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A STATISTICAL ANALYSIS OF SEAT BELT EFFECTIVENESS IN 1973-1975 MODEL CARS INVOLVED IN TOWAWAY CRASHES

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16. Abstract Standardized injury rates and seat belt effectiveness measures are derived from a probability sample of towaway accidents involving 1973-1975 model cars. The data were collected by NHTSA-sponsored teams in five different geographic regions. Weighted sample size available for the analysis is 15,818 occupants for which there is complete information on belt usage, AIS injury level, age, crash configuration, vehicle weight, and damage severity.

In order to obtain the standardized injury rates and effectiveness measures as well as estimates of their precision, several alternative procedures utilizing techniques for analysis of complex categorical data were examined. In Volume I, these techniques and their application to the data are described in detail. Results are presented for various injury levels for both the overall population as well as various subsets of interest (e.g., by model year, impact site or vehicle damage severity). A sensitivity analysis is carried out to determine the effect on the estimates of including various subsets of the control variables. Finally, the estimates are reworked using direct injury costs derived largely from insurance data.

Volume II contains a variety of tables detailing who was involved in the accidents investigated, where and when they occurred, and what make and model car was involved. This volume also serves as a "Fact Book" of information describing belt usage by various sub-populations; occupant injuries (including fatalities and belt-caused injuries); malfunction, defeat or maladjustment of belts; ejection; and problems encountered by unusual occupants.

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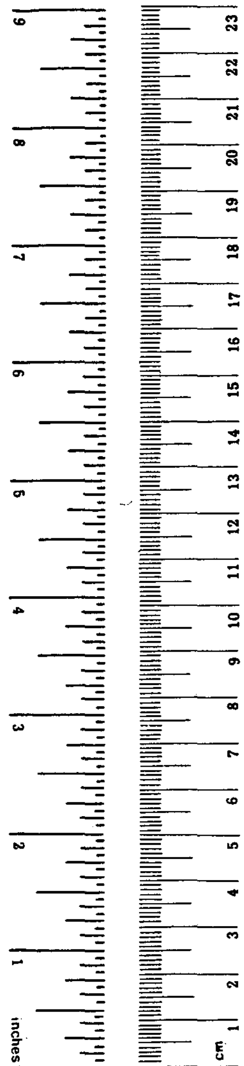
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

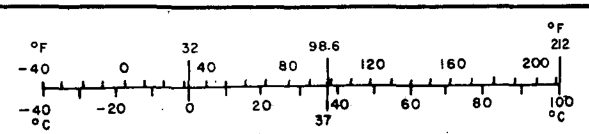
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



TECHNICAL SUMMARY

The many safety belt effectiveness studies in the literature agree on the positive benefits of these systems but vary considerably in their estimates of the magnitude of the effectiveness. Reasons for this disagreement include: (1) differing reporting thresholds for the accident data upon which the studies were based; (2) a variety of injury criteria even when using the K, A, B, C, O scale, due to state and regional differences; (3) differential attempts to control for certain variables which interact with belt usage, ranging from no attempt to control for vehicle damage severity, driver age, etc., to somewhat limited attempts that might control for one or two variables but most likely not some of their important interactions; and (4) varying investigative biases and inaccuracies in the data (especially police-reported accident data).

An additional problem with available information on safety belt effectiveness is that generally there are no rigorous estimates of the precision of the measures presented. All of these difficulties present serious problems for the policy makers faced with interpreting the results of the various studies.

The current study, which is part of the Restraint Systems Evaluation Program (RSEP) of the National Highway Traffic Safety Administration, has attempted to overcome these many problems. For this study, there is detailed information on over 15,000 (weighted) towaway accidents involving 1973-75 model passenger cars. A reasonably uniform reporting threshold can be expected since the accidents are towaway accidents. In addition, the limitation of the data to 1973-75 model year cars assures that the safety features in the vehicles are reasonably comparable and also guarantees uniformity in type of restraint system available to the outboard front seat occupants. This Level 2 data combines information from police reports with subject and witness interviews, hospital information, and investigation of the vehicle. National representativeness is strived for by utilizing NHTSA-sponsored accident investigation teams in Western New York, Michigan, Miami, San Antonio, and Los Angeles. And, finally, the effects of some of the most important confounding variables are accounted for in the multivariate analyses employed. To the extent possible, the corresponding estimates of the precision of the resulting effectiveness measures are derived.

In order to maximize the likelihood of obtaining detailed information on injured occupants, a stratified probability sample of towaway accidents was obtained. Occupants of vehicles in which at least one outboard front seat occupant was transported to a treatment facility were sampled at 100 percent. Otherwise, vehicles were selected basically at a 50 percent rate using the odd/even status of the terminal digit of the license plate as the randomizing mechanism.

On the basis of the available 15,818 weighted observations for which there was complete information on belt usage and injury level within the various combinations of crash configuration, vehicle damage severity, vehicle weight, and occupant age, 58.5 percent of the occupants were unrestrained, 16.1 percent wore a lap belt only and 25.4 percent wore both lap and shoulder belts. As the belt systems would generally be 3-point systems, it is not surprising to begin seeing greater usage of both belts than the lap belt alone--even in accidents. Belt usage by vehicle model year is given in Table S.1. As expected, lap and shoulder belt usage jumps considerably with the 1974 model vehicles which

Table S.1. Belt usage by model year.

Model Year	None	Lap	Lap-Shoulder	Total
1973	4646 (64.4%)[1]	2143 (29.7%)	430 (6.0%)	7219 (45.7%)[2]
1974	3615 (52.9%)	317 (4.6%)	2901 (42.5%)	6833 (43.3%)
1975	973 (55.8%)	84 (4.8%)	687 (39.4%)	1744 (11.0%)
Total	9234 (58.5%)	2544 (16.1%)	4018 (25.4%)	15796[3]

[1]Row percent
[2]Column percent
[3]Excludes 22 1976 models

were equipped with integral 3-point belts with inertial reels and locking retractors. In addition, an ignition interlock system was introduced which prevented the motorist from starting the car without first buckling up. For the 1974 vehicles the percentages for "none" and "lap" then primarily indicate defeat of the system or possibly reporting errors.

Also of interest is the restraint usage by injury (AIS) distribution for the sample (see Table S.2). For "injured" defined as "AIS $\geq$ 2", 9.4 percent of the sample was injured; for AIS $\geq$ 3, 2.4 percent; and for AIS = 6 (fatal), 0.54 percent. For AIS $\geq$ 2, the unadjusted or baseline injury rates from Table S.2 are 12.1 percent, 7.4 percent and 4.7 percent for the unrestrained (U), lap (L), and lap and shoulder (LS) belt categories, respectively. The corresponding injury rates for AIS $\geq$ 3 and AIS = 6 are 3.2, 1.5, 1.2 and 0.8, 0.2, 0.3, respectively.

