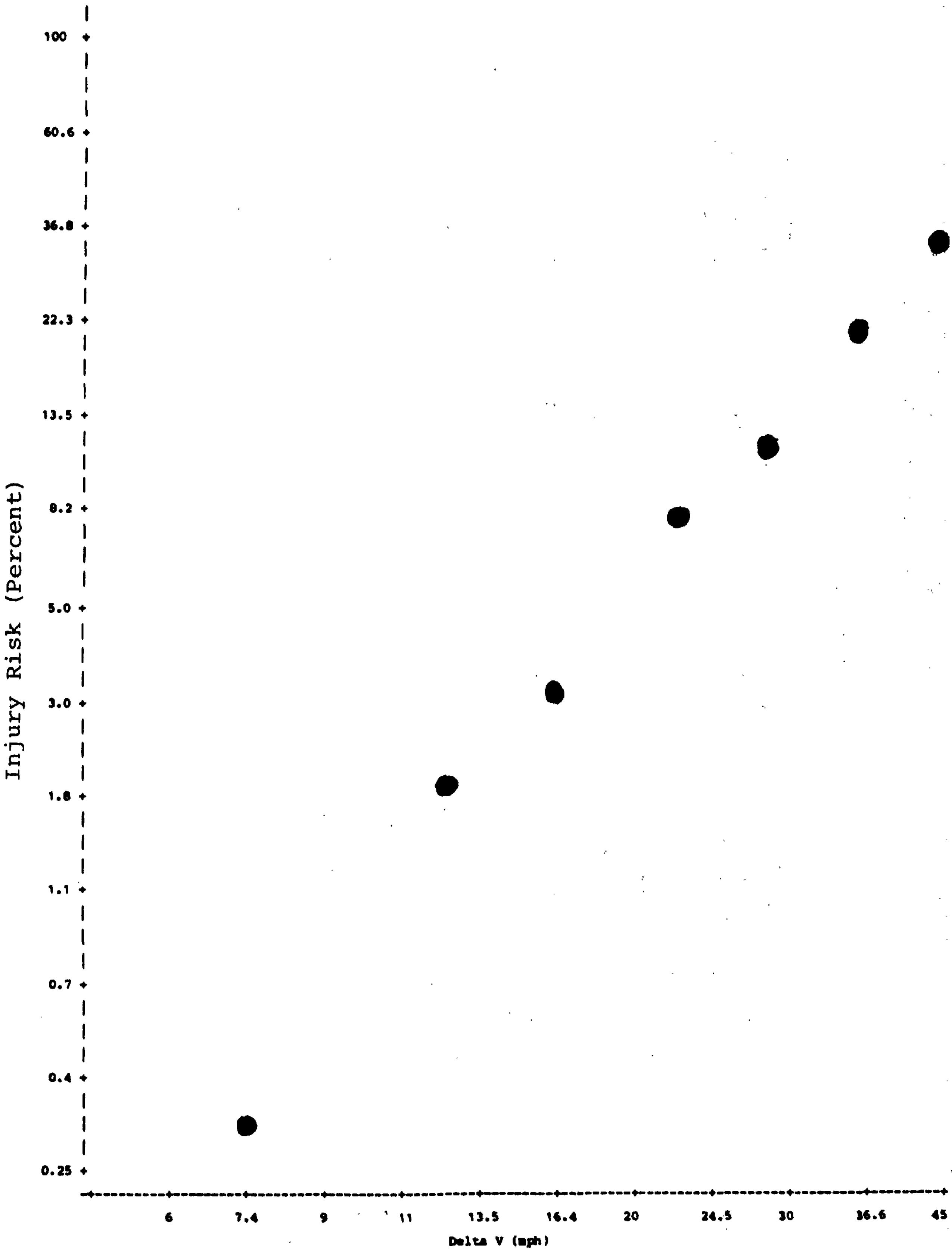
HOSPITALIZING HEAD* INJURY RATES OF UNRESTRAINED PASSENGERS
AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V

O B S E R V E D

Delta V (mph)	N of Children	Hosp. by Head Injury (n_1)	Hosp. - But Not by Head Inj. (n_2)	Hosp. - Unk. Source (n_3)	Estimated n Hosp. by Head Inj. $(n_1 + \frac{n_1}{n_1 + n_2} n_3)$	Injury Risk (n/N %)
Less than 10	871.69	2.00	1.13	1.00	2.64	0.30
10-15	819.21	12.33	5.00	2.00	13.75	1.68
15-20	489.08	10.71	5.13	4.00	13.41	2.74
20-25	192.83	12.58	6.13	1.00	13.25	6.89
25-30	73.75	6.00	3.13	1.00	6.66	9.03
30-40	47.92	8.33	2.33	2.00	9.89	20.64
40-50	15.25	4.13	3.00	2.13	5.36	35.15
-----	------				-----	-----
All SPEEDS	2509.73				64.96	2.59

* Head, face or neck

FIGURE 6-1
HOSPITALIZING HEAD INJURY RATES OF UNRESTRAINED
PASSENGERS AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V



In all, there were 64.96 children hospitalized by head injuries in a sample of 2509.73 children, a head injury risk of 2.59 percent for front and back seats combined.

Table 6-9 shows torso injury risk as a function of Delta V, for front and back seats combined. Here, too, the risk escalates rapidly as Delta V increases: from 0.15 percent in towaways with Delta V $\leq$ 10 to 34.7 percent when 40 < Delta V $\leq$ 50. But the rate of increase is not quite as steady as for head injuries. For example, the rates climb more slowly between 20 and 40 mph than before or after those intervals. The slight unsteadiness is undoubtedly due to sampling error, because there are only half as many torso injuries (30.75) to work with as head injuries (64.96). That sample of torso injuries has been stretched up to (but not beyond) the limit of its information content in Table 6-9.

Nevertheless, when torso injury risk is graphed against Delta V on log log paper, as in Figure 6-2, they deviate only very little from a straight line with slope 2.8 (the correlation of log DV and log Inj. Risk is .98). In other words, each 1 percent increase in Delta V is associated with a 2.8 percent increase in torso injury risk.

Since there were 30.75 torso-injury hospitalizations among 2509.73 children, the overall torso injury risk was 1.23 percent for front and back seats combined.

TABLE 6-9

HOSPITALIZING TORSO* INJURY RATES OF UNRESTRAINED PASSENGERS AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V

O B S E R V E D

Delta V (mph)	N of Children	Hosp. by Torso Injury (n_1)	Hosp. - But Not by Torso Inj. (n_2)	Hosp. - Unk. Source (n_3)	Estimated n Hosp. by Torso Inj. $(n_1 + \frac{n_1}{n_1 + n_2} n_3)$	Injury Risk (n/N %)
Less than 10	1.69	1.00	2.13	1.00	1.32	0.15
10-15	819.21	3.33	14.00	2.00	3.71	0.45
15-20	489.08	6.00	9.83	4.00	7.52	1.54
20-25	192.83	6.46	12.25	1.00	6.81	3.53
25-30	73.75	3.00	6.13	1.00	3.33	4.52
30-40	47.92	2.33	8.33	2.00	2.77	5.78
40-50	15.25	4.13	3.00	2.13	5.29	34.69
-----	------				-----	-----
All SPEEDS	2509.73				30.75	1.23

* Chest, abdomen, back, pelvis or shoulders

FIGURE 6-2
HOSPITALIZING TORSO INJURY RATES OF UNRESTRAINED
PASSENGERS AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V

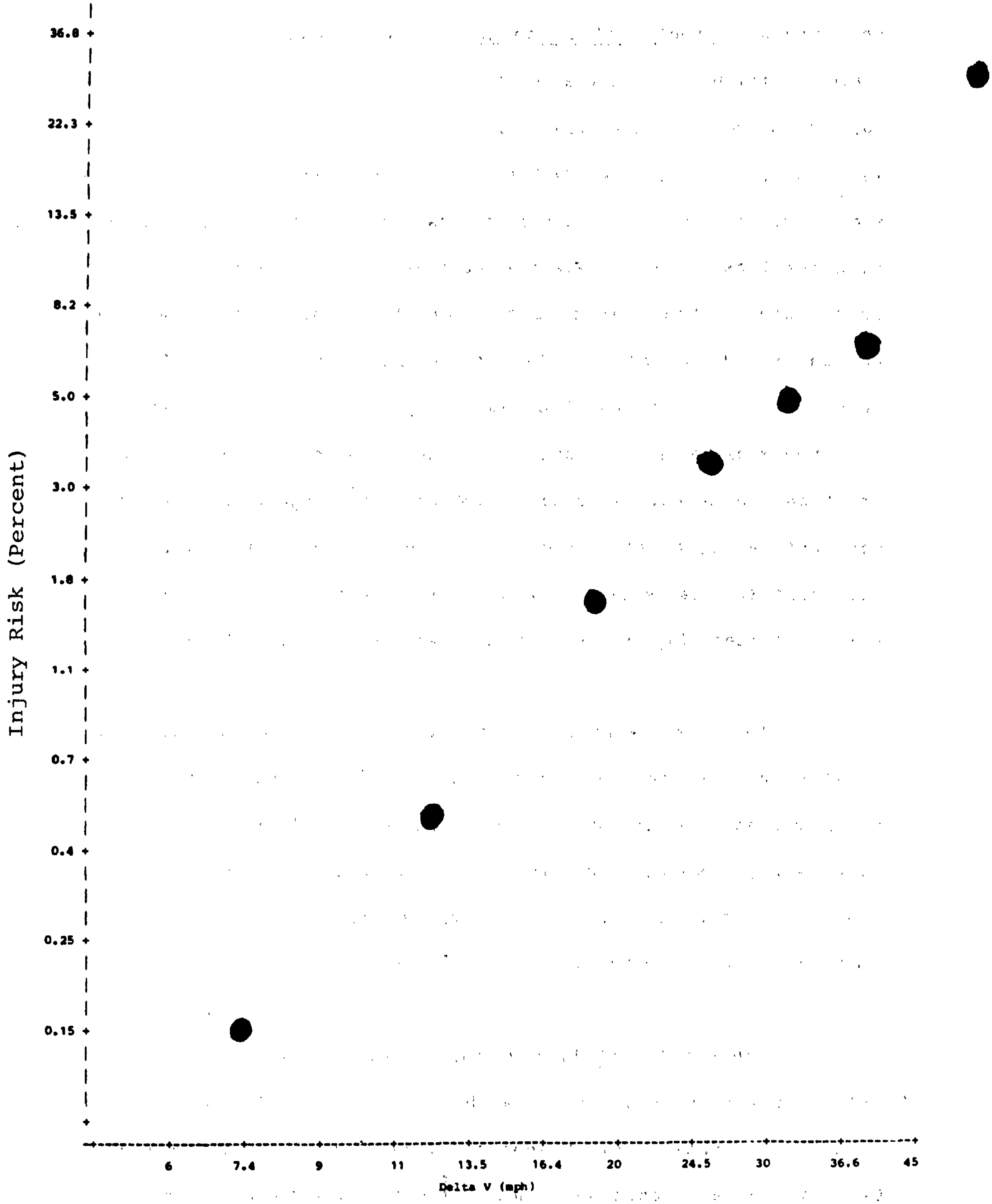


Table 6-10 shows head injury rates as a function of Delta V for unrestrained front-seat passengers only. Head injury risk increases steadily from 0.65 percent at Delta V $\leq$ 10 to 68.2 percent at 40 < Delta V $\leq$ 50, but not quite as steadily as in Table 6-8 since the sample size has been reduced by a third, to 43.77 hospitalizations. When injury risk is graphed against Delta V on log log paper, the data points still come very close to a straight line. The correlation coefficient is .989 which is "low" only in comparison to the .996 obtained for the combined front and rear seat occupants. More importantly, the slope of the line is 2.5, which is identical to the one for the combined groups. In other words, front-seat passengers alone have the same head injury response to increased Delta V as front and rear-seat passengers, combined; only injury risk is higher, by a constant ratio, at all speeds. Specifically, the overall head injury rate for front-seat passengers is 3.50 percent, which is 1.352 times higher than the 2.59 percent injury risk for front and rear seats combined.

In other words, the smoothest, most statistically reliable relationship between Delta V and head injury for unrestrained front-seat passengers aged 1-5 is obtained by taking the data from Table 6-8 (front and back seats, combined) and multiplying each injury risk by 1.352. These are the data that will be used to calibrate the HIC values for unrestrained front-seat dummies in the sled tests of Chapter 7.

Table 6-11, similarly, shows torso injury rates as a function of Delta V for front seat only. With just 22.41 injuries in the sample, the data are stretched a bit beyond the limits when they are subdivided into Delta V classes: observed injury rates actually dropped between 15-20 and

TABLE 6-10

HOSPITALIZING HEAD* INJURY RATES OF UNRESTRAINED FRONT-SEAT PASSENGERS AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V

O B S E R V E D

Delta V (mph)	N of Children	Hosp. by Head Injury (n_1)	Hosp. - But Not by Head Inj. (n_2)	Hosp. - Unk. Source (n_3)	Estimated n Hosp. by Head Inj. $(n_1 + \frac{n_1}{n_1 + n_2} n_3)$	Injury Risk (n/N %)
Less than 10	458.25	2.00	0	1.00	3.00	0.65
10-15	381.75	8.33	4.00	0	8.33	2.18
15-20	242.75	9.58	3.00	3.00	11.86	4.89
20-25	100.21	7.58	0	0	7.58	7.56
25-30	47.38	5.00	2.00	0	5.00	10.55
30-40	15.79	4.33	1.33	1.00	5.10	32.30
40-50	4.25	2.13	1.00	1.13	2.90	68.24
-----	------				-----	-----
All SPEEDS	1250.37				43.77	3.50

INJURY RISK FOR FRONT & BACK SEATS COMBINED 2.59

RATIO: FRONT ONLY/FRONT & BACK 1.352

* Head, face or neck

TABLE 6-11

HOSPITALIZING TORSO* INJURY RATES OF UNRESTRAINED FRONT-SEAT PASSENGERS AGED 1-5 IN FRONTAL TOWAWAY CRASHES, BY DELTA V

		O B S E R V E D				
Delta V (mph)	N of Children	Hosp. by Torso Injury (n_1)	Hosp. - But Not by Torso Inj. (n_2)	Hosp. - Unk. Source (n_3)	Estimated n Hosp. by Torso Inj. $(n_1 + \frac{n_1}{n_1 + n_2} n_3)$	Injury Risk (n/N %)
Less than 10	458.25	1.00	1.00	1.00	1.50	0.33
10-15	381.75	3.33	9.00	0	3.33	0.87
15-20	242.75	6.00	6.58	3.00	7.43	3.06
20-25	100.21	1.33	6.25	0	1.33	1.33
25-30	47.38	3.00	4.00	0	3.00	6.33
30-40	15.79	1.33	4.33	1.00	1.56	9.88
40-50	4.25	3.13	0	1.13	4.25	100.00
All SPEEDS	1250.37				22.41	1.79

INJURY RISK FOR FRONT & BACK SEATS COMBINED 1.23

RATIO: FRONT ONLY/FRONT & BACK 1.461

* Chest, abdomen, back, pelvis or shoulders

20-25 mph since there were only 1.33 actual injuries in the latter interval. Elsewhere, though, the rates increased steeply with Delta V. The graph of log (injury risk) versus log (Delta V) is still respectably close to a straight line (r = .91) whose slope is identical to the one obtained for combined front and rear seats. The overall torso injury risk for front seat passengers alone is 1.79 percent, which is 1.461 times the risk for front and rear seats combined. In other words, the best relationship between Delta V and torso injury risk for unrestrained front-seat passengers is obtained by taking the data from Table 6-9 (front and rear sets, combined) and multiplying each injury risk by 1.461. These are the data that will be used to calibrate upper and lower spine acceleration values for the unrestrained front-seat dummies.

CHAPTER 7

STATISTICAL ANALYSES OF SLED TEST DATA

The three preceding chapters estimated the overall effectiveness of child safety seats when used, unable to make a distinction between correct and incorrect usage or among the various types of seats. But two of the main objectives of the evaluation were to determine what benefits were lost as a result of seat misuse and to see if there were any sharp differences among the major types of seats. The goals were accomplished by a sled testing program specifically designed for the purpose of evaluation. Sled tests were run with unrestrained 3-year-old dummies at a variety of speeds, impact angles and seat positions [46]. Identical tests were run with dummies in various types of toddler seats, correctly and incorrectly used. The differences between the restrained and unrestrained dummies are transformed by a statistical procedure, in this chapter, into measures of injury-reducing effectiveness.

The procedure was planned to produce estimates of injury risk which duplicate those found for unrestrained front-seat children in highway accidents (Section 6.4) and it did so. It correctly estimated injury reduction for unrestrained children in the back seat, relative to the front seat, to be about 50 percent for serious head and torso injuries in frontal crashes. When the effectiveness estimates generated by the procedure for the various seat types and misuse modes were averaged, based on the frequency of occurrence of those conditions in the general population

(Section 2.1.2), they yielded overall effectiveness values that are amazingly consistent with the preceding chapters:

o 42-48 percent serious injury reduction for children classified as "safety seat users" by police (76% of correct users and partial misusers, 58% of gross misusers--see Section 3.2.4)--duplicating the 44 percent estimate from FARS (Table 4-9) and the 43-45 percent from Pennsylvania (Table 5-3).

o 49-58 percent serious injury reduction for children classified as "safety seat users" by NASS teams (correct and partial misusers, only--see Section 6.1)--duplicating the 56 percent effectiveness found in NASS-NCSS-RSEP (Table 6-3).

o The four types of correctly used safety seats tested here were estimated to have an average HIC of 466 and 42 chest g's at 27.5 mph impact speed. The corresponding results in NHTSA compliance tests for Standard 213 were 459 HIC and 40 chest g's (see Section 3.4.3 for a complete discussion).

Because the procedure generated such accurate overall effectiveness estimates for those situations that could be tested by other data sources, it is possible, despite caveats over a number of details in the sled test procedure, to place a good deal of confidence in the procedure's other results:

o The overall effectiveness of safety seats, based on 1984 usage patterns (including all gross misusers) is about 40-46 percent.

o Correctly used seats reduce serious injuries by about 61-67 percent. The major types of seats, when correctly used, are all very effective and the sled test results do not show substantial differences between types.

o Partially misused seats reduce serious injuries by 33-59 percent, depending on the degree of misuse. The occurrence-weighted average effectiveness is on the order of 38-48 percent.

o Children in grossly misused seats have about the same injury risk as unrestrained children.

7.1 Overview and objectives of the sled testing and analysis procedure

The goal of the procedure is to estimate the injury-reducing effectiveness of safety seats--both overall and for specific types of seats in specific correct or incorrect use modes. "Effectiveness" is the injury reduction relative to the unrestrained child passenger. In other words, it is not enough to conduct sled tests with restrained dummies and state that the results are highly encouraging. It is also necessary to conduct identical tests with unrestrained dummies and to measure the difference between restrained and unrestrained. Moreover, it is not enough to measure that difference in terms like Head Injury Criterion (HIC) and similar quantities; instead, those quantities must be translated into actual reductions of injury in highway accidents. In order to perform such a translation, two conditions must be met. First, the types of surfaces contacted by the dummies in the sled tests (resulting in HIC, chest acceleration, etc.) must be representative of the vehicle interior surfaces struck by children in actual crashes--in short, the sled buck needs to be the passenger compartment of a real car. Second, the values of HIC, etc., observed [for the unrestrained dummy] in the sled tests need to be related to the levels of injury risk [for unrestrained children] in highway crashes of the same severity. That is the only realistic way in which an observed reduction of x percent in HIC, say, can be used as a basis for claiming a y percent reduction of injury risk. Finally, if it is desired to produce estimates of overall injury reduction for safety seats, the test program must be comprehensive: not just one brand of safety seat but every type that is well-represented on the highway; not just one or two modes of misuse but every mode that commonly occurs; back seat as well as front seat occupants; not just one test speed but the range of speeds at which serious injuries normally occur on the highway; oblique as well as straight frontal tests. These considerations, to a large extent, determine the shape of the test procedures.

It is also important to note those items that are <u>not</u> goals of the test procedure. It is not a goal to obtain sled test results that duplicate what was found in compliance tests for Standard 213, or to check if seats could meet Standard 213 in certain misuse modes, or to assess in any way the appropriateness of the criteria used in Standard 213 or postulate benefits for any potential changes in the standard--the only goal is to evaluate the seats that are actually, currently in the Nation's cars. It is also not a goal to measure the extent to which the current (effective 1-1-81) version of the standard increased benefits over earlier versions. Importantly, the procedure is not an examination of the failure thresholds of safety seats, or of the factors that might cause safety seats to fail in use.

Certain other limitations of the sled test program should be summarized at this point. It was limited to frontal and oblique frontal impacts (which account for 55 percent of child passenger hospitalizations--see Section 6.3); side impact tests may be conducted at a later date. Only toddler seats and 3-year-old dummies were used because injury criteria had not been defined and analyzed for infant dummies. The analysis was limited to head and torso injuries caused by blunt impacts, since abdominal penetration sensors for child dummies had not been developed at the time of the tests. (They were subsequently developed by Weber and Melvin at UMTRI - see letter 74-09-N17-009 to the NHTSA Docket, dated 8/14/85.) The neck injury parameters measured in the tests did not give realistic predictions of neck injury risk (see Section 7.5, Step 12). Moreover, the 3-year-old dummy is larger than the median child in toddler seats on the highway and, perhaps, more likely to contact vehicle interior surfaces when restrained. The sled buck and crash pulse simulated a barrier impact in a Chevrolet Citation, which has a "soft" crash pulse. A different-sized car or more severe crash pulses would certainly have affected results (see Section 3.4.3). The four brands of safety seats used in the tests need not have the same performance as other brands of the same generic "types," (although Section 3.4.3 suggests that the four brands were generally representative of their generic types). The shield booster type of seat, which became popular during and after 1984, was not included in these 1983 tests. As a result, the tests provide no additional information about a type of seat which meets Standard 213 criteria (including head and chest injury and head excursion) in frontal crashes with 3 year old dummies, but which has raised concern among researchers about abdominal loading and excursion of larger or smaller dummies (see Hall et al's 9/5/85 letter to NHTSA Docket 74-09-N17-018 or Weber and

Melvin's 8/14/85 letter to Docket 74-09-N17-009). Finally, all results are subject to sampling error since dummy injury responses vary from test to test, especially those of unrestrained dummies.

The procedure consisted of 24 steps which could be grouped into three larger categories: planning the sled tests, running the sled tests and statistical analysis. The first 9 steps are described one-by-one in Appendix 1, while steps 10-24 are described in the remainder of this chapter, with a presentation of the results and caveats generated at each point. The steps were:

Planning the sled tests

1. Select the types of seats to be tested and the correct/mis-use modes.

2. Design sled buck and test setup, select crash modes to be simulated.

3. Select and obtain dummies.

4. Define list of injury criteria to be measured.

5. Determine range of test speeds, sled pulse at each speed.

Running the sled tests

6. Schedule the test matrix.

7. Test calibration of dummies.

8. Replace/repair damaged equipment (sled buck, seats)

9. Perform sled tests

10. Data reduction and computation of injury criteria

Statistical Analysis

11. Compare sled test results to the literature on injury criteria and injury risk.

12. Select the injury parameters to be used in the statistical analysis.

13. Express the injury parameters as a function of Delta V for each restraint use mode.

14. For unrestrained front-seat passengers, calibrate the injury parameters observed in the sled tests against injury rates observed in frontal highway accidents of the same speed. Obtain injury risk as functions of injury criteria.

15. Calculate injury risk as a function of Delta V, for each restraint use mode, by applying, sequentially, the functions developed in Steps 13 and 14.

16. Check that the Delta V-injury risk function for unrestrained front-seat passengers is consistent with injury rates in the highway accident data.

17. Obtain the actual distribution of Delta V in frontal towaway crashes from the accident data.

18. Calculate overall injury risk for each restraint use mode by integrating the Delta V-injury risk functions over the Delta V distribution in crashes. Calculate injury reduction for each restraint mode relative to the unrestrained child.

19. Check that the overall injury risk for unrestrained front-seat occupants, unrestrained back-seat occupants and lap-belted occupants are consistent with the rates observed in accident data.

20. Average the effectiveness of the various restraint use modes--weighted by the frequency of occurrence of those use modes in the Hardee's Restaurant survey--to estimate the overall effectiveness of safety seats in 1984.

21. Check that the overall effectiveness estimates are consistent with results from FARS, Pennsylvania and NASS-NCSS-RSEP.

22. Find the average effectiveness of correctly used, partially misused and grossly misused seats.

23. Find the effectiveness of moving a restrained child from the front seat to the back seat.

24. Find the average effectiveness of tether-type, tetherless, partial shield, full shield and booster seats, taking into account the levels of misuse observed for each type in the Hardee's survey.

7.2 Planning and running the sled tests

Steps 1 to 9 of the sled test procedure are documented in Appendix 1 of this report, including the rationale for the particular safety seats, dummies, crash speeds, etc., used in the sled tests; an overview of the contractor's techniques and accomplishments; and some statistical analyses to address issues of data quality and dummy repeatability.

7.3 Step 10 - Data reduction: sled test results

The accelerometer traces were analyzed by computer programs which calculated the Head Injury Criterion (HIC) and the 3 millisecond peaks for chest and lower spine g's, neck tension, head rotation, mean strain criterion, etc. The Total Laceration Index (TLI) was calculated by hand, based on the number and type of cuts in the chamois skin coverings of the dummy heads. All data and a synopsis of the films are documented in Appendix B of the contractor's final report and explained in pp. 67-93 of that report [46].

The most important data from the tests, however, are summarized in Appendix 2 of this evaluation. The results are listed separately by restraint use mode (see Table 7-1) and seat position (front or back seat). For each use mode/seat position combination, the tests are listed by impact speed. The leftmost column indicates the contractor's sled test number, allowing reference to Table 2 of Appendix 1 and the contractor's report. "Speedgp" indicates the targeted impact speed (15, 25 or 35; however, a few of the speed selection tests--Step 5--were run at intermediate speeds and this variable is left blank). The next column shows the actual impact

TABLE 7-1

RESTRAINT USE MODES SELECTED FOR SLED TESTS

Number	Name	Safety Seat Brand	Safety Seat's Harness/Shield Use	Vehicle's Lap Belt Use	Safety Seat's Tether/ Vehicle's Shoulder Belt Use
1	Unrestrained	-----	----	----	----
2	Lap belt	-----	----	around dummy	(shoulder belt behind dummy)
3	Tethered seat-correct	Strolee Wee Care 597A	harness correct	correct	tether correct
4	Tethered seat-no tether	Strolee Wee Care 597A	harness correct	correct	tether not used
5	Gross misuse-no harness	Strolee Wee Care 597A	harness not used	correct	tether not used
6	Tethered seat-no tether & belt too low	Strolee Wee Care 597A	harness correct	improperly routed thru tubular structure at base of seat	tether not used
7	Gross misuse-no belt	Strolee Wee Care 597A	harness correct	not used	tether not used
8	Tetherless seat-correct	Century 100	harness correct	correct	N/A
9	Tetherless seat-belt too low	Century 100	harness correct	improperly routed thru base of seat	N/A
10	Full shield type-correct	Cosco/Peterson Safe-T-Shield	shield correct (no harness)	correct	N/A
11	Booster seat-correct	Century Safe-T-Rider	N/A	correct	shoulder belt in front, tethered harness in back seat
12	Booster seat-no upper body support	Century Safe-T-Rider	N/A	correct	shoulder belt behind dummy tethered harness not used

speed. The fourth shows estimated Delta V, which is 7.2 percent higher than the impact speed, because the sled rebounds from the target to some extent. (It is not the actual Delta V, which could not be calculated due to the problem with the sled-mounted accelerometer--Step 9.) "Crashmode" tells whether the test was straight frontal or oblique. The last 4 columns are the outcomes of the sled tests: HIC; chest g's; "abdomen" g's which are the lower spine g's, and "torso" g's, which are the sum of chest and abdomen g's. In the 7 cases where one of the summands was missing, torso g's were estimated by taking double the other summand. That estimate was considered adequate because upper and lower spine g's had nearly the same mean (43 vs. 42) and standard deviation (21 vs. 23) as well as a correlation coefficient of .8 (based on 126 observations where both were known). The highest HIC recorded in the program was 2858 (for a grossly misused seat); the highest chest g's, 122 (grossly misused seat); and the highest lower-spine g's, 149 (unrestrained).

In Appendix 3 of this report, the sled test outcomes are graphed as a function of Delta V. There are two graphs for each restraint use mode (except that the two gross misuse modes, nos. 5 and 7, were superimposed because there are fewer data points for them than for the other modes). The first shows HIC, the second, torso g's. Front and back seat occupants are shown on the same graph, but the front-seat dummies are indicated by 1's (or 3's if torso g's had to be estimated) and the back-seat dummies by 2's (or 4's if torso g's were estimated). The graphs are useful for showing what happened in the sled tests and when something unexpected happened.

The correctly used safety seats (use modes 3, 8, 10 and 11) and the adult lap belt (use mode 2) as a rule did not allow the dummy to contact any vehicle interior surface (except in some tests with the full shield type seat). The HIC's and torso g's, some of which are quite high, are so-called "noncontact" phenomena actually involving contact between the dummy and the restraint system, the dummy with itself and, above all, the whiplike motion of the body when one part of it is restrained while another is still in motion. The lack of contact with the vehicle interior was clearly documented by the films, the absence of chalk marks, and the absence of spikes in the accelerometer traces. Since the vehicle interior was not involved, there were no large differences between the results for the front and back seat dummies (with one exception noted below).

The unrestrained dummies (mode 1) and the grossly misused seats (modes 5 and 7) allowed unhindered contact between the dummy and the vehicle interior. HIC and torso g's were mainly due to the contacts, as evidenced by the ringing accelerometer traces. There were larger differences between the results for the front and back seats. There was also more scatter in the results than for the correctly restrained dummies.

The partially misused seats (modes 4, 6, 9 and 12) usually did not allow the dummy to contact the vehicle interior at 15 or 25 mph. At those speeds the results resembled the ones for correctly used seats, although they were not as favorable because the misuse aggravated whiplike motion in the dummies. At 35 mph, some of the seats allowed enough head excursion for severe contact HIC's or leg excursion for contacts that jolted the lower spine accelerometer. Other seats were damaged to the point of allowing the dummies to escape. In either case, the injury parameters resembled those for unrestrained dummies (higher in the front than in the back seat, wide scatter).

The graphs for the unrestrained dummy (use mode No. 1) show high repeatability in the front seat. All the points labeled "1" closely fit a straight line, both on HIC and torso g's. The back seat dummies (points labeled "2" or "4") are quite scattered for HIC, reflecting the great variety of head contacts seen in the films. HIC was sometimes much lower than in the front seat, sometimes just as high. Torso g's for the back seat dummies were less scattered and well below the level for the front seat.

Lap belted dummies (use mode No. 2) generally had highly repeatable results which were much less severe than those for unrestrained dummies, except for HIC at 35 mph. Here, the whiplike motion of the dummies' heads was severe and somewhat variable from test to test (HIC of 1255 to 2097). Throughout, there was little difference between the front and back seats.

The tethered seat (mode No. 3) was the exception to the rule that correctly used seats were unaffected by seat position. The HIC's at 35 mph were much higher in the front seat (1179-1826) than in the back seat (648-758), even though no contact with the vehicle took place at either position. The films suggested that the attachment of the tether to the rear seat belt (for the front-seat dummy) is less satisfactory than its attachment to a fixed anchorage point (for the rear seat dummy). Moreover, the car's front-seat cushion allowed the tubular structure of the safety seat to dig in at the front and partially tip the seat. As a result the dummy's head pitched forward and downward and then snapped back at high speed. The same thing happened, to a lesser extent, to the dummy's chest. At lower sled speeds, the seat performed very well and repeatably, with little difference between front and back seats.

When the tether was not used (mode No. 4) extremely severe head contacts occurred at 35 mph, resulting in even higher HIC's (1513-2673). The seat performed well and very repeatably for the head at lower speeds and for the torso at all speeds, although not as well as when the tether was used.

The behavior of dummies in grossly misused seats (modes 5 and 7) closely resembled that of unrestrained dummies. The films showed similar kinematics. One exception was that the dummy sitting in a safety seat was launched on a higher trajectory and usually broke the windshield, while the unrestrained dummy did not.

When the tether was not used and, furthermore, the belt was routed too low on the tubular seat structure (mode No. 6), HIC had a bimodal distribution. At 15 mph and half of the 25 mph tests, the seat held together and HIC was moderately repeatable and unaffected by seat position. In the 35 mph tests and half of the 25 mph tests, the tubular structure gave way and the dummy pitched head first toward the vehicle interior, resulting in high HIC's (2017-2196 @ 35 mph) in the front seat and dispersed results (620-1598 @ 35 mph) in the back seat. Torso g's were highly repeatable since contact was usually minor or avoided entirely.

The graphs for the correctly used tetherless seat (mode No. 8) were well behaved: repeatable, unaffected by seat position and favorable results (although HIC reached 1008 in one of the 35 mph tests). At lower speeds, its performance was slightly inferior to the correctly used tethered seat.

When the belt was routed too low on the tetherless seat (mode No. 9), it allowed relatively severe whiplike motion of the head at 35 mph, with HIC ranging from 1041 to 1777. The seat held up well and did not allow dummy contact with the vehicle interior. As a result, the graphs look just like those for correctly used seats, except that the results are not as favorable.

The seat with a full shield (use mode No. 10) did a good job in preventing whiplike motion of the head and, as a result, kept HIC relatively low at all speeds (e.g., 614-1062 @ 35 mph). The films show it was accomplished in part by the shield itself but also, to a large extent, because the lack of a harness allowed the lower body greater forward motion than in other correctly used seats. Thanks to that slight submarining, the head had to "catch up" to the torso and did not whip in front of it. Of course, the relatively low HIC's were thus offset by higher torso g's, especially if there was enough leg excursion to allow a foot contact strong enough to jolt the lower spine sensor (which is what happened in test No. 2809, which had 138 torso g's at 25 mph and is a very evident outlier in the graph).

The correctly used booster seat (mode No. 11) performed splendidly at all speeds (HIC was 356-410 @ 35 mph). The upper and lower torso were about equally well restrained, resulting in a minimum of whiplike motion. The accelerometer traces showed that this system begins to decelerate the dummies earlier than the others and takes advantage of the early onset by maintaining a moderate, steady deceleration over a long time period. The graphs show exceptional repeatability and little or no effect for seat position or impact angle (frontal vs. oblique).

Finally, when the booster seat is used without upper body restraint (mode No. 12), it functions much like a lap belt (mode No. 2) at 15 and 25 mph. At 35 mph, the dummy's head sharply contacts the vehicle interior (because the booster seat under the child allows more excursion than a lap belt alone). As a result, HIC's were high for the front-seat occupant (2022-2278) but not so high for the back-seat occupant (1126-1215).

The preceding results were certainly influenced by the selection of crash pulses, sled bucks and dummies. Specifically, the use of a test setup resembling NHTSA's compliance tests for Standard 213 would have changed some of the findings. The "moderate, steady deceleration" experienced here with correctly used booster seats (mode No. 11) is to a considerable extent due to the "soft" sled pulse used here (see Appendix 1, Step 5), and would not have been quite as "moderate" in the higher g environment of compliance tests. Likewise, the lap belt (mode No. 2) and misused booster seat (mode No. 12), which gave adequate protection here up to 25 mph, might have allowed excessive noncontact HICs at lower speeds if peak g's had been higher (see also Table 3-2). Thus, the three systems allowing direct contact between the dummy and the car's lap belt could be expected to fare worse in a compliance test environment--and they did fare worse in actual compliance tests (see Section 3.4).

On the other hand, the tethered seat (mode No. 3), especially when used in the front seat, as noted above, had a tendency to dig into the car's seat cushion and tip over partially, allowing the dummy's head to pitch forward and downward and then snap back. The tetherless-harness only seat (mode No. 8) allowed the same thing to a lesser extent. This undesirable phenomenon, which increased HIC, is due to the relatively "loose" way that lap belts and tethers had to be installed in the Citation sled buck (and probably many real cars) as compared to the sled buck used in compliance tests. The tendency may have been yet further aggravated by the GM dummy, which has a larger head and more flexible neck than the Part 572 (see Appendix 1, Step 3) and/or the reuse of the sled buck's lap belts (Step 8). These seats, then, performed better in a compliance test environment, despite higher sled g's (see Section 3.4).

7.4 Step 11 - Review previous analyses of sled test data

It is appropriate to introduce the analysis procedure of this report by first reviewing the analysis presented in the contractor's final report [46], pp. 127-169, and demonstrating where and why it needed to be modified. The contractor's analysis was based on a procedure developed by Kahane in 1983, consisting of the following elements.

(1) Calculate injury parameters as a function of Delta V, by restraint system, seat position and crash mode, using the sled test results.

(2) Calculate the probability of serious injury as a function of the injury parameters, relying on exogenous data sources such as tests with human surrogates, biomechanical models, and other findings in the biomechanics research literature.

(3) Apply the two preceding functions in sequence to obtain injury risk as a function of Delta V.

(4) Integrate this function over the distribution of crash speeds found in highway accident files and obtain overall injury risk with each restraint system.

The first element consists of fitting some type of curves to the actual sled test results. There are several ways to do it, but they are really not too different from one another. The third element is entirely straightforward. The fourth element could be sensitive to the choice of highway accident file, but not too sensitive since NCSS, NASS and similar files have comparable Delta V distributions. The only really controversial element is the second: the use of the biomechanics literature to equate injury parameters to injury risk.

The extensive literature in the field of biomechanics was quickly narrowed down for that purpose. Many studies are prescriptive rather than descriptive: they say, for example, that a HIC over 1000 is bad, but they do not quantitatively express how bad--i.e., how likely it is to have AIS $\geq$ 3 [1] if HIC = 1000. Many of the descriptive studies are deterministic rather than probabilistic--e.g., they equate a certain level of HIC to a certain level of AIS. (For example, every person with a HIC of 1000 has an

AIS of exactly 3.) Deterministic relationships could have been used to calculate injury rates, but they were not felt to be realistic. There was too much evidence that the response of different subjects on different trials of the same experiment will not always be the same. Probabilistic models, on the other hand, associate a certain probability distribution of injury with a certain level of an injury parameter (e.g., 50 percent of persons with HIC = 1000 will have an AIS of 3 or more). The probability of injury increases at a gradual rate as the injury parameter increases. Dose-response models in pharmacology have typically been expressed in those terms and they are appropriate for the impact-injury problem as well.

Two probabilistic models were available in the literature. Grush, Henson and Ritterling developed logistic curves expressing the probability of fatal head injuries as a function of head peak g's and fatal chest injuries as a function of chest peak g's for adults. The study was performed at Ford in 1971 [27]. In 1982, Mertz and Weber of GM calibrated the probability of AIS $\geq$ 3 head, neck, chest and abdomen injury induced by deploying air bags for 3-year-old child surrogates (i.e., mostly pigs) as functions of the specific injury parameters measured on the GM child dummy [49]. Obviously, the latter study was more relevant to the sled testing project in terms of the occupants' age and injury level.

The contractor used logistic curves based on Mertz and Weber's data, with the following modifications [46], p. 143 and pp. 147-150:

o Mertz's HIC-head injury relationship was based on direct application of their statistical procedure to inappropriate experimental data (75 percent of their cases had low HIC and low injury and were basically worthless for the analysis) and was felt to be unrealistic (no AIS $\geq$ 3 injuries when HIC = 1470; everybody injured when HIC = 1730). It was replaced by a logistic curve similar to Grush's with the 50 percent injury rate prescribed to occur at the traditional value of HIC = 1000.

o Neck injuries were not included in the analysis at all because none of the dummies in the sled tests experienced enough neck tension to even register on Mertz's curve.

o The curve on chest injury was moved slightly to the left so that the 50 percent injury rate would be at the traditional value of 60 g's. That made it virtually identical to Grush's curve.

o The curve for abdominal injury was based on the lower spine g data, without any further modification.

These curves were applied to the HIC's, chest g's and lower spine g's observed in the sled tests to obtain injury risk as a function of Delta V. The injury risk functions were integrated over the range of Delta V experienced in frontal towaway accidents [46], pp. 150-159. The overall injury rates predicted by the model (average of direct frontal [46], p. 160 and oblique, p. 162) for unrestrained front seat child passengers were entirely unrealistic for the chest and abdomen, as is evident from a comparison with actual injury rates in towaway crashes (from Table 6-7):

	MODEL	NCSS-NASS-RSEP
	Percent with "serious" injury	Percent with hospitalizing injury
Head	4.0	3.1
Chest	8.9	0.6
Abdomen	28.7	1.1

Since the model exaggerated chest and abdominal injury rates by factors of 15 and 26, respectively, it is clear that the injury parameter/injury curves were drawn much too far to the left--i.e., children can usually tolerate higher impact forces in crashes than the force which registers as 60 g's on the GM dummy.

In addition, the curves were too steep--i.e., a 1 percent reduction in an injury parameter resulted in too large a reduction of the predicted injury risk. The evidence for this conclusion is the unrealistically high injury reductions relative to the unrestrained child ascribed by the model to the various restraint systems (for front-seat passengers in frontal impacts [46], p. 160):

Head injury reduction	
Booster seat	99 percent
Tetherless seat	81 percent
Chest injury reduction	
Booster seat	93 percent
Lap belt only	91 percent
Abdominal injury reduction	
Tethered seat - no tether and lap belt too low	96 percent
Lap belt only	92 percent

Apparently, the principal reasons that the injury parameter/injury curves led to unrealistic results were:

o Mertz's data consisted of test subjects being slapped by deploying air bags. That is a quite different mode of impact from unrestrained children hitting vehicle interior surfaces or restrained children twisting around in their restraint system--with possibly different injury responses for the same amount of HIC or chest g's.

o The test subjects were mostly pigs who have exceedingly delicate abdomens [77]. As a result, abdominal injuries were greatly overpredicted.

o The curves based on laboratory-collected experimental data were always too steep--both Mertz's and Grush's. In laboratory experiments, conditions are more controlled than on the highway and impact forces tend to be applied over and over in about the same way. When everything else is equal, injury risk can be quite sensitive to the injury parameter that is being varied. But in highway crashes, the impact force is delivered in all sorts of different ways. There is a mix of circumstances that produce high injuries with low values of the injury parameters and vice versa. Even at low values of HIC, there are some serious injuries and at high values there are some persons with little or no injury. The net result is that the HIC-injury curve based on highway accident data (if such a curve could be measured) is probably less steep than any curve that has been drawn to date based on laboratory data involving human surrogates.

In short, the problems with the preceding model show that a way must be found to calibrate injury parameter-injury relationships from accident data if the analyst desires to use the injury parameters to predict injury risk in highway accidents.

7.5 Data Analysis

Step 12 - Select injury parameters for analysis If the injury parameter-injury relationships are to be calibrated from accident data, the analysis has to be limited to those body regions and levels of injury severity where satisfactory accident data exist.

In particular, the strategy is to express the injury parameters as a function of Delta V for the unrestrained front-seat occupant--from the sled test data--and injury risk as a function of Delta V--from accident data. By composing the second function with the inverse of the first, the injury parameter-injury risk relationship is established.

Section 6.4 used NCSS-NASS-RSEP data to establish statistically meaningful relationships between Delta V and the risk of being hospitalized by a head injury; also, by a torso injury (chest and/or abdomen). The accident sample size was not large enough for statistically valid relationships between Delta V and chest injury alone, or abdominal injury alone, or neck injury. The accident sample was also unsuitable for good statistical results on AIS $\geq$ 3 or AIS $\geq$ 2 injury rates but well-suited for measuring the risk of hospitalization.

Thus, the accident data limit the analyses to finding relationships between

- o hospitalizing head injury and a head injury parameter

- o hospitalizing torso injury and a torso injury parameter

Five injury parameters were measured for the head (Step 4): HIC, Mean Strain Criterion, head rotation, neck tension and the Total Laceration Index. It might have been possible to use a judiciously weighted and normalized sum of the five as a head injury parameter; instead it was decided to rely upon HIC, for which a great deal more experience has been accumulated in injury analyses than for the others. Furthermore, the values of HIC experienced in the sled tests were consistent with intuitive expectations for 15-35 mph impacts. The observed values of the other parameters were far out of line with values expected for adults, suggesting differences between children and adults that are not yet understood: a large percentage of the dummies had "fatal" head rotation and Mean Strain Criterion while none of them had enough neck tension to even register on Mertz's injury scale.