Table S.2. Belt usage by injury level.

Belt Usage \ Injury Level	Total	AIS $\geq$ 2 (Moderate)	AIS $\geq$ 3 (Serious)	AIS = 6 (Fatal)
None	9242 (58.4%)[1]	1114 (12.1%)[2]	299 (3.2%)	70 (0.8%)
Lap	2544 (16.1%)	188 (7.4%)	38 (1.5%)	4 (0.2%)
Lap & Shoulder	4032 (25.5%)	191 (4.7%)	48 (1.2%)	12 (0.3%)
Total	15818	1493 (9.4%)	385 (2.4%)	86 (0.5%)

[1]Column percent
[2]Percent of total within belt category

Defining belt effectiveness as the relative decrease in injury as one becomes progressively more restrained, the overall unadjusted effectiveness measures for AIS $\geq$ 2 are .388, .612, and .365 for U vs. L, U vs. LS, and L vs. LS, respectively. For AIS $\geq$ 3, the corresponding effectiveness estimates are .531, .618, and .187. These overall injury rates and effectiveness measures provide unadjusted baseline estimates for subsequent comparisons.

To what extent does belt usage vary according to car size or crash configuration? Certainly, to make a fair comparison between the belt systems, it is important to control for the more important variables which interact with belt usage. Due to limitations on the quantity and distribution of the data along with the results of an investigation described in Appendix C of this report, it was decided to post-stratify (or control for) the following: crash configuration, vehicle damage severity, vehicle weight, and occupant age. The distribution of the available sample for each of these variables is given in Table S.3.

To appropriately control for these variables in a multivariate analysis procedure for categorical data, two estimation approaches are examined and the results compared in considerable detail, since each is not without limitations. As they yield fairly similar results, the limiting assumptions become more tolerable.

The first procedure, referred to as weighted least squares (GENCAT) estimation, utilizes categorical data techniques analogous to those of the general linear model applied to continuous variables. To derive estimates of standard errors, matrix inversion is required which necessitates collapsing the factor level combinations of the post-stratifying variables to 48 final

Table S.3. Sample distribution by crash configuration, damage severity, vehicle size, and occupant age.

Variable	Percent	Variable	Percent
CRASH CONFIGURATION		DAMAGE SEVERITY	
Front		1. Minor	45.8
1. Head-on with vehicle	6.5	2. Moderate	38.4
2. Rear-end, striking	15.7	3. Moderately severe	11.2
3. Angle, striking	21.7	4. Severe	4.6
4. Head-on with fixed object	13.2	VEHICLE SIZE	
Side		1. Subcompact (<2700 lbs)	30.5
5. Angle struck in left side	13.2	2. Compact (2700-3599)	25.4
6. Angle struck in right side	12.9	3. Intermediate (3600-4100)	22.9
7. Sideswipe	3.3	4. Full-sized (>4100)	21.2
8. Skidded sideways into fixed object	4.9	OCCUPANT AGE	
Rear		1. 10 - 25	47.7
9. Rear-end, struck	6.8	2. 26 - 55	42.6
Rollover		3. 56+	9.7
10. Rollover	1.9		

strata. This is done in a hypothesis testing framework utilizing log-linear model techniques.

The alternative procedure, referred to as Mantel-Haenszel-type estimation, expresses the standardized injury rate associated with a given restraint system as a bilinear form based on the vector of stratum injury rates (for that particular restraint system) and the vector of stratum weights. Estimates of the rates and their standard errors are then derived assuming random weights uncorrelated with the stratum injury rates.

Finally, effectiveness estimates are obtained from the derived standardized injury rates from both procedures. The corresponding standard errors are calculated utilizing a Taylor series expansion of the effectiveness measure.

Table S.4 presents the estimation results for the overall population for various injury levels and for non-fatal costs. As there are only 86

Table S.4. Injury (cost) rates and effectiveness estimates by belt usage.

Estimate[1]	Restraint System[2]	Injury AIS≥2		Injury AIS≥3		Average Cost (Non-fatals)	
		Unadj.	GENCAT	Unadj.	GENCAT	Unadj.	Mantel-Haenszel
$\hat{R}$	U	.121	.116	.032	.031	$147	$144
	L	.074	.080	.015	.017	100	109
	LS	.047	.051	.012	.013	83	90
$\hat{E}$	U vs L	.388	.309	.531	.463	.316[3]	.239
	U vs LS	.612	.565	.618	.568	.434	.377
	L vs LS	.365	.371	.187	.196	.173	.181

[1] $\hat{R}$ = injury (cost) rate
$\hat{E}$ = effectiveness estimate

[2] U = unrestrained
L = lap belted
LS = lap and shoulder belted

[3] Proportionate reduction in cost

fatals, adjusted estimates are not presented for this injury level. The unadjusted estimates provide a baseline for comparison purposes. Table S.5 provides similar results for AIS≥2 for particular subsets of interest.

Using the GENCAT estimation procedure, for AIS≥2 the overall adjusted injury rates become 11.6 percent, 8.0 percent, and 5.1 percent for unrestrained, lap belted, and lap and shoulder belted occupants, respectively.

Table S.5. Effectiveness estimates for the various damage and impact site levels.

Population		Restraint System	GENCAT Effectiveness Estimate AIS≥2	GENCAT Effectiveness Estimate AIS≥3
Damage	Minor	U vs L	.243	.461
		U vs LS	.564	.498
		L vs LS	.424	.068
	Moderate	U vs L	.286	.344
		U vs LS	.602	.653
		L vs LS	.443	.471
	Moderately Severe	U vs L	.329	.549
		U vs LS	.548	.623
		L vs LS	.326	.164
	Severe	U vs L	.418	.494
		U vs LS	.508	.489
		L vs LS	.154	-.010
Impact Site[1]	Front	U vs L	.231	.494
		U vs LS	.530	.539
		L vs LS	.389	.089
	Side	U vs L	.403	.413
		U vs LS	.589	.582
		L vs LS	.311	.288
	Rear	U vs L	.233	.385
		U vs LS	.478	.355
		L vs LS	.319	-.048

[1]Rollover is omitted due to severe sample size limitations (N=265).

Again, with belt effectiveness defined as the relative decrease in injury (AIS≥2) as one becomes progressively more restrained, the overall effectiveness measures become .309, .565, and .371 for U vs. L, U vs. LS, and L vs. LS, respectively. Approximate 95 percent confidence intervals are correspondingly given by (.223, .395), (.505, .625), and (.263, .479). For comparison purposes, confidence intervals for the Mantel-Haenszel-type estimates are given by (.204, .384), (.459, .581), and (.207, .433), respectively.

It is of interest to note that the primary overall effect of controlling for crash configuration, damage severity, vehicle weight and occupant age is to increase the crude injury rate for lap belted occupants from 7.4 percent to 8.0 percent while decreasing the rate for unrestrained occupants. This results in considerably reduced effectiveness of the lap belt; likewise for lap and shoulder belted occupants. In addition, the greater the stratification, the greater the effect on the resulting estimates; that is, the GENCAT estimates are intermediate between the unadjusted estimates and the Mantel-Haenszel-type estimates.

It is to be expected that accounting for each of the control variables will differentially affect the overall injury rates and therefore the effectiveness estimates; likewise for various combinations of the control variables. To examine this effect, a detailed sensitivity analysis was carried out based on the data available for the Interim Report. In essence, the analysis was aimed at the question: "What is the effect of controlling for vehicle damage? crash configuration? damage by crash configuration? etc." Although sensitivity across various subsets of the data was also examined, attention here is focused on the overall effectiveness measures. Each entry in Table S.6 represents the difference between the unadjusted effectiveness estimates and those estimates derived

Table S.6. Sensitivity analysis: Examination of the effect on the unadjusted belt effectiveness estimates of controlling for different combinations of those variables most highly associated with injury (AIS≥2).[1]

Subset	(GENCAT estimate) - (Unadjusted estimate)		
	U vs L	U vs LS	L vs LS
Crash configuration (C)	-.0553	-.0271	+.0072
Vehicle weight (W)	-.0062	+.0158	+.0280
Vehicle damage (D)	-.0354	-.0120	+.0121
Age/seating position (A)	+.0039	-.0003	-.0038
C × W	-.0596	-.0148	+.0271
C × D	-.1065	-.0605	+.0027
C × A	-.0055	-.0051	-.0027
W × D	-.0416	-.0059	+.0254
W × A	+.0030	+.0101	+.0121
D × A	-.0396	-.0144	+.0123
C × W × D	-.0633	-.0204	+.0223
C × W × A	-.0088	+.0072	+.0177
C × D × A	-.0614	-.0354	+.0009
W × D × A	-.0444	-.0006	+.0348
C × W × D × A	-.0918	-.0204	+.0430

[1]Results derive from Interim Report (Reinfurt, Silva, Hochberg, 1975).

with the subset of control variables cited. For example, accounting for crash configuration reduces the unadjusted effectiveness estimate of lap belts by .0553 (from .3110 to .2557) whereas accounting simultaneously for crash configuration and damage reduces the unadjusted estimate by .1065.

Generally, it would seem that controlling for vehicle damage is most important, with crash configuration next in importance. This is also confirmed in the analysis described in Appendix C. Clearly, controlling for age/seating position has the least effect on the crude effectiveness estimates.

After ascertaining that reasonably adequate data was available for estimating the direct cost of injury for each occupant on the Level 2 file, the necessary data was acquired and the methodology developed. Estimates of medical expenses (hospital, emergency room, professional services) for specific injuries and treatments on the file were computed from insurance data and lost wages from standard economic expenses and average disability estimates.

With the derived cost estimates assigned to the Level 2 file, estimated overall standardized non-fatal costs for each belt category are presented in Table S.4. Due to a most skewed direct cost distribution, the usefulness of the resulting estimates may be somewhat limited.

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I. INTRODUCTION

The great variety of studies on the subject of safety belt effectiveness have one thing in common - they virtually all agree that these active restraint systems available in all recent model cars sold in the United States are effective in reducing injuries and deaths in motor vehicle collisions. One important aspect in which they disagree is the magnitude of this effectiveness. As alternatives to these systems are being considered, it is most important to know, as nearly as possible, the "true" effectiveness of lap belt and lap and shoulder belt systems, and this implies knowledge about the precision of these estimates derived, for example, from a well-controlled field study of accidents.

As described in detail in Kahane, Lee, and Smith (1975), most studies of safety belt effectiveness have been based solely on existing traffic accident records (Level 1 data) provided by reporting police agencies. This data source generally provides the necessary quantity of data but lacks much of the needed data quality. Clearly, even a Highway Patrol accident reporting system cannot be considered nationally representative as, among other things, it would overrepresent rural crashes. In addition, generally such sources do not provide information on certain important variables or else not in sufficient detail to be used in an appropriate analysis. As these variables (e.g., specific crash configuration, damage severity, vehicle weight) have an important effect on injury severity, information on them must be available in adequate detail. Also, one of the most important variables, injury, is typically described by the K, A, B, C, O scale, which is extraordinarily broad, ill-defined and very subjective, making it most unsatisfactory for analysis purposes.

In addition, there are often numerous investigative biases and inaccuracies in the Level 1 accident data as, for example, serious conflict between police-reported and occupant-reported belt usage (see Hochberg and Reinfurt, 1974). Furthermore, reporting thresholds differ so greatly (even within some states) that a given study may be based on a rather non-homogeneous or biased sample of accident reports.

Clearly, studies based on in-depth accident investigations (Level 3 data) avoid most of the above-mentioned pitfalls. However, they would not meet the requirement of being nationally representative nor would they provide a large random sample upon which to base subsequent statistical inference.

This study is based on an intermediate level of data referred to as Level 2 accident data. It combines information provided from police reports with subject and witness interviews, hospital information, and investigation of the vehicle. The data derives from five NHTSA-sponsored teams distributed across the United States (namely, Western New York, Michigan, Miami, San Antonio (Texas), and Los Angeles; see Figure 1.1).