The sled tests did not measure a single comprehensive torso injury parameter, but they did measure chest (upper spine) g's, lower spine g's and acceleration of the seismic masses on the dummy's anterior torso [86]. The latter, however, were believed to be useful mainly for investigating bag slap and were not used. The "most judicious" weighted sum of chest and lower spine g's was felt to be their simple sum, henceforth designated as "torso g's," because the two measures had similar means (43 vs. 42) and standard deviations (21 vs. 23) and a .8 correlation. (A case could have been made for weighting lower spine g's more heavily because abdominal injuries are more common than chest injuries--see Table 6-7--but it would have rested on the dubious assumption that chest injury is determined only by chest g's and abdominal injury by the lower spine g's. It is more likely that both parameters can be associated with either type of injury.) Note that torso g's are defined here to be the <u>sum</u>, not the average of upper and lower spine g's--i.e., 120 torso g's are equivalent to 60 g's each on the upper and lower spine.

In summary, the injury parameter-injury relationships that will be established are

- HIC vs. hospitalizing head injury

- Torso g's (chest + lower spine) vs. hospitalizing torso injury

<u>Step 13 - Injury parameters as a function of Delta V, by restraint use mode</u>

The graphs in Appendix 2 of this report show strong relationships between Delta V and the injury parameters. It is only a matter of finding the most suitable way to express them mathematically.

The first question is whether to perform separate analyses of frontal and oblique crashes. A single analysis on lumped data would be much more desirable, statistically, because injury parameters would be estimated from twice as large a sample of data points. But it can result in mathematically biased estimates if the data sets to be lumped differ greatly from one another. The sled test results were classified by restraint use mode (1-12), seat position (front or back) and speed group (15, 25, 35) and, for each combination, the average result for the frontal tests was compared to the oblique tests. In the 44 situations where a comparison could be made, the correlation between frontal and oblique HIC was .89; the correlation between frontal and oblique torso g's was .91. The ratio of oblique HIC to frontal HIC averaged 1.01; the ratio of oblique torso g's to frontal torso g's average 0.92. In view of the high correlations and relative similarity between frontal and oblique results, it was concluded that they could be lumped together in a single analysis. (The mathematical bias of averaging frontal and oblique sled test results and then conducting the analysis is minimal in comparison to the risk of sampling error of conducting separate analyses--with very few data points for each--and then averaging the effectiveness results.)

How about separate analyses for front and back seat occupants? The graphs in Appendix 3 and their discussion in Step 10 made it clear that front and rear seat dummies had more or less similar patterns on the injury parameters in the correct restraint use modes (except the tethered seat at 35 mph) and partially misused seats (except in some cases at 35 mph where dummies contacted the vehicle interior), although, in most cases, the rear seat dummy had slightly better results. To verify the point, these sled test results were classified by restraint use mode (2, 3, 4, 6, 8, 9, 10, 11, 12) and speed group (15; 25; 35 except for use modes 3, 6 and 12) and, for each combination, the average result for the front seat was compared to the back seat. In the 24 situations where a comparison could be made, the correlation between front seat and back seat HIC was .96; the correlation between front seat and back seat torso g's was .94. The ratio of back seat HIC to front seat HIC averaged .85; the ratio of back seat to front seat torso g's averaged .97. In view of the high correlations and relative similarity between front-seat and back-seat results, it was concluded that a single, lumped analysis was adequate for an overall effectiveness estimate for the correctly used and partially misused restraints (even for use modes 3, 6 and 12, since the divergence occurs only at the high end of the scale and the mathematical error for averaging before analyzing will have only a small impact on the overall effectiveness estimate). Only in Step 23, where restrained rear seat occupants are compared to restrained front-seat, are the two groups analyzed separately. But for unrestrained children and grossly misused safety seats, the discrepancies between the front and back seat are large at all speeds. Lumping the data and performing a single analysis would not give nearly the same effectiveness estimate as taking the average of separate front and back-seat effectiveness estimates--and the latter is mathematically more correct. It should be noted that lumping of the data for the overall effectiveness analyses does not imply that front and back-seat occupants have equal injury risk (in fact, as stated above, back-seat occupants had 15 percent lower HIC than front-seat, even when both were restrained); it is only a mathematical technique for analyzing the data more efficiently.

Finally, the two gross misuse modes (5 and 7) are lumped together (but separate for front and back seats) because of the similarity of their results and the relative shortage of data points for each mode. (A number of tests in these modes were cancelled because they would have damaged the sled buck excessively.)

A total of 13 analyses will be performed:

1F. Unrestrained - front seat

1R. Unrestrained - rear seat

2. Lap belt only

3. Tethered seat - correct use

4. Tethered seat - tether not used

5F. Gross misuse - front seat

5R. Gross misuse - back seat

6. Tethered seat - tether not used and belt too low

8. Tetherless seat - correct use

9. Tetherless seat - belt too low

10. Full shield - correct use

11. Booster - correct use

12. Booster - no upper body restraint

The next task is to interpolate and extrapolate from the individual sled test results (as graphed in Appendix 3) to obtain predictions of HIC and torso g's for any value of Delta V. Various types of regression were tried and found unsatisfactory. Linear regression caused predictions of zero for the injury parameters at sometimes moderately high speeds. Log-log regression avoided that problem but fit the points poorly and resulted in unrealistic extrapolations. The contractor's two-piece linear regression was a good procedure, but not simple enough.

Thanks to the lumping of frontal and oblique impacts and front and back seat occupants, there are typically 4 observations for each of the 3 target speeds (15, 25 and 35 mph impacts, corresponding to Delta V's of 16.08, 26.8 and 37.52, respectively) in each restraint mode. Usually, those observations are tightly clustered in the graphs, suggesting that their average is a good estimate of the mean of a much larger number of repetitions of those sled tests. It would be nice for the Delta V-injury parameter functions to go directly through the average values at the 3 target speeds and also through the origin (zero injury parameters at zero Delta V). The simplest way to accomplish it is by a straight line from the origin to the average value for the 15 mph impacts; another straight line from there to the average value for the 25 mph impacts; and a third straight line from there, through the average value for the 35 mph impacts and beyond--a three-piece linear continuous function. Table 7-2 shows the average values of HIC and torso g's for each restraint use mode at the 3 target impact speeds. Appendix 4 of this report contains graphs of HIC and torso g's as functions of Delta V for each of the restraint use modes. Some of the trends that are evident from the graphs are:

o Properly used restraint systems perform very well, except lap belt only at high speeds. The HIC problem with the tethered seat at high speeds and the relatively higher torso g's with shield-type seats (which were already mentioned in Step 10) are also noticeable. Even though the sled tests differed in many ways from Standard 213 compliance tests, it should be noted that <u>every</u> correctly used seat achieved the Standard 213 goals of HIC $<$ 1000 and torso g's $<$ 120 (more or less equivalent to chest g's $<$ 60) at 30 mph barrier speed (Delta V = 32.16).

TABLE 7-2

AVERAGE VALUES OF HIC AND TORSO G's BY
RESTRAINT USE MODE AND SPEED

Restraint Use Mode		Average HIC for Impact Speed of			Average Torso g's for Impact Speed of		
		15	25	35	15	25	35
1 F	Unrestrained-front seat	277	856	1709	70	161	232
1 R	Unrestrained-rear seat	229	559	959	38	85	81
2	Lap belt only	71	435	1612	26	64	104
3	Tethered seat-correct use	103	351	1193	40	61	94
4	Tethered-tether not used	113	506	2014	35	74	113
5 F	Gross misuse-front seat	270	667	1759	66	164	210
5 R	Gross misuse-rear seat	42	522	1806	53	120	171
6	Tethered-no tether & belt too low	168	551	1608	42	76	114
8	Tetherless-correct use	120	419	846	49	75	96
9	Tetherless-belt too low	172	564	1506	38	72	108
10	Full shield-correct use	90	383	796	52	99	115
11	Booster-correct use	56	254	393	45	79	81
12	Booster-no upper body restraint	60	481	1660	37	69	102

o Partially misused seats protect the head fairly well up to 25-30 mph but allow high HIC's above that speed as they begin to allow contact with the vehicle. They protect the torso well at all speeds, but not as well as correctly used seats. Partially misused seats were generally predicted to have HIC over 1000 in 30 mph barrier impacts but well below 1000 in 20 mph impacts. Torso g's were below 120 even at 30 mph.

o In the front seat, grossly misused safety seats had nearly the same performance as unrestrained dummies. In the back seat, the unrestrained dummies repeatedly contacted a force limiting device with their torsos (the flexible Citation front seatback). The dummies in the grossly misused seats were not as lucky at the higher speeds, since they vaulted over the seatback. But their heads were reasonably well protected at the lower speeds. The unrestrained front-seat dummy exceeded the Standard 213 injury criteria at well below 30 mph impact speed.

Step 14 - Calibrate injury parameter/injury risk relationships Now that HIC and torso g's have been expressed as functions of Delta V for the unrestrained front-seat child dummy, it is possible to go ahead with the crucial step of taking the Delta V-injury risk relationship from accident data and associating the levels of injury risk and the injury parameters that occur with the GM dummy at a given level of Delta V.

The values of injury risk as a function of Delta V for unrestrained child passengers (age 1-5, front and back seats combined) in frontal towaway crashes were presented in Table 6-8 (for head injuries resulting in hospitalization) and Table 6-9 (for torso injuries). Based on the discussion in Section 6.4, the most accurate injury rates for unrestrained front-seat passengers, only, were obtained by multiplying the head injury rates in Table 6-8 by 1.352 and the values in Table 6-9 by 1.461. Those multiplications have been carried out and the products are shown in Table 7-3, opposite the median value of Delta V in the class intervals used in Tables 6-8 and 6-9. (For example, 7 mph is the median Delta V in towaways less than 10 mph, and 0.41% of the unrestrained front-seat child passengers in crashes with Delta V < 10 had a hospitalizing head injury; 0.22%, a hospitalizing torso injury.)

Table 7-3 also shows the values of HIC and torso g's for unrestrained 3-year-old dummies in the front seat, in frontal crashes at those levels of Delta V, based on the 3-piece-linear relationships established for restraint use mode 1F in Step 13, viz.

$$\text{HIC} = \begin{cases} (DV/16.08) \times 277 \text{ if } DV < 16.08 \\ 277 + ((DV - 16.08)/10.72) \times (856.05 - 277) \text{ if } 16.08 \leq DV < 26.8 \\ 856.05 + ((DV - 26.8)/10.72) \times (1709 - 856.05) \text{ if } DV \geq 26.8 \end{cases}$$

$$\text{torso g's} = \begin{cases} (DV/16.08) \times 69.6 \text{ if } DV < 16.08 \\ 69.6 + ((DV - 16.08)/10.72) \times (160.7 - 69.6) \text{ if } 16.08 \leq DV < 26.8 \\ 160.7 + ((DV - 26.8)/10.72) \times (232.3 - 160.7) \text{ if } DV \geq 26.8 \end{cases}$$

TABLE 7-3

HIC, HEAD INJURY RISK, TORSO G's AND TORSO INJURY RISK
AS FUNCTIONS OF DELTA V FOR UNRESTRAINED FRONT-SEAT
CHILD PASSENGERS IN FRONTAL CRASHES

Delta V (mph)	HIC*	Percent of Children Hospitalized by Head Injury **	Torso g's*	Percent of Children Hospitalized by Torso Injury **
7	121	0.41	30	0.22
12	207	2.27	52	0.66
17	327	3.71	77	2.25
22	597	9.29	120	5.17
27	872	12.21	162	6.61
34	1429	27.90	209	8.46
44	2225	47.52	276	50.75

* From sled tests (using GM dummy)
** From NCSS-NASS-RSEP

Thus, Table 7-3 provides seven matched pairs of HIC and head injury risk which can be used for calibrating the relationship between those two variables; likewise, for torso injuries. Several forms of regression were tried in search of the best relationship: linear, log (injury risk) against injury parameter or against log (injury parameter), log odds (injury risk) against injury parameter or against log (injury parameter). The regressions that best fit the data points in Table 7-3 were:

$$\log \frac{\text{head injury risk}}{(1 - \text{head injury risk})} = -13.33 + 1.72 \log (\text{HIC})$$

and

$$\log (\text{torso injury risk}) = -13.70 + 2.215 \log (\text{torso g's})$$

They fit the observed data exceptionally well, as evidenced by the correlation coefficients (.99 and .98, respectively; both with df = 5) and Figures 7-1 and 7-2, which graph the actual data points from Table 7-3 (●) and the regression lines (P). The preceding formulas are equivalent to

$$\text{Head injury risk} = \frac{\text{HIC}^{1.712}}{615{,}400 + \text{HIC}^{1.712}}$$

$$\text{Torso injury risk} = \frac{\text{Torso g's}^{2.215}}{890{,}900}$$

FIGURE 7-1: PROBABILITY OF HOSPITALIZING HEAD INJURY AS A FUNCTION OF HIC
(data points and regression line)

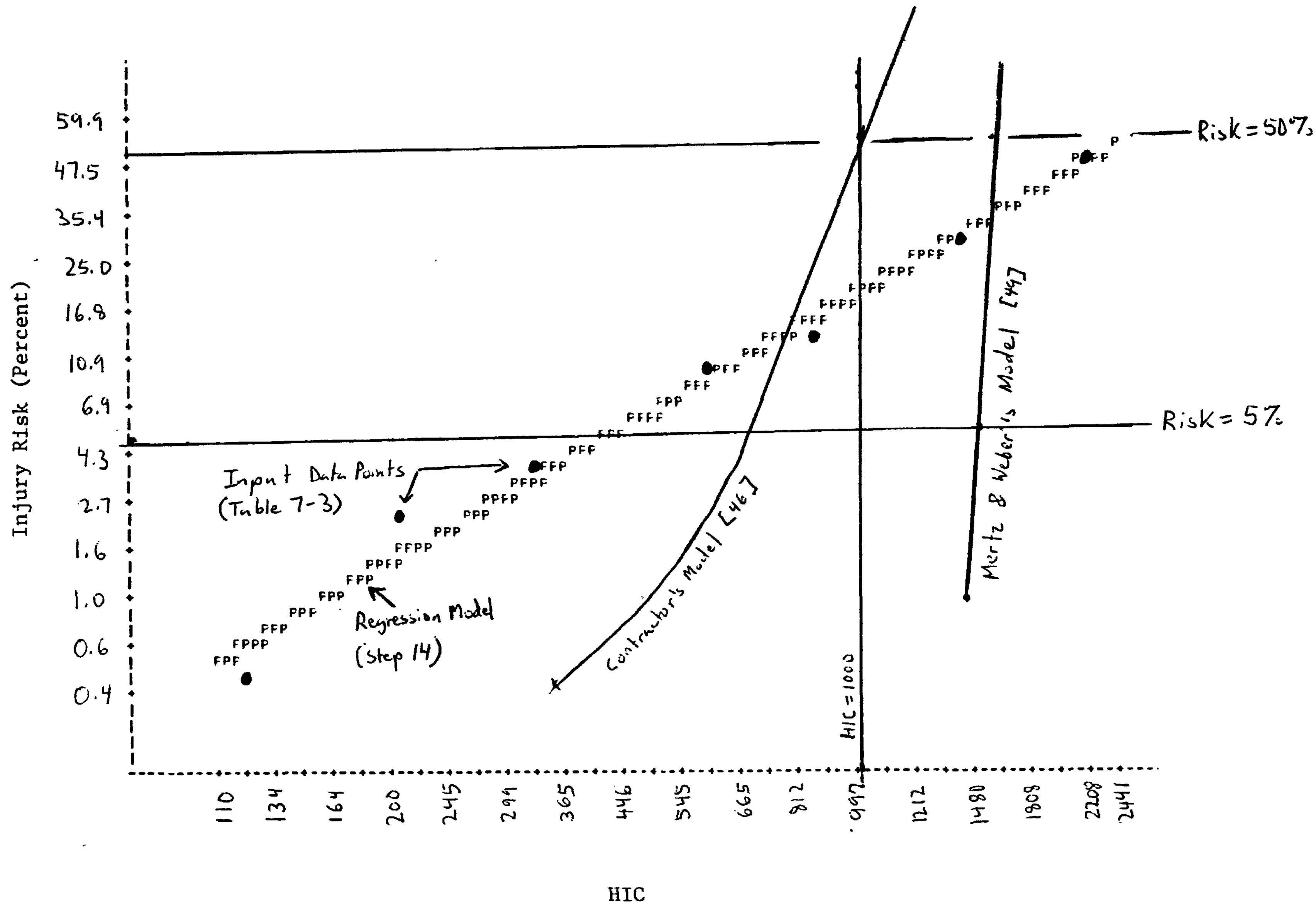
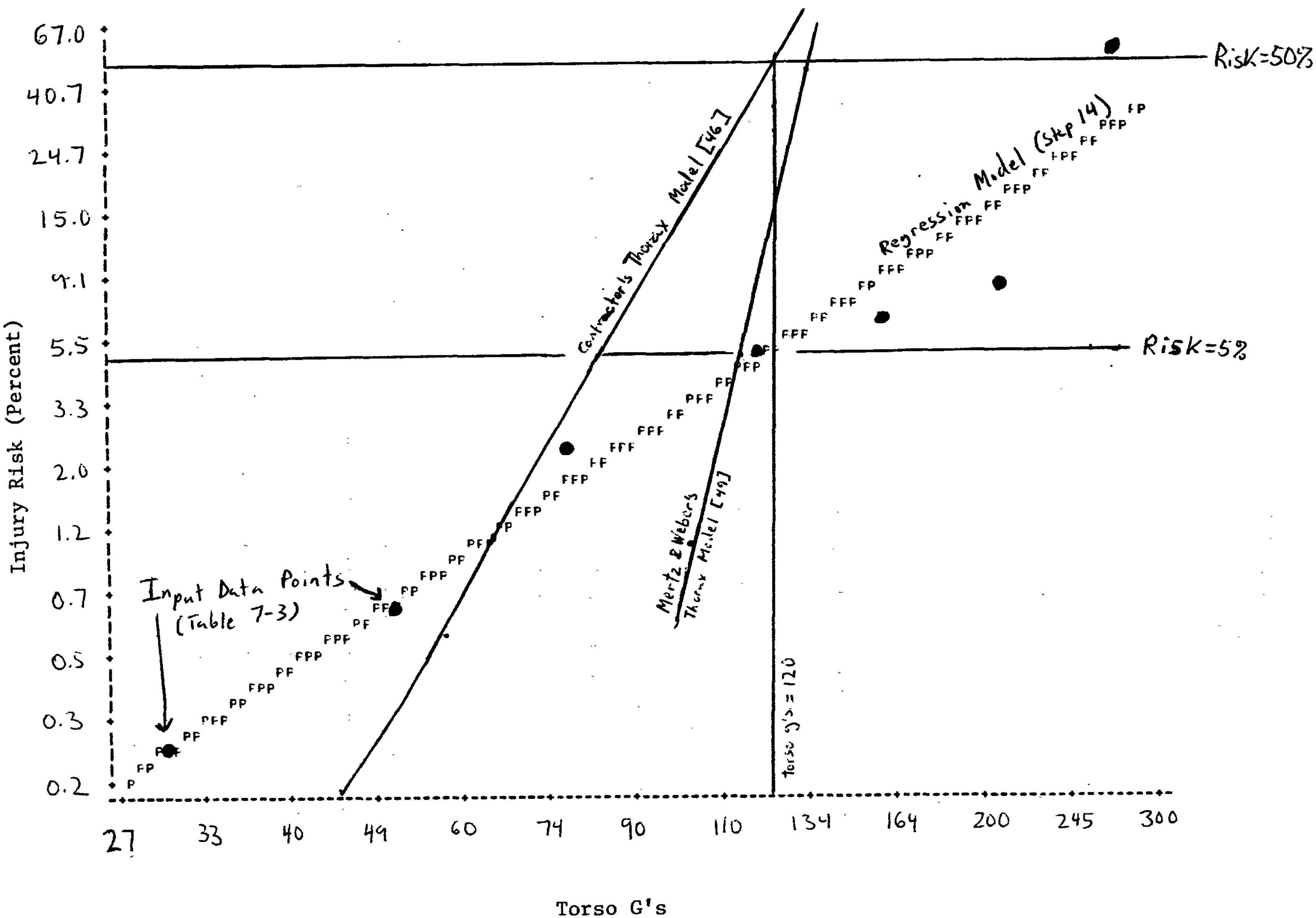


FIGURE 7-2: PROBABILITY OF HOSPITALIZING TORSO INJURY AS A FUNCTION OF TORSO G's
(data points and regression line)



Some of the principal points on the regression lines are

HIC	Percent with Hosp. Head Injury	Torso g's	Percent with Hosp. Torso Injury
431	5	120	4.5
500	6.4	126	5
1000	18.2	200	14.0
2000	42.1	355	50
2407	50		

Mertz and Weber's injury parameter-injury risk curves [49] are superimposed on the regression lines in Figures 7-1 and 7-2. So are the ones used in the NHTSA contractor's final report. (In both cases, double chest g's are used as a substitute for torso g's.) It is obvious that their curves are incomparably steeper than the regression lines and, while they may be suitable for modeling the laboratory data on which they are based, they are not useful for describing the levels of injury risk that occur in accident data.

<u>Step 15 - Injury risk as a function of Delta V, by restraint use mode</u> The injury parameter-injury risk functions of Step 14 are composed on the Delta V-injury parameter functions of Step 13. The latter were three-piece linear functions defined by the data in Table 7-2. (Keep in mind that impact speeds of 15, 25 and 35 mph correspond to Delta V's of 16.08, 26.8 and 37.52, on the average.)

Thus, for example, the head injury risk for unrestrained front-seat child passengers is

$$[(DV/16.08) \times 277]^{1.712} / (615{,}400 + [(DV/16.08) \times 277]^{1.712})$$

when DV < 16.08,

$$\frac{[277 + ((DV - 16.08)/10.72) \times (856 - 277)]^{1.712}}{615{,}400 + [277 + ((DV - 16.08)/10.72) \times (856 - 277)]^{1.712}}$$

when 16.08 $\leq$ DV < 26.8, and

$$\frac{[856 + ((DV - 26.8)/10.72) \times (1709 - 856)]^{1.712}}{615{,}400 + [856 + ((DV - 26.8)/10.72) \times (1709 - 856)]^{1.712}}$$

when DV $\geq$ 26.8.

Note that 277, 856 and 1709 are the average values of HIC that were observed for unrestrained front-seat occupants at the three sled test speeds (Table 7-2). For other restraint use modes, substitute their HIC values for 277, 856 and 1709 in the preceding formulas.

Likewise, the torso injury risk for unrestrained front-seat child passengers is

$$\frac{[DV/16.08 \times 70]^{2.215}}{890{,}900}$$

when DV < 16.08,

$$\frac{[70 + ((DV - 16.08)/10.72) \times (161 - 70)]^{2.215}}{890{,}000}$$

when $16.08 \leq DV < 26.8$, and

$$\frac{[161 + ((DV - 26.8)/10.72) \times (232 - 161)]^{2.215}}{890{,}000}$$

when $DV \geq 26.8$ (or the injury risk is 1 if the preceding quantity is greater than 1). Note that 70, 161 and 232 are the average values of torso g's that were observed for unrestrained front-seat occupants at the three sled test speeds (Table 7-2). For other restraint use modes, substitute their torso g values for 70, 161 and 232 in the preceding formulas.

Step 16 - Compare predicted injury rates to accident data, for unrestrained front-seat occupants This is the first crucial validation of the Delta V-injury risk models developed in Step 15. Do they accurately duplicate the Delta V-injury relationships found in accident data? Figures 7-3 and 7-4 show that the injury rates predicted by the model for unrestrained front-seat passengers (P) match the actual injury rates, as a function of Delta V, in the NASS-NCSS-RSEP accident data (●) very closely, both for head and torso injuries. (That is the only validation that can be carried out at this step, because there were insufficient accident data in the other restraint use modes for meaningful injury rates as a function of Delta V.)

Of course, it is not surprising that the model correlates so well with the unrestrained, front-seat accident data because the injury parameter-injury relationships were calibrated from those data in Step 14. The only reasons for possible noncorrelation are sampling error in the accident data (substantial, especially for torso injuries, where there were

FIGURE 7-3: PROBABILITY OF HOSPITALIZING HEAD INJURY AS A FUNCTION OF DELTA V, UNRESTRAINED FRONT SEAT CHILD PASSENGERS IN FRONTAL TOWAWAYS (predicted vs. actual)

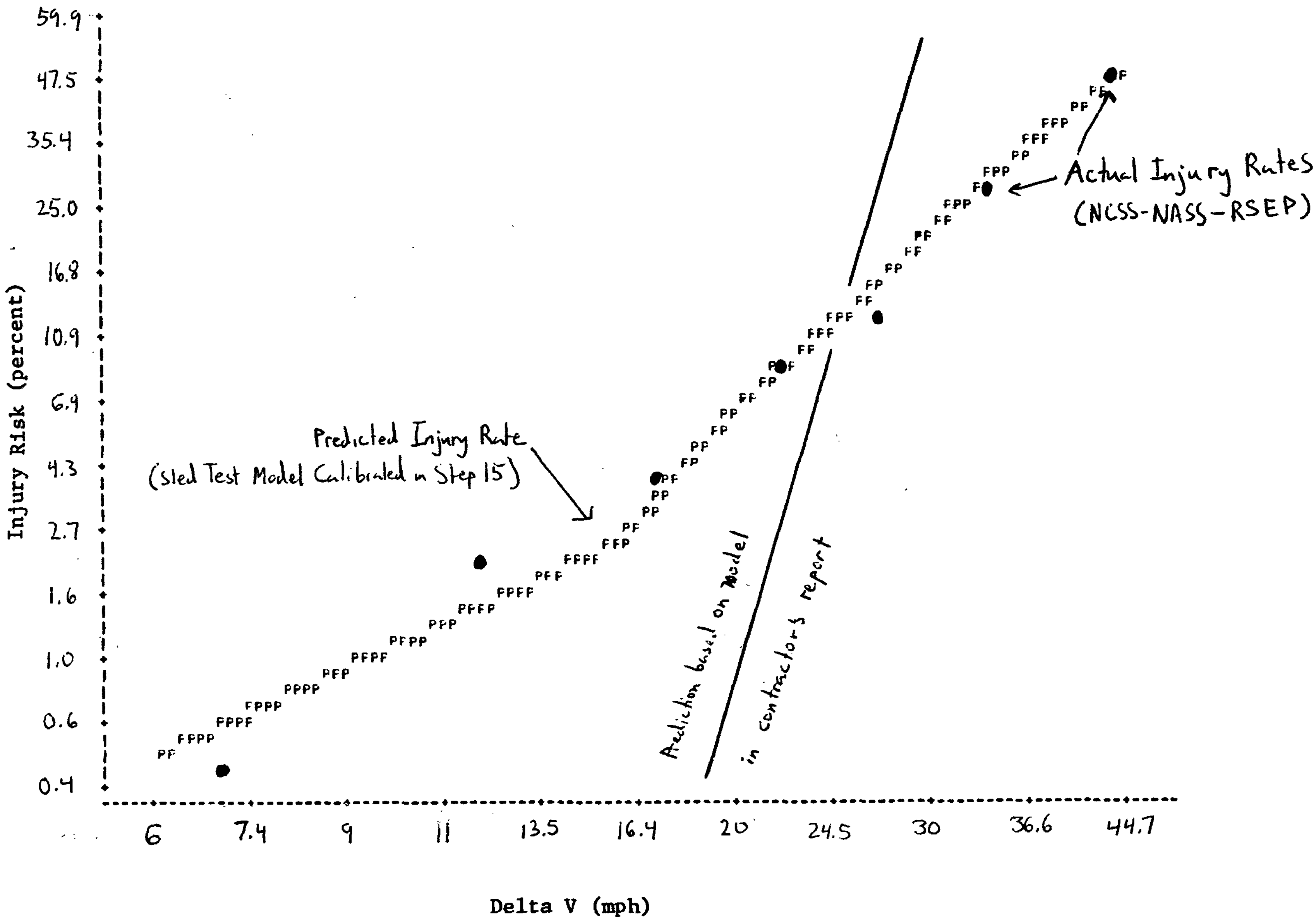
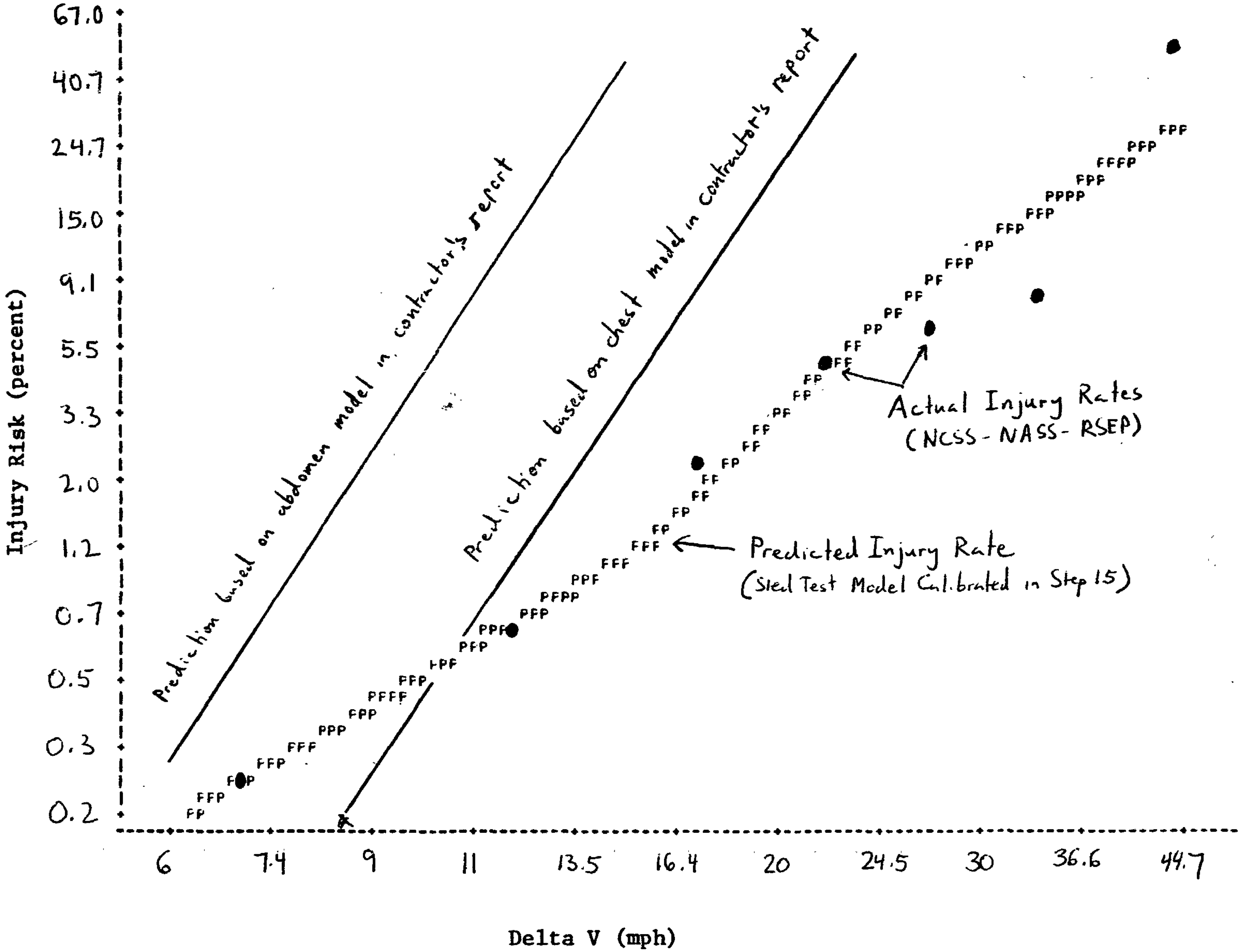


FIGURE 7-4: PROBABILITY OF HOSPITALIZING TORSO INJURY AS A FUNCTION OF DELTA V, UNRESTRAINED FRONT SEAT CHILD PASSENGERS IN FRONTAL TOWAWAYS (predicted vs. actual)



only 2-6 observed hospitalizations in each Delta V class interval), sampling error in the sled test data (only 2 unrestrained front-seat tests at each of the 3 target speeds) and computational biases introduced by the modeling procedure (e.g., use of 3-piece linear approximations, choice of regression equation, etc.) But the errors introduced by those sources are small, as evidenced by the excellent fit seen in Figures 7-3 and 7-4. For contrast, the Delta V-injury relationships developed from biomechanical data in the contractor's final report are also shown in the figures. They are incomparably steeper than the ones observed in accident data.

Step 17 - Obtain Delta V distribution from accident data The functions developed in Step 15 predicted the injury rate at each value of Delta V. In order to find the aggregate injury rate for all Delta V's combined, it is necessary to know the Delta V distribution of child passengers in frontal towaway crashes. Table 7-4 shows their distribution in the NASS-NCSS-RSEP data. (Delta V was calculated by the same procedure as in Section 6.4--i.e., using the full CRASH program when possible, otherwise using the CRASH routines to calculate a barrier equivalent velocity based on the Collision Deformation Classification of the case vehicle and adjusting that velocity by the formula developed in Section 6.4.) The median Delta V is 12 mph, the 90th percentile is 22 mph, and the 99th percentile is 38 mph. The most common Delta V's in frontal towaways are 8-14 mph. Figure 7-5 is a bar graph of the frequency density function of Delta V.

TABLE 7-4

DELTA V DISTRIBUTION FOR 1-5 YEAR OLD PASSENGERS
IN FRONTAL TOWAWAYS (NASS-NCSS-RSEP)*

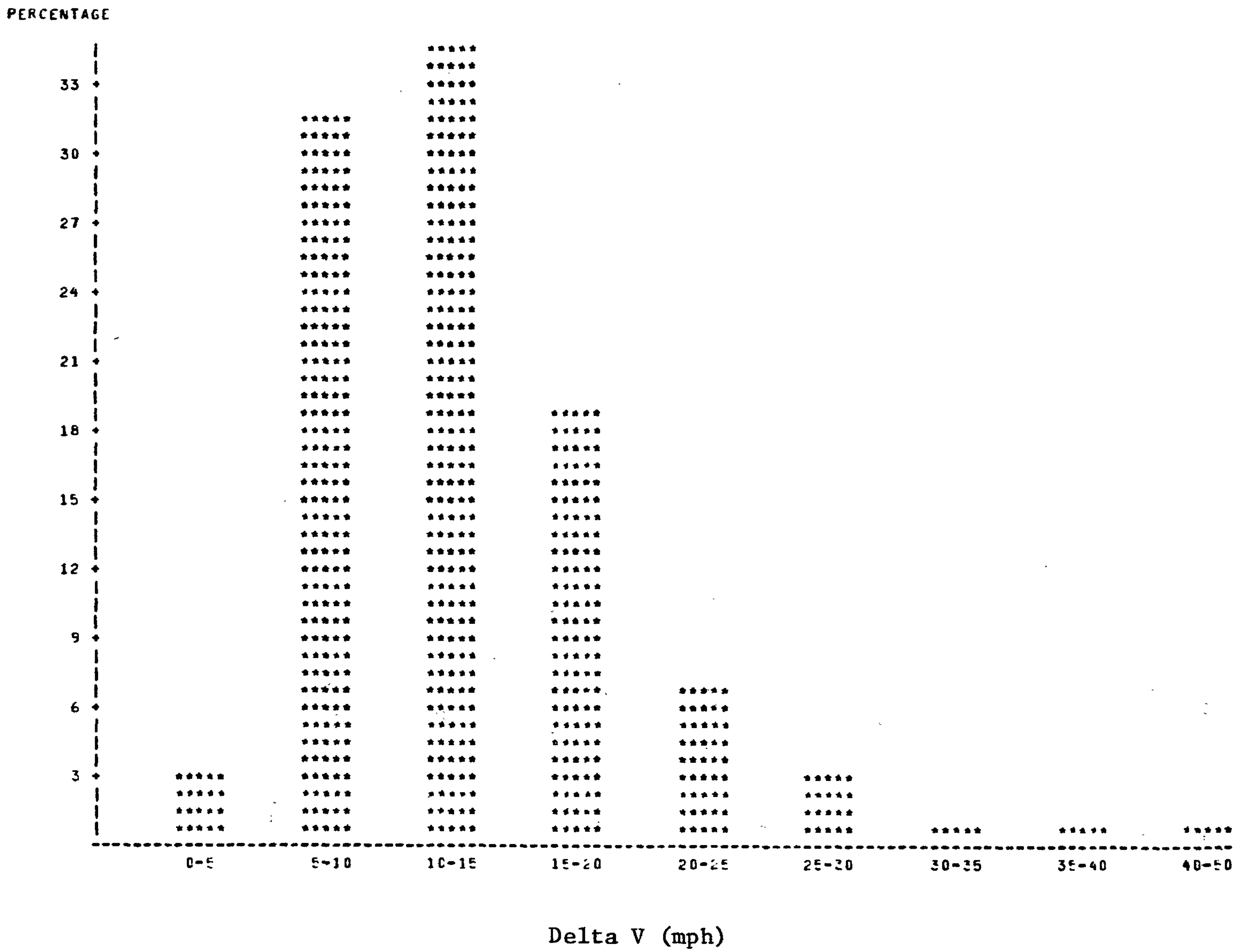
Delta V (mph)	Percent of Children	Cumulative (%) of Children	Delta V (mph)	Percent of Children	Cumulative (%) of Children
1	0.068	0.068	24	2.668	94.974
3	1.702	1.770	25	0.560	95.534
4	1.347	3.116	26	0.679	96.213
5	1.935	5.055	27	0.238	96.451
6	4.176	9.231	28	0.717	97.168
7	3.811	13.042	29	0.513	97.682
8	12.363	25.404	30	0.238	97.919
9	9.006	34.410	31	0.102	98.021
10	4.607	39.017	32	0.407	98.428
11	7.558	46.575	33	0.117	98.546
12	7.248	53.823	34	0.181	98.727
13	5.501	59.324	35	0.102	98.829
14	9.576	68.900	37	0.140	98.969
15	5.548	74.447	38	0.102	99.071
16	5.331	79.778	39	0.272	99.342
17	4.344	84.122	40	0.038	99.380
18	1.969	86.091	41	0.136	99.516
19	1.823	87.915	42	0.034	99.550
20	0.513	88.428	43	0.034	99.584
21	0.989	89.417	44	0.178	99.762
22	2.403	91.820	46	0.068	99.830
23	0.487	92.307	48	0.102	99.932
			49	0.068	100.000

* Based on 2946 weighted (1071 unweighted) cases. Delta V was calculated by the CRASH program in 54 percent of the cases and estimated from the Collision Deformation Classification in 46 percent.

FIGURE 7-5

DELTA V DISTRIBUTION OF FRONTAL TOWAWAY CRASHES INVOLVING CHILDREN

PERCENTAGE BAR CHART



7.6 Effectiveness by use mode

Step 18 - Overall injury reduction by restraint use mode The probability of injury at a given level of Delta V (Step 15) is multiplied by the number of crashes at that Delta V to obtain the number of injuries at that Delta V. The numbers of injuries at the various levels of Delta V are summed to obtain the aggregate number of injuries.

It would be inappropriate, however, to take the sum over all possible levels of Delta V because the sled tests were only conducted over a Delta V range of 16 to 38 mph. It is possible to extrapolate the HIC and Torso g estimates somewhat outside that range, but not too far. There is special concern about the lowest speeds (Delta V < 10 mph) that HIC and torso g's might not be meaningful predictors of injury. It would be more appropriate to limit the analysis to a Delta V range of 10 to 50 mph. According to Table 6-6, 95 percent of the child passengers hospitalized in frontal crashes were within that range. The lower limit (10 mph) is just 6 mph below the test speed range. The upper limit is 12 mph above it. That is a rather long extrapolation, but acceptable because there are so few crashes in the 45-50 mph range (limited effect on the results) and because it helps this analysis coincide with the 6 highest class intervals of Delta V used in the NASS-NCSS-RSEP analysis (Section 6.4).

Thus, the aggregate measure of hospitalizing head injury risk in restraint use mode j is

$$\sum_{i=10}^{49} H_j(i)\, p(i \leq DV < i+1) \Bigg/ \sum_{i=10}^{49} p(i \leq DV < i+1)$$

where $H_j(i)$ is the head injury risk, as a function of Delta V, for use mode j, as derived in Step 15 and $p(i \leq DV < i + 1)$ is the percentage of children whose Delta V is i (truncated to the nearest integer), as displayed in Table 7-4. Similarly, overall torso injury risk is

$$\sum_{i=10}^{49} T_j(i)\, p(i \leq DV < i+1) \Bigg/ \sum_{i=10}^{49} p(i \leq DV < i+1)$$

where $T_j(i)$ is the Delta V-torso injury risk relationship for use mode j.

Finally, it is useful to define the "risk of hospitalization" as

$$\sum_{i=10}^{49} [1 - (1 - H_j(i))(1-T_j(i))]\, p(i \leq DV < i+1) \Bigg/ \sum_{i=10}^{49} p(i \leq DV < i+1)$$

It is, mathematically, the proportion of children who would have hospitalizing head and/or torso injuries _if_ the occurrence of those two types of injury were statistically independent events. In fact, Tables 6-6 - 6-11 make it clear they they are not independent, but overlap much more heavily than would be expected by chance alone. On the other hand, those tables show a number of hospitalizing injuries to other body regions (arms, legs, whole body). By happy coincidence, the proportion of _unrestrained front seat_ occupants hospitalized for any reason (head, torso, arms, legs, etc.) is always remarkably close to the "risk of hospitalization" as defined above. For example:

Type of Crash (Refer to Tables 6-6, 6-7)	Head Inj. per 1000 H	Torso Inj. per 1000 T	"Risk of Hospitalization" 1-(1-H)(1-T)	Actual Hospitalizations per 1000 - Including Arms, Legs, etc.
All towaways	25.14	11.31	36.17	38.22
Frontal towaways	30.59	15.40	45.52	43.95

Thus, in the case of the unrestrained front-seat child passenger, the "risk of hospitalization" as defined in the model can be used as a surrogate for the actual, overall risk of hospitalization. Likewise, because safety seats are at least as effective in reducing arm and leg injuries as head and torso injuries (see Section 5.4.1), the reduction in "risk of hospitalization" relative to the unrestrained front-seat occupant can be used as a surrogate for overall effectiveness. But in the case of the unrestrained rear-seat occupant, the reduction of "risk of hospitalization" needs to be interpreted narrowly--i.e., applying only to the head and torso--because the back seat's benefits for arms and legs is much lower than for the head and torso (see Section 6.3).

Table 7-5 displays the model's principal results: the risk of hospitalizing head injury, hospitalizing torso injury and overall "hospitalization" in frontal crashes with Delta V 10-50 mph, by restraint use mode. The unrestrained front-seat occupant was the most vulnerable in all three categories, with 44.71 children per 1000 hospitalized by head injuries, 24.39 by torso injuries and 65.21 hospitalized by any type of injury. The gross misuse of a safety seat in the front seat of a car was about equally dangerous (39.25, 22.15 and 58.36).

Based on the series of sled tests used for this model, the booster seat provided the highest level of head injury protection (only 4.74 hospitalizations per 1000 children). The other three types of seats, when correctly used, were also highly protective (11.38 -14.96 hospitalizations). The 4 partial misuse modes, the lap belt, and the back-seat dummy (unrestrained or in a grossly misused seat) obtained relatively similar, modest levels of head injury protection (18.44-26.60 hospitalizations per 1000 children) because they were effective in the lower-speed impacts (see Appendix 4). As described earlier (Step 10, also Section 3.4), sled tests with a higher g environment, such as NHTSA's compliance test procedures, would have produced less favorable results for booster seats and the lap belt.