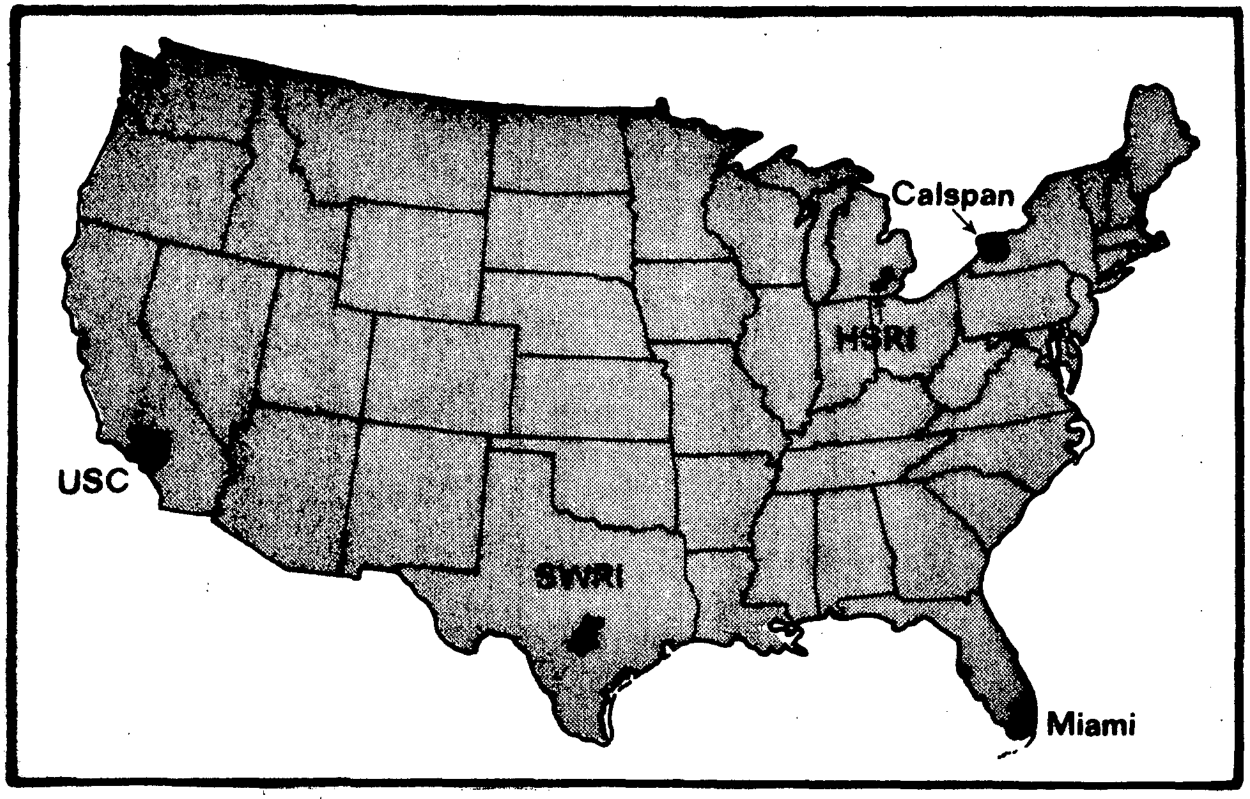

Figure 1.1. Location of Level 2 accident investigation teams

Of interest are towaway accidents involving 1973 and newer model passenger cars. As "towaway" is reasonably well-defined, the reporting threshold should be consistent across the five teams. By limiting the study to 1973 and newer model cars, there is a guarantee that relatively similar belt systems are available in all cars and that the presence or absence of other safety features is comparable for all cars in the sample.

Working within certain time constraints, it was decided to carry out *stratified random* sampling in each of the areas in order to obtain an effective sample size in excess of 15,000 occupants. As only the outboard front seat occupants have both lap and shoulder belts available for use, this analysis is limited to these two seat positions. With respect to the stratification, all vehicles where hospital treatment was involved for at least one of the front-seat occupants were sampled at 100 percent. The remaining vehicles were sampled at essentially 50 percent. Exceptions to this scheme are detailed in Appendix B. For the "non-hospitalized" cases, the occupants of these vehicles are included in the sample on the basis of the odd/even status of the terminal digit of the license plate. This stratification provides additional precision in the resulting effectiveness estimates through an increased effective sample size and allows detailed information on all of the occupants of special interest (namely, those generally more serious injured). In addition, that particular subgroup is generally easier to track down for follow-up interview.

To the extent possible, information was collected for each sampled occupant on some 168 variables. Refer to Appendix A for a complete listing of these variables. It should be noted that there is extensive important information on vehicle damage through the Collision Deformation Classification (CDC), including object contacted and inches of crush, along with detailed injury information through the Occupant Injury Classification (OIC) which utilizes the Abbreviated Injury Scale (AIS).

As can be seen from Appendix A, there is detailed information on virtually all of the crash variables which should affect injury severity, including information on the occupant (e.g., age, sex, height, weight, seat position, belt use), vehicle (e.g., make and model (weight), body style, mileage, extent of damage), and environment and crash situation (e.g., accident type, crash configuration, road type).

In Volume II of this final report, a "Fact Book" about towaway accidents of new cars is presented. The tables therein include some 21,829 weighted observations and utilize the majority of the 168 variables of information available on the file. The "Fact Book", for example, shows the differential belt usage as a function of vehicle size and/or model year, crash configuration, damage severity, seat position and occupant age. Likewise, for unrestrained occupants, the corresponding injury severity distributions are presented. Belt effectiveness estimates for AIS $\geq$ 2, AIS $\geq$ 3, and AIS = 6, are presented for the overall sample as well as certain subsets of interest.

The major effort described in this volume involves appropriately comparing standardized injury rates (R) for various belt groups (unrestrained (U), lap (L), lap and shoulder (LS)) and the corresponding effectiveness measures (E) for the overall sample as well as for selected subsets, such as occupants of compact cars, various crash configurations, etc. In the process, estimates of the precision of these injury rates and effectiveness measures are obtained wherever possible. The post-stratification variables (see Table 1.1 and Appendix B) used as control variables in the analysis are essentially those suggested in Kahane et al. (1975), namely, crash configuration, damage severity, vehicle size, and occupant age. The analysis described in Appendix C verifies the selection of this particular set of control variables. Obviously any analysis is constrained by the number of factor level combinations and the distribution of the sample across these combinations. For this reason, the ten crash configuration levels are combined in the subsequent analysis according to crash type (i.e., grouping configurations by crash severity; e.g., head-on combined with rollover) or impact site (i.e., grouping by area of case vehicle damage; e.g., angle struck in left side with sideswipe).

Thus, categorical data estimation procedures utilized provide a comparison of injury rates and corresponding effectiveness measures for the three belt usage categories-- overall and for selected subsets -- controlling for the interacting effects on injury of the variables given in Table 1.1.

Table 1.1 Post stratification variables.

Crash Configuration

1. Head-on with vehicle
2. Rear-end, striking
3. Rear-end, struck
4. Angle, striking
5. Angle, struck in left side
6. Angle, struck in right side
7. Rollover
8. Sideswipe
9. Head-on with fixed object
10. Side of vehicle into fixed object

Damage Severity

1. Minor (e.g., 12-FDEW-1, 12-FYEW-1, 12-FLEW-1, 12-FLEE-1, 12-FLEE-2)
2. Moderate (e.g., 12-FDEW-2, 12-FYEW-2, 12-FLEW-2, 12-FLEW-3, 12-FLEE-3, 12-FLEE-4)
3. Moderately severe (e.g., 12-FDEW-3, 12-FYEW-3, 12-FLEW-4, 12-FLEE-5)
4. Severe (e.g., 12-FDEW-4, 12-FYEW-4, 12-FLEW-5, 12-FLEE-6)

Vehicle Size

1. Subcompact (< 2700 lbs.)
2. Compact (2700 - 3599)
3. Intermediate (3600 - 4100)
4. Full-sized (> 4100)

Occupant Age

1. 10-25
2. 26-55
3. 56+

An alternative to using the categorical variable AIS to define an occupant's injury severity is to use the associated direct costs of medical bills, lost wages, etc., due to the injuries sustained. After it was deemed possible to obtain some reasonably good accident cost data, direct cost estimates were derived for each case on the Level 2 file. The components of these estimates included the following costs (when applicable): emergency room, in-patient, professional services, lost wages, and funeral services. Standardized costs by belt category were then computed along with effectiveness estimates and the corresponding standard errors. These results are presented in Chapter IV.

Finally, limitations of the Level 2 project along with recommendations are discussed in Chapter V.

II. THE DATA; GENERAL METHODOLOGY

The Data

In the Level 2 restraint system file, there is detailed and complete information on 15,818 "occupants" on which the analyses are based. The basic observations have been weighted by the appropriate inverse sampling fractions and are such that there is no missing data for the six variables of interest (belt usage, injury, crash configuration, damage severity, vehicle size, and occupant age/seating position). The actual sampling scheme is detailed in Appendix B.

As indicated previously, the data consist of detailed occupant information (see Appendix A) for towaway crashes involving 1973-75 model cars. These crashes occurred in 1974 and 1975 in five geographic regions across the United States (namely, Western New York State, Michigan, Miami, San Antonio, and Los Angeles; see Figure 1.1). The data were collected primarily by special NHTSA-sponsored teams of accident investigation specialists combining information from police reports, occupant and witness interviews, hospital or other injury information, and investigation of the vehicle.

For the multivariate analysis, attention is focused on belt usage (3 levels), AIS injury (initially 7 levels), crash configuration (initially 10 levels), vehicle damage severity (4 levels), vehicle weight (4 levels) and occupant age (3 levels). See Table 1.1 for the description of the levels of the post-stratification variables.

Belt usage determination derives from a combination of information from the police report, occupant interview, investigation of the vehicle, and occasionally location and description of injuries.

The AIS injury severity for a given occupant is defined to be the maximum severity of the first three injuries (i.e., max (var 135, var 141, var 147); see Appendix A) unless either the police injury code or the treatment mortality code indicates a fatality (i.e., var (129) = 1 or var (130) = 7, respectively). In this case, the AIS code is assigned a 6 indicating a fatality. In this report "injured" will refer to either moderate or worse injury (AIS $\geq$ 2), serious or worse (AIS $\geq$ 3), or fatal (AIS = 6). The most comprehensive and reliable results correspond to AIS $\geq$ 2 injuries and will be discussed initially in Chapter III.

The belt usage by injury level distribution for the weighted sample is given in Table 2.1. Overall, 9.4 percent of the sample suffered at least moderate injuries (AIS $\geq$ 2), 2.4 percent experienced at least serious injuries, and 0.5 percent were killed. Table 2.1 shows that 58.4 percent of the sample was unrestrained, 16.1 percent wore a lap belt only, and 25.5 percent wore both lap and shoulder belts. As the belt

Table 2.1 Belt usage by injury level.

Belt Usage \ Injury Level	Total	AIS $\geq$ 2 (Moderate)	AIS $\geq$ 3 (Serious)	AIS = 6 (Fatal)
None	9242 (58.4%)[1]	1114 (12.1%)[2]	299 (3.2%)	70 (0.8%)
Lap	2544 (16.1%)	188 (7.4%)	38 (1.5%)	4 (0.2%)
Lap & Shoulder	4032 (25.5%)	191 (4.7%)	48 (1.2%)	12 (0.3%)
Total	15818	1493 (9.4%)	385 (2.4%)	86 (0.5%)

[1]Column percent
[2]Percent of total within belt category

systems would generally be 3-point systems and since many of the cars would have an ignition interlock, it is not surprising to begin seeing greater and greater usage of both belts -- even in accidents.

Note that Table 2.1 provides crude, unconditional injury rates for each belt category. Thus, for this file of towaway crashes, the overall injury (AIS $\geq$ 2) rates are $\hat{R}_1$=.121, $\hat{R}_2$=.074, and $\hat{R}_3$=.047 for the unrestrained (U), lap belt (L), and lap and shoulder (LS) belt categories, respectively. Defining effectiveness as the reduction in injury as one becomes progressively more restrained, we have overall effectiveness measures of

$$\hat{E}_{12} = \frac{\hat{R}_1 - \hat{R}_2}{\hat{R}_1} = .388$$

$$\hat{E}_{13} = \frac{\hat{R}_1 - \hat{R}_3}{\hat{R}_1} = .612$$

$$\hat{E}_{23} = \frac{\hat{R}_2 - \hat{R}_3}{\hat{R}_2} = .365$$

for U vs L, U vs LS, and L vs LS, respectively. These overall injury rates and effectiveness measures provide unconditional baseline estimates for subsequent comparisons.

It should be noted that although $\hat{E}_{23}$ is a function of $\hat{E}_{12}$ and $\hat{E}_{13}$, namely,

$$\hat{E}_{23} = \frac{\hat{R}_1}{\hat{R}_2}\left(\hat{E}_{13} - \hat{E}_{12}\right),$$

nevertheless, $\hat{E}_{23}$ is presented throughout in order to facilitate comparisons between L and LS.

The corresponding unadjusted injury rates and effectiveness estimates for the other injury categories are as follows:

AIS $\geq$ 3:	$\hat{R}_1 = .032$	$\hat{E}_{12} = .531$
	$\hat{R}_2 = .015$	$\hat{E}_{13} = .618$
	$\hat{R}_3 = .012$	$\hat{E}_{23} = .187$
AIS = 6:	$\hat{R}_1 = .0076$	$\hat{E}_{12} = .792$
	$\hat{R}_2 = .0016$	$\hat{E}_{13} = .607$
	$\hat{R}_3 = .0030$	$\hat{E}_{23} = -.893$

The apparent instability of the estimates for fatals undoubtedly derives from the small sample size.