All of the correctly used seats except for the full shield type, all the partially misused seats, the lap belt and the back seat (unrestrained) gave a high degree of protection from torso injuries (3.31-6.64

TABLE 7-5

INJURY RISK IN FRONTAL CRASHES WITH DELTA V 10-50 MPH
BY RESTRAINT USE MODE (SLED TEST ANALYSIS RESULTS)

	Restraint Use Mode	Head Injury Hospitalizations per 1000 Children	Torso Injury Hospitalizations per 1000 Children	Hospitalizations per 1000 Children
1 F	Unrestrained-front seat	44.71	24.39	65.21
1 R	Unrestrained-rear seat	26.07	5.03	30.83
2	Lap belt only	18.44	3.31	21.26
3	Tethered seat-correct use	14.96	4.53	19.20
4	Tethered-tether not used	24.96	4.89	29.11
5 F	Gross misuse-front seat	39.25	22.15	58.36
5 R	Gross misuse-rear seat	20.52	12.75	31.61
6	Tethered-no tether & belt too low	26.60	6.02	31.97
8	Tetherless-correct use	14.11	6.64	20.51
9	Tetherless-belt too low	26.38	5.06	30.89
10	Full shield-correct use	11.38	8.94	20.00
11	Booster-correct use	4.74	5.68	10.36
12	Booster-no upper body restraint	19.25	4.67	23.43

hospitalizations per 1000 children as opposed to 24.39 for the unrestrained front-seat occupant). The full shield type (8.94) and the rear-seat dummy in a grossly misused seat (12.75) were not as well protected.

The last task of this step is to estimate the overall effectiveness of each restraint use mode (front and back seat, combined) relative to the unrestrained child (front and back seat, combined). Two measures of effectiveness will be defined. The first one is based directly on the sled test results. It is the reduction in the "risk of hospitalization" due to head and/or torso injuries in frontal crashes. That risk is shown for each restraint use mode in Table 7-5. For unrestrained children, take the simple arithmetic average (48.02) of the risk for the front seat (65.21) and the back seat (30.83)--because 1-5 year-old child passengers are equally distributed between the front and back seats (see Table 6-7). Then compare the risks of hospitalization in the other use modes to 48.02. The percentage reductions are shown in the left column of Table 7-6. In the case of grossly misused seats, the average of the injury risks for the front and back seat occupants (44.99) was compared to 48.02, indicating a 6 percent reduction relative to unrestrained. That reduction would have to be considered "nonsignificant" considering the relatively small numbers of sled tests involved (see the discussion at the end of this step); furthermore, the 6 percent injury reduction did not take into account facial lacerations, which were considerably more severe for the grossly misused seat than for the unrestrained dummy [46], p. 89. Under those circumstances, the best

TABLE 7-6

OVERALL REDUCTION OF SERIOUS INJURIES,
RELATIVE TO UNRESTRAINED CHILDREN,
BY RESTRAINT USE MODE

Restraint Use Mode		Percent Reduction of Hospitalizations Due to: Head or Torso Injuries in Frontal Crashes	Any Type of Injury in Any Crash
2	Lap belt only	56*	63*
3	Tethered seat: correct use	60	66
4	Tethered seat: tether not used	39	49
5	Grossly misused safety seat	0**	0**
6	Tethered seat: no tether & belt too low	33	44
8	Tetherless seat: correct use	57	64
9	Tetherless seat: belt too low	36	46
10	Full shield: correct use	58	65
11	Booster: correct use	78*	82*
12	Booster: no upper body restraint	51*	59*
Unrestrained: back seat vs. front seat		53	26***

*Outcome would have been less favorable in a higher g testing environment, such as the one in NHTSA compliance tests (see Section 3.4.3).

**Sled test model yields 6 percent reduction. Actual reduction assumed to be zero.

***Based on accident data, not sled test model.

estimate is that grossly misused seats are no better but also no worse than being unrestrained. All the other use modes showed substantial injury reductions relative to unrestrained: 57-78 percent for the correctly used seats, 56 percent for lap belt only and 33-51 percent for the partially misused seats.

An unrestrained child had 53 percent lower head and torso injury risk in the back seat (30.83) than in the front seat (65.21), in frontal crashes.

The second measure of effectiveness is a generalization from head and torso injuries in frontal crashes (the subject of the sled tests) to all types of injuries in all types of crashes. About 50 percent of all unrestrained front seat hospitalizations occur in frontal crashes <u>and</u> are due to head or torso injuries (see Tables 6-6 and 6-7), so this generalization involves making an assumption about the other half of the serious injuries. It is assumed that correctly used safety seats are about equally effective, relative to the unrestrained front-seat passenger, in frontal and nonfrontal crashes. The same assumption is made for partially misused seats. The assumptions are based on the concept that safety seats are designed to effectively restrain children in side impacts and rollovers, except in those cases where intrusion of the vehicle structure is quite severe; it is further supported by analogy to lap and shoulder belts for adults--they were shown in the Restraint Systems Evaluation Project [70] to have about equal effectiveness, at the moderate-to-serious injury level, in frontal and nonfrontal crashes. It is further assumed that safety seats are at least as effective in preventing serious arm and leg injuries as head and torso injuries: that assumption is strongly supported by the Pennsylvania results (Section 5.4.1).

Neither of these assumptions is made for the unrestrained back-seat occupant relative to the unrestrained front-seat passenger. In fact, Tables 6-6 and 6-7 show both assumptions are false. But the effectiveness of moving an unrestrained child to the back seat (all types of injuries in all types of crashes) is already known from the accident data and nothing needs to be assumed: 24 percent reduction of hospitalizations in NASS-NCSS-RSEP (Table 6-5), 26 percent fatality reduction in FARS, for children aged 1-5 (Table 4-11), and 35 percent reduction of K, A or B level injuries in Pennsylvania (Section 5.3). The 26 percent reduction in FARS is based on a larger sample than the others and a computational procedure that controls for biases most effectively: let it be the best estimate for serious injury reduction, back seat unrestrained versus front seat unrestrained.

The second measure of effectiveness is defined as follows:

$$1 - \frac{R_j}{0.5\ R_{1F} + 0.5\ ((1 - .26)\ R_{1F})} = 1 - \frac{R_j}{87R_{1F}} = 1 - \frac{R_j}{56.73}$$

where

R_j = Hospitalizations per 1000 children, use mode j (last column of Table 7-5)

R_{1F} = Hospitalizations per 1000 children, front seat unrestrained = 65.21

In other words, the hospitalization risk for unrestrained children (front and back seats, combined; all types of injuries in all types of crashes) is the average of the front seat risk and the back seat risk (which is 26 percent lower, based on FARS).

The effectiveness estimates are shown in Table 7-6, in the right column. They represent the best estimates from the sled test analysis. (The more direct, more conservative estimates by the first measure of effectiveness will also be used to provide a range of effectiveness.) Correctly used safety seats were highly beneficial, reducing hospitalizations by an estimated 64 to 82 percent. The lap belt was 63 percent effective (a possible overestimate, because the assumption about equal effectiveness in nonfrontal impacts is more tenuous here than for safety seats). The 4 types of partially misused seats ranged from 44 to 59 percent. The results were consistent with intuition in that greater degrees of misuse had lower effectiveness. For example, the tethered seat with the tether left off (mode 4) reduced injuries by 49 percent; if, in addition, the lap belt was misrouted (mode 6), the effectiveness was 44 percent.

An appropriate question at this point is if the differences in effectiveness shown in Table 7-6 are real, or "significant." A partial answer may be obtained by assessing the sampling error in the sled test analysis procedure. Analysis of variance was performed on the sled test results, to determine the coefficient of variation for HIC and torso g's in repetitions of basically identical tests. The coefficient of variation for HIC was about 30 percent for restrained dummies and, in the front seat, for unrestrained or grossly misused seats; it was 15 percent for torso g's. The

Delta V-HIC and Delta V-torso g relationships are each based on at least 9 sled tests, so the errors of overall head injury risk and torso injury risk, in each restraint use mode, would be approximately 30 / $\sqrt{9}$ = 10 percent and 15 / $\sqrt{9}$ = 5 percent, respectively. For most use modes, the overall "risk of hospitalization" is about 3 parts head injury to 1 part torso injury and has coefficient of variation

$$\sqrt{\frac{[.1\ (3x)]^2 + [.05\ (x)]^2}{4x}} = 8 \text{ percent}$$

For the correctly used safety seats, whose observed effectiveness is on the order of 65 percent the 2 sigma sampling error of the difference in effectiveness of 2 systems is

$$2\ (1-.65)\ \sqrt{(.08)^2 + (.08)^2} = 8 \text{ percent}$$

For the partially misused seats, whose observed effectiveness is on the order of 45 percent, the sampling error for the difference between two misuse modes

$$2\ (1-.45)\ \sqrt{(.08)^2 + (.08)^2} = 13 \text{ percent}$$

Of course, this discussion of sampling error does not take into account factors unrelated to sample size: above all, the choice of a "soft" sled pulse, which aided booster seats and lap belts (in comparison to a compliance test environment); the unfavorable interaction of tethered seats with the Citation sled buck, the particular brands of seats used in the tests, which might have been atypical of their generic "type" (but probably weren't--see Section 3.4.3); procedural, measurement or computational errors, including those documented in preceding steps. The nonsampling factors are primarily discussed in Section 3.4.

Now, back to the questions about the observed differences of effectiveness:

1. Do these sled tests "prove" that correctly used booster seats are more effective than the 3 other types of correctly used seats included in the project? Yes, if sampling error alone is considered. No, when the other factors are accounted for, such as the less favorable results for booster seats in the NHTSA compliance tests, with their higher g environment (see Section 3.4.3).

2. Are the observed differences between tethered, tetherless and shield-type seats significant? Obviously not.

3. Are correctly used seats more effective than partially misused ones? Definitely yes.

4. Are partially misused seats more effective than grossly misused ones? Definitely yes.

5. Is there a significant difference between grossly misused seats and unrestrained? No.

Step 19 - Compare effectiveness results to accident data for front-seat unrestrained, back-seat unrestrained and lap-belted children This second validation of the sled test results is more difficult than the first one (Step 16) because the accident data used here are not the ones that were used to calibrate the model.

The validation begins with a comparison of the actual NASS-NCSS-RSEP risk of hospitalization for unrestrained front-seat passengers aged 1-5 in frontal crashes with Delta V 10-50 mph and the comparable rates predicted by the sled test analysis (Table 7-5):

<table>
<tr><th></th><th>Head Inj. Hosp. per 1000 Children</th><th>Torso Inj. Hosp. per 1000</th><th>Head or Torso Inj.Hosp. per 1000</th><th>Any Hosp. per 1000</th></tr>
<tr><td>NASS-NCSS-RSEP</td><td>51.48</td><td>26.40</td><td>59.25</td><td>67.44</td></tr>
<tr><td>Sled test analysis</td><td>44.71</td><td>24.39</td><td colspan="2">65.21</td></tr>
</table>

There is some discrepancy between the actual and predicted head injury rates because, as can be seen from Figure 7-3, the sled test model underpredicts head injuries in the 10-20 mph range (which is included in the overall injury risk calculation); the 0-10 mph segment, where the model compensated by overpredicting, was excluded from the analysis. But the risk of torso injury and the overall risk of hospitalization are predicted very closely by the model. The accuracy of the predictions should be contrasted to those of the contractor's model (Step 11), which overpredicted chest and abdominal injury risk by factors of 15 and 25.

The next comparison completely severs the "umbilical cord" of the calibration data set. How well do the sled test results predict injury reduction for the unrestrained back seat occupant relative to the front seat occupant in frontal crashes with Delta V 10-50 mph?

Back Seat vs. Front Seat: Reduction (%) of

	Head Inj. Hosp.	Torso Inj. Hosp.	Head and/or Torso Inj. Hosp.
NASS-NCSS-RSEP	51	64	50
Sled test results (unrestrained)	42	79	53
Sled test results (average of unrestrained and gross misuse)	45	62	49

The sled test model comes very close to predicting the overall reduction in hospitalizations due to head and/or torso injuries achieved by moving an unrestrained child to the back seat (53 vs. 50). It undershoots the head injury reduction (42 vs. 51) and overshoots the torso injury reduction (79 vs. 64) by moderate amounts. The sled tests results for unrestrained rear seat occupants are notoriously variable, however, as evidenced by the graphs in Appendix 3 and by the analysis of variance discussed in Step 18. They have double the sampling error of the front seat unrestrained or the correctly used and partially misused restraints. In order to avoid discrepancies due to sampling error, it is perhaps better to compare the NCSS-NASS-RSEP results to the average of the sled test results for unrestrained and grossly misused seats, a use mode that resembles the unrestrained condition (i.e., take the average of 1R and 5R in Table 7-5 and compare it to the average of 1F and 5F). With this larger sample of sled test data, the correlation between predicted and observed is superb:

45 vs. 51 percent head injury reduction; 62 vs. 64 percent for torso and 49 vs. 50 percent for head and torso, combined. The results are a genuine corroboration of the validity of the sled test model, because the sled tests with back-seat occupants were never used in calibrating the model.

Thirdly, how do the sled test results for lap belt only compare to findings from accident data? The sled test model predicted that lap belts reduce hospitalizations by 63 percent (Table 7-6). That is consistent with the 71 percent reduction observed in NASS-NCSS-RSEP (Table 6-3; it was based on a small sample and had confidence bounds of 35-90 percent). It is also thoroughly consistent with the 59 percent reduction of K + A injuries observed in Pennsylvania (Table 5-3). It is, on the other hand, twice as large as the 33 percent fatality reduction observed in FARS--but that, too, is consistent with what was seen in the sled tests. Appendix 4 and Table 7-2 clearly show that lap belts' head protection is outstanding at low-to-moderate speeds but rapidly deteriorates beyond 25 mph and eventually catches up to unrestrained, somewhere around 40 mph. It would have begun deteriorating at an even lower speed in crashes with higher g forces, such as those in compliance tests. Thus, it is appropriate for lap belts to be twice as effective against hospitalizations (which have a median Delta V of 20 mph in frontal crashes--see Table 6-8) as fatalities (which have a median Delta V of 35 mph in frontals [71] and, in all likelihood, higher g forces as well). Correctly used safety seats, by contrast, continued to be effective at high speeds in the sled tests; so did being unrestrained and riding in the back seat.

Table 7-5 predicted that lap belts (front and back seats combined) reduced head injuries by 59 percent and torso injuries by 86 percent relative to the unrestrained front-seat passenger. Those results are consistent with Pennsylvania accident data for lap belts (Tables 5-5 and 5-6) vs. unrestrained front-seat passengers (Tables 5-7 and 5-8), showing 53* percent reduction of K + A level head injuries, 58 percent fewer K + A + B level head injuries, 54 percent lower rate of concussions/dizziness, 75* percent fewer concussions, 78* percent fewer skull and facial fractures and 66* percent fewer K + A + B level chest, stomach and internal injuries.

Thus, the sled test model yields credible results for lap belts, both in a generalized way (all types of injuries in all types of crashes) and for particular injury types. The lap-belted dummy's HIC's were largely due to noncontact phenomena (whiplike motion of the head--see Step 10) while the unrestrained dummy's HIC's were due to contacting the vehicle's interior surfaces. The sled test analysis did not differentiate between contact and noncontact HIC's; nevertheless it produced credible estimates for lap belts. That supports the hypothesis that contact and noncontact HIC's are equally harmful--an important tacit assumption in the modeling procedure.

---

*Statistics based on a small number of injuries and subject to more sampling error than the others.

7.7 Aggregate effectiveness of safety seats

Step 20 - Estimate the overall effectiveness of the 1984 mix of correctly and incorrectly used safety seats Table 7-6 presented the model's estimates of safety seat effectiveness by use mode. In order to obtain a single estimate of the average effectiveness of safety seats, given the mix of correct and incorrect usage that was prevalent in 1984, it is necessary to take a weighted average of the estimates in Table 7-6. Each estimate is given a weight corresponding to its frequency of occurrence on the highways in 1984.

The Hardee's Restaurant survey provided statistics on how frequently each of the 8 major types of toddler seats (as defined in Table 1-1) was encountered on the highway in 1984 (Table 2-2) and, for each type of seat, the frequency of correct use and each of the major misuse modes (Table 2-1). As mentioned in Appendix 1, Step 1, however, it was not possible to sled-test each seat type in each misuse mode. The seat/use mode combinations that were not sled tested have to be matched up with tested combinations that resemble them most closely in terms of seat design, expected dummy kinematics or NHTSA compliance test results (Section 3.4). The matchings and their rationales were as follows:

o Any grossly misused seat was deemed equivalent to the grossly misused tethered seat, since the dummy (with or without the seat) becomes a projectile. Sled test results for use mode 5 (grossly misused tethered seat) were applied to it.

o The sled test results for harness-only tetherless seats (modes 8 and 9) were also applied to partial-shield tetherless seats. The latter, as defined in Section 1.6, are basicly similar to harness-only seats except that the partial shield simplifies using the seat correctly. The compliance test results strongly support that assumption (see Section 3.4.3).

o The results for full-shield seats (mode 10) also apply to shield booster seats. The compliance tests support this hypothesis--at least for HIC and head excursion with a 3-year-old dummy.

o The tethered belt-around (GM Love) seat was not tested in this program but was extensively tested in the compliance tests and the studies reviewed in Section 3.3. When correctly used, its HIC and chest g's were low. Its head excursion was significantly lower than other tethered seats and second lowest only to booster seats in frontal impacts. Its performance was superior to all other types in lateral impacts. Therefore, when correctly used, it is assumed to have effectiveness equal the best performer in this program (which was the booster seat - mode 11). When the tether was not used, it was shown in Section 3.3 to perform about as well as other tether-equipped seats with the tether unused (mode 4).

o Tetherless belt-around seats should function like a harness-only tetherless seat when correctly used (mode 8) or with the lap belt misrouted--i.e., without the detachable shield (mode 9). The compliance tests did not fully support this hypothesis but agreed that the tetherless belt-around ought to have effectiveness equal to the worst performer in this program (which happened to be the harness-only tetherless seat).

o A misuse mode that was not sled tested consists of routing the car's lap belt around child and seat but not buckling the safety seat's harness (and also not fastening the tether). It is quite common in the belt-around seats and occasionally seen in the other toddler seats. It is not a gross misuse because the child should not become a projectile. These cases have been assigned to sled test use mode 6 (tethered seat--no tether and belt too low), the least effective of the partial misuse modes, because similar amounts of head excursion could be expected.

o A full-shield seat with the lap belt misrouted may perform like a harness-only seat with the belt misrouted (mode 9).

o Some full-shield type seats come with an optional harness. If the harness was used, the seat essentially functions like a correctly used harness-only seat (mode 8).

With those equivalences, Table 7-7 takes all of the 816 Hardee's observations of toddler seats in Table 2-1 and assigns them to one of the 9 sled test use modes. The right column of Table 7-7 gives the occurrences of each of the 9 sled test use modes on the highway, based on the 1984 mix of correctly used and misused toddler seats. For example 14 out of 816, or 1.7 percent of all children in toddler seats enjoyed a level of protection equivalent to a correctly used tethered seat. The 8 middle columns of Table 7-7 show the distribution of sled test use modes for each major type of toddler seat. For example, among the 161 tethered seats, 14 were correctly used, 73 correctly used except for the tether, 54 grossly misused and 20 had

Table 7-7

1984 MIX OF SAFETY SEAT USE MODES BY
SAFETY SEAT TYPE (ACTUAL COUNTS FROM HARDEE'S SURVEY)

Protection Equivalent to Use Mode:	SEAT TYPE								ALL SEATS COMBINED
	Tethered	Harness only	Partial Shield	Full Shield	Shield Booster	Booster	Tethered Belt-Around	Tetherless Belt-Around	
3 Tethered seat: correct use	14								14
4 Tethered seat: no tether	73						11		84
5 Gross misuse	54	45	28	0	4	17	1	12	161
6 Tethered seat: no tether & belt too low	20	5	4	1			15	43	88
8 Tetherless seat: correct use		93	106	2				10	211
9 Tetherless seat: belt too low		32	52	3				20	107
10 Full shield type: correct				11	35				46
11 Booster seat: correct						46	6		52
12 Booster seat: no upper body restraint						53			53
N of observations	161	175	190	17	39	116	33	85	816

protection equivalent to use mode 6 (viz., 18 had the tether off and the belt too low and 2 had the belt around the child and the harness and tether off).

The right column of Table 7-7 provides the weight factors needed to calculate the overall effectiveness of restraints in 1984. The best estimate of effectiveness--the reduction of any type of hospitalization in any type of crash, relative to the unrestrained child--is obtained by applying the weights to the effectiveness estimates in the right column of Table 7-6:

$$\text{"hospitalization reduction"} = \frac{\sum_{\substack{i=3 \\ i \neq 7}}^{12} w_i e_i}{\sum_{\substack{i=3 \\ i \neq 7}}^{12} w_i} = \frac{14 \times 66 + 84 \times 49 + \ldots + 53 \times 59}{816} = 46 \text{ percent}$$

Note that 46 percent is the estimated effectiveness of safety seats as they are actually used by the public--i.e., with all gross and partial misusers included.

A more conservative estimate--the reduction of hospitalizing head and/or torso injuries in frontal impacts--is obtained by applying the weights to the effectiveness estimates in the left column of Table 7-6. That estimate is 40 percent. Both estimates are shown in the top line of Table 7-8.

TABLE 7-8

SLED TEST RESULTS: OVERALL EFFECTIVENESS OF SAFETY SEATS
(1984 MIX OF CORRECT AND INCORRECT USAGE)

	Reduction of Hospitalizations Relative to Unrestrained Children (%)	
	Low Estimate Head/Torso Injuries in Frontal Crashes	Best Estimate All Injury Types All Crashes
OVERALL EFFECTIVENESS (All correct users, partial & gross misusers)	40	46
BY DEGREE OF MISUSE:		
Correctly used seats	61	67
Partially misused seats	38	48
Grossly misused seats	0	0
SLED TESTS RESULTS AVERAGED TO SIMULATE		
"State data" effectiveness (where 24% of correct users & partial misusers and 42% of gross misusers are reported as "unrestrained")	42	48
"NASS data" effectiveness (correct users & partial misusers only: nearly all gross misusers are reported as "unrestrained")	49	58

<u>Step 21 - Compare safety seat effectiveness results to accident data</u> The most crucial validation of the sled test model can now be performed: do the results match the effectiveness of safety seats found in accident data? Of course, current accident data (May 1985) do not provide effectiveness estimates by seat type and/or misuse mode; that is what necessitated the sled test program in the first place. So the validation is limited to comparing the <u>overall</u> effectiveness of safety seats detected in the various sources.

Even for overall effectiveness, the comparison is not totally straightforward, because certain types of seat misusage are reported as "unrestrained" by accident investigators. So the accident statistics cannot be compared directly to the sled test effectiveness of 40 to 46 percent derived in Step 20.

In the NASS-NCSS-RSEP data, children in grossly misused seats were mostly defined to be "unrestrained" (see Section 6.1). "Safety seat users" included the correctly used and partially misused seats, only. The corresponding estimate from the sled tests should also exclude the grossly misused seats--i.e., apply the weights in Table 7-7 to the effectiveness estimates in Table 7-6 for modes 3-4, 6 and 8-12, only. The best estimate of effectiveness, based on the sled tests, is a 58 percent reduction of overall hospitalization risk, as shown in the last line of Table 7-8. A more conservative estimate is 49 percent reduction of hospitalizing head and/or torso injuries in frontal crashes. That range matches up exceedingly well with the NASS-NCSS-RSEP accident data which showed a 56 percent reduction in hospitalization risk for safety seats (see Table 6-3; confidence bounds were 30-75%). Note that this was a genuine check of the validity of the sled test results, since the NASS-NCSS-RSEP data on restrained children were never used in calibrating the model.

Data files based on police reports, such as FARS and Pennsylvania, also have grossly misused seats underrepresented among their reported safety seat users. The North Carolina survey, in which police reports were followed up by interviews with parents of crash-involved children (see Section 3.2.4) showed that grossly misused seats are underreported by 42 percent while partially misused and correctly used seats are underreported by only 24 percent. In order to make the sled test results comparable to the "overall effectiveness" observed in FARS or Pennsylvania, the weight factor assigned to gross misuse in Table 7-10 should be diminished by 42 percent and the weight factors assigned to all the other use modes, by 24 percent. Based on the sled tests, the best estimate is

$$\text{"hospitalization reduction"} = \frac{(1 - .24) \times 14 \times 66 + (1 - .24) \times 84 \times 49 + (1 - .42) \times 161 \times 0 + (1 - .24) \times \ldots}{(1 - .24) \times 14 + (1 - .24) \times 84 + (1 - .42) \times 161 + (1 - .24) \times \ldots}$$

$$= 48 \text{ percent}$$

A more conservative estimate, based on head/torso injuries in frontal crashes, is 42 percent. The estimates are shown in the next-to-last line of Table 7-8.

The range of 42-48 percent from the sled tests fits very well with the FARS estimate that safety seats would reduce fatalities of 1-3 year old children by 44 percent if everyone used them, given the 1980-84 mix of grossly misused, partially misused and correctly used seats in police-reported data (Table 4-9). It fits equally well with the 1981-83 Pennsylvania findings that safety seats reduce K + A level injuries by 43 percent and K + A + B level injuries by 45 percent. It is, in fact, especially appropriate that the FARS and Pennsylvania results should be toward the lower end of the sled test effectiveness range. They are based on accident data whose median year was 1982. At that time, the mix of safety seats on the highway included a larger proportion of seats that were often misused (especially seats with tethers) than the mix in the 1984 Hardee' survey used for weighting the sled test results. As seats become easier to use, average effectiveness of the mix of correctly and incorrectly used seats should rise by a few percent. (See Section 8.2.1 for additional discussion.)

<u>Step 22 - Effectiveness of correctly used, partially misused and grossly misused seats</u> Now that the validity of the overall effectiveness estimate based on sled tests has been established, the weight factors in Table 7-7 and effectiveness by use modes in Table 7-6 will be used to obtain aggregate injury reductions for certain subpopulations of the safety seat users.

The average effectiveness of correctly used safety seats is obtained by taking the weighted average for use modes 3, 8, 10 and 11. The best estimate is

$$\text{"hospitalization reduction"} = \frac{14 \times 66 + 211 \times 64 + 46 \times 65 + 52 \times 82}{14 + 211 + 46 + 52} = 67 \text{ percent}$$

A more conservative estimate, based on head/torso injuries in frontal crashes, is 61 percent; both estimates are shown in the middle section of Table 7-8.

The range of 61-67 percent hospitalization reduction for correctly used seats is quite compatible with the 71 percent fatality reduction for correctly used seats predicted from the Tennessee case-by-case accident analysis (see Section 3.2.5). As crash severities went up, the partially misused seats clearly became less effective in the sled tests. But FARS showed that safety seats (correctly used and misused, combined) were just as effective in preventing fatalities as serious injuries. Thus, if partially misused seats are less effective in preventing fatalities than serious injuries, correctly used seats would have to compensate by being more effective in preventing fatalities than serious injuries.

The average reduction in hospitalizations for partially misused seats is obtained by taking the weighted average of use modes 4, 6, 9 and 12. The best estimate is 48 percent; a more conservative estimate is 38 percent.

The effect of grossly misused seats has already been estimated in Step 18 to be close to zero.

If the effectiveness of correctly used seats is 61-67 percent but the average effectiveness of seats in actual use (1984 mix of correct and incorrect use) is just 40-46 percent, it can be concluded that about 1/3 of the potential serious injury-reducing benefits of seats are lost because so many of the seats are incorrectly used.

Step 23 - Safety seat users: back seat vs. front seat In all the analyses so far, sled test results for restrained dummies in the back seat and the front seat were lumped together in order to obtain a statistically more reliable estimate for each use mode. Only the unrestrained dummies and grossly misused seats were subjected to separate analyses for the front and back seats. One of the evaluation objectives, however, is to compare the injury risk of restrained children in the front and back seats. It can only be achieved here if the sled test analyses documented in Steps 13, 15 and 18 are repeated without lumping the front and back seat data, thereby obtaining separate injury risk estimates for the two seat positions, by use mode. These estimates, analogous to the lumped injury rates in the right column of Table 7-5, were:

Restraint Use Mode		Hospitalizations per 1000 Children	
		Front Seat	Back Seat
3	Tethered - correct use	26.80	11.01
4	Tethered - tether not used	29.90	28.57
6	Tethered - no tether & belt too low	43.84	22.64
8	Tetherless - correct use	21.58	19.69
9	Tetherless - belt too low	28.55	33.23
10	Full shield - correct use	20.17	20.37
11	Booster - correct use	11.05	9.71
12	Booster - no upper body support	29.78	16.94

Large sampling errors are evident in the preceding estimates--e.g., use modes 9 and 10 had slightly higher injury risk in the back than in the front--and the numbers are not suitable for effectiveness estimates for individual use modes. But when the data are aggregated across use modes, sampling error is not excessive.

For example, the weighted average injury risk for correctly used restraints (modes 3, 8, 10 and 11) in the front seat, using the weights of Table 7-7, is

$$\frac{14 \times 26.80 + 211 \times 21.58 + 46 \times 20.17 + 52 \times 11.05}{14 + 211 + 46 + 52} = 19.91$$

As in Step 18, the best estimate for injury risk of unrestrained front-seat occupants is 65.21. Thus, the effectiveness of correctly used restraints in the front seat (relative to front seat unrestrained) is 69 percent, the first entry in Table 7-9.

Similarly, the weighted average injury risk for correctly used restraints in the back seat is

$$\frac{14 \times 11.01 + 211 \times 19.69 + 46 \times 20.37 + 52 \times 9.71}{14 + 211 + 46 + 52} = 17.80$$

which is 73 percent lower than the injury risk for an unrestrained child in the <u>front</u> seat (the first entry in the left column of the bottom half of Table 7-9).

TABLE 7-9

SLED TEST RESULTS: OVERALL EFFECTIVENESS OF SAFETY SEATS, BY SEAT POSITION

(1984 MIX OF CORRECT AND INCORRECT USAGE)

Reduction (%) of Hospitalizations Relative to:

	Front Seat Unrestrained
FRONT SEAT RESTRAINED	
Correctly used seats	69
Partially misused seats	49
Grossly misused seats	0
OVERALL (1984 mix)	48

	Front Seat Unrestrained	Back Seat Unrestrained	Front Seat Same Restraint
BACK SEAT RESTRAINED			
Correctly used seats	73	63	11
Partially misused seats	59	45	20
Grossly misused seats	26	0	26
OVERALL (1984 mix)	58	43	20

In Step 18, the best estimate of injury risk for an unrestrained child in the back seat was 48.26, i.e., 26 percent lower than in the front seat. Thus, the effectiveness of a correctly used restraint in the back seat relative to rear seat unrestrained is 1 -(17.80/48.26) = 63 percent (the first number of the second column in the bottom half of Table 7-9).

Finally, the injury reduction for moving a correctly restrained child from the front seat to the back seat is 1 -(17.80/19.91) = 11 percent. That number appears in the right column of the bottom half of Table 7-9.

Similar calculations can be performed for partially misused seats. As shown in Table 7-9, the injury reductions were 49 percent (restrained front-seat vs. unrestrained front), 59 percent (restrained back seat vs. unrestrained front seat), 45 percent (restrained back seat vs. unrestrained back seat) and 20 percent (restrained back seat vs. restrained front seat).

As in Step 18, it is concluded that children in grossly misused seats have about the same injury risk as unrestrained children. Thus, a grossly misused seat in the back seat of a car is approximately 26 percent safer than the same seat in the front of the car--i.e., same reduction as for unrestrained children.

The right column in the bottom half of Table 7-9 shows a sequence of effectiveness estimates that is consistent with intuition: 11 percent injury reduction for moving a correctly restrained child from the front seat to the back seat, 20 percent reduction for moving a partially restrained child and 26 percent for a child in a grossly misused seat. The more fully a child is restrained, the less of a difference it should make whether the child is in the front or back seat, because contacts with the vehicle interior are less likely to occur.

The 1984 mix of restrained children--in correctly used, partially or grossly misused safety seats--had a 48 percent lower risk of serious injuries in the front seat than did an unrestrained child in the front seat. In the back seat, restrained children (1984 mix) had 58 percent fewer injuries than front seat unrestrained, 43 percent lower than back seat unrestrained and 20 percent lower than front seat restrained.

The 20 percent estimate for injury reduction: back seat restrained vs. front seat restrained is about midway between the 10-20 percent estimate from Pennsylvania (Section 5.3.2) and the 35 percent estimate from FARS (Section 4.5), both of which were subject to sampling error.

The sled test data support two conclusions about the value of the back seat for restrained children:

o The benefits of a child safety seat and the car's back seat are nearly additive. The injury reduction for moving a restrained child to the back seat (20% relative to restrained front seat) are almost as large as for an unrestrained child (26% relative to restrained front seat) - for the 1984 mix of correctly used and misused seats.

o The best protection parents can give their children is a correctly used seat in the back seat of their car. Serious injury risk is 73 percent lower than unrestrained front seat.

Step 24 - Effectiveness in actual use, by type of seat The sled test results of this chapter were compared to the findings of NHTSA compliance tests in Section 3.4.3. It was concluded that the two series of tests point to a similar value for the overall average effectiveness of all types of correctly used safety seats (61-67 percent serious injury reduction, according to Table 7-8). On the other hand, the two series disagreed on what were the most effective types of seats. Here, with relatively lower sled g's and looser installation of seats, the booster seat had the best results. In the compliance tests, with substantially higher sled g's at a given speed, conventional toddler seats with harnesses had significantly lower HICs than boosters or shield-type seats. Both test series may be considered representative of a portion of the highway crash environment. When both data sets are taken into account, no significant differences among the various types of correctly used seats could be justified. Therefore the preliminary conclusion was that they were all more or less equally effective--61-67 percent reduction of serious injuries--when the full range of frontal crashes is taken into account. The conclusion might be revised when test data on abdominal loading or with dummies of other sizes become available.

Thus, in calculating the effectiveness of a specific type of seat (taking into account the 1984 mix of correct and incorrect usage), the weight factors in Table 7-7 are applied to the effectiveness numbers in Table 7-6 with the exception that the effectiveness numbers for correctly used seats (modes 3, 8, 10 and 11) are replaced by 67 (for "best" estimates) or 61 (for a "more conservative" estimate)--because all correctly used seats are concluded to be about equally effective, at least in frontal crashes of an average-sized car.

For example, the best estimate for tethered seats is

$$\text{hospitalization reduction} = \frac{14 \times 67 + 73 \times 49 + 54 \times 0 + 20 \times 44}{14 + 73 + 54 + 20} = 34 \text{ percent}$$

All of the best estimates (based on all types of hospitalizations in all types of crashes) as well as the more conservative estimates (based on head/torso injuries in frontal crashes) are shown in Table 7-10.

Effectiveness was closely tied to the ease of use. The best performers were the tetherless-full shield type (55-62% reduction of hospitalizations), shield booster (55-60%), conventional booster seat (47-54%) and tetherless-partial shield type (45-51%), all of which had a gross misuse rate lower than 15 percent and correct use rate higher than 45 percent. In fact, the tetherless-full shield and shield booster had gross misuse lower than 11 percent and correct use higher than 75 percent. The next (somewhat overlapping) category of performers included tethered belt-around (39-49%) and tetherless belt-around (32-41%) which had gross misuse below 15 percent but also had less than 20 percent correct usage and the harness-only type (40-45%) which was correctly used 53 percent of the time, but also had 26 percent gross misuse. The worst performer was the tethered seat (27-34% reduction of hospitalizations) which was grossly misused 34 percent of the time and correctly used only 9 percent of the time. (By the way, none of the specific seats included in the generic "tethered" type are still being manufactured. The only tethered seat still on the market, the Century Love Seat, is a "tethered belt-around" type.)

TABLE 7-10

SLED TEST RESULTS:* SERIOUS INJURY REDUCTION
BY TYPE OF SAFETY SEAT
(1984 MIX OF CORRECT AND INCORRECT USAGE)

Safety Seat Type	Reduction of Hospitalizations Relative to Unrestrained Children (%)	
	Low Estimate Head/Torso Injuries in Frontal Crashes	Best Estimate All Injury Types All Crashes
Tethered	27	34
Tetherless- harness only	40	45
Tetherless - partial shield	45	51
Tetherless - full shield	55	62
Shield booster	55	60
Booster	47	54
Tethered belt-around	39	49
Tetherless belt-around	32	41
ALL SAFETY SEATS	40	46

*Estimates are based on frontal tests in Chevrolet Citation sled buck and NHTSA compliance tests with 3-year-old dummies. Different results might have been obtained if side impact tests had been included, or if abdominal loading had been measured, or a smaller car were used, or a different-sized dummy.

All of the preceding results must be considered preliminary at this time. They were based on the sled tests described in this chapter and the compliance tests analyzed in Section 3.4. All of the tests, in other words, were frontal or frontal-oblique. The various types of seats may act quite differently in side impacts (specifically, earlier research described in Section 3.3 suggested that the tethered belt-around type may have a definite advantage in side impacts). The results are based on a Chevrolet Citation sled buck: an average-sized car. In a much smaller car, conventional boosters, tethered belt-around or tethered seats, which allow significantly less head excursion than the other types (see Table 3-5), might have had a definite advantage. All tests used a 3-year-old dummy. A substantially larger or smaller dummy might have yielded different results: this is especially the case for shield-equipped seats, since the shield is positioned to contact the right portion of the dummy's anatomy when the dummy is within the manufacturer's specified height/weight range for that seat. Use of such seats by dummies outside the recommended range could have resulted in undesirable kinematics.

The results should not be viewed as a criticism of tethers per se. Tethers are excellent for those parents who will take the necessary steps to use them correctly. They may be especially advantageous in small cars and in side impacts. The results merely reflect the fact that the vast majority of owners of tethered seats currently do not use the tethers.

Conversely, the excellent results for full-shield and shield-booster seats should not be viewed at this time as an endorsement of those types above other seats. To be sure, the full-shield and shield-booster seats are exceptionally easy to use correctly. They also had low HIC's in the sled tests of this chapter (Step 10). But these pluses should be tempered by their relatively higher HICs in the compliance tests and higher torso g's in both test series. More generally, NHTSA has relatively little test experience with these seats. In particular, it is unknown to NHTSA whether these seats would perform as well in side impacts or rollovers as a seat with a harness. It is also unknown if performance changes significantly for a dummy that is substantially larger or smaller than a 3-year-old. Researchers have expressed concern about the potential for high abdominal loads with these seats (e.g., Weber and Melvin in NHTSA Docket letter 74-09-N17-009, dated 8/14/85 and Hall et al in letter 74-09-N17-018, dated 8/14/85).

In short, all the seats are quite effective when correctly used: certainly better than misused seats. Purchasers should above all consider what type of seat they will use correctly - every time their child goes for a ride.

CHAPTER 8

THE BENEFITS OF SAFETY SEATS - 1979 TO 1984

Observational surveys of children's safety seat and lap belt usage were reviewed in Chapter 2. Chapters 3-6 described accident studies, including the levels of safety seat and belt usage in the accident data files. Section 8.1 compares observational and accident data and concludes that usage of child seats increased from 15 percent for the 0-4 year old passenger population in 1979 to 46 percent in 1984. Correct use of safety seats increased even more dramatically: 3 percent of all child passengers were correctly restrained in 1979, 18 percent in 1984. Use of lap belts increased from 3 to 14 percent.

Chapter 7 used sled tests as a basis for estimating the effectiveness of correctly used, partially misused and grossly misused safety seats. Those estimates can be combined with the observational survey results in Chapter 2 to give estimates of the overall effectiveness of safety seats in each year between 1979 and 1984. Section 8.2 shows that overall effectiveness increased from 27 percent in 1979 to 46 percent in 1984 because a much higher proportion of safety seats were used correctly in 1984. Section 8.2 compares these estimates to the ones based on accident data and presented in Chapters 3-6: the consistency between the various studies is remarkable after the year of the accident data and their source is taken into account.

Section 8.4 shows that, thanks to the increases in both usage and effectiveness, the number of children whose lives were saved by safety seats or lap belts increased from about 40 in 1979 to nearly 200 in 1984.

8.1 Restraint system usage: observational surveys vs. accident data

8.1.1 Safety seats

Section 2.2 reviewed the results of five observational studies of safety seat usage by children aged 0-4. Overall usage had a consistent definition and pattern across the 5 surveys, remaining stable at 15 percent from 1974 to 1979 and then climbing steadily to 46 percent in 1984 as State laws and educational campaigns were implemented throughout the United States. Attempts to break down the overall usage into two groups--correct users/partial misusers vs. gross misusers/users of home child carriers as car seats--were slightly complicated by differences among the surveys in their definitions of misuse. Those differences were resolved in Section 2.2, however, and a consistent pattern emerged: gross misuse/home child carriers declined steadily as a percentage of all child seat users, from 60 percent in 1974 to 20 percent in 1984, thanks to improved design and labeling of the seats, educational campaigns and the virtual elimination of home child carriers from use in automobiles. As a result, Tables 2-3 and 2-5 showed the percentages of child passengers who were in correctly used or partially misused seats or in grossly misused seats/home child carriers during 1974 and in 1979-84, year by year. Those percentages are replicated in the first 3 lines of Table 8-1: correct use/partial misuse increased sixfold from 6 to 36 percent while gross misuse/home child carriers remained stable near 10 percent.

TABLE 8-1

USAGE OF SAFETY SEATS BY CALENDAR YEAR, CHILD PASSENGERS AGED 0-4
OBSERVATIONAL SURVEYS VS. ACCIDENT DATA

		1974			1979	1980	1981	1982	1983	1984
OBSERVATIONAL SURVEYS										
	Correct users & partial misusers	6.1			7.6	11.5	15.4	22.1	31.5	36.6
OBSERVED	Gross misuse/home child carriers	9.4			7.6	8.2	8.9	9.5	10.1	9.7
	TOTAL (observed)	15.5			15.2	19.7	24.3	31.6	41.6	46.3
STATE ACCIDENT DATA										
REPORTED	New York		8	9						
	New Jersey		9							
	Maryland				6					
	Idaho			4						
	Pennsylvania*							20		
	Tennessee*								36	
	North Carolina*									20
Expected	based on usage surveys**	10.1			10.2	13.5	16.9	22.3	29.8	33.4
NHTSA ACCIDENT DATA										
Reported	RSEP/NCSS/NASS*	7		5	8	13	16	20	29	
Expected,	based on usage surveys***	6.1			7.6	11.5	15.4	22.1	31.5	36.6

* Numbers in Chapters 3, 5, 6 adjusted to reflect children aged 0-4
** 76% of correct users/partial misusers + 58% of gross misusers/home child carriers
*** Correct users/partial misusers only

How do the observational surveys compare to safety seat usage reported in accident data? A glance at Table 8-1 shows that safety seat usage in State accident data is consistently well below what was observed in the surveys. For example, the 1974-78 New York accident files had 8-9 percent safety seat usage when there was 15 percent in observational surveys and the 1981-83 Pennsylvania files had 20 percent usage (for 0-4 year olds) rather than the 32 percent in the observational surveys.

But the unique North Carolina accident file documented in Section 3.2.4 provides an explanation for the discrepancy and a method for predicting its size in other files. The North Carolina data record police-reported restraint usage side-by-side with a more accurate assessment based on a detailed interview with parents. They showed that almost all police-reported safety seat users were, in fact, in safety seats, but that police significantly underreported safety seat usage, especially when the seat was grossly misused. Specifically, 42 percent of children in grossly misused safety seats/home child carriers were reported as "unrestrained" by police but only 24 percent of the children in correctly used or partially misused seats were so reported.

Are those levels of underreporting consistent with the usage seen in other State accident files? The seventh line of Table 8-1 shows the usage that would be expected in State files, based on the observation surveys and the above rates of underreporting--i.e., taking away 42 percent of the gross misusers and 24 percent of the correct users/partial misusers. The expected usage in State files ranges from 10 percent in 1974 to 33 percent in 1984, well below what was actually observed in the surveys. The two largest State accident files, New York and Pennsylvania, match these expectations closely. New York had 8-9 percent safety seat usage in 1974-78, when 10 percent was expected. Pennsylvania had 20 percent in 1981-83 (without a buckle-up law) when 22 percent was expected (based on the 19 city survey, which included some jurisdictions with buckle-up laws). New Jersey also matches the expected level closely. Maryland, Idaho and North Carolina are lower while Tennessee, the pioneer in buckle-up laws, is higher than the expected levels based on nationwide surveys; these discrepancies probably reflect State-to-State differences in actual usage. On the whole, the various State accident files show usage levels consistent with the extent of underreporting experienced in North Carolina. That provides a degree of confidence that in the other States, as in North Carolina, the police-reported safety seat user group contains children who really used the seats, but is somewhat biased toward the children who did not grossly misuse them. Conversely, it also provides confidence that the observational surveys did not overreport actual usage.

In NASS, investigators were specifically instructed to report children in grossly misused safety seats/home child carriers as "unrestrained." Therefore, safety seat usage in NASS needs to be compared to correct use/partial misuse in the observational surveys, not overall usage. The last two lines of Table 8-1 show remarkably close agreement between the NHTSA accident files and the observational surveys all the way from 1974 through 1983, a period in which correct use/partial misuse increased from 6 to 32 percent. Again the accident and observational data validate one another.

8.1.2 Lap belts

One of the principal discrepancies in the data described in Chapters 2-6 was that children's lap belt usage in the observational surveys was substantially lower than what was reported in the accident data. The first line of Table 8-2 shows lap belt usage in the observational surveys. It is, at least, internally consistent. Usage was 3.9 percent in 1974, dropping to 1.6 percent in 1979 (a half decade during which belt wearing by adults also declined). It increased slowly to 3.1 percent in 1982 and then more rapidly to 6.9 percent in 1984, as many States passed laws allowing lap belt use in lieu of safety seats [84].

The most reliable accident data are the North Carolina study, NCSS and NASS. North Carolina's assessment of belt use was based on a detailed interview with parents; the 14 percent usage rate in their 1983-84 study is more than double the 5-7 percent in the observational surveys of those years.

NCSS and NASS base their determination of restraint use on a detailed examination of the vehicle in addition to the interview. Because sample sizes were small, usage rates for the individual years fluctuated, but on the average they show at least double what was found in the observational surveys--e.g., 12 percent in 1983, when the surveys showed 4.6 percent (see Table 8-2).

TABLE 8-2

USAGE OF LAP BELTS BY CALENDAR YEAR, CHILD PASSENGERS AGED 0-4,
OBSERVATIONAL SURVEYS VS. ACCIDENT DATA

	1974			1979	1980	1981	1982	1983	1984
OBSERVATIONAL SURVEYS	3.9			1.6	1.9	2.2	3.1	4.6	6.9
STATE ACCIDENT DATA									
New York		13	12						
New Jersey		14							
Maryland				12					
Idaho			4						
Pennsylvania						16			
Tennessee							6		
North Carolina								14*	
NHTSA ACCIDENT DATA									
NCSS		2							
NCSS-NASS				4					
NASS				1	6	2	10	12	
"BEST ESTIMATE"				3.2	3.8	4.4	6.2	9.2	13.8

*Parent-reported

State accident data consistently indicated a high rate of lap belt use. New York, New Jersey, Maryland and Idaho data of the 1974-84 period had 9-14 percent usage of lap belts by children, not too far below the levels for adults. In Pennsylvania data (1981-83) it was 16 percent (when children with unknown restraint use are excluded) . Even in Tennessee, where lap belts are prohibited by law for children under 4, usage was 6 percent in 1982-83 in the bi-level accident data. In a 1983 report, Kahane et al. expressed concern that many of the reported lap belt users might actually have been in safety seats. But the North Carolina study (Section 3.2.4) suggests otherwise: except for infants, most of the police-reported lap belt users were indeed wearing lap belts. If anything, police may have underreported lap belt usage in North Carolina. Furthermore, the Pennsylvania data (Section 5.4.2) showed injury patterns for the reported lap belt users which were clearly different from those of children in safety seats and were intuitively reasonable for lap belted children.

It is concluded that the observational surveys, while accurate for safety seats, must be underreporting the percentage of children in lap belts. The conclusion is reached with reluctance and only after alternative explanations were exhausted. Obviously, it is harder to observe that a small child used a lap belt than a safety seat -- hence, presumably, the underreporting. Based on the NASS data, especially for the last few years, the best estimate is that actual lap belt usage is about double what was recorded in the observational surveys. (That may still be an underestimate for the earlier years; one of the reasons for the 1983-84 increase in the observational surveys could be that the new contractor placed greater emphasis on observing lap belts.)

8.2 Serious casualty reduction: sled tests vs. accident data

8.2.1 Safety seats

The usage statistics reviewed in Section 8.1.1 have two implications for effectiveness estimates. One is that the "overall effectiveness of safety seats" did not remain constant over time but increased steadily from 1979 to 1984 because an ever larger fraction of the seats were being used correctly. Secondly, the effectiveness estimates from State accident data should be higher than the true casualty reduction because gross misusers of safety seats are often reported as "unrestrained" by police; the estimates from NASS should be even higher because gross misusers are always reported as "unrestrained" in NASS. These two factors account for most of the differences among the various effectiveness estimates documented in Chapters 3-6; when controlled for, nearly all of those estimates agree closely with what would be predicted from the sled test results and the usage surveys.

The sled tests of Chapter 7, supported by the analysis of NHTSA compliance tests (Section 3.4), showed that all major types of seats, when correctly used, are highly effective in reducing serious head and torso injuries in frontal crashes (Tables 7-5, 3-3 and 3-4). The average effectiveness (overall reduction of hospitalizations) of correctly used seats was 67 percent (Table 7-8).

The only accident study that specifically focuse on correctly used seats is the Tennessee case-by-case analysis of fatals (Section 3.2.5), which indicated a 71 percent fatality reduction. That is close to the 67 percent hospitalization reduction seen in the sled tests; indeed a detailed analysis of the sled test results (Table 7-2, Appendix 4) suggests that correctly used seats may be slightly more effective against life-threatening injuries than against nondangerous hospitalizing injuries.

The sled tests showed that the various types of seats, in various different partial misuse modes, had fairly similar levels of effectiveness, ranging from 44 to 59 percent (Table 7-6). The average was 48 percent reduction of hospitalizations (Table 7-8), with a slightly lower fatality reduction suggested by the detailed sled test results.

Finally, the sled tests indicated little or no injury reduction for grossly misused seats (Tables 7-5 and 7-6). Likewise, home child carriers are usually unsecured to the car or, if secured, have a high chance of escaping the lap belt in a crash. They, too, should be estimated to have zero effectiveness.

In short, the sled tests suggest hospitalization reductions of 67 percent for correctly used seats, 48 percent for partially misused seats and zero for grossly misused safety seats or home child carriers. The numbers, although based on the 1984 mix of safety seat types, are relatively insensitive to changes in that mix since there was not much variation between seats. Moreover, the same numbers can be used for fatality reduction because the slightly increased benefit for correctly used seats is more or less cancelled by the decreased benefit for partially misused seats.

Table 2-5 gave year-to-year estimates of the percentage of child passengers in correctly used safety seats, partially misused safety seats, and grossly misused safety seats/home child carriers. It was based on observational surveys and sales data analyses. The usage rates were duplicated in the first 3 lines of Table 8-3. In 1979, only 2.7 percent of all child passengers were in correctly used safety seats; in 1984, 17.9 percent. During the same period, gross misuse/home child carriers remained almost unchanged. The increase in overall safety seat use was highlighted by a proportionately greater increase in correct use, as the manufacturers made the seats easier to use.

Let C,P and G be the percentages of children in correctly used safety seats, partially misused safety seats, and grossly misused safety seats/home child carriers. Assuming 67, 48 and 0 percent effectiveness for the three levels of usage, the sled tests predict an overall reduction of serious injuries, for all seat users combined, of

$$(67 C + 48 P + 0 G)/(C + P + G)$$

In 1979, when half the seats were grossly misused safety seats or home child carriers, the overall effectiveness was 27 percent. As shown in the fourth line of Table 8-3, the effectiveness increased by 3-5 percent every year and reached 46 percent in 1984: not far from double the 1979 level!

TABLE 8-3

EFFECTIVENESS OF SAFETY SEATS BY CALENDAR YEAR
SLED TESTS VS. ACCIDENT DATA

	1979	1980	1981	1982	1983	1984
			U S A G E (%)			
Correct users (C)	2.7	4.0	5.4	8.0	12.3	17.9
Partial misusers (P)	4.9	7.5	10.0	14.1	19.2	18.7
Gross misusers/home child carriers (G)	7.6	8.2	8.9	9.5	10.1	9.7
SLED TESTS	E F F E C T I V E N E S S (% Serious Injury Reduction)					
Overall Effectiveness (67C + .48P)/(C + P +G)	27	32	35	38	42	46

STATE ACCIDENT DATA

Observed	New York (K+A)	28	34	36 <-- Maryland (K+A)	FARS K	43	52 <-- NC KA
	New York (K+A+B)	26	24	33 <-- Maryland (K+A+B)	Penna KA	43	37 <-- NC KAB
	New Jersey	19			Penna KAB	45	80 <-- Tenn. KA
					Michigan KA	43	59 <-- Tenn. KAB

	1979	1980	1981	1982	1983	1984
Expected from sled tests*	31	35	38	41	45	48

NHTSA ACCIDENT DATA

	1979	1980	1981	1982	1983	1984
Observed NCSS-NASS-RSEP			56			
Expected from sled tests (67C + 48P)/(C + P)	55	55	55	55	55	58

* .76 (.67C + .48P)/(.76C + .76P + .58G)

What effectiveness do the sled tests predict for analyses of State accident data? The North Carolina study (Section 3.2.4) found that 76 percent of correct users and partial misusers were reported, by police, as having used a safety seat, but only 58 percent of gross misusers. Thus, the police-reported population of safety seat users contains 76 percent of C and P but only 58 percent of G. The effectiveness for this population would be

$$[67\ (.76C) + 48\ (.76P) + 0\ (.58G)]/(.76C + .76P + .58G)$$

In 1979, this biased effectiveness was 31 percent (or 4 points higher than the unbiased overall effectiveness). As shown in Table 8-3, it increased by 2-4 percent each year and reached 48 percent in 1984 (2 points higher than the unbiased estimate). The amount of bias expected in the State data estimate declined because the proportion of grossly misused seats became smaller.

The actual estimates based on State data correspond nicely to the expectations based on sled tests. The FARS data showed a 43 percent fatality reduction for safety seats (Table 4-9). The median calendar year for safety seat users was "1982 1/2"; thus the FARS estimate corresponds exactly to the sled test prediction (41 for 1982 and 45 for 1983 --i.e. 43 for 1982 1/2).

The median calendar year for safety seat users in Pennsylvania was also 1982 1/2. The reduction of K + A injuries was 43 percent (Table 5-3), again corresponding exactly to the sled test prediction. The reduction of K + A + B injuries, 45 percent, was also very close.

The Michigan study was also based on 1982 1/2 data and showed a 43 percent reduction of K + A injuries for safety seats, when used (Section 3.2.7). Again, this matches the sled test prediction.

The earliest effectiveness prediction from the sled tests is made for 1979 and it is 31 percent. Some of the accident studies are based on data prior to 1979 and, appropriately, their estimates were lower than 31 percent. The 1975 New Jersey data showed 19 percent reduction of K + A + B injuries (Section 3.2.1). The initial New York study - median year 1976 for the safety seat users - estimated 28 percent reduction of K + A and 26 percent reduction of K + A + B injuries (Section 3.2.1). The study of subsequent New York data (median year 1977) showed a bit higher effectiveness: 34 percent reduction of K + A and 24 percent reduction of K + A + B (Section 3.2.2). In Maryland, where the median year was 1979, the effectiveness was yet higher: 36 percent for K + A and 33 percent for K + A + B, both close to the sled test prediction (Section 3.2.2).

At the other end of the time line, the North Carolina data showed 52 percent fewer K + A injuries for <u>police</u>-reported safety seat users and 37 percent fewer K + A + B injuries (Section 3.2.3). The data were collected in 1983 1/2 and straddle the sled test prediction of 46.5 percent for that moment in time.

The only discordant results are those of the Tennessee bi-level study conducted in 1982-83 which showed 80 percent reduction of K + A injuries and 59 percent at the K + A + B level. As explained in Section 3.2.6, there were a number of factors that could have biased the study in favor of safety seats.

In NASS, children in grossly misused safety seats or home child carriers were reported as "unrestrained." The population of reported safety seat users consisted only of correct users and partial misusers. The expected effectiveness for that population, based on sled tests, would be

$$(67 C + 48 P)/(C + P)$$

The last line in Table 8-3 shows that this effectiveness is 55 percent in each year from 1979 through 1983 and 58 percent in 1984. NASS-NCSS-RSEP could hardly agree more: safety seats reduced hospitalizations by 56 percent in the combined accident files (Table 6-3). (That estimate, however, was based on a small sample and had confidence bounds of ± 20 percent. Its almost perfect match with the sled test prediction may partly be a matter of luck.)

All in all, the sled tests do a remarkable job predicting what was found in the accident data. Conversely, the accident data confirm the validity of the sled test predictions. The overall effectiveness estimates based on sled tests - the fourth line of Table 8-3 -- should be considered valid for calculating benefits of safety seats during the 1979-84 time period, when applied in combination with the overall usage figures from the observational surveys. Their validity extends to fatal as well as serious nonfatal injuries.

8.2.2 Lap belts

Unlike safety seats, there is no reason why lap belt effectiveness for toddlers riding in passenger cars should change over time or as a function of the accident data source. Both of those factors related to correct vs. incorrect use of safety seats, whereas lap belts are, as a general rule, "correctly" used. On the other hand, unlike safety seats, lap belt effectiveness varies considerably as a function of injury severity. As evidenced by the sled tests and the accident data, lap belts are not too beneficial in extremely severe crashes, limiting their fatality reduction benefit (see Table 7-2 and Appendix 4). They are also of limited value against certain types of minor injuries (see Section 5.4.2). But they achieve their highest effectiveness in the moderate-to-serious injury range.

Table 8-4 recapitulates the effectiveness estimates for lap belts in the sled tests and the various accident data files.

The FARS analysis indicates a 33 percent fatality reduction (Section 4.3), which will be used in calculating life-saving benefits of lap belts. That number is consistent with the sled test results, which showed lap belts effective for small children in frontal crashes with Delta V up to 30 mph, but not beyond (Appendix 4). It is also consistent with effectiveness estimates for "lap belt only for adults" [25], p. IV-2.

TABLE 8-4

EFFECTIVENESS ESTIMATES FOR LAP BELTS
(CHILD PASSENGERS AGED 0-4)

Data Source	Percent Reduction of Fatalities	Hospitalizations	K+A Inj.	K+A+B Inj.
FARS 1975-84	33	---	---	---
NCSS-NASS-RSEP	--	71*	---	31**
Sled tests	--	56***	---	---
Pennsylvania 1981-83	--	---	59	42
New York 1975-78	--	---	46	29
Maryland 1977-80	--	---	59	46
North Carolina 1983-84	--	---	61	34
New York 1974,77	--	---	54	36
New Jersey 1975	--	---	---	61
Tennessee 1983-83	--	---	47*	26

* Very small sample (4-6 injured cases)

** Children transported to treatment facilities

*** Hospitalizations due to head or torso injuries in frontal crashes. Effectiveness would probably have been lower in a higher g testing environment such as the one in NHTSA compliance tests.

The sled tests and all the accident studies suggest that lap belt effectiveness is higher than 33 percent for moderate-to-serious nonfatal injuries. The sled tests of Chapter 7 indicated a 56 percent reduction for hospitalizing head and torso injuries in frontal crashes (Table 7-6). That figure would probably have been lower if the tests had been run in a higher g environment, such as the one in NHTSA compliance tests. NCSS-NASS-RSEP showed 71 percent overall reduction of hospitalizations - but the sample was too small (4 lap-belted hospitalizations) for the estimate to be meaningful. Six analyses of State data produced estimates of K + A injury reduction ranging from 46 to 61 percent; three of them, however, were not adjusted for differences in vehicle damage severity between the lap-belted and unrestrained children.

Based on these data sources, it would appear that lap belts reduce nonfatal hospitalizations by approximately 50 percent. At the next lower injury level (emergency room treatments, K + A + B injuries), Table 8-4 suggests that the effectiveness of lap belts drops again to about 35 percent.

8.2.3 Unrestrained children: back seat vs. front seat

The benefits of moving an unrestrained child from the front seat to the back seat of a car have not changed from year to year and also do not vary much as a function of injury severity. The top half of Table 8-5 recapitulates the effectiveness estimates in the sled tests and the accident data files.

TABLE 8-5

INJURY REDUCTION FOR BACK SEAT VS. FRONT SEAT

Data Source	Percent Reduction of Fatalities	Hospitalizations	Hosp. Head & Torso Inj. in Frontal Crashes	K+A Inj.	K+A+B Inj.
A. UNRESTRAINED: BACK SEAT VS. FRONT SEAT					
FARS 1975-84	27	---	---	---	---
NCSS-NASS-RSEP	--	24	55	---	14*
Sled tests	--	---	53	---	---
Pennsylvania 1981-83	--	---	---	-8	35
New York 1975-78	--	---	---	40	39
Maryland 1977-80	--	---	---	28	32
B. RESTRAINED: BACK SEAT VS. FRONT SEAT					
FARS 1980-84**	35	---	---	---	---
Sled tests**	--	---	20	---	---
Pennsylvania 1981-83**	--	---	---	-28	11
New York 1975-78***	--	---	---	52	41
Maryland 1977-80***	--	---	---	46	48

* Children transported to treatment facilities

** Children in safety seats

*** Children in safety seats or lap belts

The FARS analysis showed that children in the back seat have a 27 percent lower fatality risk than children of the same age in the front seat (Section 4.4). The analysis was based on thousands of fatalities and is statistically precise. It was also designed in a manner to minimize biases.

The NCSS-NASS-RSEP data revealed a 24 percent reduction in hospitalizations for back seat passengers - about the same as the FARS result. Three State accident files produced 6 estimates for moderate-to-serious injuries (three at the K + A level and three at the K + A + B level). The average of the 6 estimates is 28 percent.

Thus, the serious injury reduction gained by moving an unrestrained child to the back seat is about the same as the fatality reduction: 27 percent.

The sled tests suggested that unrestrained children in the back seat are 53 percent less likely to be hospitalized by head or torso injuries in frontal crashes than unrestrained children in the front seat. That is nearly identical to the 55 percent reduction observed for such injuries in NCSS-NASS-RSEP - i.e., the accident data validate the sled test results. Both of the estimates, however, are double the overall reduction of serious injuries in all types of crashes - because the back seat is minimally effective in nonfrontal crashes and in protecting the arms and legs (see Section 6.3). In other words, the sled tests should not be used as an indication of overall injury reduction for moving an unrestrained child to the back seat.

8.2.4 Restrained children: back seat vs. front seat

The bottom half of Table 8-5 recapitulates the casualty reductions for moving a restrained child from the front seat to the back seat. The most reliable effectiveness indicator, perhaps, is the sled test analysis (Chapter 7, Step 23), which showed a 20 percent reduction of hospitalizations for the 1984 mix of correctly used and misused safety seats. The reduction, by misuse mode, was: 11 percent fewer injuries for a correctly used seat in the back relative to a correctly used seat in the front; 20 percent for partially misused seats - back vs. front; and 26 percent for grossly misused seats. These reductions were intuitively reasonable and, moreover, suggest that the benefit of moving a "restrained" child from the front to the back have decreased over time as fewer and fewer of the seats are being misused.

The FARS data for 1980-84 indicate a 35 percent lower fatality risk for safety seat users in the back seat, relative to safety seat users in the front (after controlling for the child's age). Unlike the FARS estimate for unrestrained children, it is based on only 70 fatalities in each seat position and subject to a fair amount of sampling error. Six estimates from 1975-83 State data files averaged 28 percent. Thus, the accident data are fairly consistent with the sled test results, especially considering that the accident data were collected prior to 1984 and can be expected to show slightly higher effectiveness, since there were more misusers.

In fact, the sled test data can be used to calculate the year-by-year changes in the effectiveness of moving a restrained child from the front to the back seat. In Chapter 7, Step 23, the numbers of hospitalizations per 1000 crash-involved children (10-50 mph Delta V) were

	Front Seat	Back Seat
Correctly used seat	19.91	17.80
Partially misused	33.14	26.64
Grossly misused	65.21	48.26

When these injury rates are weighted by the year-to-year distributions of misuse modes shown in the top part of Table 8-3, the following injury reductions are obtained

Injury Rate for Safety Seat Users	1979	1980	1981	1982	1983	1984
Front seat	46.82	43.80	41.95	39.43	37.01	34.74
Back seat	35.88	33.84	32.59	30.90	29.28	27.75
Reduction (%)	23	23	22	22	21	20

In other words, the average benefit of moving a restrained child from the front to the back seat has decreased slightly, from 23 to 20 percent, since 1979. More and more children are being correctly restrained: a condition in which there is relatively little difference (11 percent) between the back and the front seat. In 1979, when half of all child seat users were in grossly misused safety seats or home child carriers, the benefits of moving restrained and unrestrained children to the back seat were nearly the same (23 vs. 26 percent).

8.3 Nonserious injury reduction

Estimates on the reduction of minor injuries are available only from the accident data files, since the sled tests only analyzed serious injuries. Table 8-6 lists the reductions of overall injury risk estimated from each of the accident studies documented in Chapters 3-6. Estimates are listed for safety seats, lap belts and for back seat vs. front seat (unrestrained).

Overall injury reduction for safety seats is generally lower than their fatal and serious injury reduction. The North Carolina, Michigan and Tennessee estimates in Table 8-6 are a bit overstated because they have not been adjusted for differences in child's age, seat position, etc. Based on the Pennsylvania experience (Section 5.2), such adjustment could have lowered them by about 10 points--to 35, 39, and 38 percent, respectively. In conclusion, Table 8-6 suggests that the overall injury reduction for safety seats was about 25 percent in the late 1970's and gradually worked its way up to the 35-40 percent range by 1984, as more and more seats were being used correctly.

All of the lap belt effectiveness estimates in Table 8-6 are close to 30 percent, especially if those not adjusted for seat position, vehicle damage, etc., had been so adjusted.

The nonserious injury reduction for moving an unrestrained child from the front to the back seat would appear to be around 25 percent. For moving a restrained child from the front to the back seat, it is about 20 percent.

TABLE 8-6

OVERALL INJURY REDUCTION FOR CHILD PASSENGER SAFETY MEASURES

Data Source	Percent Reduction, Any Type of Injury			
	Safety Seats	Lap Belts	Unrestrained Back vs. Front Seat	Restrained Back vs. Front Seat
Pennsylvania 1981-83	31	31	34	18***
NCSS-NASS-RSEP	30	31	14	--
North Carolina 1983-84**	45	41	--	--
Michigan 1978-83**	49	--	--	--
Tennessee 1982-83**	48	29	--	--
New York 1975-78	25	24	27	29****
Maryland 1977-80	17	22	22	19****
New York 1974,77	30	30	--	--
New Jersey 1975**	20	48	--	--
Idaho 1975**	13	38	--	--

* Children transported to treatment facilities

** Data not adjusted for differences in children's age, vehicle damage severity, etc.

***Safety seat users only

****Safety seat and lap belt users

8.4 Lives saved, 1979-84

Sections 8.1 and 8.2 provided year-by-year estimates of the overall usage of safety seats and lap belts and the overall effectiveness. With those statistics it is possible to calculate the lives saved each year by the two safety measures.

Table 8-7 shows, on the first line, the actual child passenger fatalities, age 0-4, in cars and trucks (but excluding buses and motorcycles). They decreased from 694 in 1979 to 551 in 1984, with the largest drop coming in the last year. The first job is to determine the number of deaths that would have occurred in each year if safety seat and lap belt usage had been zero.

Let U_1 be overall safety seat usage. It increased from 15.2 percent in 1979 to 46.3 percent in 1984, as shown in the second line of Table 8-7. E_1 is the life-saving effectiveness of safety seats. E_1 is not a constant: Section 8.2.1 demonstrated that effectiveness increased from 27 percent in 1979 to 46 percent in 1984, as proportionately more and more seats were used correctly. U_2, lap belt usage, increased from 3.2 percent to 13.8 percent of child passengers. E_2, the effectiveness of lap belts, was a constant 33 percent.

The number of fatalities that would have occurred if safety seat and lap belt usage had been zero is:

$$Z = \frac{\text{Actual fatalities}}{1 - U_1E_1 - U_2E_2}$$

TABLE 8-7

LIVES SAVED BY SAFETY SEATS AND LAP BELTS, 1979-84
(CHILD PASSENGERS AGED 0-4)

			1979	1980	1981	1982	1983	1984
Actual passenger fatalities, age 0-4 (F)			694	688	632	632	617	551
Safety seats	usage (U_1)	%	15.2	19.7	24.3	31.6	41.6	46.3
	effectiveness (E_1)	%	27	32	35	38	42	46
Lap belts	usage (U_2)	%	3.2	3.8	4.4	6.2	9.2	13.8
	effectiveness (E_2)	%	33	33	33	33	33	33
Fatalities if restraint usage had been zero: $Z = F/(1-U_1E_1 - U_2E_2)$			732	744	702	735	776	743
Lives saved by safety seats (U_1E_1Z)			30	47	60	88	135	158
Lives saved by lap belts (U_2E_2Z)			8	9	10	15	24	34
Lives saved by restraints			38	56	70	103	159	192

Table 8-7 shows that Z would have been 732 in 1979 and 743 in 1984: little or no net change. Moreover, the fluctuations of Z in the intermediate years (within a range of 702 to 776) may be considered "noise." The 6 values of Z had a standard deviation of 24, which is slightly less than would be expected if Z were a random (Poisson) variable. In other words, the entire reduction in actual fatalities is due to restraints.

The number of lives saved by safety seats, U_1E_1Z, was just 30 in 1979, 47 in 1980 and 60 in 1981. As buckle-up laws begin to take effect, it rose more rapidly -- to 88 in 1982, 135 in 1983 and 158 in 1984. That 5.3 fold increased in 5 years was made possible because usage and effectiveness increased at the same time throughout the period.

The number of lives saved by lap belts increased from 8 in 1979 to 34 in 1984.

The total number of child passengers saved by restraints increased from 38 to 192. By 1984, restraints were saving over 25 percent of the child passenger fatalities that might have occurred (Z). During the last 5 years, child restraints have become one of the most beneficial safety devices regulated by NHTSA, in terms of the actual number of lives saved.

8.5 Injuries saved in 1984

By 1984, the use of a safety seat reduced the risk of hospitalization by 46 percent and the risk of lesser injuries by 37 percent; lap belts reduced hospitalization by 50 percent and less serious injuries by 30 percent (see Sections 8.2 and 8.3). Usage rates were 46.3 percent for safety seats and 13.8 percent for lap belts. These percentages will have to be applied to the baseline numbers of child passenger injuries that would have occurred in 1984 if nobody had been restrained.

Actually, the baseline numbers are calculated for 1983, the most recent full year for which NASS data are available (as of June 1985). Rather than using directly the NASS national estimate of child passenger injuries, which has considerable sampling error, the following procedure is used:

Let F = child passenger fats., age 0-4, in cars, light trucks, vans, MPV's, FARS 1983

= 617

S = lives saved by restraints in 1983 (see Table 8-7)

= 159

f = all occupant fats., in cars, light trucks, etc., FARS 1983

= 29,410

C_f = proportion of fatals which are children, zero restraint use

$$= \frac{F + S}{f + S}$$

= 2.624%

Now let F_1 = child fats. in cars only, FARS 1977-79 = 1720

f_1 = all occ. fats., in cars, 1977-79 = 82,743

H_1 = child nonfatal hospitalizations in cars, NCSS = 84

h_1 = all occ. nonfat. hosp. in cars, NCSS = 5,436

I_1 = child nonhosp. injured in cars, NCSS = 1,172

i_1 = all occ. nonhosp. injured in cars, NCSS = 42,171

R_h = underrepresentation of children among hospitalizations

$= (H_1 f_1) / (h_1 F_1)$

$= .7434$

R_i = overrepresentation of children among minor injuries

$= (I_1 f_1) / (i_1 F_1)$

$= 1.337$

In other words, children would have constituted 2.624 percent of occupant fatalities in 1983, but a smaller percentage of hospitalizations and a larger percentage of the minor injuries (based on 1977-79 NCSS and FARS data, which were large samples in which nearly all children were unrestrained).

C_h = proportion of hospitalization which are children, zero restraint use

$= R_h C_f = 1.951\%$

C_i = proportion of minor injuries which are children, zero restraint use

$= R_i C_f = 3.508\%$

Finally let

h = actual nonfatal hospitalizations in cars, light trucks and MPV's, NASS 1983

= 246,000

i = actual nonhosp. occ. injured in cars, light trucks and MPV's, NASS 1983

= 2,811,000

U_1 = usage of safety seats in 1984 = 46.3%

E_{h1} = effectiveness of safety seats in 1984, hospitalizations = 46%

E_{i1} = effectiveness of safety seats in 1984, minor injuries = 37%

U_2 = usage of lap belts in 1984 = 13.8%

E_{h2} = effectiveness of lap belts, hospitalizations = 50%

E_{i2} = effectiveness of lap belts, minor injuries = 30%

Then H = child hospitalizations in 1983 or 1984, zero restraint use

$= C_h h/(1 - C_h U_1 E_{h1} - C_h U_2 E_{h2})$

= 4,800 child passengers hospitalized

and I = children with minor injuries in 1983 of 1984, zero restraint use

$= C_i i/(1 - C_i U_1 E_{i1} - C_i U_2 E_{12})$

= 99,000 child passengers injured but not hospitalized

The injury saving benefits of safety seats and lap belts in 1984 were:

	Hospitalizations Prevented	Reductions of Minor Injury to No Injury
Safety seats	$U_1E_{h1}H$ = 1,020	$U_1E_{i1}I$ = 17,000
Lap belts	$U_2E_{h2}H$ = 330	$U_2E_{12}I$ = 4,000
All restraints	1,350	21,000

8.6 Potential for saving additional lives

In 1984, safety seats eliminated 158 fatalities, over five times the number they saved as recently as 1979. But even larger savings could be achieved were it not for these problems:

- the majority of seats are still at least partially misused.
- some parents never restrain their children.
- other parents use a safety seat for their newborn but stop using it before the child reaches age 5.

In Section 8.4 it was calculated that 743 child passengers aged 0-4 would have died if restraint use had been zero; 158 of them were saved at the 1984 levels of usage (46.3%) and effectiveness (46%). Savings could have been higher with further increases in usage and effectiveness, as follows:

	Effectiveness	
Usage	46% (1984 mix of correct/incorrect)	71%* (all seats used correctly)
46.3% (1984 level)	158	244
68.4% (1984 level for infants-no dropoff for toddlers)	233	360
100%	341	527

*See Section 8.2.1 - estimate based on Tennessee fatality analysis and slightly higher than sled test result for serious nonfatal injuries.

8.7 Cost-effectiveness

The cost effectiveness of safety seats is expressed as the number of Equivalent Fatality Units (EFU) saved per million dollars of cost. This method of assessing the cost effectiveness of a safety device was developed in NHTSA's evaluation of energy-absorbing steering assemblies [35], pp. 211-214 and modified to its present form in the evaluation of side structure improvements [37], pp. 398-401. Each life saved by a safety device is a benefit of 1 EFU. Each person who avoids nonfatal hospitalization is assigned a benefit of 0.0592 EFU (based on a 1982 assessment of average cost of injuries of persons who were hospitalized after a crash).

Cost-effectiveness will be calculated for 3 types of safety seat users:

(1) Parents who buy a safety seat for their child at birth (or an infant seat at birth and a booster seat later) and correctly use the seat until the child's fifth birthday.

(2) Parents who use the seat till the child turns 5, but with the mix of correct and incorrect use modes characteristic of 1984.

(3) Parents who use the seat throughout the child's first year, but then drop off their usage in later years; 1984 mix of correct and incorrect use modes. In other words, the average parent who buys a safety seat.

During 1979-84, an average of 738 child passengers aged 0-4 would have died each year if restraint usage had been zero and 4,800 would have been hospitalized, but would have survived (see Sections 8.4 and 8.5). Since an average of 3,460,000 children were born in the United States per year during 1975-84 [33], [88], the likelihood of dying before age 5 as a passenger is

$$\frac{738}{3,460,000} = 213 \text{ per million children}$$

and the likelihood of being hospitalized is

$$\frac{4,800}{3,460,000} = 1387 \text{ per million children.}$$

The ideal parents, who use the seats correctly until their children turn 5, will have

$$71\% \times 213 \times 10^{-6} = 151 \times 10^{-6}$$

reduction of the chance of the child being killed and

$$67\% \times 1387 \times 10^{-6} = 929 \times 10^{-6}$$

reduction of the chance of hospitalization. In other words, they may expect a benefit of

$$151 \times 10^{-6} + .0592\ (929 \times 10^{-6}) = 206 \times 10^{-6} \text{ EFU}$$

During 1984-85, a convertible infant/toddler seat typically cost $45 at a discount store [4], [83]. (For the same price, the parents could purchase an infant seat plus a booster seat.) The parents will receive

$$\frac{206}{45} = 4.6 \text{ EFU benefit per million dollars of cost}$$

These conscientious parents are not only doing their best to protect their child but they are also enjoying a level of cost effectiveness for their safety seat that compares favorably to most other auto safety devices [35], p.214, [37], p.400, [40], p. 58. (Some children, who exceed 40 pounds before their fifth birthday, may necessitate the purchase of an additional booster seat because they have outgrown their toddler seat. On the other hand, some parents may be able to obtain a cost savings by passing the seat on to a younger child.)

<u>The persistent but sometimes mistaken parents</u> who use the seats until their child turns 5, but with the 1984 mix of correct and incorrect use modes, will save

$$46\% \times 213 \times 10^{-6} = 98 \times 10^{-6} \text{ lives}$$

and

$$46\% \times 1387 \times 10^{-6} = 638 \times 10^{-6} \text{ hospitalizations.}$$

Their benefit will be

$$98 \times 10^{-6} + .0592\ (638 \times 10^{-6}) = 136 \times 10^{-6} \text{ EFU}$$

and the cost effectiveness of their seats is

$$\frac{136}{45} = 3.0 \text{ EFU per million dollars of cost}$$

<u>The average parents</u> will use the seats:

always	at age 0	when 26 percent of the harm occurs
90% of the time	at age 1	when 20 percent of the harm occurs
75% of the time	at age 2	when 21 percent of the harm occurs
40% of the time	at age 3	when 17 percent of the harm occurs
25% of the time	at age 4	when 16 percent of the harm occurs

The distribution of harm is based in 1975-79 FARS fatality counts (before safety seats had a significant impact on the infant fatalities). The dropoff rates for seat usage from age 0 to age 1 is based on NASS and FARS data (Tables 6-4 and 4-6). The dropoff rates after age 1 are based on the 1984 Hardee's survey [14], pp. 32-33. Given the 1984 mix of correct and incorrect use modes, the parents will save

$$46\% \times 213 \times 10^{-6}(.26 + .9 \times .20 + .75 \times .21 + .4 \times .17 + .25 \times .16)$$

$$= 69 \times 10^{-6} \text{ lives}$$

and

$$46\% \times 1387 \times 10^{-6} (.26 + .9 \times .20 + .75 \times .21 + .4 \times .17 + .25 \times .16)$$

$$= 450 \times 10^{-6} \text{ hospitalizations}$$

Their benefit will be

$$69 \times 10^{-6} + .0592 (450 \times 10^{-6}) = 96 \times 10^{-6} \text{ EFU}$$

and the cost effectiveness of their seats is

$$\frac{96}{45} = 2.1 \text{ EFU per million dollars of cost}$$

The concept of Equivalent Fatality Units was developed to express in a single number the benefits of safety devices that save lives <u>and</u> prevent serious injuries, thereby allowing comparisons of alternative safety devices. Minor injuries and property damage are not included in the calculation of EFU, since they are in no sense "equivalent" to fatalities in terms of life endangerment, suffering, etc. In most cases, the fatality reduction contributes more EFU than the serious injury reduction (e.g., 69 vs. 27 in the preceding example). The more EFU saved per million dollars of cost, the more cost effective the safety device.

APPENDIX 1

PLANNING AND RUNNING THE SLED TESTS

(Steps 1-9 of the sled testing and analysis procedure described in Chapter 7)

Step 1 - Select seats and use modes Four distinctive generic "types" of toddler seats were identified during the initial planning of the sled tests in 1982-83: the "tethered" seat with a harness and with the car's lap belt permanently routed through the frame, as exemplified by the Strolee Wee Care 500 series; the "tetherless" seat, quite similar to the preceding one except that it had no tether, as exemplified by the Century Trav-L-Guard, Teddytot Astroseat, Cosco/Peterson Safe-T-Seat and quite a few others; the "shield" type exemplified by the Ford Tot Guard; and the "tethered belt-around" type (Child Love Seat), which has a tether and in which the car's lap belt goes around the seat and the child. Radovich of NHTSA then identified booster seats as an "up and coming" and quite different method for protecting toddlers and they were added while the Love Seat was deleted because of its declining market share and its relative similarity to the tethered-type seat. One of the most widely used seats in each class, as inferred from 1983 observational survey data [61], was selected for the sled testing.

- o Strolee Wee Care 597A, as a "tethered" seat
- o Century 100 (which had superseded the Trav-L-Guard), as a "tetherless" seat
- o Cosco Peterson Safe-T-Shield (which is far more widely used than the Ford Tot-Guard) as a "shield" type
- o Century Safe-T-Rider as a "booster" seat

Besides the Love Seat mentioned above, three other types of seats were not tested. The "tetherless-partial shield" type, as exemplified by the Century 200 and Questor One Step should have biomechanical properties quite similar to the tetherless type, since it requires use of a harness and the purpose of the partial shield, to a greater or lesser extent, is to assure correct use of the harness. The "tetherless belt-around" type, found only among Bobby-Mac seats, has a harness and no tether and requires the car's lap belt to be hooked around a detachable shield which, in turn, is over the child. When correctly used, its biomechanical properties should resemble the tetherless seat. The "shield booster" seat, as exemplified by the Collier Keyworth Co-Pilot, somewhat resembles the Ford Tot-Guard, but it has a smaller shield and it should only be used by larger children. In frontal crashes, at least some of its biomechanical properties might resemble the shield-type toddler seat. (These hypotheses were subsequently tested and generally confirmed in Section 3.4.3.)

The misuse modes that were most common in 1983 observational data [61] were:

- o not using the tether, on a tethered seat, thereby allowing greater movement to the upper part of the seat, in turn, allowing children to contact the vehicle's interior surfaces.

- o routing the lap belt through the seats' tubular frame, but at a lower place than recommended by the manufacturer. (In a tethered seat, this misuse is commonly accompanied by nonuse of the tether.) It allows greater movement of the upper part of the seat, possibly to the point of tipping over. Also, it can cause the belt loads to be applied to parts of the seat which were not intended to be exposed to them. Breakage of those parts allows yet further movement of the seat.

- o not using the harness or shield, allowing the child to become a projectile in a crash.

- o not using the car's belt to secure the seat to the car, allowing seat and child to become a projectile.
- o in a booster seat, routing the car's shoulder belt behind the child (or not using the tethered harness that comes with the seat, if the seat is located at a position where there is no shoulder belt), providing no restraint for the child's upper body.

The four brands of seats were paired off with the misuse modes. A total of six seat/misuse mode combinations were selected for sled testing. In addition, the four seats were tested in the correct use mode; so were unrestrained and lap-belted dummies. In all, 12 restraint use modes were selected for testing, as shown in Table 1. (The numbering system in Table 1 is the same as the one used in the sled testing contractor's report.)

A glance at Table 1 shows that the testing did not encompass every possible seat/misuse combination -e.g., gross misuse of a tetherless seat. That is because some of the use modes, tested for one seat, could be generalized to other types of seats. In the case of gross misuse, for example, where a child leaves the seat entirely, the results should be about the same for all types of seats: only one type needs to be tested and the results are used for the other types. Likewise, a tetherless harness-only seat is similar to a partial shield type; a full shield type toddler seat is similar to a shield-booster seat (at least, in frontal crashes). More tenuously, a Bobby-Mac seat with the car's belt around the child but the harness and shield not used is deemed roughly equivalent to a tethered seat with the tether not used, the lap belt too low on the frame and the harness correctly used - since both modes would allow similar amounts of head excursion. Table 7-7, which is discussed in Step 20 of Chapter 7, shows how

TABLE 1

RESTRAINT USE MODES SELECTED FOR SLED TESTS

Number	Name	Safety Seat Brand	Safety Seat's Harness/Shield Use	Vehicle's Lap Belt Use	Safety Seat's Tether/ Vehicle's Shoulder Belt Use
1	Unrestrained	-----	----	----	----
2	Lap belt	-----	----	around dummy	(shoulder belt behind dummy)
3	Tethered seat-correct	Strolee Wee Care 597A	harness correct	correct	tether correct
4	Tethered seat-no tether	Strolee Wee Care 597A	harness correct	correct	tether not used
5	Gross misuse-no harness	Strolee Wee Care 597A	harness not used	correct	tether not used
6	Tethered seat-no tether & belt too low	Strolee Wee Care 597A	harness correct	improperly routed thru tubular structure at base of seat	tether not used
7	Gross misuse-no belt	Strolee Wee Care 597A	harness correct	not used	tether not used
8	Tetherless seat-correct	Century 100	harness correct	correct	N/A
9	Tetherless seat-belt too low	Century 100	harness correct	improperly routed thru base of seat	N/A
10	Full shield type-correct	Cosco/Peterson Safe-T-Shield	shield correct (no harness)	correct	N/A
11	Booster seat-correct	Century Safe-T-Rider	N/A	correct	shoulder belt in front, tethered harness in back seat
12	Booster seat-no upper body support	Century Safe-T-Rider	N/A	correct	shoulder belt behind dummy tethered harness not used

each of the use modes commonly experienced with each type of safety seat is assumed equivalent to one of the use modes actually sled tested - thereby allowing the sled tests to be generalized to an overall effectiveness estimate for safety seats.

Step 2 - Design sled buck, test setup and crash modes The sled buck had to be the passenger compartment of a passenger car, in order that the dummies' injury measurements realistically simulate the injury producing contacts experienced by car passengers in highway accidents. A 1981 Chevrolet Citation 4 door sedan was chosen for producing the sled buck because it was close to the median--in terms of mass, interior room and component stiffness--among cars currently (1985) produced and sold in the United States. The passenger compartment structure was severed from the hood and trunk regions and mounted on the sled as described in [46], pp. 10-12.

The sled itself was of the decelerator type. The sled buck was gradually accelerated to the desired impact speed by pneumatic pistons. The crash event was then simulated by allowing the sled buck to be stopped by a system of steel bands and rollers programmed to deform at a rate which reproduces the deceleration pulse seen in vehicle-to-barrier impacts.

The program was limited to frontal and oblique frontal impacts (which account for 55 percent of child passenger hospitalizations). Side impacts were also of great interest; however, in order to realistically simulate occupant-vehicle interactions in side impacts, it would be necessary to have door structures intrude into the passenger compartment of the sled buck just as they do in full-scale vehicle crash tests or highway accidents. The state of the art in sled testing had not advanced to that point in 1982-1983; NHTSA hopes to conduct side impact sled tests with toddler seats, including door intrusion phenomena, in 1986.

The limitation to frontal crashes made it possible to seat up to 4 dummies in the sled buck on each test (2 in the front seat and 2 in the back) because interactions between dummies (which would cause accelerometer responses unrelated to contacts with the vehicle's interior surfaces) are minimal with child dummies in frontal crashes. The few interactions that did occur were filtered out of the calculations of HIC, etc.

The use of 4 dummies per test did necessitate one important modification of the sled buck. The steering column and other items characteristic of the driver's position had to be replaced by a simulated right front passengers' position since, of course, 3-year-olds are rarely in the driver's seat. The contractors approach [46], p.12, was to use a sheetmetal structure which simulated the clearances but not the force-deflection characteristics of the right-front passenger's position and to run the correctly restrained use modes in the driver's seat. On the single occasion when a correctly restrained dummy contacted the sheetmetal structure, the results were not used and another sled test was run with that restraint system in the right front seat.

Experience with 30 degree oblique vehicle-to-barrier crash tests indicates that dummies tend to impact with the passenger compartment on a line about 11 degrees to the side of the longitudinal axis (since the car is rotated during the impact). Thus, the oblique impacts were simulated by mounting the sled at an 11 degree angle and using a crash pulse characteristic of 30 degree barrier crashes [46], pp. 60-65. Only 1:00 (right corner) sled tests were run, because the unrestrained and poorly restrained dummies were always sitting on the right (see above) where they might interact with side structures in a right corner impact. None of the correctly restrained dummies sitting on the left showed enough excursion to raise concern that they would have contacted side structures if they had been sitting, instead, on the right.