Crash configuration was determined using variables 22, 24, 60, 61, and 63 as given in Appendix A. As previously noted, for analysis purposes the original ten crash configuration levels were combined into four categories according to two different schemes. The first scheme groups the various crash configurations according to proportion injured (and hence severity) to form a "crash type" variable. The second scheme is based on the primary region of damage on the vehicle and results in an "impact site" variable. More specifically, the two derived crash configuration variables are defined as follows:

Crash Type

1. (Head-on with vehicle) + (Head-on with fixed object) + (Rollover) + (Side of vehicle into fixed object)

2. (Angle, struck in left side) + (Angle, struck in right side)

3. (Rear-end, striking) + (Angle, striking)

4. (Rear-end, struck) + (Sideswipe)

Impact Site

1. Front: (Head-on with vehicle) + (Rear-end, striking) + (Angle, striking) + (Head-on with fixed object)

2. Side: (Angle, struck in left side) + (Angle, struck in right side) + (Sideswipe) + (Side of vehicle into fixed object)

3. Rear: (Rear-end, struck)

4. Rollover: (Rollover)

Note that the original crash configuration category, "other non-collision," is not included in any of the new variables. This is because there were very few such cases and the category did not logically combine with any of the other crash configuration categories. The distribution of the crash type and impact site variables by injury level and belt usage are presented in Tables 2.2 and 2.3.

Vehicle damage has 4 levels and is defined using variables 1, 22, 24, 60, 61, 63, and 64 as given in Appendix A and hence primarily utilizes the Collision Deformation Classification (CDC). The distribution of damage categories by injury level and belt usage is given in Table 2.4. For one reason or another (e.g., delay in notification of investigation team, inability to locate case vehicle), damage severity information was most frequently missing among the control variables.

The attrition due to damage severity is most unfortunate as damage severity is the most important post-stratifying variable. To examine possible biases introduced by this attrition, the extract file with complete information on all variables of interest was compared with the original file (see Table 2.5). The marginal distributions for both files indicate that the extract file is not a biases subset of the original file with respect to the post-stratifying variables.

Vehicle weight also has 4 levels and is defined using the vehicle make/model code (variables 39, 40 in Appendix A). Table 2.6 shows the distribution of vehicle weight by injury level and belt usage. Note the relatively uniform distribution across the vehicle weight categories.

Since no drivers and very few right front seat occupants were under 10 years of age, it was decided to delete that age category. The resulting distribution for the three age groups is given in Table 2.7.

Finally, seat position was examined as a potential stratifying variable, However, of those variables considered, seat position was found to be by far the least important for which to control (see Appendix C). By deleting this relatively unimportant variable, the number of strata is reduced by half. This is especially important for the investigation involving serious and fatal injuries where the number of injured occupants is relatively small.

Table 2.2. Injury level by belt usage and crash type.

Injury Level	Belt Usage	Crash Type 1	2	3	4	Total
Total		3820 (24.2%)[1]	4456 (28.2%)	6033 (38.1%)	1509 (9.5%)	15818
All Occupants	None	2527 (66.2%)[2]	2484 (55.7%)	3515 (58.3%)	716 (47.4%)	9242 (58.4%)
	Lap	552 (14.5%)	759 (17.0%)	953 (15.8%)	280 (18.6%)	2544 (16.1%)
	Lap & Shoulder	741 (19.4%)	1213 (27.2%)	1565 (25.9%)	513 (34.0%)	4032 (25.5%)
AIS≥2	None	474 (18.8%)[3]	284 (11.4%)	308 (8.8%)	48 (6.7%)	1114 (12.1%)
	Lap	66 (12.0%)	44 (5.8%)	65 (6.8%)	13 (4.6%)	188 (7.4%)
	Lap & Shoulder	73 (9.9%)	54 (4.5%)	51 (3.3%)	13 (2.5%)	191 (4.7%)
AIS≥3	None	155 (6.1%)	76 (3.1%)	52 (1.5%)	16 (2.2%)	299 (3.2%)
	Lap	21 (3.8%)	10 (1.3%)	4 (0.4%)	3 (1.1%)	38 (1.5%)
	Lap & Shoulder	24 (3.2%)	14 (1.2%)	6 (0.4%)	4 (0.8%)	48 (1.2%)
AIS=6	None	44 (1.7%)	20 (0.7%)	4 (0.1%)	2 (0.1%)	70 (0.8%)
	Lap	2 (0.4%)	1 (0.1%)	0 (0.0%)	1 (0.4%)	4 (0.2%)
	Lap & Shoulder	7 (0.9%)	4 (0.4%)	0 (0.0%)	1 (0.2%)	12 (0.3%)

[1]Row percentage

[2]Belt usage rate within crash type group

[3]Injury distribution belt usage within crash type group

Table 2.3. Injury level by belt usage and impact site.

Injury Level	Belt Usage	Impact Site: Front	Side	Rear	Rollover	Total
Total		8852 (56.0%)[1]	5673 (35.9%)	1028 (6.5%)	265 (1.7%)	15818
All Occupants	None	5410 (61.1%)[2]	3185 (56.1%)	457 (44.5%)	190 (71.7%)	9242 (58.4%)
	Lap	1360 (15.4%)	957 (16.9%)	213 (20.7%)	14 (5.3%)	2544 (16.1%)
	Lap & Shoulder	2082 (23.5%)	1531 (27.0%)	358 (34.8%)	61 (23.0%)	4032 (25.5%)
AIS≥2	None	661 (12.2%)[3]	395 (12.4%)	25 (5.5%)	33 (17.4%)	1114 (12.1%)
	Lap	115 (8.5%)	58 (6.1%)	12 (5.6%)	3 (21.4%)	188 (7.4%)
	Lap & Shoulder	105 (5.0%)	72 (4.7%)	11 (3.1%)	3 (4.9%)	191 (4.7%)
AIS≥3	None	158 (2.9%)	121 (3.8%)	6 (1.3%)	14 (7.4%)	299 (3.2%)
	Lap	18 (1.3%)	16 (1.7%)	3 (1.4%)	1 (7.1%)	38 (1.5%)
	Lap & Shoulder	23 (1.1%)	22 (1.4%)	3 (0.8%)	0 (0.0%)	48 (1.2%)
AIS=6	None	33 (0.6%)	31 (1.0%)	1 (0.2%)	5 (2.6%)	70 (0.8%)
	Lap	2 (0.1%)	1 (0.1%)	1 (0.5%)	0 (0.0%)	4 (0.2%)
	Lap & Shoulder	4 (0.2%)	8 (0.5%)	0 (0.0%)	0 (0.0%)	12 (0.3%)

[1] Row percentage

[2] Belt usage rate within impact site group

[3] Injury distribution by belt usage within impact site group

Table 2.4. Injury level by belt usage and damage level.