Step 3 - Select dummies After some discussions it was decided to use the 3-year-old dummy developed at General Motors by Wolanin et al [86] rather than the Part 572 child dummy used, for example, in Standard 213 compliance testing. The principal arguments in favor of the GM dummy were that it allowed additional injury parameters (i.e., for the neck and lower spine, plus head rotation in addition to the usual HIC) and that Mertz and Weber [49] had performed biomechanics research with animals to relate the injury parameters on the dummies to actual levels of injury risk--possibly completing a major task of this evaluation (see Section 7.1). (It should be noted that GM developed the dummy primarily for measuring the effects of air bag deployment on out-of-position occupants, rather than general purpose trauma research, and that the dummy uses the 6-year-old Part 572 head.)

In retrospect, it might have been better not to use the GM dummy. The additional injury parameters such as neck tension and head rotation were not subsequently used in the statistical analysis, while the biomechanics results of Mertz et al were not at all applicable to this project, as will be shown in Step 11 (Chapter 7). In other words, the purported advantages of the GM dummy were not realized, while there were several disadvantages. The block design of its upper torso, while perhaps appropriate for monitoring air bag slap phenomena, seems to bear little resemblance to a human chest and may be responsible for the high torso accelerations experienced at moderate speeds. There were also fears that the neck design may have aggravated the repeatability of head acceleration measurements. As explained in Clark and Kahane's addendum to the contractor's report [10], relatively little is known about the measurement characteristics of the GM dummies, especially about the relevance of the calibration test described in Step 7.

Step 4 - Select injury parameters The list of injury parameters for the project (generally corresponding to those that were used by GM in connection with their dummy [49]) was:

- o Head Injury Criterion (HIC)
- o Mean Strain Criterion for the head
- o Head sagittal plane rotational velocity and acceleration
- o Neck tension (3 millisecond peak)
- o Upper spine acceleration (usually called "chest g's" - 3 millisecond peak)
- o Lower spine acceleration (3 millisecond peak)
- o Facial laceration index, based on number and size of cuts in the chamois coverings which were added to the GM dummies

As will be discussed in Steps 11 and 12, however, only HIC, chest g's and lower spine g's were used in the statistical analysis.

Step 5 - Select test speeds and crash pulses The objective of the project was to test the effectiveness of safety seats over the range of speeds at which serious injuries normally occur on the highway. NHTSA accident data (Tables 6-8 and 6-9) suggest that 90 percent of the hospitalizations of unrestrained toddlers in frontal crashes were in a Delta V range of 10 to 45 mph. Those speeds could be construed as the outer limits of the range suited for the sled tests.

The contractor performed 7 initial sled tests at impact speeds ranging from 11 to 39 mph (or Delta V's from 12 to 42 mph, when rebounding of the sled after impact is taken into account), mostly with an unrestrained dummy in the front seat and a correctly used Century 100 in the back seat [46], pp. 34-44. The 11 mph test produced HIC's (130) and upper and lower spine g's (33 and 4) on the unrestrained dummy which were too low to "register" on Mertz and Weber's scales of injury risk as a function of injury parameters; 15 mph was the speed at which unrestrained dummies began to show values of those parameters which could be translated into meaningful injury rates on their scales. At 35 mph, the correctly restrained dummies were beginning to show torso injury parameters which, according to the Mertz scales, suggested that the limits of effectiveness for the restraint systems were not far away. Also, as a practical consideration, 35 mph was the limit at which unrestrained and incorrectly restrained child dummies could be run in sled tests without unacceptable damage to the dummies or other equipment. Thus, the test speeds used in the program were 15 mph, 35 mph and the mid-range value of 25 mph. Three speeds were needed, rather than just the two extreme values, to enable a more accurate interpolation of the injury parameters at intermediate speeds.

The contractor sought to design the system of steel bands and rollers so as to reproduce the crash pulses actually observed in frontal vehicle-to-barrier impacts of Chevrolet Citations (many of which had been performed in earlier NHTSA contracts) [46], pp. 44-54. The targets were to achieve peak sled decelerations of 8, 14, and 20 g's in the frontal impacts at 15, 25, and 35 mph, respectively. Based on the oblique barrier crash experience of other vehicles, the contractor targeted 7,14 and 22 peak g's for the oblique impacts. These targets are rather mild in comparison with barrier test experience of other cars. Specifically, NHTSA compliance tests for Standard 213 develop close to 15 peak g's at 18.5 mph (misuse tests) and 22 g's at 27.5 mph (correct use tests) - those decelerations were intended to represent barrier crashes of the average car of the mid-to-late 1970's. The choice of sled pulse has a significant influence on dummy performance in various restraint systems, as Section 3.4 analyzes in detail. The Citation pulse used here, while "soft" in comparison to the average barrier impact, is probably realistic in comparison with the range of crash pulses experienced in highway accidents (which are usually milder than barrier tests). Ten tests were run with the sled buck (unoccupied but ballasted to simulate the weight of occupants) to assure that these targets, as well as the stopping distance, Delta t, and the shape of the sled pulse could be repeatably achieved.

<u>Step 6 - Schedule the sled test matrix</u> The program called for dummies in each of the 12 restraint use modes (Table 1) to appear in 12 sled tests: 2 seat positions (front, back) x 2 angles (frontal, oblique) x 3 speeds (15, 25, 35 mph). In general, correctly restrained dummies should sit on the left, since any dummy contacting the sheetmetal structure at the driver's instrument panel (see Step 2) would have to be retested. Four dummies should be tested at a time, whenever possible, to minimize the number of tests needed; however, when a tethered seat is correctly used in the front, no dummy can be placed behind it since the tether is attached to the rear lap belt. Based on these considerations, the contractor developed a schedule of 42 sled tests [46], pp. 3-14 - 3-17.

The actual program, however, consisted of 36 sled tests (not including the 7 used for speed selection and 10 for crash pulse tailoring, described above). A number of changes were made in the original schedule without significantly compromising program goals:

- It soon became evident that grossly misused seats resulted in about the same injury parameters as unrestrained runs, but they were causing costly damage to the sled buck. As a needed economy, the oblique impacts with grossly misused seats as well as the front-seat 35 mph frontal impact in mode 7 were not run, since the injury pattern had already become clear from the first 11 tests conducted in those modes.

- The 15 mph oblique tests with correctly used and partially misused seats could also be omitted since little difference was expected from the 15 mph frontal test for dummies that were reasonably well restrained and most unlikely to contact any vehicle structure.

- When data traces were lost for a few dummies, 2 additional sled tests had to be scheduled and, in 3 other cases, a dummy was placed in a position that would have been vacant, per original plan.

- Four dummies were placed in positions that would otherwise have been vacant because the first test in a particular restraint use mode had unexpected results and it was desired to see if those results would be repeated. (They were.)

The actual matrix of 36 tests is shown in Table 2.

Step 7 - Calibration test for the dummies Prior to the entire sled test series and, generally, after every third sled test, the contractor performed the Part 572 calibration test [11] on each of the 4 dummies. The test consisted of a head impact at 7 feet per second and a thoracic impact at 13 feet per second, using a rigid cylindrical probe 3 inches in diameter and weighing 10.375 pounds. The quantities that were measured were the peak g's of the head, upper spine and lower spine accelerometers and the time between initial contact and peak force. One objective of the calibration tests was to assure that each dummy's measurement characteristics were not changing as

TABLE 2

SLED TEST MATRIX

Contractor's Test Number	Targeted Impact Speed (mph)	Restraint Use Mode Number (see Table 1) at: Left Front	Right Front	Left Rear	Right Rear
		FRONTAL IMPACTS			
2754	15	3	1*	vacant	9*
2761	25	3	1	vacant	8
2768	35	3	1	vacant	9
2775	15	2	9	3	5*
2776	25	2	9	3	5
2777	35	2	9	3	5
2786	15	8	12	4	1
2787	25	8	12	4	1*
2788	35	8	12	4	1*
2797	15	10	5	8	9**
2798	25	10	5	9	vacant
2799	35	10	5	8	vacant
2808	15	4	1**	10	7
2809	25	4	vacant	10	7
2810	35	4	vacant	10	7
2817	15	11	6	2	12
2818	25	11	6	2	12
2819	35	11	6	2	12
2828	15	vacant	7	11	6
2829	25	vacant	7	11	6
2830	35	vacant	vacant	11	6
2837	25	vacant	4***	6***	1**
2838	35	3***	4***	vacant	1**
		OBLIQUE IMPACTS			
2843	15	4	1	2	1
2844	25	2	1	2	1
2845	35	2	1	2	1
2854	25	3*	4	vacant	4
2855	35	3	4	vacant	4
2856	25	11	10	11	12
2857	35	11	vacant	11	12
2866	25	8	12	3	9
2867	35	8	12	3	9
2868	25	9	vacant	8	6
2869	35	9	10	8	6
2870	25	3**	6	vacant	10
2871	35	vacant	6	vacant	10

* HIC and/or chest g's were lost
** Retest to replace lost data
*** Retest to obtain extra data points

a result of repeated exposure to sled tests. That goal was satisfied in all cases except the lower spine response on dummy no. 5 (the four dummies had been labelled with the numbers 1,3,4 and 5 before they were shipped to the contractor): the calibration results in Appendix A of [46] show no drift or trend in the head or chest g's for any dummy or in the lower spine g's for dummies 1, 3, and 4. Moreover, not counting no. 5's lower spine, only 6 of the 121 calibration readings (5 percent) were more than 10 percent away from the median for their dummy and body region.

The second objective of the calibration tests, one would have to think, is to check that the 4 dummies had measurement characteristics similar to one another. Here, the tests were unsuccessful. Appendix A shows that the average head g's were 162 for dummy no. 5, 214 for no. 3, 232 for no. 4 and 245 for no. 1 (a 51 percent discrepancy from least severe to most severe). The sum of chest and lower spine g's averaged 28 for dummies 1 and 3 and 29 for dummy no. 5 but 34 for no. 4. These discrepancies were evident after a few calibration tests but were downplayed and essentially ignored throughout the sled testing program. What do they mean? The alarming possibility, of course, is that the dummies might respond differently to identical sled test impacts, analogous to the discrepancies on the calibration tests. A second possibility is that the Part 572 calibration procedure is not appropriate for the GM dummy. (In fact, little is known about the measurement characteristics of the GM dummy.) A third is that, more generally, the calibration tests, which involve a low-speed impact by a rigid, light object say little about the dummy's behavior in sled tests, which involve a high-speed impact into a deformable structure, with the full momentum of the dummy behind the impact.

A statistically acceptable approach to circumvent the dummy problem would have been to change the seat positions assigned to the dummies in a quasi-random way from sled test to sled test. Then no particular restraint use mode would have been associated with a specific dummy. Instead, the problem was intensified by always seating the dummies as follows:

Seat Position	Dummy No.	Avg. Calibration Test Results	
		Head	Torso
Left front	3	214	28
Right front	1	245	28
Left rear	5	162	29
Right rear	4	232	34

In other words, the left side positions, which as a general rule were occupied by the correctly restrained dummies, always used the dummies with lower results on the head calibration tests and, in the back seat, on the torso test, as well. If the discrepancies on the calibration tests carry over to the sled tests, it would be a serious bias in favor of the correctly restrained dummies.

Luckily, the rule about which restraint systems were tested on the left side was not ironclad. There were 11 cases in which a restraint use mode was tested on the left side and then again, at the same speed, and in the same seat (front or back) on the right side (or vice versa). For example, a speed selection test (Step 5) on one side and a regular test on the other, or a frontal and an oblique, or a first run and a repeat runnecessitated by data loss on another body region). Table 3 lists those 11 pairs of tests and shows that the average of the HIC's experienced by the left side dummies (740) is virtually identical to the average for the right side dummies (727), given the variability that occurred in the sled tests. In fact, it is slightly higher -- whereas the calibration tests had been much lower on the left side dummies. Table 3 also shows that the average chest g's on the left rear dummy (45.5) were nearly the same as those for the right rear dummy (47.5) in the 4 pairs of tests that involve the back seat. (Lower spine g's were missing for the right side dummy in 2 of the 4 tests and could not be included in these calculations.)

Finally, as mentioned above, Table A-8 of [46] shows that dummy no. 5 (left rear) underwent a 50 percent increase in the calibration test result for the lower spine, starting at test no. 2850. The pairs of sled tests conducted with this dummy, one of them before no. 2850 and one thereafter, but both with the same speed and restraint use mode, were:

Restraint Use Mode	Speed		Lower Spine g's Before No. 2850	After No. 2850
3	25		35	31
3	35		42	43
8	35		52	53
11	25		41	45
11	35		47	40
		Average	43.4	42.4

TABLE 3

COMPARISON OF LEFT AND RIGHT SIDE DUMMY RESPONSES UNDER SIMILAR TEST CONDITIONS

Restraint Use Mode (see Table 1)	Targeted Impact Speed (mph)	Seat Position	HIC Left-Side Dummy	HIC Right-Side Dummy	Chest g's Left-Side Dummy	Chest g's Right-Side Dummy
6	25	Back	576	178	30	55
9	25	Back	404	660	36	27
10	25	Back	427	300	58	55
10	35	Back	614	1062	58	53
4	25	Front	497	737	NO	
4	35	Front	1513	1745		
9	25	Front	508	685	CALIBRATION	
9	35	Front	1487	1041		
10	25	Front	448	355	PROBLEM	
10	35	Front	831	676		
10	35*	Front	831	559	ENCOUNTERED	
		AVERAGE	740	727	45.5	47.5

*Right side dummy was run at 39 mph. Value of HIC has been multiplied by 35/39.

The average lower spine g's on the sled tests after no. 2850 (42.4) was virtually identical to those on similar tests before no. 2850 (43.4). Thus, the 50 percent increase on the calibration tests had no parallel in the sled tests.

It is concluded that the 4 GM dummies were repeatable, interchangeable instruments for sled testing purposes. The use of a Part 572 calibration test for GM dummies gave no useful indication of their measurement characteristics under sled test conditions. It is recommended that calibration test procedures for other dummies be similarly analyzed to see if they are any more useful as predictors of dummy behavior in sled tests.

Step 8 - Repair or replace damaged equipment Even 3-year-old child dummies can cause severe damage to the sled buck when they are unrestrained or incorrectly restrained and impact speeds are high. The contractor replaced windshields, instrument panel/gloveboxes and front seats whenever they were damaged by dummy impacts or by their own momentum change during impact. An exception was made if the damage was judged to be purely cosmetic. As a general rule, the front seat was replaced after 25 and 35 mph tests but not after 15 mph tests [46] , pp. 14-15. The dummies fortunately did not contact or deform the windshield header or any other structural member of the passenger compartment.

Following NHTSA instructions, the contractor inspected the safety seats after every test and replaced them only if there was any evidence of damage. It would have been a better procedure to have used new seats on each test, since restraints are designed and made on the principle of energy absorption and as such are intended to be used only once. Repeated use could alter energy absorption or structural properties and result in altered performance or make the seats more prone to damage. The contractor's report documents 23 seats that were damaged during a sled test. Clark and Kahane's addendum [10], p.3, analyzes those cases and divides them into two groups. The majority involved a misused seat, usually being tested for the first time, which was damaged in a specific way: the car's lap belt was misrouted around structures that, as is obvious from their appearances, were never designed to withstand the forces applied by the belt. It is safe to say that most or all of these phenomena would have occurred even if seats had been replaced after each test. A minority involved correctly used seas, most of which had successfully endured several previous tests including, in some cases, a 35 mph test. In these cases, there is more cause for concern that previous use of seats could have made them more vulnerable to damage.

Since the sled test program was not an investigation of seats' damageability in crashes, however, the fact that correctly used seats were damaged is, by itself, not important. What would be important is if damage to the seats were to increase the injury risk for the dummies. If this damage were the result of an unrealistic test procedure (i.e., reuse of seats) it would be a bias against the effectiveness of correctly used seats.

Table 4 provides strong evidence that the types of damage sustained by correctly used seats in the sled tests did not increase injury risk to dummies in correctly used seats that were damaged during the test. The average HIC was 761 and the average torso g's were 105. It also lists the HIC and torso g's for matching tests (same restraint use mode, speed and

TABLE 4

COMPARISON OF DUMMY RESPONSES WITH DAMAGED AND UNDAMAGED SEATS (CORRECT USE MODES)

Restraint Use Mode (see Table 1)	Targeted Impact Speed (mph)	Seat Position	HIC Damaged Seat	HIC Avg. of Undamaged Seats	Torso g's* Damaged Seat	Torso g's* Avg. of Undamaged Seats
3	35	Front	1179	1689	117	94
8	35	Front	777	1008	95	81
8	35	Rear	721	863	104	101.5
10	25	Rear	300	427	73	138
10	35	Front	676	695	110	102
10	35	Rear	614	695**	133	102**
10	35	Rear	1062	695**	105	102**
		AVERAGE	761	867	105	103
3	35	Rear	648	N.A.	85	N.A.
3	35	Rear	758	N.A.	82	N.A.

* Sum of chest and lower spine g's
** Front seat occupants

seat position) where seats were not damaged. There, HIC averaged 867 and torso g's, 103 -- certainly no better, on the whole, than the damaged seats. (Table 4 lists 2 additional cases of damaged seats where no matching undamaged cases existed but where HIC and torso g's were obviously satisfactory, considering the impact speed.) The results are understandable considering the minor nature of the damages in the correctly used seats, as documented in [46], pp. 95-120. Only one dummy in the 9 damaged seats in Table 4 contacted a vehicle interior surface with its face or torso and that one, only after the shield had largely slowed down the dummy (HIC was 676); among the 8 matching tests with undamaged seats in Table 4 there was likewise one dummy with slight head contact (HIC was 300). It is concluded that the reuse of seats did not significantly bias the sled test results.

Following NHTSA instructions, the contractor also reused the vehicle's lap belts until they were visibly stretched or damaged. At that time, they were replaced with original equipment manufacturer's belts. It would have been a better procedure to replace belts after each test and to make sure that replacement belts came from the same roll. Even without obvious failures, belt stretch and metal loads above the elastic limits can alter the response characteristics of belts which are reused. (See Section 3.4.3 for additional discussion.)

Step 9 - Run the sled tests After refurbishing the sled bucks and testing the dummies' calibration, the contractor would run a sled test. Dummy motions were documented electronically by the accelerometers (17 channels of data per dummy) and photographically by six onboard cameras operating at 1000 frames per second. On the last 13 sled tests, the two cameras on the roof were not used since the four cameras mounted to the side of the car (covering the four occupied seat positions) were reliable and provided sufficient data. The chamois face covering was used on dummies considered likely to contact the windshield (unrestrained and gross misusers). Dummy faces were coated with colored chalk to leave a record of contacts with vehicle interior surfaces. (See also [46], pp. 55-60.)

An additional accelerometer was placed on the sled to measure the sled pulse and, in particular, the peak g's (deceleration) experienced by the sled. It is important that all tests at a particular speed and crash mode have the same sled pulse, because changes in the rate of deceleration and the stopping distance can significantly affect injury risk and those effects would wrongly be attributed to the restraint system. Thus, it was alarming that the acceleration/time histories from this accelerometer, as shown for each sled test in Appendix B of the contractor's report [46], displayed unacceptable variations in peak g's, with some gross outliers and an overall coefficient of variation of 8 percent. Fortunately, the variations were not real but due to a fault in the accelerometer. As described in the addendum to the contractor's report [10], Clark requested the contractor to perform additional shake table tests which confirmed the malfunction in the accelerometer; Kahane demonstrated mathematically the inconsistencies in the sled pulses and developed an adjustment factor. The adjusted peak g's had a coefficient of variation of only 4 percent which is close to the 3 percent variation experienced with a "HYGE" accelerator sled [44] (which is considered a very repeatable sled). Kahane's calculations have since been confirmed by another sled test study recently performed by the contractor ("Sled Tests for Evaluating Federal Motor Vehicle Safety

Standard 207," NHTSA Contract No. DTNH22-84-C-06011). In that study, a correctly functioning accelerometer showed a very acceptable 3-4 percent coefficient of variation for peak g's for the same sled and type of sled buck that was used for testing the safety seats.

The sled tests were usually successful, necessitating only 2 full scale retests (see Table 2). On three other occasions a retest was avoided because there was room for one more dummy on a subsequent test which had been planned for only 2 or 3 dummies. All data were lost on 3 dummies and those systems were retested. Data were discarded from one test with a Strolee seat in which the tether had been improperly attached and came loose during the test; it was successfully rerun.

When the anterior-posterior (AP) or inferior-superior (IS) channels of the head, upper spine or lower spine accelerometers malfunctioned, the injury parameter for that body region was considered unknown and a retest was performed (resulting in repeated measures for the other body regions). An exception was the IS channel for the head: since the dummies were equipped with additional IS accelerometers at the front and back of the head, the weighted average of their readings was substituted for the IS channel at the center of the head (this happened 3 times). In all, 2 dummies were rerun when data were lost for one body region; 7 others were not rerun because the problem occurred in the speed selection tests or because the loss was for the lower spine and upper spine data were available, or vice versa. The right-left (RL) channel failed in the head of the number 5 dummy on the 16th test and was never repaired; RL channels of other dummies had one-time failures on 4 other tests. Since the RL acceleration of the head was typically an order of magnitude lower than the AP and the IS in these frontal crashes, and as a result contributes less than 1 percent of the value of HIC, it was deemed acceptable to set the RL acceleration term to zero.

On 2 tests, a restrained dummy in the front was hit in the head by an unrestrained dummy vaulting over the seatback. Those contracts were obviously irrelevant to the sled testing program and their acceleration spikes were masked out before calculating HIC.

APPENDIX 2

SLED TEST RESULTS

(Chapter 7)

Notes:

(1) TESTNO = contractor's test number

(2) SPEEDGP = targeted impact speed, where applicable

(3) SPEED = actual impact speed

(4) DV = 1.072 x SPEED (impact speed plus average rebound)

(5) CHEST = upper spine g's (3 millisecond clip)

(6) ABDOMEN = lower spine g's (3 millisecond clip)

(7) TORSO = CHEST + ABDOMEN if both are known
If one of the summands is unknown, TORSO is set to double the other summand.

---------- RESTRAIN=(1) UNRESTRAINED SEATAREA=FRONT SEAT ----------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2736	.	11.1	11.9	FRONTAL	130.0	31.9	3.6	35.5
2808	15	15.1	16.2	FRONTAL	178.0	37.4	23.6	61.0
2843	15	15.3	16.4	OBLIQUE	376.0	47.1	31.1	78.2
2737	.	20.8	22.3	FRONTAL	842.2	57.6	49.8	107.4
2761	25	25.2	27.0	FRONTAL	854.0	68.5	102.6	171.1
2844	25	25.1	26.9	OBLIQUE	858.1	75.6	74.7	150.3
2734	.	30.9	33.1	FRONTAL	1173.0	88.5	134.9	223.4
2769	35	35.1	37.6	FRONTAL	1793.0	100.6	149.4	250.0
2845	35	34.6	37.1	OBLIQUE	1625.0	97.5	117.1	214.6

---------- RESTRAIN=(1) UNRESTRAINED SEATAREA=BACK SEAT ----------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2786	15	15.4	16.5	FRONTAL	356	22.6	23.2	45.8
2843	15	15.3	16.4	OBLIQUE	62	15.3	.	30.6
2733	.	20.2	21.7	FRONTAL	349	42.0	24.4	66.4
2787	25	24.8	26.6	FRONTAL	603	.	31.1	62.2
2837	25	24.3	26.0	FRONTAL	572	75.6	40.6	116.2
2844	25	25.1	26.9	OBLIQUE	202	39.9	35.5	75.4
2766	35	34.3	36.8	FRONTAL	620	.	37.7	75.4
2839	35	35.9	38.5	FRONTAL	1755	46.2	49.3	95.5
2845	35	34.6	37.1	OBLIQUE	503	26.1	46.0	72.1

---------- RESTRAIN=(2) LAP BELT ONLY SEATAREA=FRONT SEAT ----------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2775	15	15.0	16.1	FRONTAL	47	11.1	17.7	28.8
2776	25	25.5	27.3	FRONTAL	435	30.1	38.2	68.3
2844	25	25.1	26.9	OBLIQUE	569	29.8	33.6	63.4
2738	35	35.5	38.1	FRONTAL	.	47.7	52.4	100.1
2777	35	34.7	37.2	FRONTAL	1418	54.7	54.4	109.1
2845	35	34.6	37.1	OBLIQUE	2097	59.2	57.4	116.6

---------- RESTRAIN=(2) LAP BELT ONLY SEATAREA=BACK SEAT ----------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2817	15	15.7	16.8	FRONTAL	132	14.2	14.9	29.1
2843	15	15.3	16.4	OBLIQUE	34	10.6	10.3	20.9
2818	25	25.1	26.9	FRONTAL	272	32.9	32.6	65.5
2844	25	25.1	26.9	OBLIQUE	464	30.4	27.0	57.4
2819	35	34.7	37.2	FRONTAL	1255	50.3	41.5	91.8
2845	35	34.6	37.1	OBLIQUE	1680	56.4	43.7	100.1

------ RESTRAIN=(3) TETHERED: CORRECT USE SEATAREA=FRONT SEAT ------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2754	15	15.5	17.0	FRONTAL	146	23.0	23.7	46.7
2761	25	25.2	27.0	FRONTAL	549	35.6	34.8	70.4
2870	25	24.5	26.3	OBLIQUE	303	24.5	24.8	49.3
2768	35	35.1	37.6	FRONTAL	1179	59.7	57.1	116.8
2836	35	35.9	38.5	FRONTAL	1552	45.1	40.7	85.8
2855	35	35.4	37.9	OBLIQUE	1826	53.2	46.2	99.4

------ RESTRAIN=(3) TETHERED: CORRECT USE SEATAREA=BACK SEAT -------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2775	15	15.0	16.1	FRONTAL	60	16.7	16.7	33.4
2776	25	25.5	27.3	FRONTAL	231	33.8	34.7	68.5
2866	25	24.7	26.5	OBLIQUE	320	26.8	30.7	57.5
2777	35	34.7	37.2	FRONTAL	648	42.7	41.8	84.5
2867	35	35.7	38.3	OBLIQUE	758	39.4	42.9	82.3

---- RESTRAIN=(4) TETHERED: TETHER NOT USED SEATAREA=FRONT SEAT ----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2808	15	15.1	16.2	FRONTAL	118	17.2	16.5	33.7
2843	15	15.3	16.4	OBLIQUE	97	15.4	13.8	29.2
2809	25	25.3	27.1	FRONTAL	497	42.3	30.5	72.8
2837	25	24.3	26.0	FRONTAL	737	43.2	38.8	82.0
2854	25	24.9	26.7	OBLIQUE	496	32.1	42.7	74.8
2810	35	35.1	37.6	FRONTAL	1513	74.9	52.6	127.5
2836	35	35.9	38.5	FRONTAL	1745	62.1	46.7	108.8
2855	35	35.4	37.9	OBLIQUE	2673	60.8	50.2	111.0

---- RESTRAIN=(4) TETHERED: TETHER NOT USED SEATAREA=BACK SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2786	15	15.4	16.5	FRONTAL	124	19.4	22.5	41.9
2787	25	24.8	26.6	FRONTAL	376	31.6	38.3	69.9
2854	25	24.9	26.7	OBLIQUE	420	32.9	38.3	71.2
2768	35	34.3	36.8	FRONTAL	1957	63.4	49.1	112.5
2855	35	35.4	37.9	OBLIQUE	2183	47.7	56.7	104.4

---- RESTRAIN=(5) GROSS MISUSE: NO HARNESS SEATAREA=FRONT SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2797	15	14.4	15.4	FRONTAL	301.3	31.5	28.0	59.5
2798	25	24.9	26.7	FRONTAL	649.0	82.9	111.5	194.4
2799	35	34.4	36.9	FRONTAL	1759.0	101.3	109.1	210.4

----- RESTRAIN=(5) GROSS MISUSE: NO HARNESS SEATAREA=BACK SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2775	15	15.0	16.1	FRONTAL	53	.	34.2	68.4
2776	25	25.5	27.3	FRONTAL	878	70.0	59.8	129.8
2777	35	34.7	37.2	FRONTAL	2858	121.6	103.9	225.5

RESTRAIN=(6) TETHERED: NO TETHER & BELT TOO LOW SEATAREA=FRONT SEAT

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2817	15	15.7	16.8	FRONTAL	197	23.0	17.5	40.5
2818	25	25.1	26.9	FRONTAL	1016	55.5	39.4	94.9
2870	25	24.5	26.3	OBLIQUE	566	49.1	26.0	75.1
2819	35	34.7	37.2	FRONTAL	2017	69.9	36.6	106.5
2871	35	35.5	38.1	OBLIQUE	2196	87.4	38.1	125.5

RESTRAIN=(6) TETHERED: NO TETHER & BELT TOO LOW SEATAREA=BACK SEAT

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2828	15	14.5	15.5	FRONTAL	139	22.5	21.7	44.2
2829	25	25.1	26.9	FRONTAL	178	55.1	23.5	78.6
2837	25	24.3	26.0	FRONTAL	576	29.9	33.9	63.8
2868	25	25.2	27.0	OBLIQUE	421	33.6	36.4	70.0
2830	35	35.5	38.1	FRONTAL	620	42.6	60.6	103.2
2869	35	34.6	37.1	OBLIQUE	1598	58.5	60.0	118.9

------ RESTRAIN=(7) GROSS MISUSE: NO BELT SEATAREA=FRONT SEAT ------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2628	15	14.5	15.5	FRONTAL	238	42.9	29.0	71.9
2629	25	25.1	26.9	FRONTAL	684	83.1	49.8	132.9

------ RESTRAIN=(7) GROSS MISUSE: NO BELT SEATAREA=BACK SEAT -------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2808	15	15.1	16.2	FRONTAL	30	20.1	16.5	36.6
2809	25	25.3	27.1	FRONTAL	166	63.6	47.1	110.7
2810	35	35.1	37.6	FRONTAL	754	61.5	54.3	115.8

----- RESTRAIN=(8) TETHERLESS: CORRECT USE SEATAREA=FRONT SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2786	15	15.4	16.5	FRONTAL	138	28.4	24.7	53.1
2733	.	20.2	21.7	FRONTAL	130	24.3	21.2	45.5
2787	25	24.8	26.6	FRONTAL	336	38.3	42.1	80.4
2866	25	24.7	26.5	OBLIQUE	414	34.7	30.2	64.9
2788	35	34.3	36.8	FRONTAL	777	49.4	45.5	94.9
2867	35	35.7	38.3	OBLIQUE	1008	41.6	39.4	81.0

----- RESTRAIN=(8) TETHERLESS: CORRECT USE SEATAREA=BACK SEAT ------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2736	.	11.1	11.9	FRONTAL	45.9	.	.	.
2735	.	12.0	12.9	FRONTAL	.	14.4	16.0	30.4
2797	15	14.4	15.4	FRONTAL	102.0	25.0	20.8	45.8
2737	.	20.8	22.3	FRONTAL	175.0	28.5	30.5	59.0
2761	25	25.2	27.0	FRONTAL	427.0	40.4	40.8	61.2
2868	25	25.2	27.0	OBLIQUE	457.0	37.5	35.5	73.0
2734	.	30.9	33.1	FRONTAL	461.3	39.4	39.3	78.7
2738	35	35.5	38.1	FRONTAL	903.0	46.5	47.2	93.7
2799	35	34.4	36.9	FRONTAL	721.0	52.1	52.0	104.1
2869	35	34.6	37.1	OBLIQUE	823.0	56.3	52.6	108.9

---- RESTRAIN=(9) TETHERLESS: BELT TOO LOW SEATAREA=FRONT SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2775	15	15.0	16.1	FRONTAL	151.0	23.4	19.3	42.7
2776	25	25.5	27.3	FRONTAL	684.5	46.8	34.9	81.7
2868	25	25.2	27.0	OBLIQUE	508.0	33.3	27.3	60.6
2777	35	34.7	37.2	FRONTAL	1040.5	57.9	47.5	105.4
2869	35	34.6	37.1	OBLIQUE	1487.0	49.5	38.1	87.6

----- RESTRAIN=(9) TETHERLESS: BELT TOO LOW SEATAREA=BACK SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2797	15	14.4	15.4	FRONTAL	193	16.2	17.7	33.9
2798	25	24.9	26.7	FRONTAL	404	35.5	34.3	69.8
2866	25	24.7	26.5	OBLIQUE	660	37.8	36.6	74.4
2768	35	35.1	37.6	FRONTAL	1777	82.7	49.4	132.1
2867	35	35.7	38.3	OBLIQUE	1721	54.6	51.3	105.9

---- RESTRAIN=(10) FULL SHIELD: CORRECT USE SEATAREA=FRONT SEAT ----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2797	15	14.4	15.4	FRONTAL	122	21.9	24.0	45.9
2798	25	24.9	26.7	FRONTAL	448	43.0	47.1	90.1
2856	25	25.5	27.3	OBLIQUE	355	47.3	.	94.6
2799	35	34.4	36.9	FRONTAL	831	52.8	60.4	113.2
2869	35	34.6	37.1	OBLIQUE	676	55.0	.	110.0
2739	.	38.7	41.5	FRONTAL	618	44.6	55.7	100.3

---- RESTRAIN=(10) FULL SHIELD: CORRECT USE SEATAREA=BACK SEAT -----

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2808	15	15.1	16.2	FRONTAL	57	23.7	34.0	57.7
2809	25	25.3	27.1	FRONTAL	427	58.0	79.6	137.6
2870	25	24.5	26.3	OBLIQUE	300	36.5	36.8	73.3
2810	35	35.1	37.6	FRONTAL	614	57.6	75.0	132.6
2871	35	35.5	38.1	OBLIQUE	1062	52.7	.	105.4

------ RESTRAIN=(11) BOOSTER: CORRECT USE SEATAREA=FRONT SEAT ------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2817	15	15.7	16.8	FRONTAL	64	23.3	23.0	46.3
2818	25	25.1	26.9	FRONTAL	233	37.7	43.3	81.0
2856	25	25.5	27.3	OBLIQUE	280	36.8	40.5	77.3
2819	35	34.7	37.2	FRONTAL	356	38.5	42.8	81.3
2857	35	34.9	37.3	OBLIQUE	436	40.2	43.4	83.6

------ RESTRAIN=(11) BOOSTER: CORRECT USE SEATAREA=BACK SEAT -------

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2828	15	14.5	15.5	FRONTAL	47	20.1	22.5	42.6
2829	25	25.1	26.9	FRONTAL	242	35.6	41.0	76.6
2856	25	25.5	27.3	OBLIQUE	260	36.2	45.4	81.6
2830	35	35.5	38.1	FRONTAL	410	40.8	47.2	88.0
2857	35	34.8	37.3	OBLIQUE	369	31.3	40.0	71.3
2739	.	38.7	41.5	FRONTAL	613	49.6	56.4	106.0

RESTRAIN=(12) BOOSTER: NO UPPER BODY RESTRAINT SEATAREA=FRONT SEAT

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2786	15	15.4	16.5	FRONTAL	79	15.7	30.0	45.7
2787	25	24.8	26.6	FRONTAL	444	28.2	41.7	69.9
2866	25	24.7	26.5	OBLIQUE	573	27.3	47.9	75.2
2788	35	34.3	36.8	FRONTAL	2022	50.3	68.0	118.3
2867	35	35.7	38.3	OBLIQUE	2278	55.4	62.3	117.7

RESTRAIN=(12) BOOSTER: NO UPPER BODY RESTRAINT SEATAREA=BACK SEAT -

TESTNO	SPEEDGP	SPEED	DV	CRSHMODE	HIC	CHEST	ABDOMEN	TORSO
2817	15	15.7	16.8	FRONTAL	40	11.1	17.8	28.9
2818	25	25.1	26.9	FRONTAL	367	25.9	33.4	59.3
2856	25	25.5	27.3	OBLIQUE	541	25.0	47.9	72.9
2819	35	34.7	37.2	FRONTAL	1126	47.2	37.9	85.1
2857	35	34.4	37.3	OBLIQUE	1215	41.2	44.4	85.6

APPENDIX 3

GRAPHS OF SLED TEST DATA POINTS: HIC AND TORSO G's BY DELTA V, RESTRAINT USE MODE AND SEAT POSITION

Notes:

(1) Torso g's are the sum of chest and lower spine g's. If one of those two quantities is unknown, torso g's are set to double the other quantity.

(2) The numerals on the graph designate the seat position

1 = front seat

2 = back seat

3 = front seat, but torso g's had to be set to double chest g's or double lower spine g's, due to missing data.

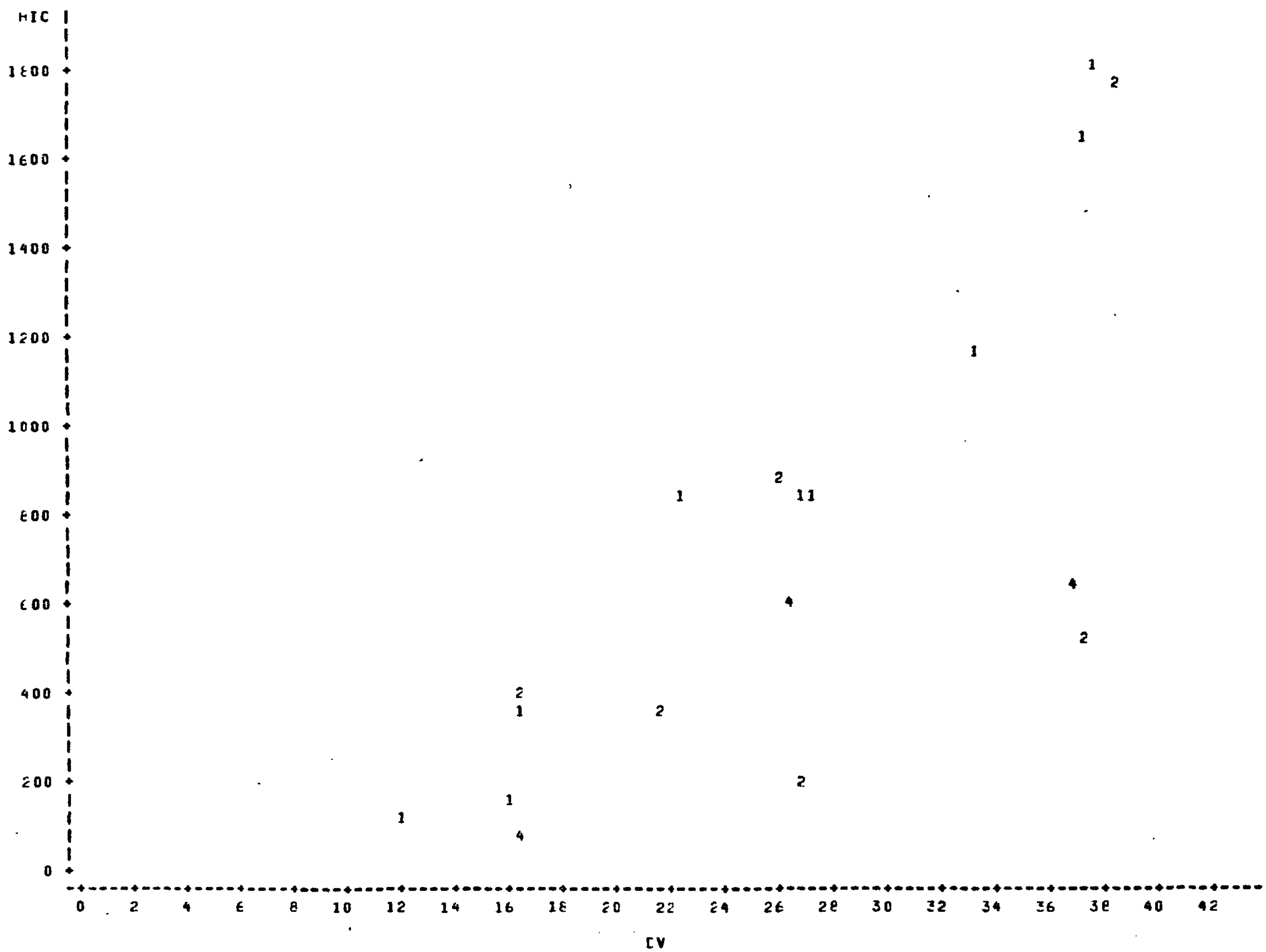
4 = back seat, but torso g's had to be set to double chest g's or double lower spine g's, due missing data.

(3) Scale varies from graph to graph!

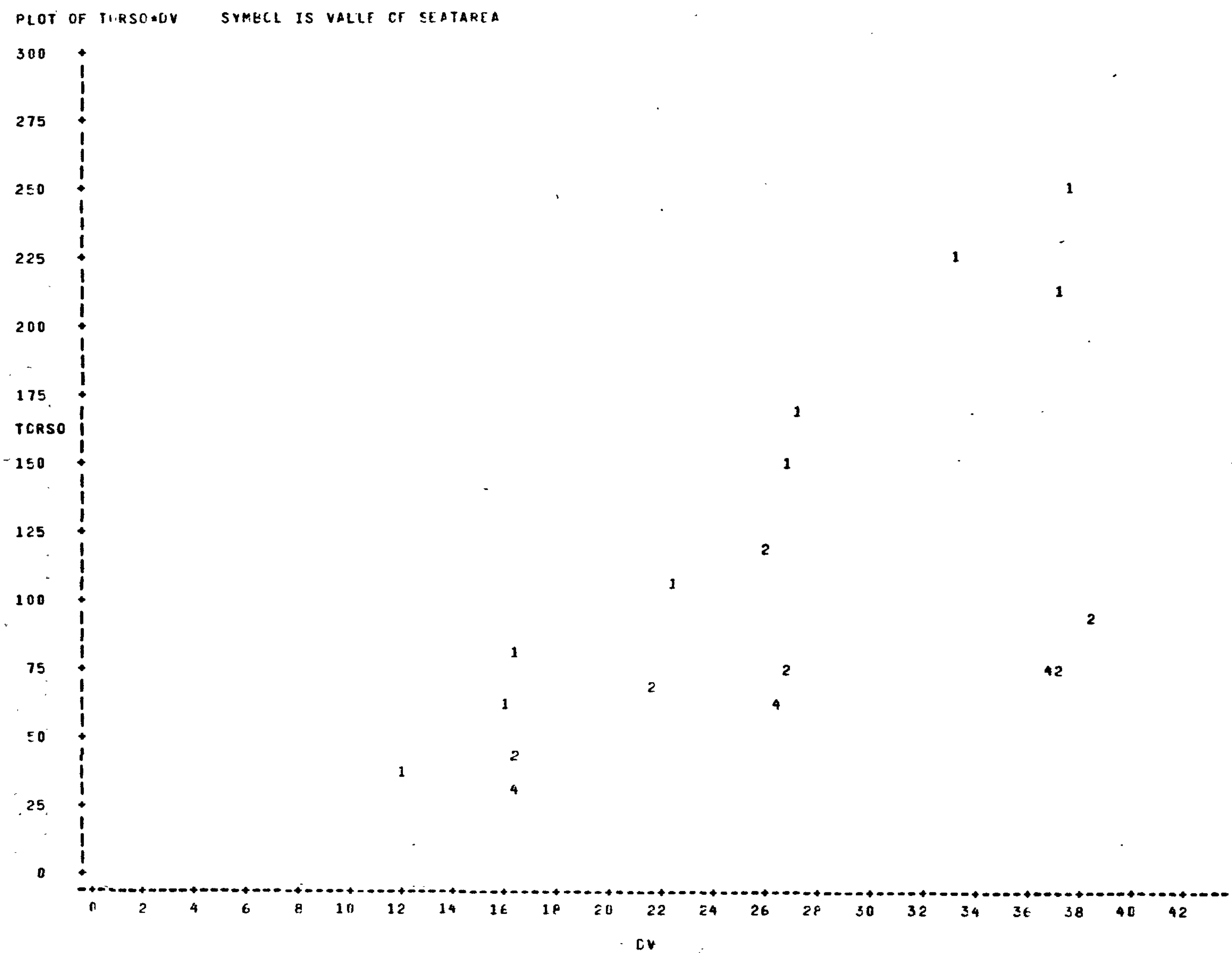
(4) Restraint use mode 5 (gross misuse: no harness) and 7 (gross misuse: no belt) have been combined and are shown after use mode 4.

1. UNRESTRAINED

PLOT OF HIC*DV   SYMBOL IS VALUE OF SEATAREA

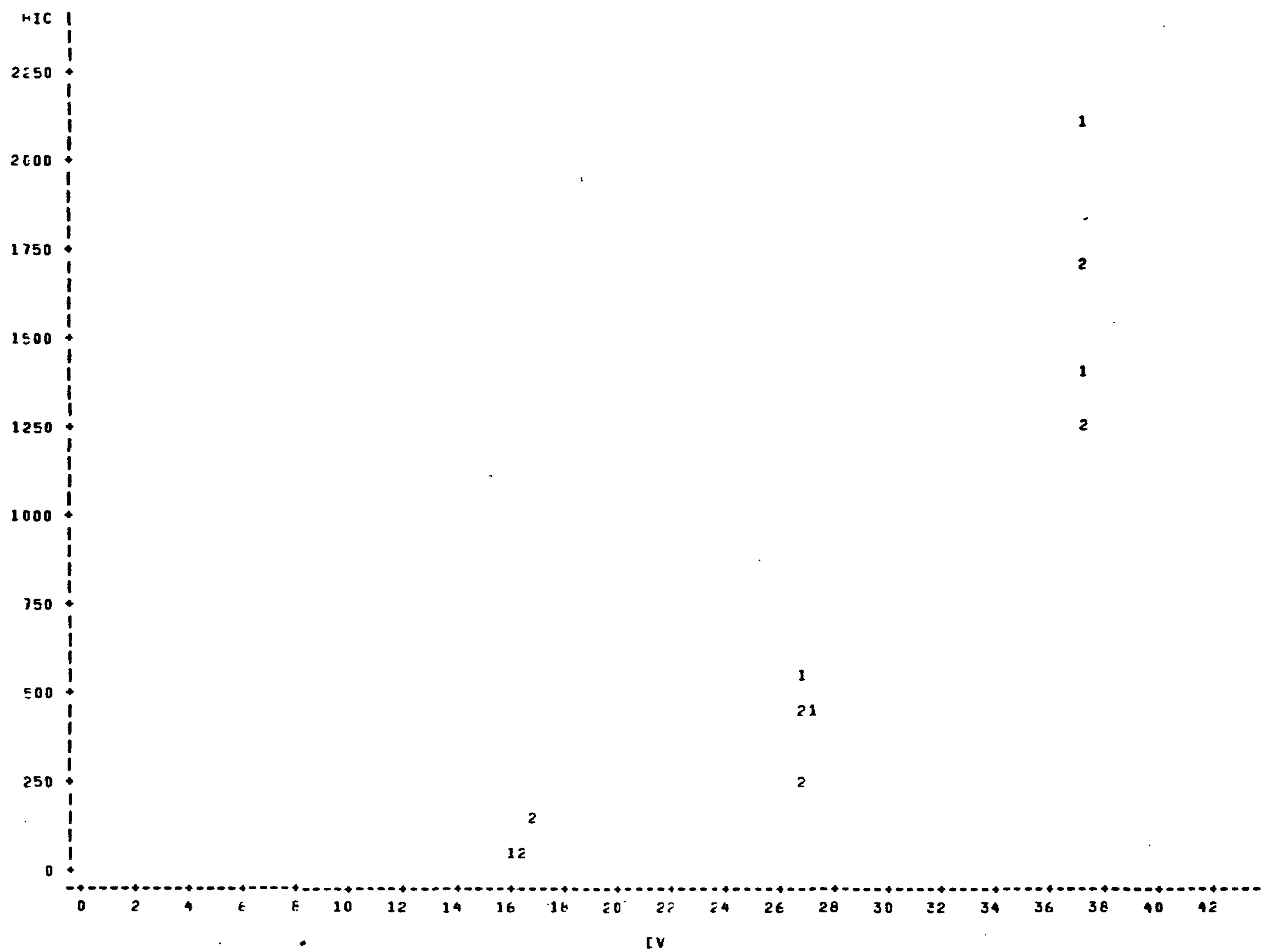


1. UNRESTRAINED



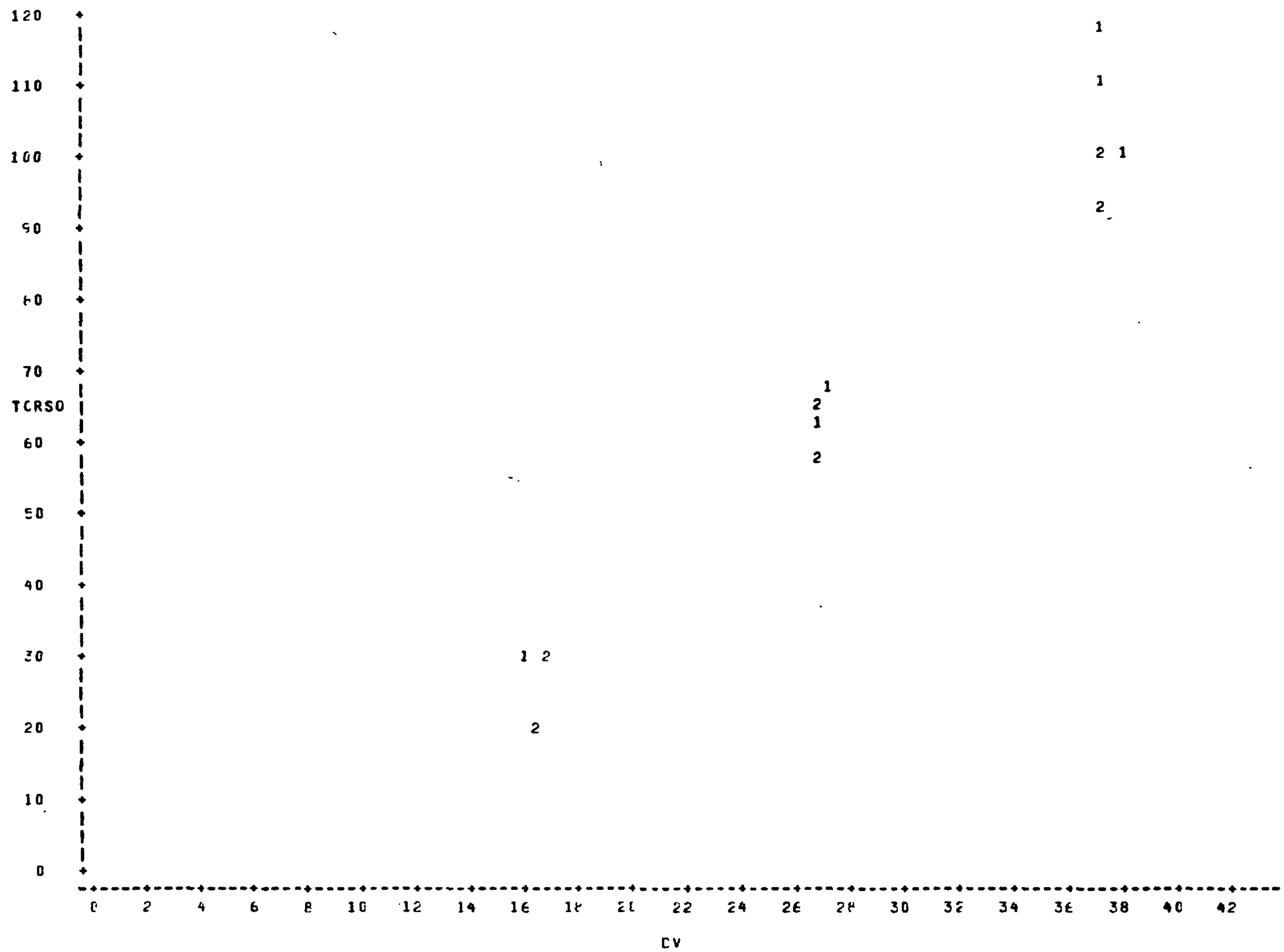
2. LAP BELT ONLY

PLOT OF HIC*DV   SYMBOL IS VALUE OF SEATAREA



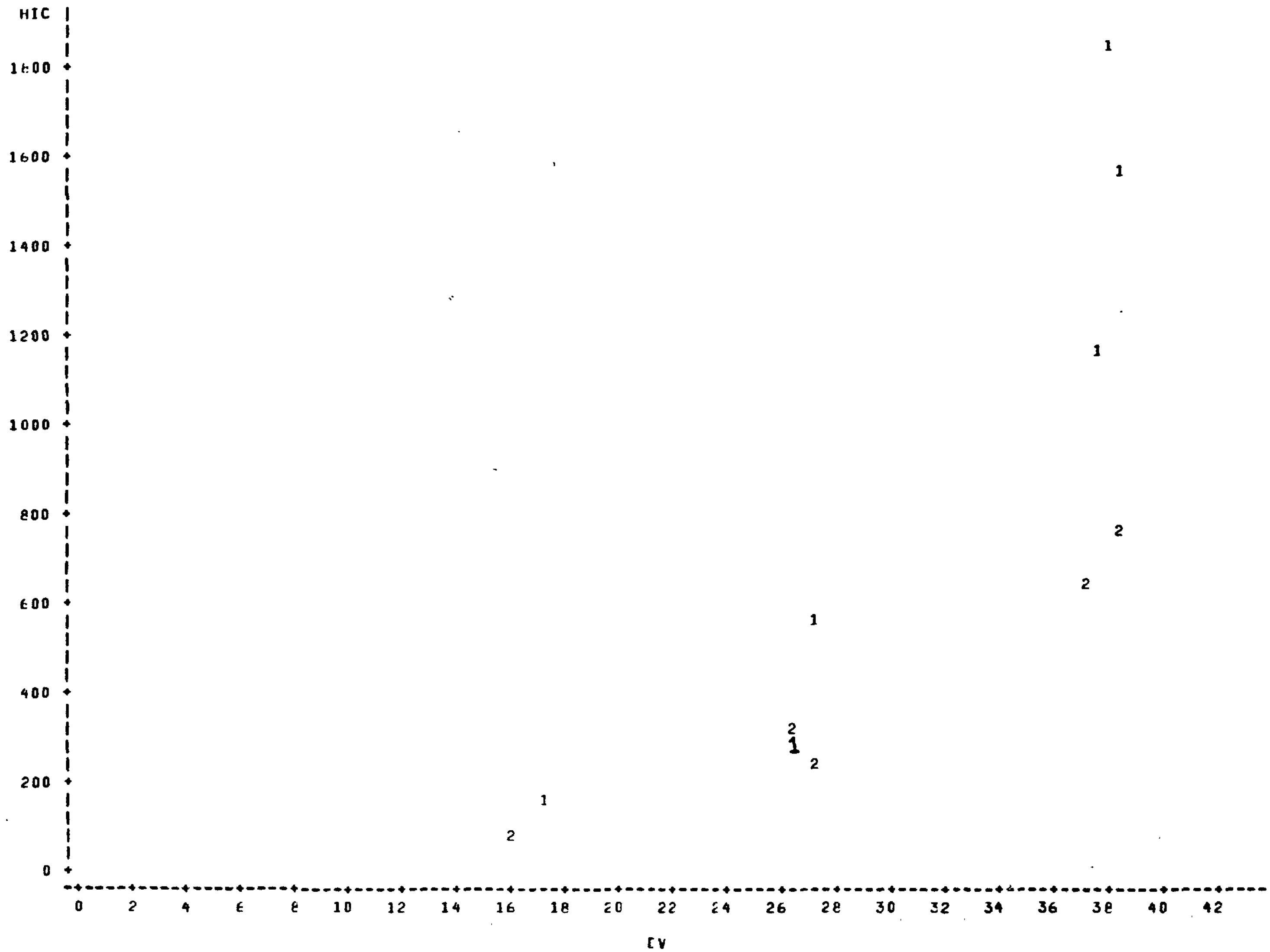
2. LAP BELT ONLY

PLOT OF TORSO*DV   SYMBOL IS VALUE OF SEATAREA



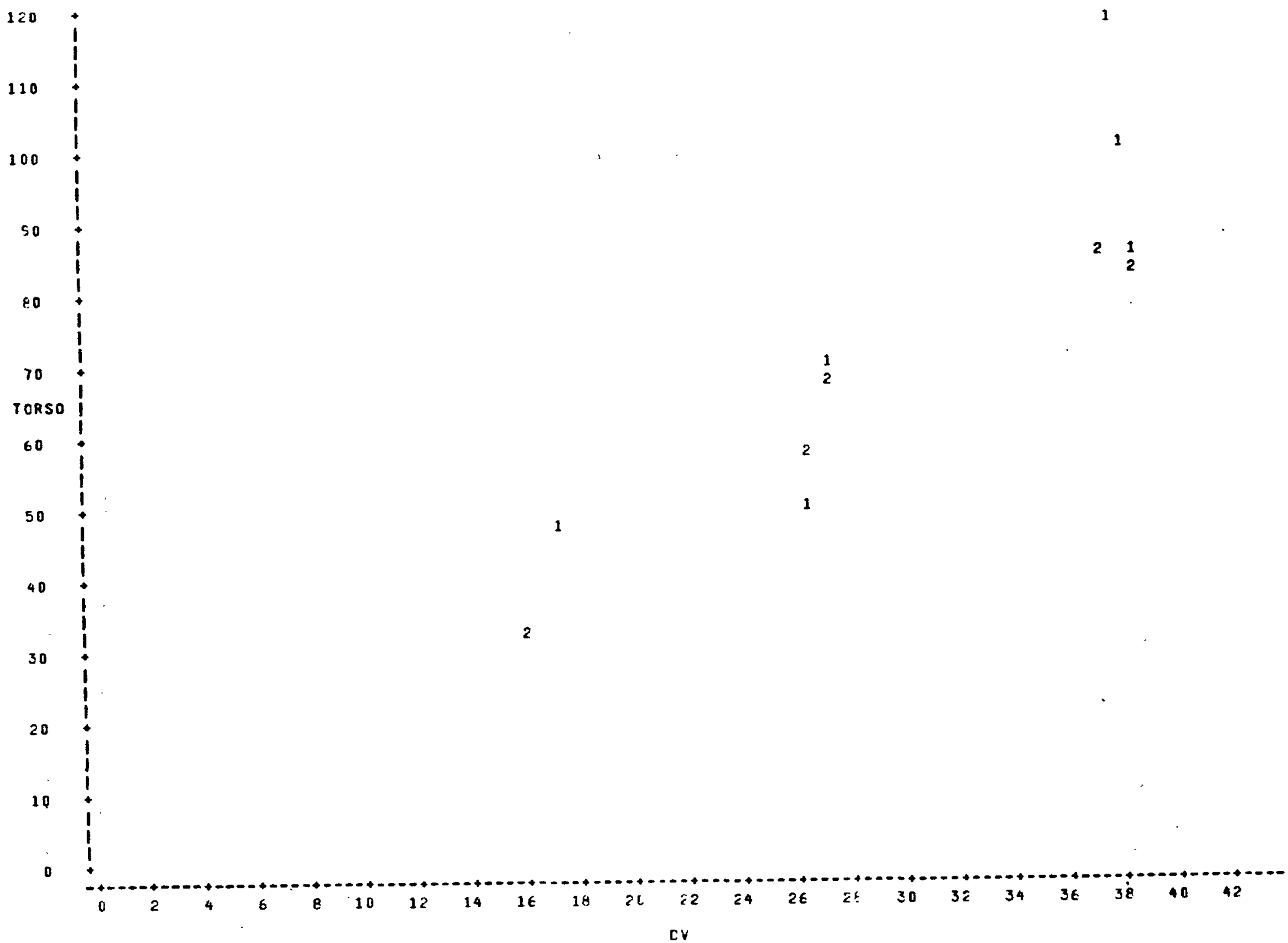
3. TETHERED: CORRECT USE

PLOT OF HIC*DV   SYMBOL IS VALUE OF SEATAREA.

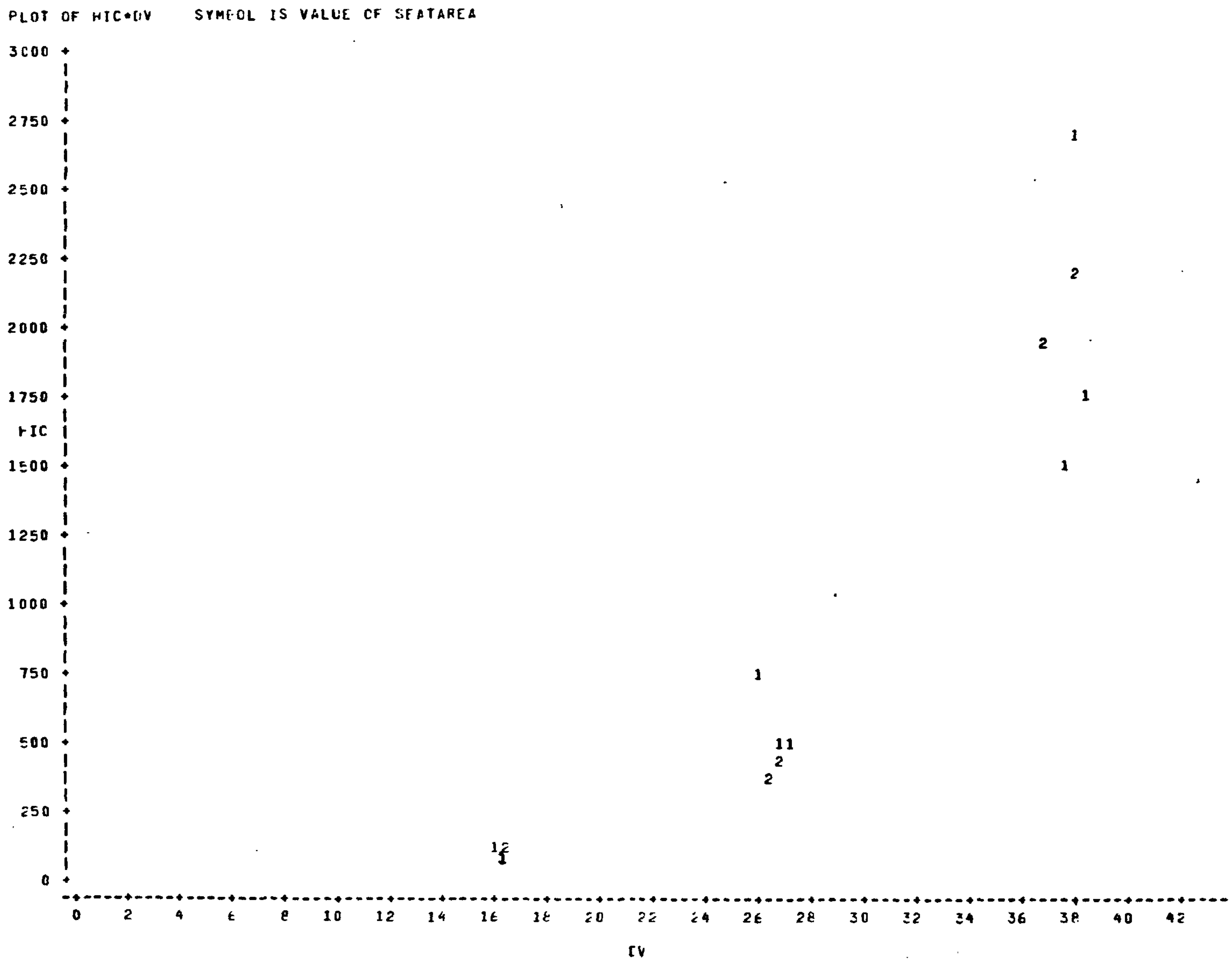


3. TETHERED: CORRECT USE

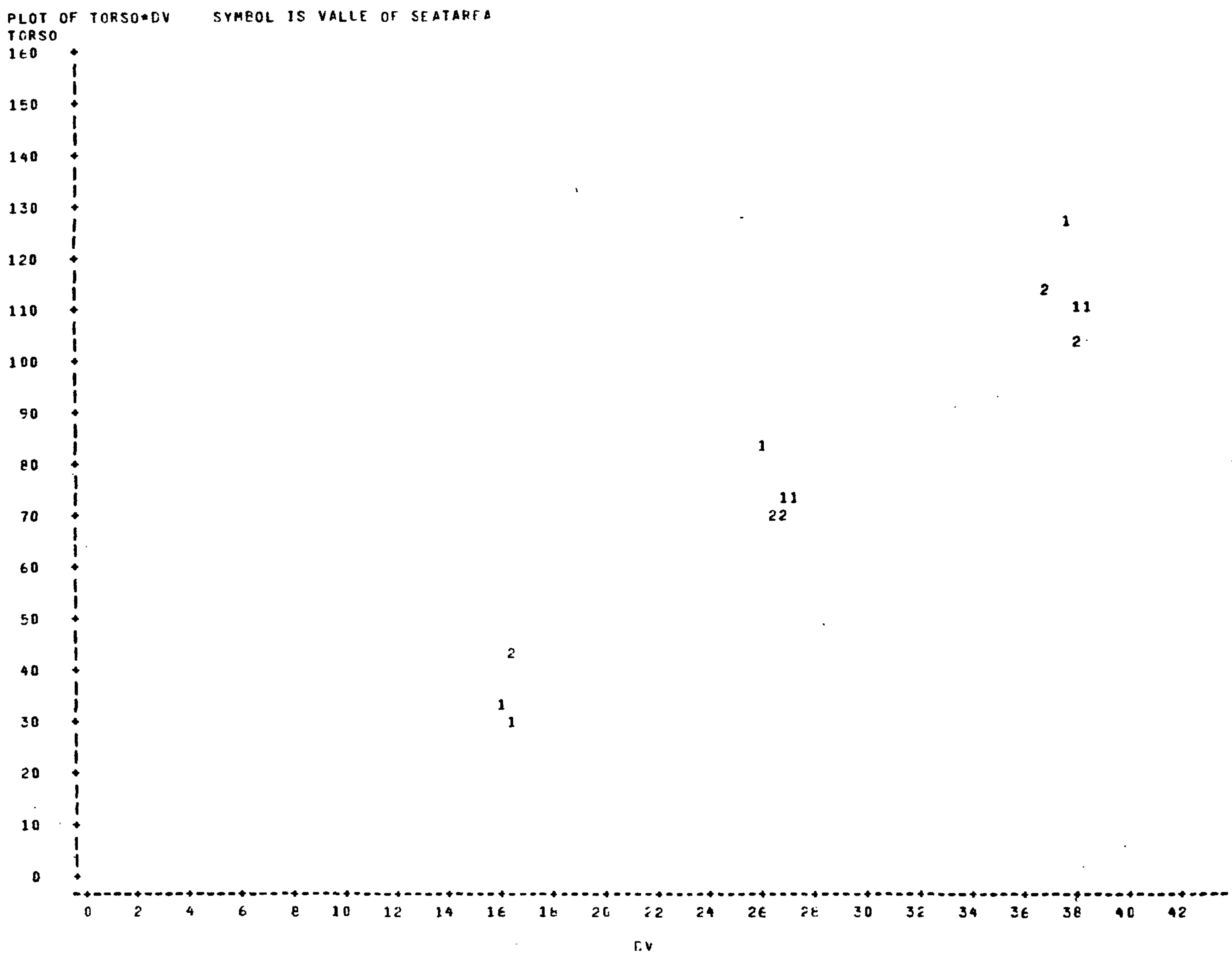
PLOT OF TORSO*DV   SYMBOL IS VALUE OF SEATAREA



4. TETHERED: TETHER NOT USED

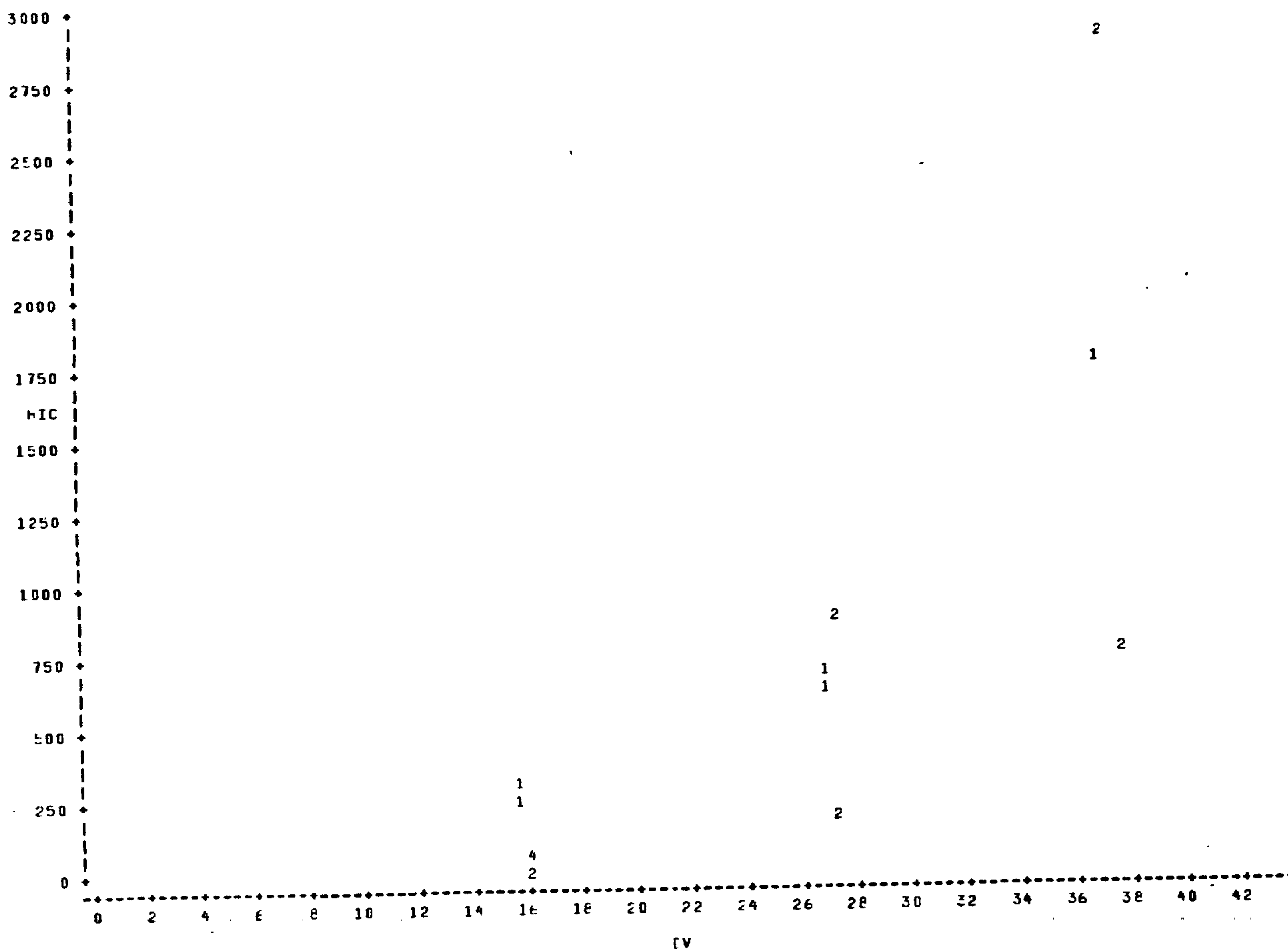


4. TETHERED: TETHER NOT USED



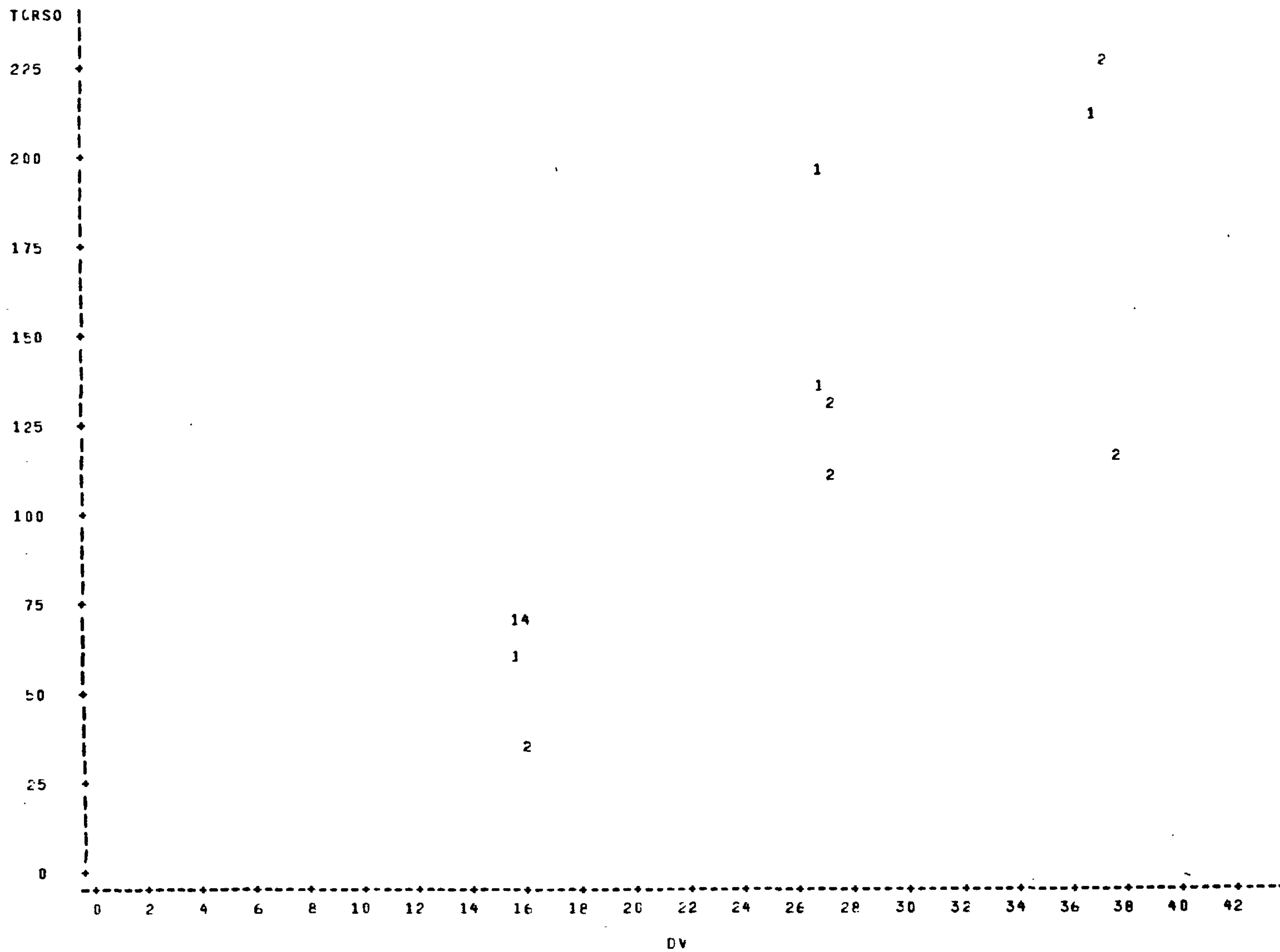
5. GROSS MISUSE: NO HARNESS and 7. GROSS MISUSE: NO BELT

PLOT OF HIC*DV SYMBOL IS VALUE OF SEATAREA

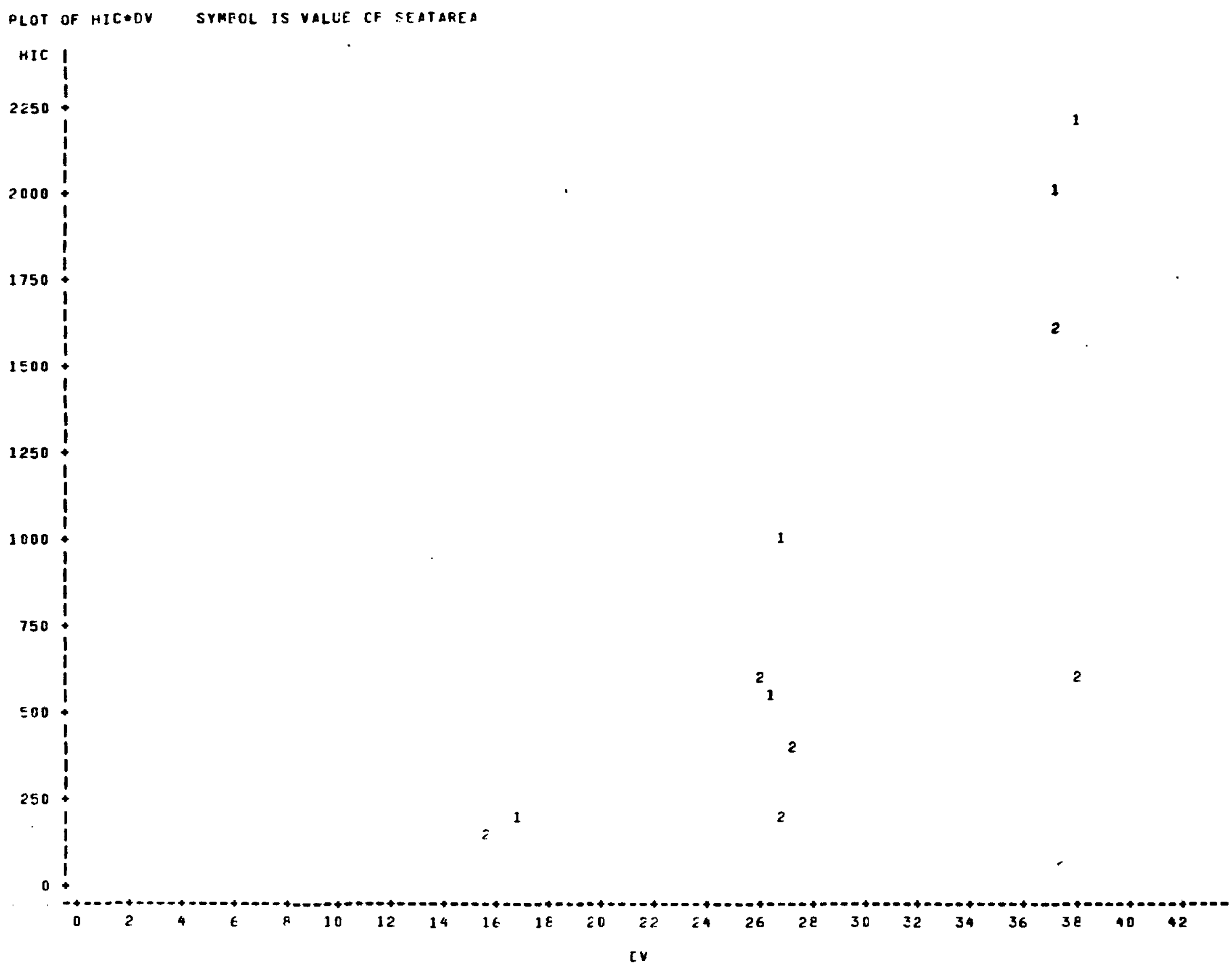


5. GROSS MISUSE: NO HARNESS and 7. GROSS MISUSE: NO BELT

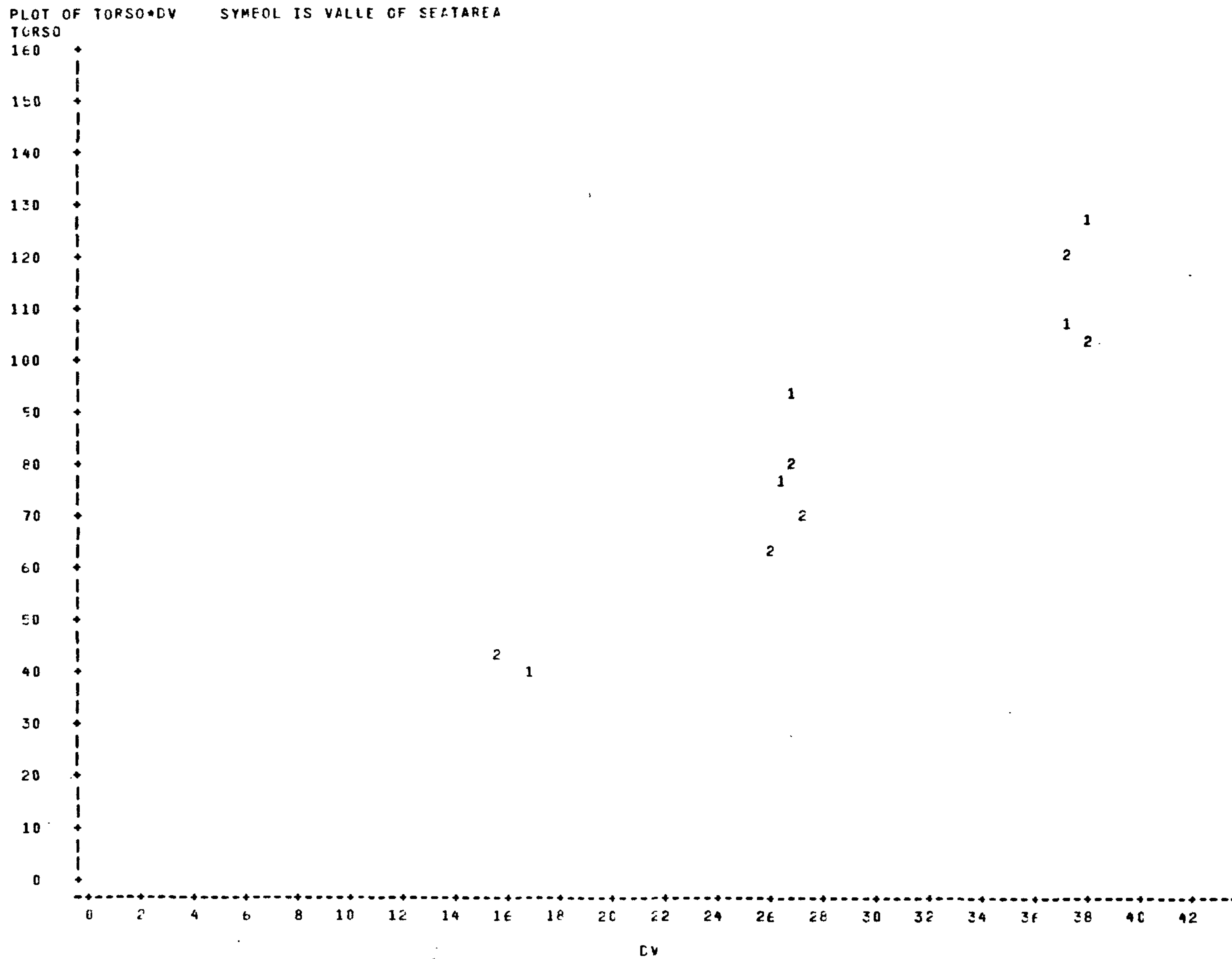
PLOT OF TORSO*DV   SYMBOL IS VALUE OF SEATAREA