Injury Level	Belt Usage	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Total
Total		7236 (45.8%)[1]	6077 (38.4%)	1780 (11.3%)	725 (4.6%)	15818
All Occu-pants	None	4075 (56.3%)[2]	3580 (58.9%)	1160 (65.2%)	427 (58.9%)	9242 (58.4%)
	Lap	1189 (16.4%)	1012 (16.7%)	230 (12.9%)	113 (15.6%)	2544 (16.1%)
	Lap & Shoulder	1972 (27.3%)	1485 (24.4%)	390 (21.9%)	185 (25.5%)	4032 (25.5%)
AIS≥2	None	227 (5.6%)[3]	408 (11.4%)	295 (25.4%)	184 (43.1%)	1114 (12.1%)
	Lap	48 (4.0%)	80 (7.9%)	36 (15.7%)	24 (21.2%)	188 (7.4%)
	Lap & Shoulder	47 (2.4%)	65 (4.4%)	41 (10.5%)	38 (20.5%)	191 (4.7%)
AIS≥3	None	42 (1.0%)	79 (2.2%)	87 (7.5%)	91 (21.3%)	299 (3.2%)
	Lap	7 (0.6%)	14 (1.4%)	7 (3.0%)	10 (8.8%)	38 (1.5%)
	Lap & Shoulder	10 (0.5%)	10 (0.7%)	9 (2.3%)	19 (10.3%)	48 (1.2%)
AIS=6	None	4 (0.1%)	16 (0.4%)	15 (1.3%)	35 (8.2%)	70 (0.8%)
	Lap	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (3.5%)	4 (0.2%)
	Lap & Shoulder	2 (0.1%)	2 (0.1%)	1 (0.3%)	7 (3.8%)	12 (0.3%)

[1]Row percentage

[2]Belt usage rate within damage group

[3]Injury distribution by belt usage within damage group

Table 2.5. Marginal distributions of the post-stratifying variables in the complete file and the "extract" file.

Level	Complete File %	Extract File %
Damage 1	46.1[1]	45.8
2	37.8	38.4
3	11.4	11.2
4	4.7	4.7
Weight 1	56.1	55.9
2	43.9	44.1
Age 1	46.6	47.7
2	43.6	42.6
3	9.8	9.7
Crash Type 1	26.5	24.2
2	26.1	28.2
3	37.3	38.1
4	10.1	9.5
Impact Site 1	57.0	55.9
2	34.3	35.9
3	6.8	6.5
4	1.9	1.7

[1] Percentages in different sections of this column are based on different totals (differential attrition).

Table 2.6. Injury level by belt usage and vehicle weight.

Injury Level	Belt Usage	Vehicle Weight Subcompact (<2700 lb.)	Compact (2700-3599 lb.)	Intermediate (3600-4100 lb.)	Full-Sized (>4100 lb.)	Total
Total		4826 (30.5%)[1]	4010 (25.4%)	3619 (22.9%)	3363 (21.3%)	15818
All Occupants	None	2665 (55.2%)[2]	2242 (55.9%)	2220 (61.3%)	2115 (62.9%)	9242 (58.4%)
	Lap	721 (14.9%)	610 (15.2%)	589 (16.3%)	624 (18.6%)	2544 (16.1%)
	Lap & Shoulder	1440 (29.8%)	1158 (28.9%)	810 (22.4%)	624 (18.6%)	4032 (25.5%)
AIS≥2	None	348 (13.1%)[3]	249 (11.1%)	263 (11.8%)	254 (12.0%)	1114 (12.1%)
	Lap	68 (9.4%)	50 (8.2%)	40 (6.8%)	30 (4.8%)	188 (7.4%)
	Lap & Shoulder	77 (5.3%)	54 (4.7%)	38 (4.7%)	22 (3.5%)	191 (4.7%)
AIS≥3	None	88 (3.3%)	65 (2.9%)	72 (3.2%)	74 (3.5%)	299 (3.1%)
	Lap	16 (2.2%)	6 (1.0%)	8 (1.4%)	8 (1.3%)	38 (1.5%)
	Lap & Shoulder	17 (1.2%)	15 (1.3%)	12 (1.5%)	4 (0.6%)	48 (1.2%)
AIS=6	None	19 (0.7%)	14 (0.6%)	17 (0.8%)	20 (0.9%)	70 (0.8%)
	Lap	1 (0.1%)	0 (0.0%)	1 (0.2%)	2 (0.3%)	4 (0.2%)
	Lap & Shoulder	7 (0.5%)	4 (0.3%)	1 (0.1%)	0 (0.0%)	12 (0.3%)

[1]Row percentage

[2]Belt usage rate within vehicle weight group

[3]Injury rate by belt usage within vehicle weight group

Table 2.7. Injury level by belt usage and age.

Injury Level	Belt Usage	Age 10-25	Age 26-55	Age 56+	Total
Total		7538 (47.7%)[1]	6741 (42.6%)	1539 (9.7%)	15818
All Occupants	None	4569 (60.6%)[2]	3785 (56.1%)	888 (57.7%)	9242 (58.4%)
	Lap	1132 (15.0%)	1145 (17.0%)	267 (17.3%)	2544 (16.1%)
	Lap & Shoulder	1837 (24.4%)	1811 (26.9%)	384 (25.0%)	4032 (25.5%)
AIS≥2	None	491 (10.7%)[3]	477 (12.6%)	146 (16.4%)	1114 (12.1%)
	Lap	85 (7.5%)	86 (7.5%)	17 (6.4%)	188 (7.4%)
	Lap & Shoulder	84 (4.6%)	83 (4.6%)	24 (6.3%)	191 (4.7%)
AIS≥3	None	113 (2.5%)	135 (3.6%)	51 (5.7%)	299 (3.2%)
	Lap	18 (1.6%)	17 (1.5%)	3 (1.1%)	38 (1.5%)
	Lap & Shoulder	18 (1.0%)	21 (1.2%)	9 (2.3%)	48 (1.2%)
AIS=6	None	28 (0.6%)	29 (0.8%)	13 (1.5%)	70 (0.8%)
	Lap	1 (0.0%)	3 (0.3%)	0 (0.0%)	4 (0.2%)
	Lap & Shoulder	6 (0.3%)	4 (0.0%)	2 (0.5%)	12 (0.3%)

[1] Row percentage

[2] Belt usage rate within age group

[3] Injury distribution by belt usage within age group

As these five variables are used in the estimation procedures that follow, their detailed sampling distributions are presented. Also of special interest is the injury level by belt usage by model year distribution (see Table 2.8). As anticipated, lap and shoulder belt usage jumped considerably with the 1974 model vehicles which were equipped with the ignition interlock system. In fact, the percentages for "none" and "lap" for the 1974 models would indicate either defeat of the interlock or possibly reporting errors.

Quality of the Data

As has been previously noted, the Level 2 file has a distinct advantage over other extant data banks, since it not only contains information at a fair level of detail, but also is sufficiently large for complex data analysis. As a result, the file is potentially of great value to accident researchers.

In order to be useful, however, the Level 2 data must be shown to be reliable. The purpose of this section is to examine the quality of the Level 2 file. In particular, two areas are investigated: 1) missing data and 2) differential coding by teams. Missing data for certain populations of occupants or accident types would bias the estimates of effectiveness. Differential coding would make it difficult to make accurate comparisons across teams or to appropriately combine the data from the various teams.