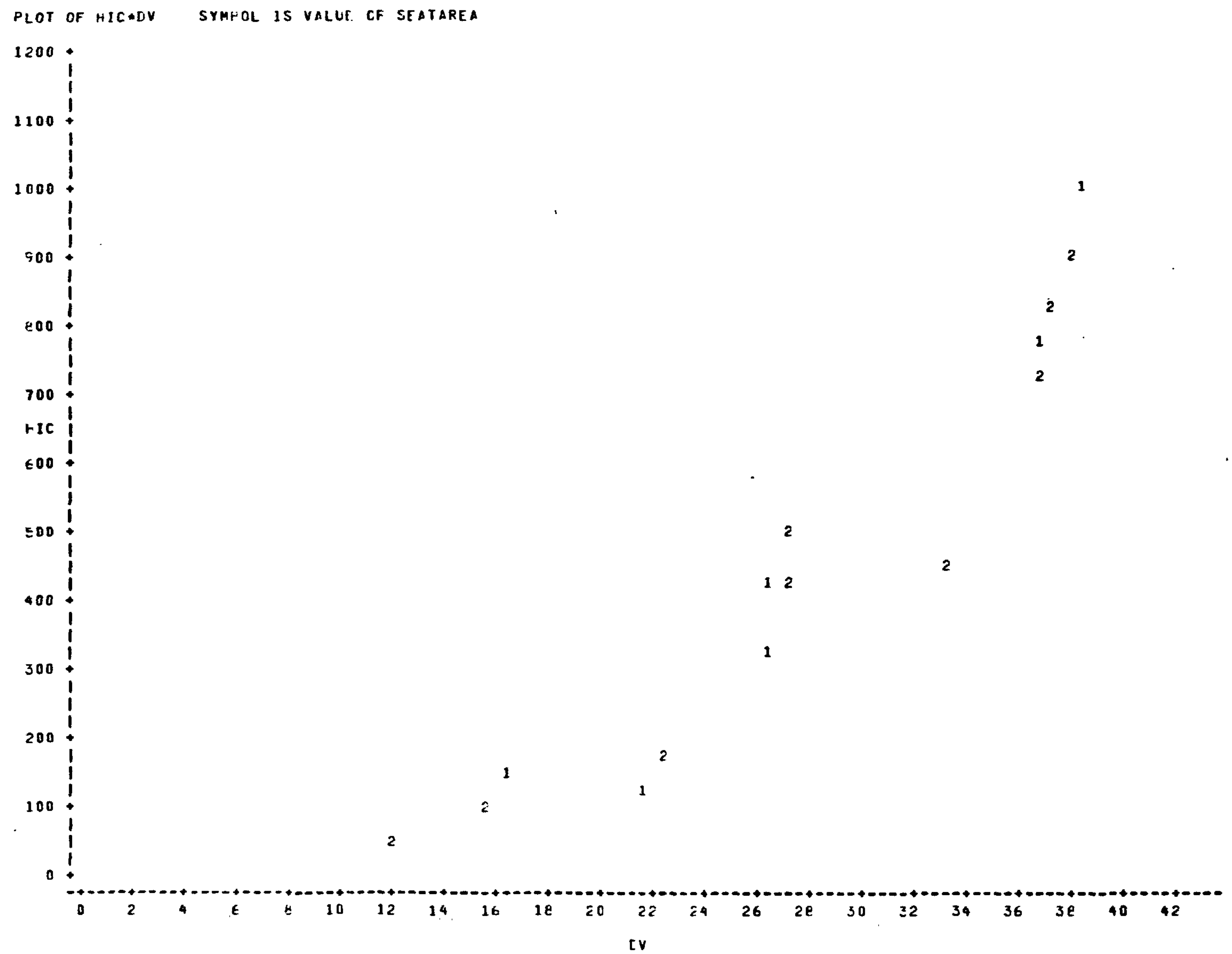
6. TETHERED: NO TETHER & BELT TOO LOW



6. TETHERED: NO TETHER & BELT TOO LOW

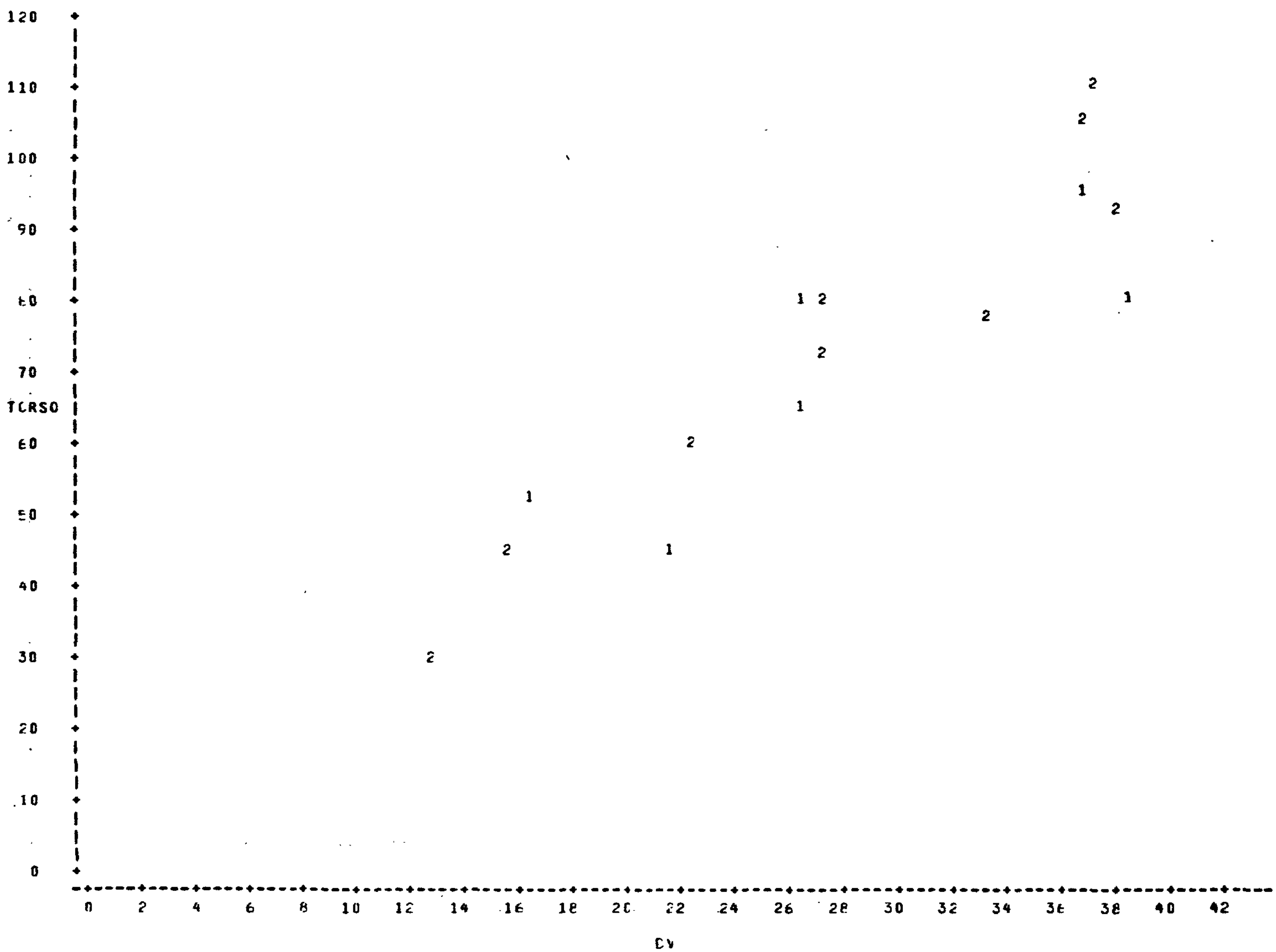


8. TETHERLESS: CORRECT USE



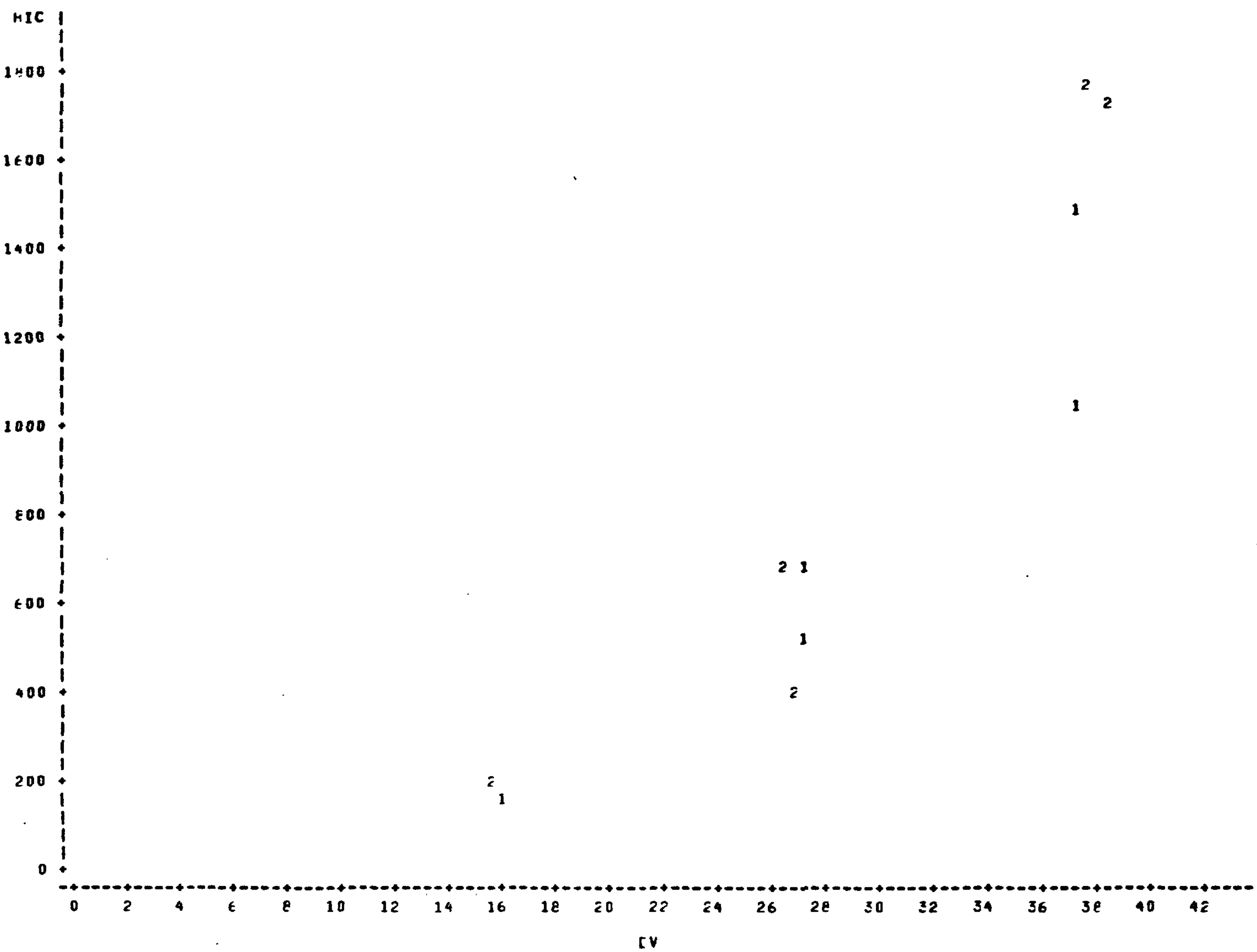
8. TETHERLESS: CORRECT USE

PLOT OF TORSO*DV   SYMBOL IS VALUE OF SEATAREA

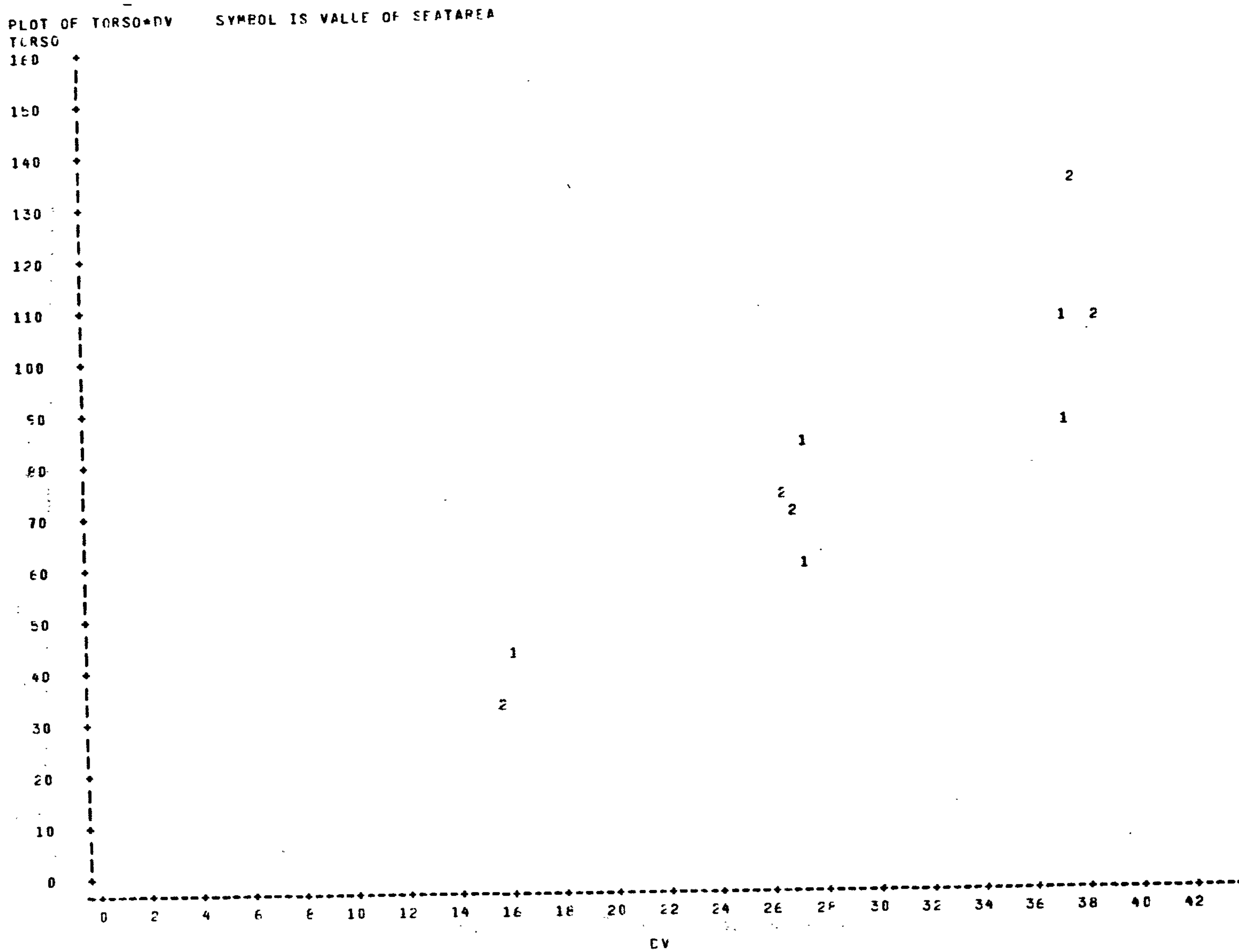


9. TETHERLESS: BELT TOO LOW

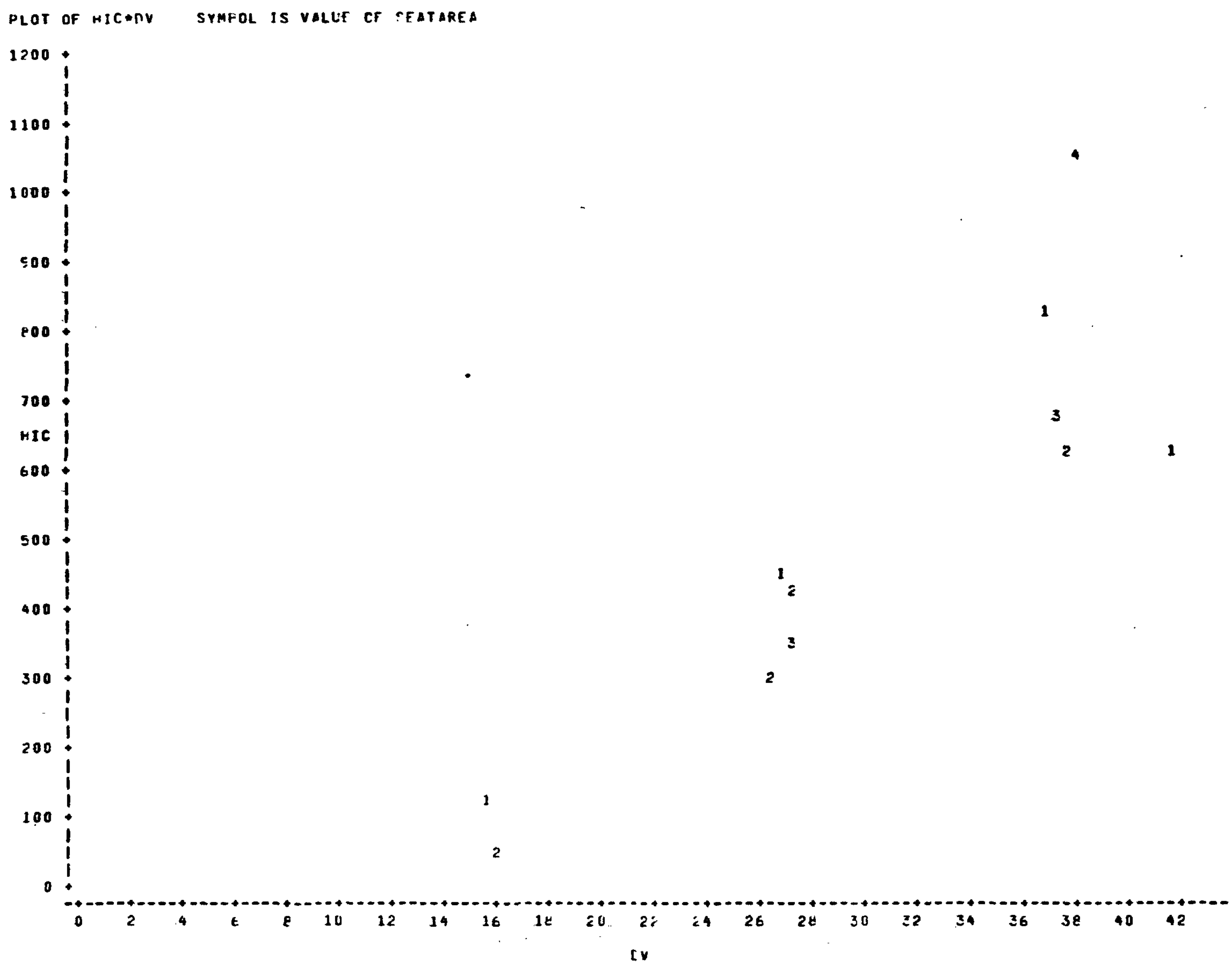
PLOT OF HIC*LV   SYMBOL IS VALUE OF SEATAREA



9. TETHERLESS: BELT TOO LOW

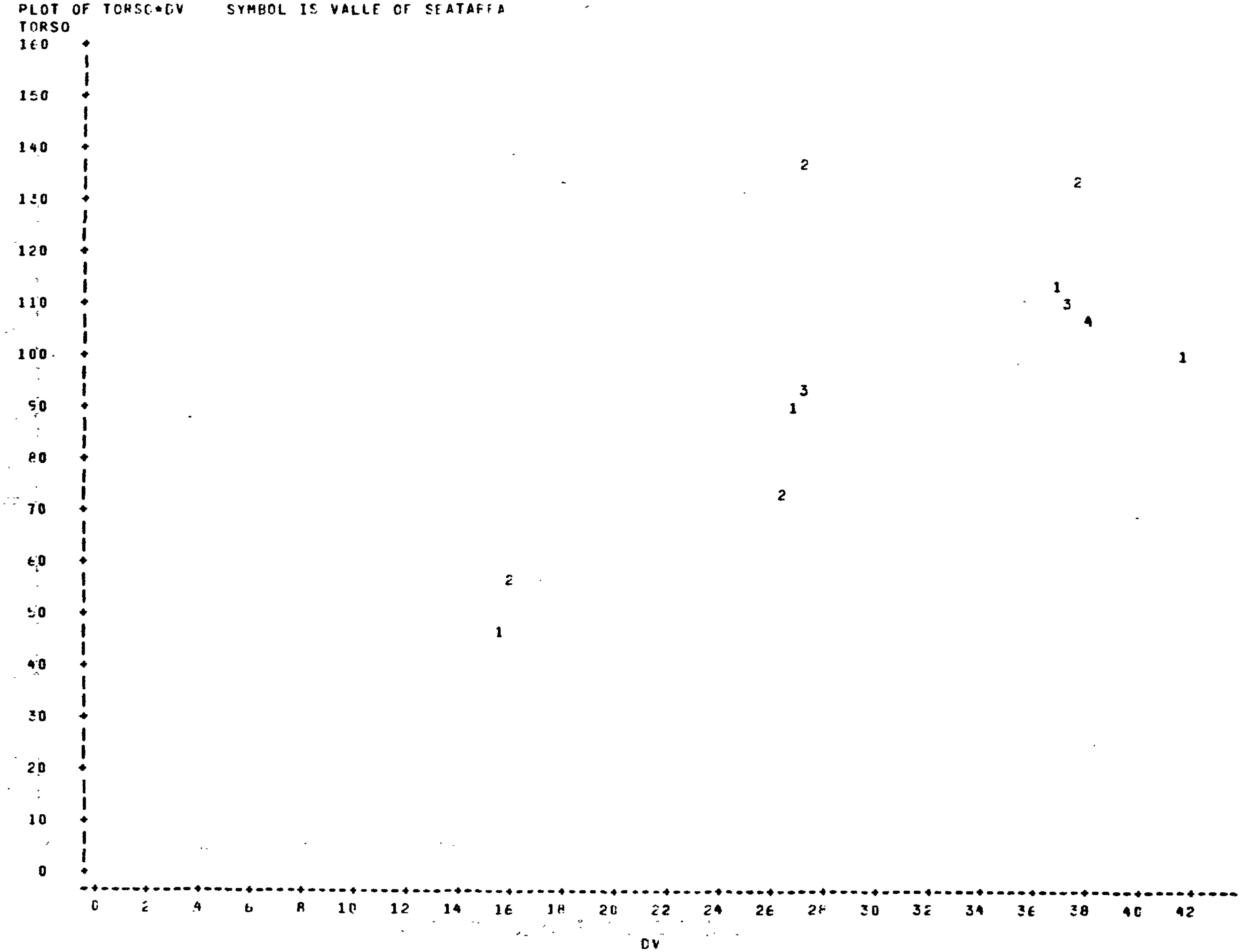


10. FULL SHIELD: CORRECT USE

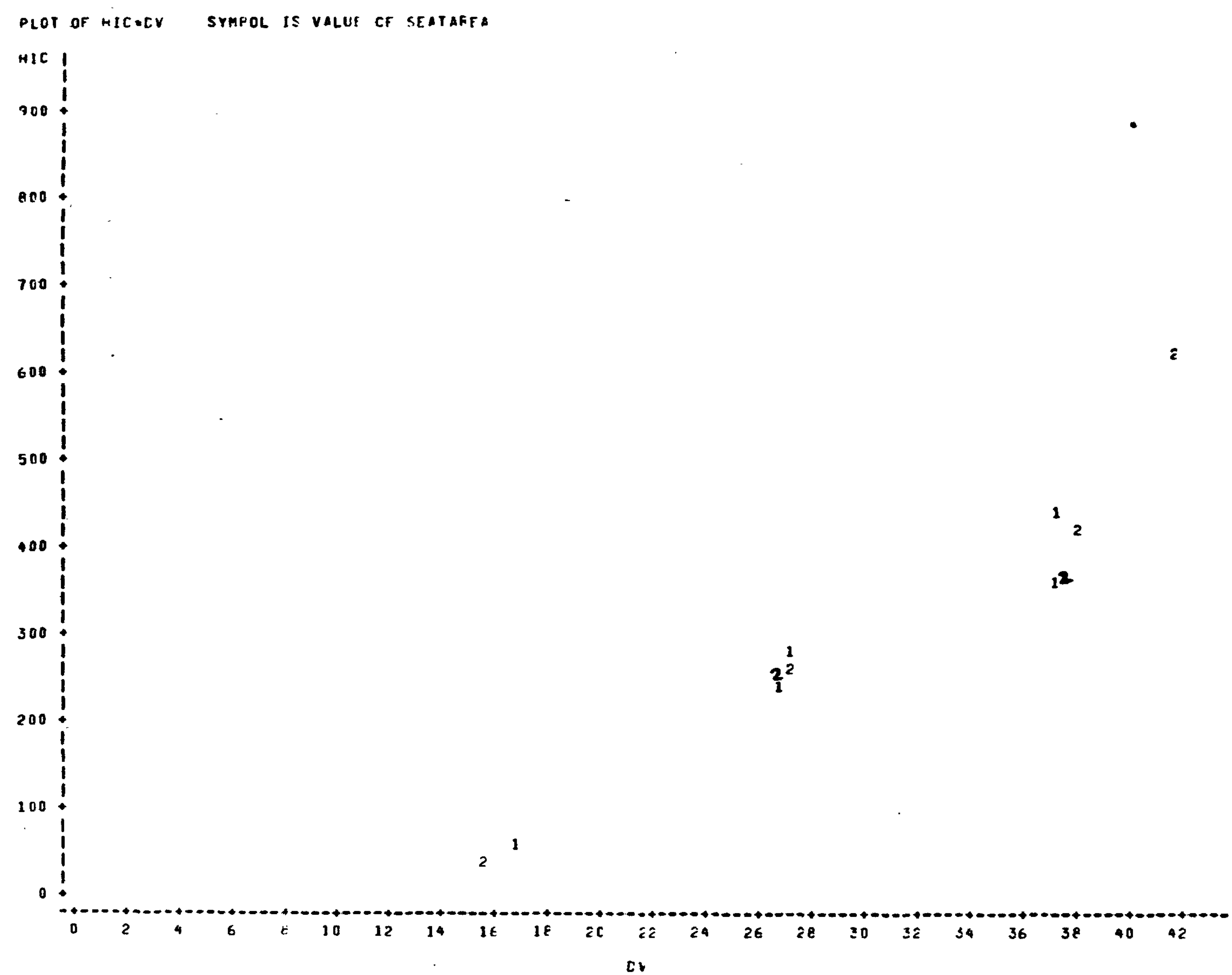


10. FULL SHIELD: CORRECT USE

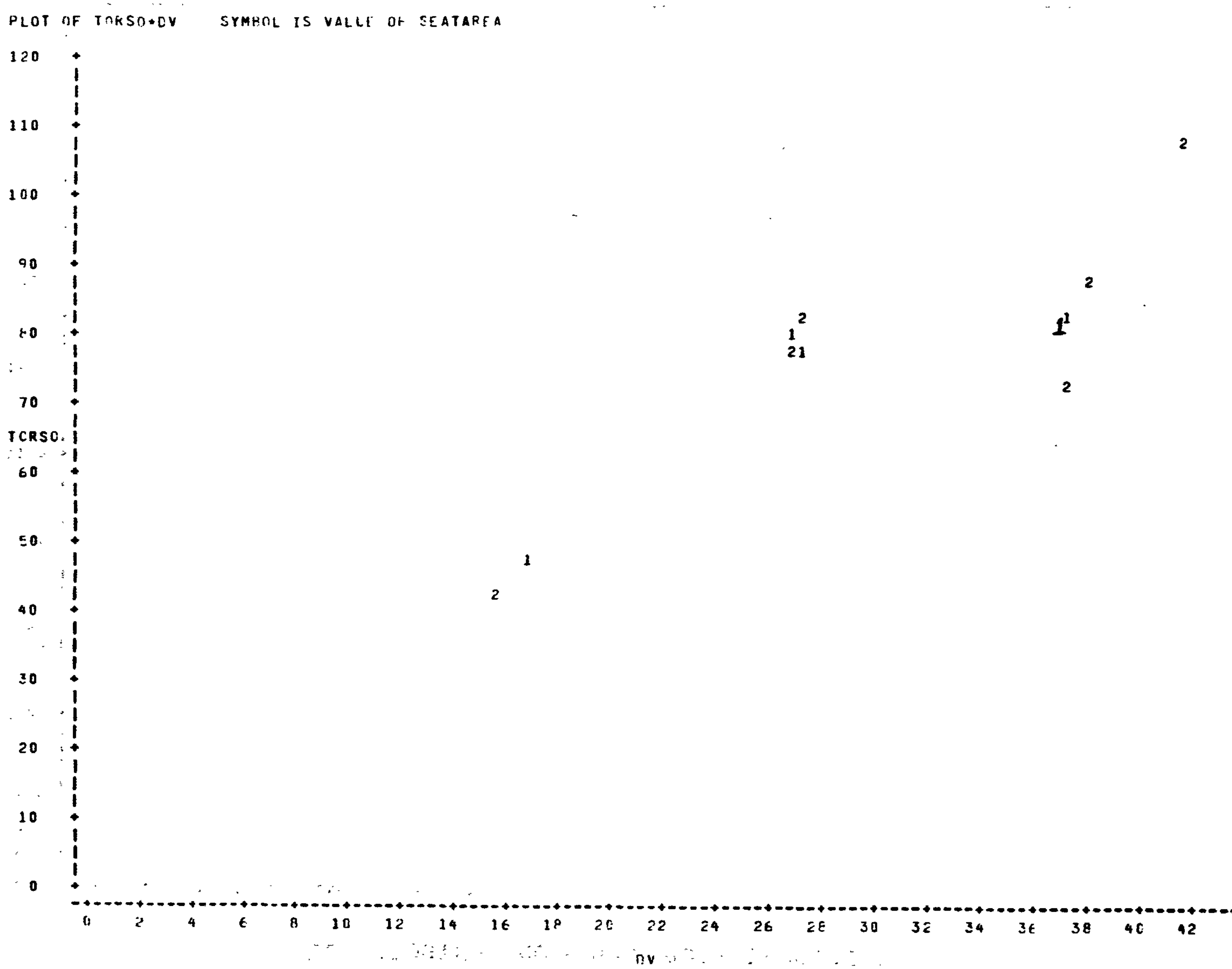
PLOT OF TORSO*DV SYMBOL IS VALUE OF SEATAFFA



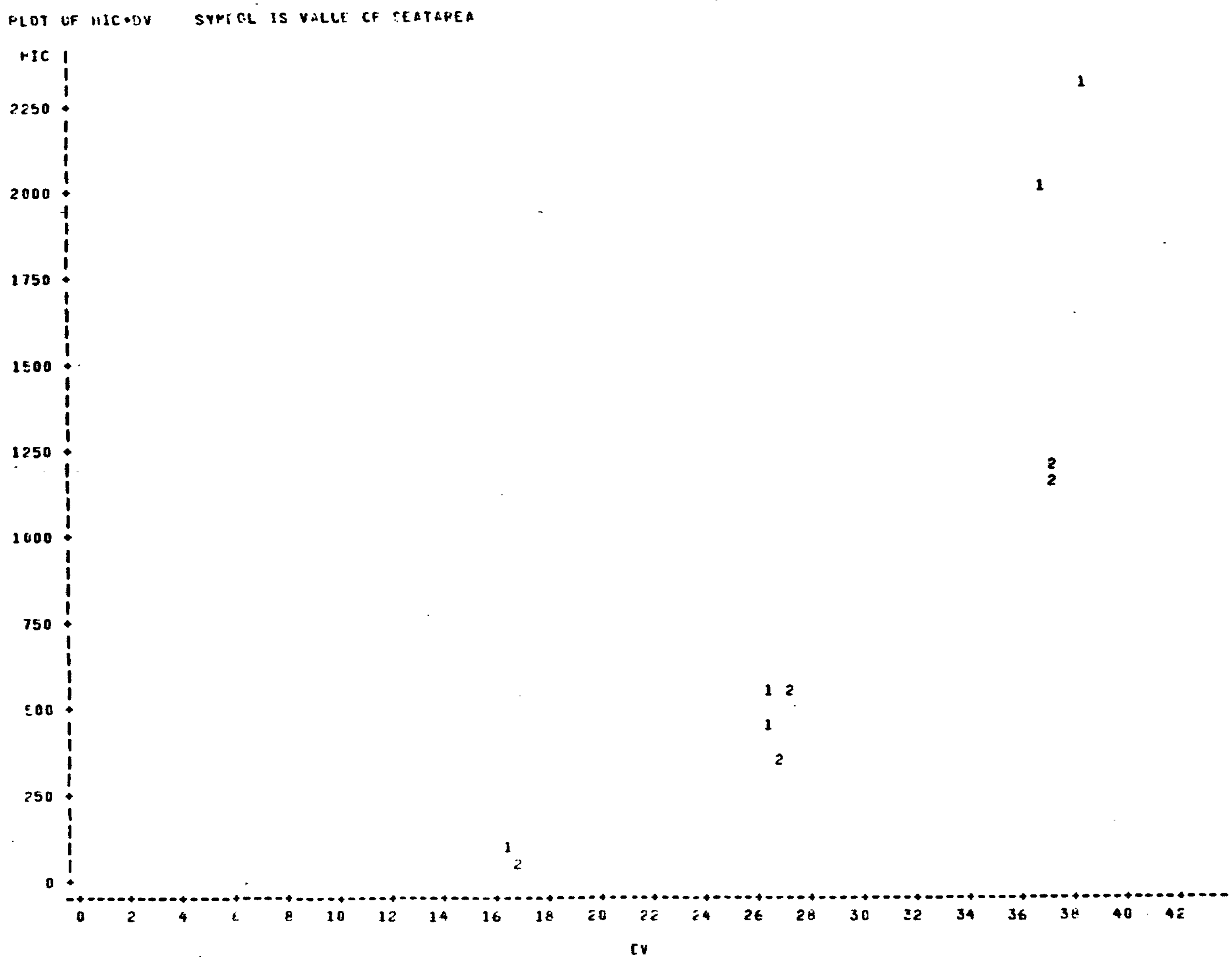
11. BOOSTER: CORRECT USE



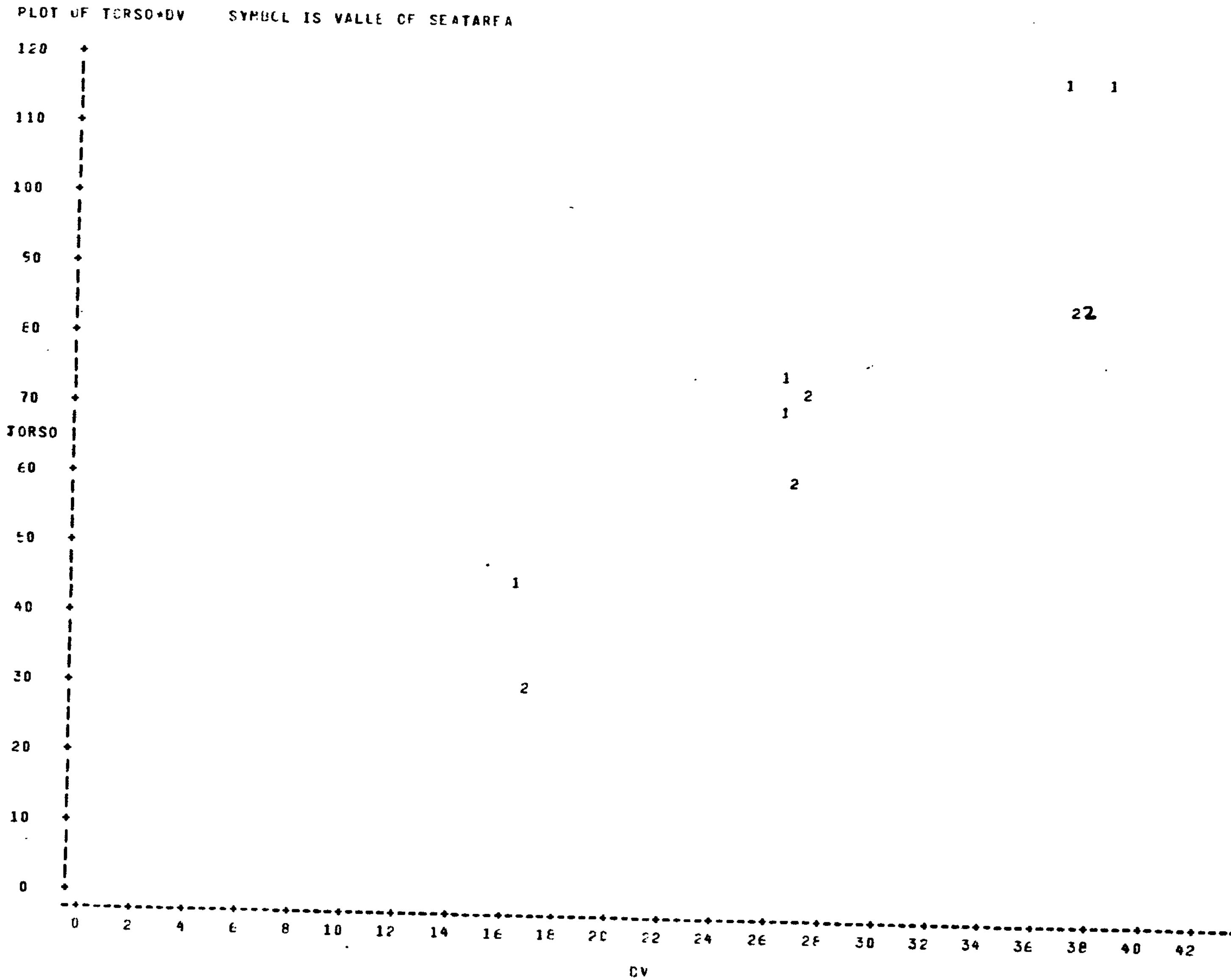
11. BOOSTER: CORRECT USE



12. BOOSTER: NO UPPER BODY RESTRAINT



12. BOOSTER: NO UPPER BODY RESTRAINT



APPENDIX 4

GRAPHS OF HIC AND TORSO G's AS FUNCTIONS OF DELTA V, BY RESTRAINT USE MODE

Notes: (1) Torso g's are sum of upper and lower spine g's

(2) correctly used seats on first two pages

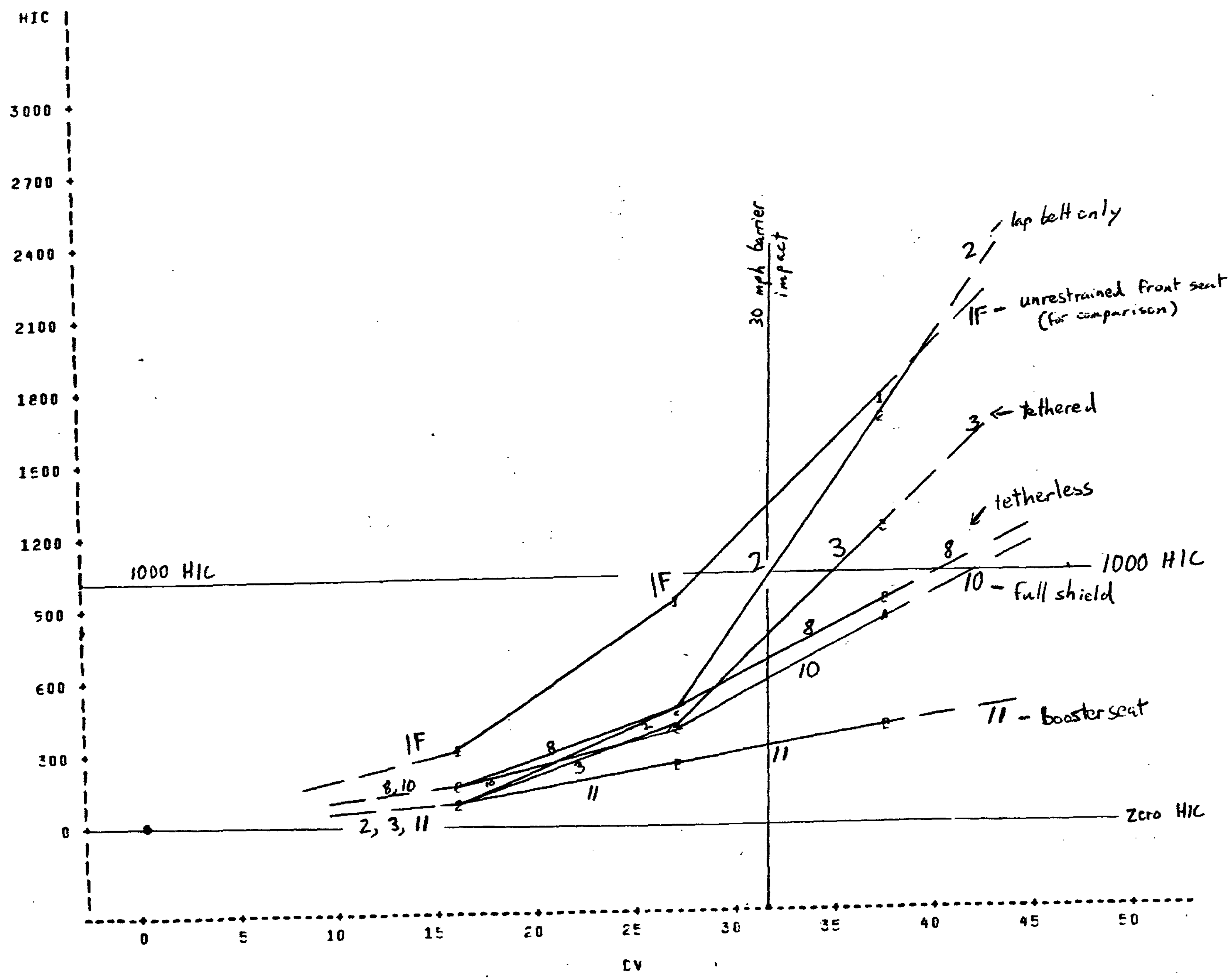
partially misused seats on third and fourth page

grossly misused seats on last two pages

unrestrained (front seat) is shown on all pages, for comparison.

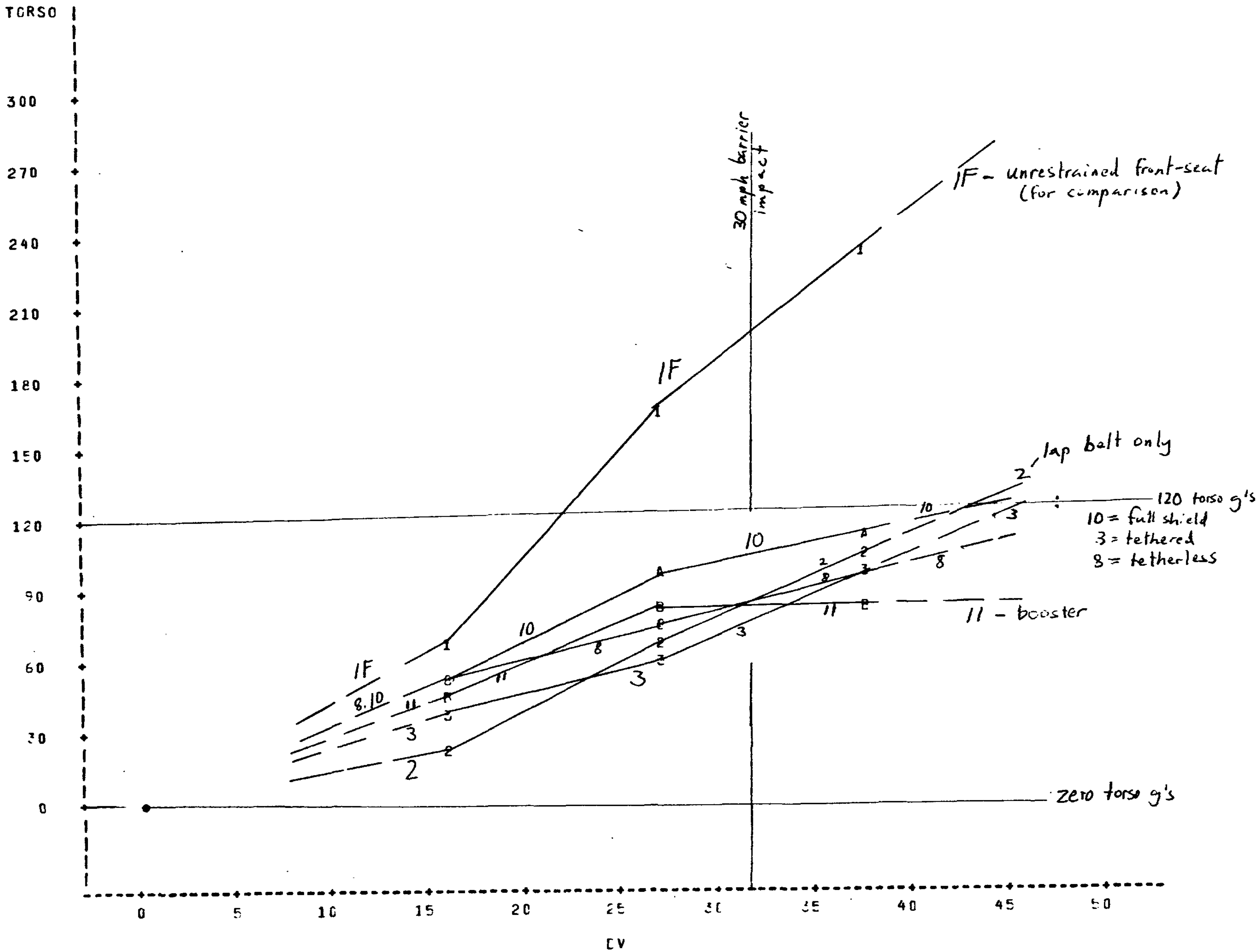
HIC BY DELTA V: CORRECTLY USED SEATS AND LAP BELTS

PLOT OF HIC*DV   SYMBOL IS VALUE OF USEMODE



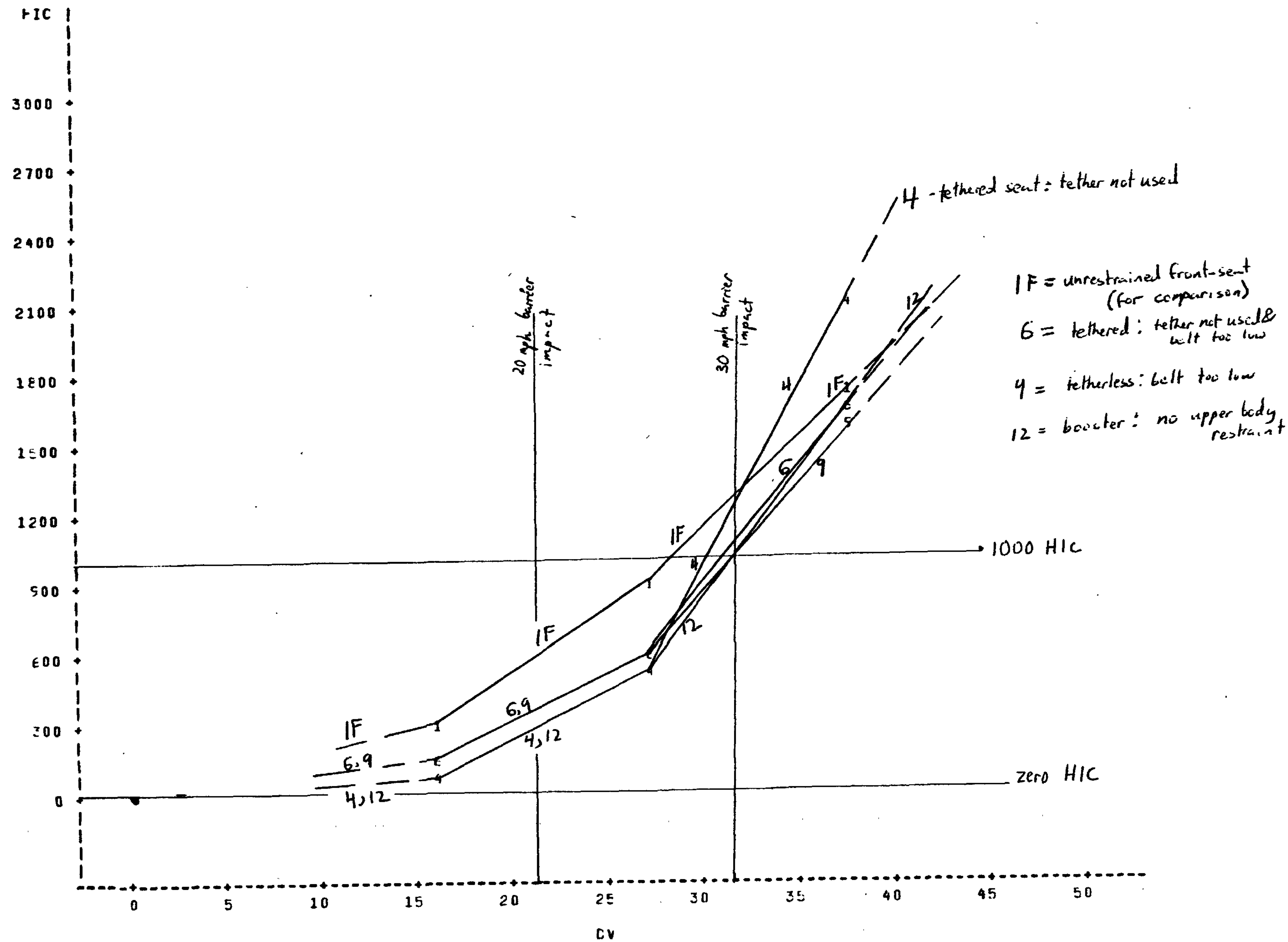
TORSO G BY DELTA V: CORRECTLY USED SEATS AND LAP BELTS

PLOT OF TORSO*DV   SYMBOL IS VALUE OF USEMODE



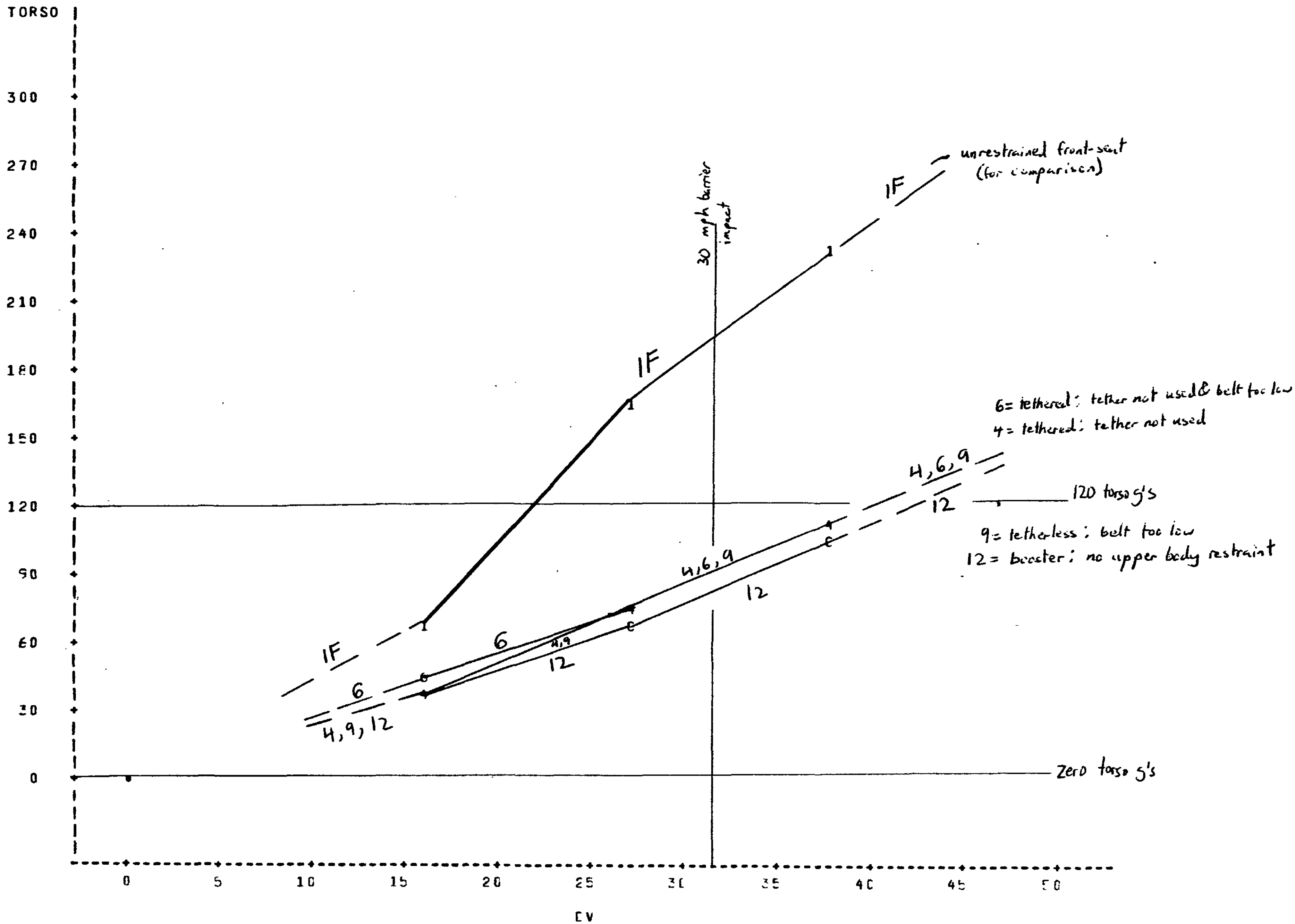
HIC BY DELTA V: PARTIALLY MISUSED SEATS

PLOT OF HIC*DV   SYMBOL IS VALUE OF USEMCDE



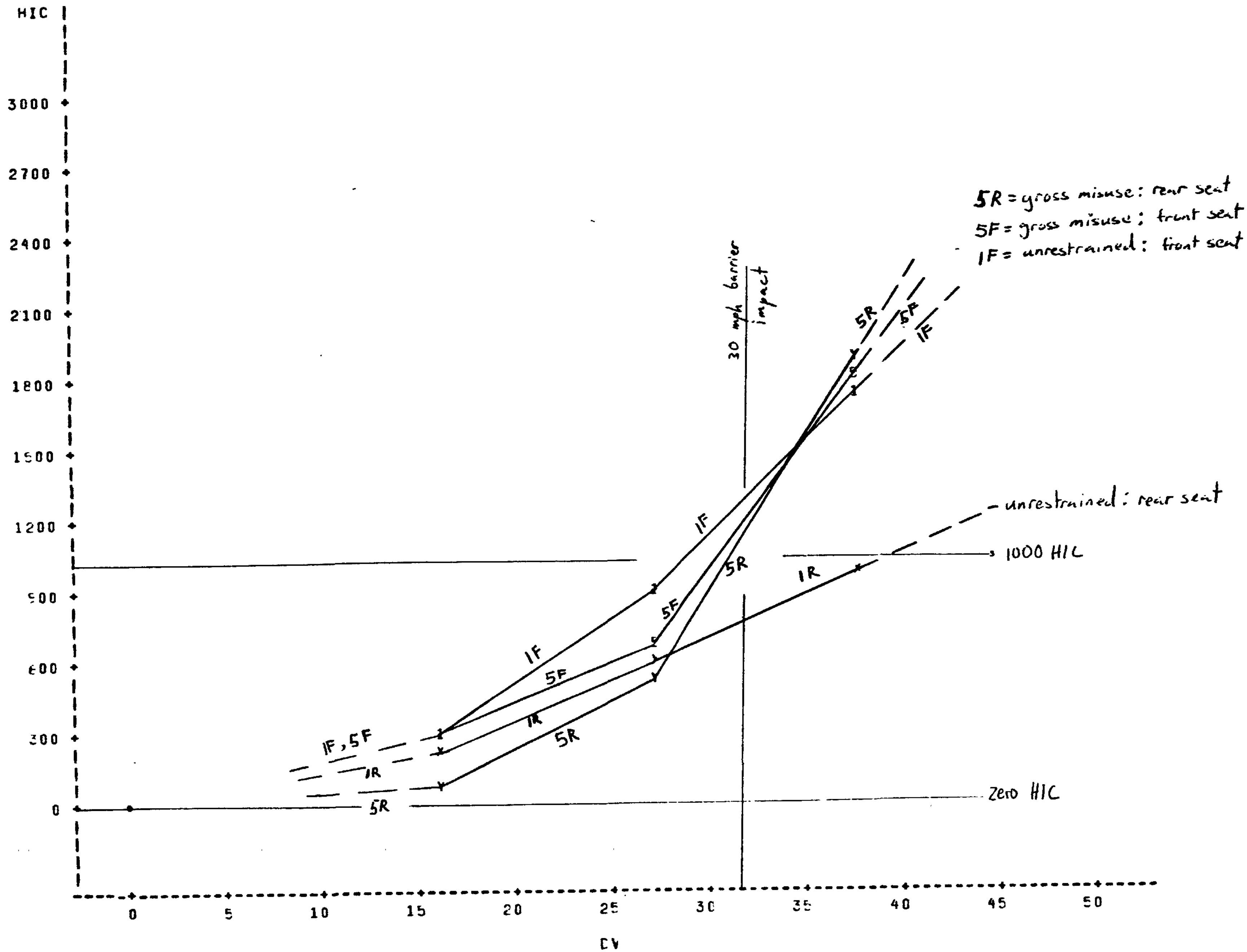
TORSO G BY DELTA V: PARTIALLY MISUSED SEATS

PLOT OF TORSO*DV   SYMBOL IS VALUE OF USEMODE



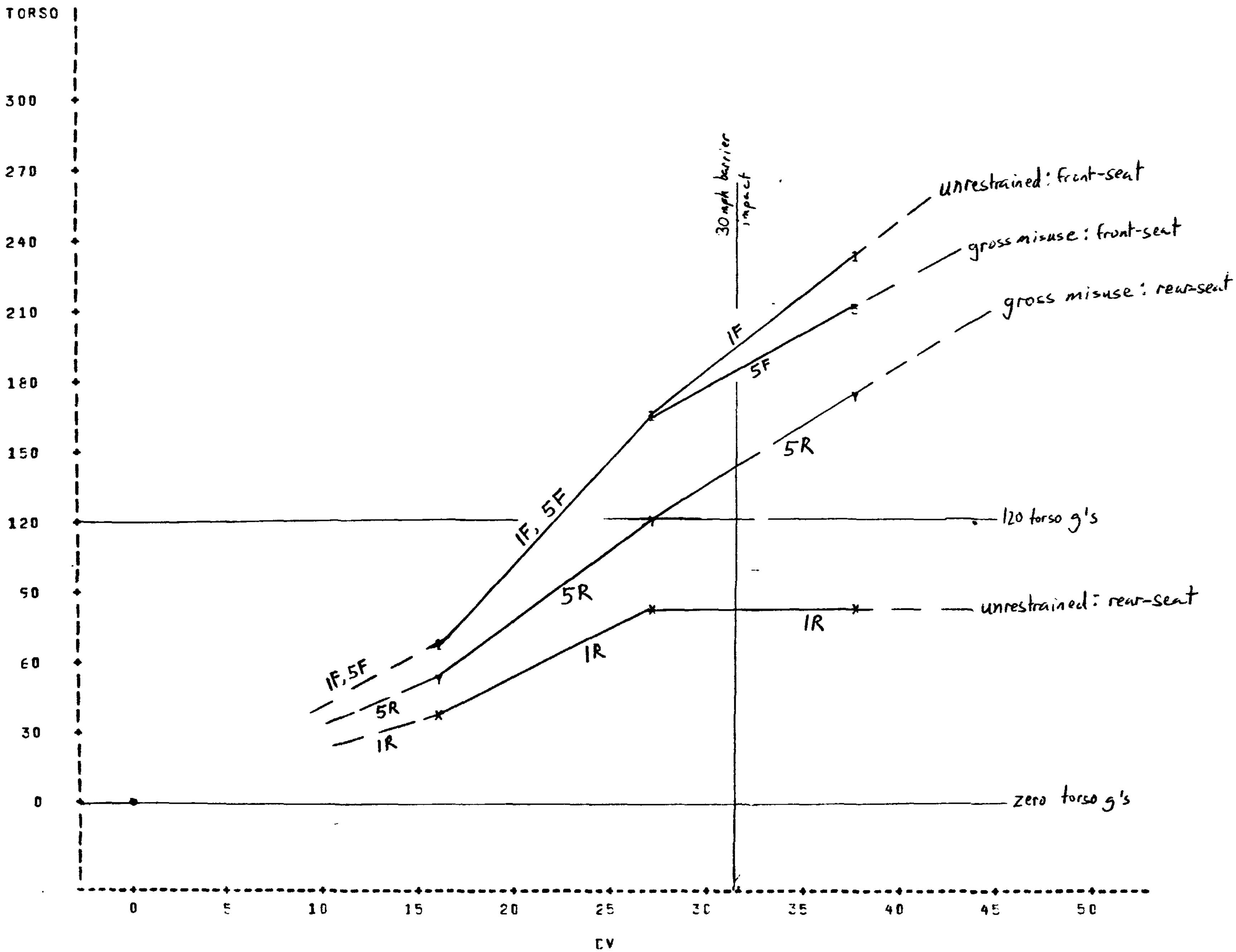
HIC BY DELTA V: UNRESTRAINED DUMMIES AND GROSSLY MISUSED SEATS

PLOT OF HIC*DV   SYMBOL IS VALUE OF USEMODE



TORSO G BY DELTA V: UNRESTRAINED DUMMIES, GROSSLY MISUSED SEATS

PLOT OF TORSO*DV   SYMBOL IS VALUE OF USEMODE



APPENDIX 5

NHTSA COMPLIANCE TEST RESULTS (1981-84)

Notes:

(1) REPTNO = Calspan's report number

(2) ACCDATE = NHTSA's acceptance date for the report. This identifier and the preceding one are used to locate reports at the NHTSA Technical Reference Library.

(3) MODEL, MODELNO: The first is usually the name by which the seat is known to the public; the second is the manufacturer's catalog number. There are some exceptions.

(4) SPEED = actual impact speed (mph)

(5) CHEST = chest g's

(6) HDEXCURS = head excursion (inches)

(7) 27.5 mph tests with correctly used seats are on the first 3 pages; 18.5 mph partial misuse tests are on the last page.

NHTSA COMPLIANCE TEST RESULTS (1981-84)
CORRECTLY USED SEATS - 27.5 MPH TESTS

SEATTYPE=TETHERED

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
1	82017	8306	STROLEE WEE CARE	599	595	27.2	351	35.8	24.7
2	82017	8306	STROLEE WEE CARE	599	595	27.1	380	41.2	28.9
3	82018	8306	STROLEE WEE CARE	597	597A	27.6	432	36.5	26.0
4	83018	8407	STROLEE WEE CARE	599	599	27.2	420	44.5	29.4
5	82015	8306	QUESTOR BOBBY MAC	SUPER	614	27.4	289	36.5	23.3

SEATTYPE=TETHERED BELTARCUND

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
6	81003	8210	CENTURY	CHILD LOVE SEAT	4600	27.6	334	38.3	23.3
7	82011	8305	CENTURY	CHILD LOVE SEAT	4600	27.5	333	38.6	22.9

SEATTYPE=TETHERLESS BELTARCUND

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
8	82013	8306	QUESTOR BOBBY MAC	CHAMPION	611	27.5	438	35.5	28.9
9	82013	8306	QUESTOR BOBBY MAC	CHAMPION	611	27.4	366	45.3	28.2
10	82014	8306	QUESTOR BOBBY MAC	DELUXE II	612	27.7	487	32.8	29.6
11	83008	8407	QUESTOR BOBBY MAC	411	411	27.3	463	35.7	27.4
12	83009	8407	QUESTOR BOBBY MAC	412	412	27.3	604	37.8	26.9
13	84019	8504	QUESTOR BOBBY MAC	412	412	27.6	545	35.6	28.7
14	84019	8504	QUESTOR BOBBY MAC	412	412	27.6	482	36.4	27.9
15	84019	8504	QUESTOR BOBBY MAC	412	412	27.5	676	34.8	29.6
16	82021	8305	KOLCRAFT	HI-RIDER	1903	27.5	514	53.6	28.1
17	82021	8305	KOLCRAFT	HI-RIDER	1903	27.3	425	35.8	27.4
18	82007	8305	WELSH	TRAVEL-TOT	567	27.3	616	40.1	29.3
19	83015	8406	WELSH	TRAVEL-TOT	7809	27.4	734	40.8	28.9
20	84024	8505	WELSH	TRAVEL-TOT	7809	27.5	743	43.6	28.2

SEATTYPE=HARNESS ONLY

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
21	83017	8407	STROLEE WEE CARE	612	612	27.4	602	47.6	26.7
22	81005	8211	CENTURY	100	4100	27.5	335	48.1	30.3
23	81010	8211	CENTURY	300	4300	27.4	393	39.5	30.7
24	81010	8211	CENTURY	300	4300	27.5	275	37.4	30.9
25	82005	8303	CENTURY	100	4100	27.6	333	46.5	29.5
26	82010	8305	CENTURY	300	4300	27.2	275	36.7	30.4
27	84005	8505	CENTURY	300	4314	27.5	325	38.0	29.8
28	84005	8505	CENTURY	300	4314	27.5	265	33.5	28.8
29	81005	8211	COSCO/PETERSON	SAFE-T-SEAT	78	27.5	395	41.1	30.2
30	82004	8303	COSCO/PETERSON	SAFE & EASY	313	27.3	232	43.5	29.3
31	82006	8303	COSCO/PETERSON	SAFE-T-SEAT	78	27.4	387	50.0	28.7
32	84009	8505	COSCO/PETERSON	SAFE-T-SEAT	178	27.5	222	34.7	29.3
33	81014	8210	QUESTOR (OTHER)	CAR SEAT	585	27.5	331	34.4	29.8
34	82003	8303	QUESTOR (OTHER)	CAR SEAT	585	27.4	304	42.2	29.3
35	83006	8406	QUESTOR (OTHER)	SAFE GUARD	301	27.4	227	38.5	29.7

NHTSA COMPLIANCE TEST RESULTS (1981-84)
CORRECTLY USED SEATS - 27.5 MPH TESTS

---------- SEATTYPE=HARNESS ONLY ----------

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
36	83020	8407	KOLCRAFT	HI-RIDER XL	1733	27.5	356	37.7	28.1
37	83020	8407	KOLCRAFT	HI-RIDER XL	1733	27.4	374	34.1	27.8
38	84015	8504	KOLCRAFT	HI-RIDER XL2	17818	27.3	315	32.6	28.9
39	84015	8504	KOLCRAFT	HI-RIDER XL2	17818	27.4	240	25.4	30.4
40	82016	8305	INTERNATIONAL	ASTROSEAT	9100A	27.3	282	35.1	30.2
41	82016	8305	INTERNATIONAL	ASTROSEAT	9100A	27.3	183	33.2	30.3
42	84013	8504	INTERNATIONAL	ASTROSEAT	9100A	27.4	289	38.8	28.6
43	81012	8211	WELSH	TRAVEL-TOT	368	27.5	404	31.5	25.5
44	81012	8211	WELSH	TRAVEL-TOT	368	27.5	316	36.4	29.5
45	84012	8505	GRACO	LITTLE TRAV'LER	310	27.4	360	36.6	29.0
46	84012	8505	GRACO	LITTLE TRAV'LER	310	27.6	257	38.1	27.9
47	83001	8406	PRIDE TRIMBLE	PRIDE-RIDE	820	27.5	277	40.6	30.5
48	83002	8406	PRIDE TRIMBLE	PRIDE-RIDE	830	27.5	556	41.8	28.4
49	84018	8503	PRIDE TRIMBLE	PRIDE-RIDE	835	27.6	347	34.4	25.3
50	82023	8305	BABYHOOD	WONDA CHAIR	810	27.4	555	38.1	26.1
51	82023	8305	BABYHOOD	WONDA CHAIR	810	27.5	451	44.5	27.4
52	82023	8305	BABYHOOD	WONDA CHAIR	810	27.6	359	40.5	27.6
53	83014	8406	BABYHOOD	WONDA CHAIR	810	27.5	248	37.5	25.7
54	83014	8406	BABYHOOD	WONDA CHAIR	810	27.5	215	36.6	25.1
55	84001	8507	BABYHOOD	WONDA CHAIR	810	27.4	313	46.6	29.0
56	84001	8507	BABYHOOD	WONDA CHAIR	810	27.5	299	45.7	29.0
57	84001	8507	BABYHOOD	WONDA CHAIR	810	27.6	280	46.8	28.5

---------- SEATTYPE=PARTIAL SHIELD ----------

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
58	83016	8407	STROLEE WEE CARE	618	618	27.4	485	42.4	28.4
59	81007	8211	CENTURY	200	4200	27.4	465	42.6	31.0
60	82009	8305	CENTURY	200	4200	27.5	338	35.5	31.0
61	84004	8505	CENTURY	200	4210	27.4	314	42.1	29.9
62	84004	8505	CENTURY	200	4210	27.6	204	32.5	28.9
63	81008	8211	COSCO/PETERSON	SAFE & SOUND	323	27.6	455	42.0	26.8
64	82005	8303	COSCO/PETERSON	SAFE & SOUND	323	27.3	648	43.4	28.5
65	83024	8406	COSCO/PETERSON	SAFE-T-MATE	376A	27.4	425	41.1	27.9
66	83024	8406	COSCO/PETERSON	SAFE-T-MATE	376A	27.4	441	34.3	30.0
67	83007	8406	QUESTOR (OTHER)	ONE STEP	402	27.2	434	38.8	28.7
68	83007	8406	QUESTOR (OTHER)	ONE STEP	402	27.4	325	33.2	28.7
69	83021	8407	KOLCRAFT	REDI-RIDER	1753	27.4	410	31.2	28.3
70	83021	8407	KOLCRAFT	REDI-RIDER	1753	27.3	332	29.2	26.6
71	83004	8406	COLLIER-KEYWORTH	SAFE & SOUND		27.3	414	34.8	29.6
72	83004	8406	COLLIER-KEYWORTH	SAFE & SOUND		27.6	330	35.7	29.2
73	84007	8504	COLLIER-KEYWORTH	ROUNDTRIPPER	503	27.5	266	35.3	29.4
74	84007	8504	COLLIER-KEYWORTH	ROUNDTRIPPER	503	27.5	205	32.4	28.9
75	84008	8504	COLLIER-KEYWORTH	SAFE & SOUND II	511	27.5	230	33.8	28.3
76	83013	8406	INTERNATIONAL	ASTROSEAT	9300A	27.4	246	32.8	28.5
77	84014	8504	INTERNATIONAL	ASTROSEAT	9300	27.5	362	33.2	30.0
78	84014	8504	INTERNATIONAL	ASTROSEAT	9300	27.5	212	32.3	28.1
79	83005	8406	GRACO	LITTLE TRAV'LER	3151	27.4	745	35.4	31.3
80	84017	8505	NISSAN	NERI	5110	27.5	528	32.6	32.2
81	84017	8505	NISSAN	NERI	5110	27.6	448	30.1	32.6
82	84017	8505	NISSAN	NERI	5110	27.6	544	33.3	31.7

NHTSA COMPLIANCE TEST RESULTS (1981-84)
CORRECTLY USED SEATS - 27.5 MPH TESTS

-- SEATTYPE=PARTIAL SHIELD --

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
83	84017	8505	NISSAN	NERD	5110	27.5	419	31.4	32.3
84	84017	8505	NISSAN	NERD	5110	27.5	517	34.7	31.5
85	84017	8505	NISSAN	NERD	5110	27.4	504	34.4	29.7

-- SEATTYPE=FULL SHIELD --

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
86	81011	8211	COSCO/PETERSON	SAFE-T-SHIELD	81	27.5	830	50.2	25.3
87	81011	8211	COSCO/PETERSON	SAFE-T-SHIELD	81	27.6	1056	40.6	28.2
88	81011	8211	COSCO/PETERSON	SAFE-T-SHIELD	81	27.5	913	37.5	27.8
89	81011	8211	COSCO/PETERSON	SAFE-T-SHIELD	81	27.6	765	35.9	26.8
90	83023	8406	COSCO/PETERSON	SAFE-T-SHIELD	1810	27.4	501	43.8	28.6
91	83023	8406	COSCO/PETERSON	SAFE-T-SHIELD	1810	27.4	533	41.3	28.3
92	84011	8505	COSCO/PETERSON	SAFE-T-SHIELD	2181	27.4	619	36.8	25.6
93	84011	8505	COSCO/PETERSON	SAFE-T-SHIELD	2181	27.6	665	37.4	28.8

-- SEATTYPE=SHIELD BOOSTER --

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
94	84021	8503	QUESTOR BOBBY MAC	LINKS	47516	27.5	633	36.8	27.3
95	84016	8503	KOLCRAFT	TOT-RIDER QUIKSTEP	19630	27.5	297	26.0	29.8
96	83003	8406	COLLIER-KEYWORTH	CO-PILOT		27.5	791	36.8	28.9
97	84006	8504	COLLIER-KEYWORTH	CO-PILOT II	971	27.5	562	32.0	28.9
98	82024	8305	FORD	TOT-GUARD		27.5	410	35.4	26.0

-- SEATTYPE=BOOSTER --

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
99	82019	8306	STROLEE WEE CARE	614	604	27.4	432	38.6	21.0
100	84022	8505	STROLEE WEE CARE	614	604	27.5	508	38.1	21.2
101	84023	8504	STROLEE WEE CARE	612	602	27.5	540	37.0	20.2
102	81008	8210	CENTURY	SAFE-T-RIDER	4760	27.4	686	47.5	20.5
103	82012	8305	CENTURY	SAFE-T-RIDER	4760	27.4	737	48.3	18.7
104	83010	8406	CENTURY	SAFE-T-RIDER II	4770	27.3	678	34.6	18.9
105	84003	8504	CENTURY	SAFE-T-RIDER II	4760	27.4	732	33.9	23.6
106	83025	8407	COSCO/PETERSON	DELUXE HI-LO	383	27.2	464	44.5	21.6
107	83026	8407	COSCO/PETERSON	HI-LO	183	27.4	415	36.5	20.9
108	82022	8305	KOLCRAFT	TOT-RIDER	15230	27.4	450	33.3	21.6
109	83013	8407	KOLCRAFT	TOT-RIDER XL	1963	27.2	364	40.2	22.3
110	83012	8406	INTERNATIONAL	ASTRORIDER	6000	27.2	460	44.0	19.9

NHTSA COMPLIANCE TEST RESULTS (1981-84)
PARTIALLY MISUSED SEATS - 18.5 MPH TESTS

----- SEATTYPE=TETHERED   MISUSE=TETHER NOT USED -----

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
1	82017	8306	STROLEE WEE CARE	599	599	18.5	112	20.3	29.2
2	82018	8306	STROLEE WEE CARE	597	597A	18.4	159	15.5	29.4
3	82015	8306	QUESTOR BOBBY MAC	SUPER	814	18.3	134	22.3	25.8

----- SEATTYPE=TETHERLESS BELTARCUAC   MISUSE=SHIELD, NO HARNESS -----

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
4	82013	8306	QUESTOR BOBBY MAC	CHAMPION	811	18.4	101	22.0	27.3
5	82014	8306	QUESTOR BOBBY MAC	DELUXE II	812	18.3	57	23.1	27.7
6	83008	8407	QUESTOR BOBBY MAC	411	411	18.6	197	25.8	28.7
7	83009	8407	QUESTOR BOBBY MAC	412	412	18.4	235	28.9	27.0
8	82007	8305	WELSH	TRAVEL-TOT	987	18.4	107	25.1	29.2
9	83015	8406	WELSH	TRAVEL-TOT	7809	18.5	157	22.0	27.4
10	84024	8505	WELSH	TRAVEL-TOT	7805	18.4	220	23.5	27.8

----- SEATTYPE=HARNESS ONLY   MISUSE=SHIELD, NO HARNESS -----

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
11	83002	8406	PRIDE TRIMBLE	PRIDE-RIDE	830	18.5	141	24.0	26.8
12	84018	8503	PRIDE TRIMBLE	PRIDE-RIDE	835	18.5	136	23.1	30.4

----- SEATTYPE=BOOSTER   MISUSE=NO TETHER HARNESS -----

OBS	REPTNO	ACCDATE	BRAND	MODEL	MODELNO	SPEED	HIC	CHEST	HDEXCURS
13	82015	8306	STROLEE WEE CARE	604	604	18.2	369	18.0	31.0
14	84022	8505	STROLEE WEE CARE	604	604	18.5	1071	16.4	29.9
15	84022	8505	STROLEE WEE CARE	604	604	18.6	431	13.6	29.2
16	84022	8505	STROLEE WEE CARE	604	604	18.6	401	14.2	29.7
17	84023	8504	STROLEE WEE CARE	602	602	18.4	582	16.9	29.7
18	82012	8305	CENTURY	SAFE-T-RIDER	4760	18.3	188	15.5	30.9
19	83010	8406	CENTURY	SAFE-T-RIDER II	4770	18.3	283	14.5	30.8
20	84003	8504	CENTURY	SAFE-T-RIDER II	4760	18.5	350	14.2	31.7
21	83025	8407	COSCO/PETERSON	DELUXE HI-LO	383	18.6	413	16.7	32.6
22	83025	8407	COSCO/PETERSON	DELUXE HI-LO	383	18.5	94	12.5	31.0
23	83025	8407	COSCO/PETERSON	DELUXE HI-LO	383	18.5	122	15.9	31.5
24	83026	8407	COSCO/PETERSON	HI-LO	183	18.3	146	14.3	30.7
25	82022	8305	KOLCRAFT	TOT-RIDER	15230	18.3	357	18.1	32.8
26	82022	8305	KOLCRAFT	TOT-RIDER	15230	18.6	370	19.6	32.1
27	82022	8305	KOLCRAFT	TOT-RIDER	15230	18.5	349	18.7	31.9
28	82022	8305	KOLCRAFT	TOT-RIDER	15230	18.6	372	17.5	32.4
29	83019	8407	KOLCRAFT	TOT-RIDER XL	1583	18.5	402	15.5	30.1
30	83012	8406	INTERNATIONAL	ASTRORIDER	6000	18.4	535	15.0	30.0

REFERENCES

[1] "The Abbreviated Injury Scale (AIS)." American Association for Automotive Medicine, Morton Grove, Illinois, 1976. (DOT HS-017 983)

[2] "Accident Facts, 1984 Edition." National Safety Council, Chicago, 1984.

[3] Bayer, A. R., Jr. and Peterson, B. S. "Child Restraint Systems Testing." National Technical Information Service, Springfield, Virginia, 1978. (DOT HS-803 408)

[4] Best Products Co., Rockville, Maryland. Prices quoted to C. J. Kahane (NHTSA), June 13, 1985.

[5] "'Cats' Cast Members Appear in DOT Child Safety Seat Public Service Announcement." Press Release No. NHTSA 01-85, Department of Transportation, Washington, January 8, 1985.

[6] Chi, G. Y. H. "The Effect of Seat Belt Usage Misclassification Errors on Seat Belt Effectiveness Estimates." Highway Safety Research Center, Chapel Hill, 1980.

[7] Chi, G. Y. H. "Statistical Evaluation of FMVSS 213 (Child Seating Systems)." National Technical Information Service, Springfield, Virginia, 1982. (DOT HS-806 238)

[8] "Child Restraints: Immunization against Tragedy." Journal of American Insurance, Volume 58, No.1, Spring 1982. (DOT HS-033 957)

[9] "Child Safety Seat Identification Guide." Manuscript prepared for NHTSA by Goodell-Grivas, Inc., 1984. (DOT HS-806 700)

[10] Clark, C. C. and Kahane, C. J. "Contract Technical Managers' Addendum" to Final Report, NHTSA Contract No. DTNH22-83-C-06010. Submission to NHTSA Docket 85-16-N01-002, 1984.

[11] Code of Federal Regulations, Title 49. Government Printing Office, Washington, 1981, Part 572.

[12] "Collision Deformation Classification." SAE Recommended Practice No. J224 MAR80, 1985 SAE Handbook, Volume 4, Society of Automotive Engineers, Warrendale, Pennsylvania, 1985.

[13] Consumer Reports, Volume 37, No. 8, August 1972, p. 484.

[14] Cynecki, M. J. and Goryl, M. E. "The Incidence and Factors Associated with Child Safety Seat Misuse." National Technical Information Service, Springfield, Virginia, 1984. (DOT HS-806 676)

[15] Decker, M. D. et al. "The Use and Efficacy of Child Restraint Devices: The Tennessee Experience, 1982 and 1983." Journal of the American Medical Association, Volume 252, No. 18, November 9, 1984.

[16] Dixon, W. J., ed. BMDP Statistical Software, 1983 Printing with Additions. University of California Press, Berkeley, 1983.

[17] "Estimated Sales of Child Safety Seats and Booster Seats." NHTSA Rulemaking, May 11, 1984.

[18] "Evaluation of Child Restraint Systems Effectiveness." Contract No. DOT-HS-9-02259 between NHTSA and Opportunity Systems, Inc., September 30, 1979.

[19] "A Family Shopping Guide to Infant/Child Automobile Restraints." Michigan Office of Highway Safety Planning, Lansing, 1979.

[20] Federal Register, Volume 35, September 23, 1970, p. 14778.

[21] Federal Register, Volume 44, December 13, 1979, p. 72131.

[22] Federal Register, Volume 46, February 17, 1981, p. 13193.

[23] Federal Register, Volume 50, January 8, 1985, p. 1036.

[24] "51 Young Lives." Tennessee Highway Patrol, Nashville, 1983. (DOT HS-034 896)

[25] "Final Regulatory Impact Analysis - Amendment to Federal Motor Vehicle Safety Standard 208 - Passenger Car Front Seat Occupant Protection." National Highway Traffic Safety Administration, Washington, 1984. (DOT HS-806 572)

[26] Goryl, M. E. and Cynecki, M. J. "Restraint System Usage in the Traffic Population," 1984 Annual Report. National Technical Information Service, Springfield, Virginia, 1985. (DOT HS-806 714)

[27] Grush, E. S., Henson, S. E. and Ritterling, O. R. "Restraint Systems Effectiveness." Report No. S-71-40, Automotive Safety Affairs Office, Ford Motor Co., September 21, 1971. (DOT HS-016 301)

[28] Hall, W. L. et al. "The Use of Telephone Interviews to Verify the Reliability of Police Accident Reports in Assessing the Effectiveness of Child Safety Seats," Final Report, NHTSA Contract No. DOT-HS-9-02259. Highway Safety Research Center, Chapel Hill, 1984. Submission to NHTSA Docket 85-16-N01-003.

[29] Harvey, M. R., Lesczhik, J. A. and McLean, R. F. "Cost Evaluation for Nine Federal Motor Vehicle Standards, Vol. 5: FMVSS 213." National Technical Information Service, Springfield, Virginia, 1979. (DOT HS-805 319)

[30] The Highway Safety Act of 1966, Public Law 89-564, as amended, 23 United States Code 401-408.

[31] "How to Help Kids Ride Safe." National Highway Traffic Safety Administration, Washington, 1979. (DOT HS-803 869)

[32] "Impact Assessment, Child Restraint Standard (FMVSS 213)." Submission to NHTSA Docket 74-09-N04-001, May 15, 1978.

[33] Information Please Almanac, Atlas & Yearbook 1985. Houghton Mifflin, Boston, 1984.

[34] "It's Your Child's Life...But it's Your Decision." Highway Safety Research Center, Chapel Hill and Governor's Highway Safety Program, Raleigh, 1984.

[35] Kahane, C. J. "An Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies: Standard 203 - Impact Protection for the Driver; Standard 204 - Rearward Column Displacement." National Technical Information Service, Springfield, Virginia, 1981. (DOT HS-805 705)

[36] Kahane, C. J. "An Evaluation of Head Restraints: Federal Motor Vehicle Safety Standard 202." National Technical Information Service, Springfield, Virginia, 1982. (DOT HS-806 108)

[37] Kahane, C. J. "An Evaluation of Side Structure Improvements in Response to Federal Motor Vehicle Safety Standard 214." National Technical Information Service, Springfield, Virginia, 1982. (DOT HS-806 314)

[38] Kahane, C. J. "An Evaluation of Windshield Glazing and Installation Methods for Passenger Cars." National Technical Information Service, Springfield, Virginia, 1985. (DOT HS-806 693)

[39] Kahane, C. J. "The National Highway Traffic Safety Administration's Evaluations of Federal Motor Vehicle Safety Standards." SAE Paper No. 840902, SAE Transactions, 1984. Society of Automotive Engineers, Warrendale, Pennsylvania, 1984.

[40] Kahane, C. J. "A Preliminary Evaluation of Two Braking Improvements for Passenger Cars: Dual Master Cylinders and Front Disc Brakes." National Technical Information Service, Springfield, Virginia, 1983. (DOT HS-806 359)

[41] Kahane, C. J. "Usage and Effectiveness of Seat and Shoulder Belts in Rural Pennsylvania Accidents." National Highway Traffic Safety Administration, Washington, 1974. (DOT HS-801 398)

[42] Kahane, C. J., Kossar, J. and Chi, G. Y. H. "Evaluation of the Effectiveness of Child Safety Seats in Actual Use." SAE Paper No. 831656, SAE Transactions, 1983 or SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[43] Kelleher, B. J. and Walsh, M. J. "Child Restraint Test Programs." Report No. 7057-V-1, Calspan Corp., Buffalo, 1982.

[44] Kelleher, B. J. and Walsh, M. J. "Sled Test Comparisons of Child Restraint Performance." SAE Paper No. 780903, Twenty-Second Stapp Car Crash Conference, Society of Automotive Engineers, Warrendale, Pennsylvania, 1978.

[45] Kelleher, B. J., Walsh, M. J., Dance, D. M. and Gardner, W. T. "An Experimental Study of the Effects of Child Restraint Improper Installation and Crash Protection for Larger Size Children." SAE Paper No. 831602, SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[46] Khadilkar, A. V. and Forrest, S. M. "Sled Tests for Evaluating Child Safety Seat Effectiveness," Final Report, NHTSA Contract No. DTNH22-83-C-06010. Submission to NHTSA Docket 85-16-N01-002, 1984.

[47] Knoop, J. C. et al. "Statistical Evaluation of the Effectiveness of Child Restraints." National Technical Information Service, Springfield, Virginia, 1980. (DOT HS-805 660)

[48] McHenry, R. R. "Extensions and Refinements of the CRASH Computer Program," Part 2. National Technical Information Service, Springfield, Virginia, 1976. (DOT HS-801 838).

[49] Mertz, H. J. and Weber, D. A. "Interpretation of the Impact Responses of a Three-Year-Old Child Dummy Relative to Child Injury Potential." Ninth International Technical Conference on Experimental Safety Vehicles, Pub. No. 84-207792, National Technical Information Service, Springfield, Virginia, 1983 (DOT HS-806 341)

[50] Mungenast, J. S. and Kahane, C. J. "Restraint Systems Evaluation Project Codebook." National Highway Traffic Safety Administration, Washington, 1977. (DOT HS-802 285)

[51] "NASS Data Collection, Coding and Editing Manual." NHTSA National Center for Statistics and Analysis, February 1979.

[52] "National Accident Sampling System, 1983." National Highway Traffic Safety Administration, Washington, 1985. (DOT HS-806 699)

[53] "National Accident Sampling System, 1982." National Highway Traffic Safety Administration, Washington, 1984. (DOT HS-806 530)

[54] National Crash Severity Study Accident Forms (used for NCSS-NASS). NHTSA National Center for Statistics and Analysis, May 1979.

[55] The National Traffic and Motor Vehicle Safety Act of 1966. Public Law 89-563, as amended, 15 United States Code 1381-1431.

[56] "Observations of Child Restraint and Safety Belt Use by Traverse Bay Area Children." Traverse Bay Area Child Passenger Safety Association, Traverse City, Michigan, 1979.

[57] Partyka, S. C. "The Analyst's Primer: Getting Started with National Accident Sampling System Data." NHTSA National Center for Statistics and Analysis, December 1983.

[58] Partyka, S. C. "Corrections for the Effect of Data Source on Restraint Effectiveness Estimates." NHTSA National Center for Statistics and Analysis, 1983.

[59] Partyka, S. C. "NCSS - The Analyst's Companion." National Highway Traffic Safety Administration, Washington, 1981. (DOT HS-805 871)

[60] Partyka, S. C. "Restraint Use and Fatality Risk for Infants and Toddlers." NHTSA National Center for Statistics and Analysis, 1984.

[61] Perkins, D. D., Cynecki, M. J. and Goryl, M. E. "Restraint System Usage in the Traffic Population." National Technical Information Service, Springfield, Virginia, 1984. (DOT HS-806 582)

[62] Phillips, B. M. "I Safety Belt Use among Drivers II Use of Child Restraint Devices, Passenger Safety Belts and Position of Passengers in Cars III Motorcycle Helmet Usage." National Technical Information Service, Springfield, Virginia, 1980. (DOT HS-805 398)

[63] Phillips, B. M. (Retired, formerly with Opinion Research Corp.). Remarks to C. J. Kahane and P. N. Ziegler (NHTSA), May 9, 1985.

[64] Phillips, B. M. "Restraint System Usage in the Traffic Population." National Technical Information Service, Springfield, Virginia, 1983. (DOT HS-806 424)

[65] "Proceedings of the National Conference on Child Passenger Protection." National Highway Traffic Safety Administration, Washington, 1981. (DOT HS-805 672)

[66] Radovich, V. G. "Development of Infant and Child Restraint Regulations and their Applications." SAE Paper No. 831665, SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[67] Radovich, V. G. (NHTSA). Remarks to C. J. Kahane (NHTSA), May 1, 1985.

[68] Radovich, V. G., Bayer, A. R., Benson, J. B. and Naab, K. N. "Development of Testing and Evaluation of Child Restraint Systems and Child Test Dummies by NHTSA." SAE Paper No. 791018, Twenty-Third Stapp Car Crash Conference, Society of Automotive Engineers, Warrendale, Pennsylvania, 1979.

[69] Reinfurt, D. W., Silva, C. Z., and Hochberg, Y. "A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes (Interim Report)." National Technical Information Service, Springfield, Virginia, 1976. (DOT HS-801 833)

[70] Reinfurt, D. W., Silva, C. Z. and Seila, A. F. "A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes." National Technical Information Service, Springfield, Virginia, 1976. (DOT HS-802 035)

[71] Ricci, L. "National Crash Severity Study Statistics." National Technical Information Service, Springfield, Virginia, 1979. (DOT HS-805 227)

[72] Sanders, R. S. and Dan, B. B. "Bless the Seats and the Children: The Physician and the Legislative Process." Journal of the American Medical Association, Volume 252, No. 18, November 9, 1984.

[73] SAS User's Guide, 1979 Edition. SAS Institute, Inc., Cary, North Carolina, 1979.

[74] Scherz, R. G. "Washington State Seat Belt Study 1970-77." Mary Bridge Children's Health Center, Tacoma, 1978. (DOT HS-023 657)

[75] Schlaifer, R. Probability and Statistics for Business Decisions. McGraw-Hill, New York, 1959.

[76] Shelness, A. and Jewett, J. "Observed Misuse of Child Restraints." SAE Paper No. 831665, SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[77] Snyder, R. G., Young, J. W. and Doyle, M. Q. "Biomechanical Evaluation of Steering Wheel Design." SAE Paper No. 820478, Occupant Crash Interaction with the Steering System, Society of Automotive Engineers, Warrendale, Pennsylvania, 1982.

[78] Spinney, B. C. "Regulatory Evaluation for Child Tether Anchorages." Submission to NHTSA Docket 80-18-N01-001, December 10, 1980.

[79] "State Accident Report Forms Catalogue, 1978 Edition." NHTSA Traffic Safety Programs, 1978.

[80] "State Child Passenger Safety Laws." NHTSA Traffic Safety Programs, March 15, 1985.

[81] Wagenaar, A. C. and Webster, D. W. "Effects of Michigan's Mandatory Child Restraint Law." The UMTRI Research Review, Volume 15, No. 4, January-February 1985.

[82] Weber, K. and Melvin, J. W. "Injury Potential with Misused Child Restraint Systems." SAE Paper No. 831604, SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[83] Weinstein, E. (National Child Passenger Safety Association). Remarks to C. J. Kahane (NHTSA), June 7, 1985.

[84] Weinstein-Lawless, E. and Siani, T. A. "The State of Child Passenger Safety Legislation in North America." SAE Paper No. 831650, SAE Child Injury and Restraint Conference Proceedings, Society of Automotive Engineers, Warrendale, Pennsylvania, 1983.

[85] Williams, A. F. "Observed Child Restraint Use in Automobiles." American Journal of Diseases of Children, Volume 130, December 1976.

[86] Wolanin, M. J. et al. "Development and Basis of a Three-Year-Old Child Dummy for Evaluating Passenger Inflatable Restraint Concepts." _Ninth International Technical Conference on Experimental Safety Vehicles_, Pub. No. 84-207792, National Technical Information Service, Springfield, Virginia, 1983. (DOT HS-806 341)

[87] "Work Plan: Sled Tests for Evaluating Child Safety Seat Effectiveness." Submitted by MCR Technology, Inc., to NHTSA, October 6, 1983.

[88] _The World Almanac & Book of Facts, 1985_. Newspaper Enterprise Association, New York, 1984.