Missing data.

It was hoped that, by using a well-defined sampling plan and established investigation teams, any given variable would be missing in no more than 10 percent of the cases. In addition, it was hoped that the cases would contain information on a smaller number of critical variables (belt usage, injury, crash type, etc.) virtually all of the time.

Tables 2.9, 2.10, and 2.11 show the percentage of missing data for important variables in each of three categories -- general information, vehicle information, and occupant information. The percentages are presented for the individual investigation teams as well as for all teams combined.

There seems to be relatively little missing data in the general class of variables with the exception of the HSRI data which appears to be missing some information concerning the environmental aspects of the accident (e.g., road and light condition) and the number of vehicles involved. Somewhat more vehicle information data is missing. While only condition of the belt warning device system, extent of first impact, and inches of crush are missing in over 20 percent of the cases, 17 out of the 25 variables show more than 10 percent missing data overall. Generally, Calspan seems to have the most missing vehicle data, followed by USC and Miami. There are only two matters of concern

Table 2.8 Injury level by belt usage and model year

Injury Level	Belt Usage	Model Year 1973	1974	1975	Total
Total		7219 (45.7%)[1]	6833 (43.3%)	1744 (11.0%)	15796[4]
All Occupants	None	4646 (64.4%)[2]	3615 (52.9%)	973 (55.8%)	9234 (58.5%)
	Lap	2143 (29.7%)	317 (4.6%)	84 (4.8%)	2544 (16.1%)
	Lap & Shoulder	430 (6.0%)	2901 (42.5%)	687 (39.4%)	4018 (25.4%)
AIS≥2	None	558 (12.0%)[3]	450 (12.4%)	106 (10.9%)	1114 (12.1%)
	Lap	144 (6.7%)	37 (11.7%)	7 (8.3%)	188 (7.4%)
	Lap & Shoulder	19 (4.4%)	154 (5.3%)	18 (2.6%)	191 (4.8%)
AIS≥3	None	154 (3.3%)	117 (3.2%)	28 (2.9%)	299 (3.2%)
	Lap	27 (1.3%)	7 (2.2%)	4 (4.8%)	38 (1.5%)
	Lap & Shoulder	4 (0.9%)	41 (1.4%)	3 (0.4%)	48 (1.2%)
AIS=6	None	44 (0.9%)	23 (0.6%)	3 (0.3%)	69 (0.7%)
	Lap	2 (0.1%)	2 (0.6%)	0 (0.0%)	4 (0.2%)
	Lap & Shoulder	1 (0.2%)	9 (0.3%)	2 (0.3%)	12 (0.3%)

[1] Row percentage

[2] Belt usage rate within model year group

[3] Injury rate by belt usage within model year group

[4] Excludes 22 1976 model vehicles

Table 2.9. Percentage of missing data cases by team for general information variables.

Variable	Team: Calspan	Miami	HSRI	SWRI	USC	Overall
Crash Configuration	4.5	13.5	2.1	5.8	3.0	5.3
Number of Occupants (front)	0.0	0.0	0.0	0.0	0.6	0.1
Number of Vehicles	0.0	0.0	14.1	0.0	0.0	2.9
Occupant Ejected	0.7	0.2	0.0	1.1	0.2	0.5
Accident Area	0.0	0.0	0.0	0.0	0.0	0.0
Limited Access	0.1	0.1	15.5	12.4	0.0	7.1
Road Surface	0.7	0.1	13.1	0.2	0.0	2.9
Surface Condition	0.6	0.3	14.4	0.2	0.0	3.2
Day of Week	0.0	0.0	0.0	0.0	0.0	0.0
Time of Accident	0.9	0.1	0.1	1.3	0.1	0.6
Light Condition	2.4	0.1	16.1	0.1	0.1	3.9

Table 2.10. Percentage of missing data cases by team for selected vehicle information variables.

Variable	Team Calspan	Miami	HSRI	SWRI	USC	Overall
Vehicle Weight	9.6	10.5	0.9	0.2	7.3	4.6
Body Style	9.1	14.0	3.6	2.1	8.7	6.4
Number of Cylinders	18.3	13.4	14.3	7.0	8.7	11.7
Transmission	29.0	14.4	16.2	6.7	15.2	15.2
Air Conditioned	32.7	14.7	17.6	6.4	16.6	16.4
Type Seat	22.3	14.5	18.7	6.6	8.2	13.3
Odometer	34.8	14.1	14.2	8.1	16.0	16.4
Condition of Warning Device System	64.1	15.3	18.5	30.9	51.4	35.9
Seat Belt						
Malfunction, Left Front	13.3	15.2	0.0	15.8	23.3	12.2
Center	14.5	14.9	0.0	7.3	10.1	8.5
Right	12.6	15.2	0.0	12.6	22.8	12.0
Defeat, Left Front	34.6	16.8	0.0	6.6	13.9	12.9
Center	30.2	15.5	0.0	3.4	5.4	9.5
Right	39.6	16.9	0.0	6.0	16.0	14.0
Maladjustment, Left Front	15.6	13.2	21.4	14.8	16.8	16.4
Center	1.5	11.5	1.2	0.7	0.8	2.4
Right	8.4	12.4	9.9	7.4	5.8	8.5
CDC (first impact)						
O'Clock	11.8	14.9	1.9	6.5	7.1	7.7
Extent	42.2	22.9	4.4	6.6	38.0	20.2
General Area	6.6	14.5	1.6	6.6	2.4	5.9
Horizontal	13.7	15.1	2.2	6.6	27.1	11.6
Vertical	17.8	15.6	2.2	6.6	34.0	13.6
Distribution	17.8	15.6	2.2	6.7	33.5	13.5
Object Contacted	26.5	28.3	4.5	1.0	15.7	12.4
Inches of Crush	45.5	23.3	14.5	6.8	40.6	23.4

Table 2.11. Percentage of missing data cases by team for selected <u>occupant</u> information variables.

Variable	Team Calspan	Miami	HSRI	SWRI	USC	Overall
Belt Usage	8.4	0.4	0.9	2.2	16.0	5.2
Ejection	0.1	0.2	0.3	2.6	0.2	0.9
Seat Position	0.0	0.0	0.0	0.1	0.0	0.1
Role	0.0	0.0	0.0	0.0	0.0	0.0
Age	3.1	0.2	0.4	1.0	2.4	1.4
Sex	2.2	0.0	0.5	0.6	1.9	1.0
Height	41.9	19.2	3.4	10.4	29.1	19.1
Weight	42.9	20.0	3.4	10.1	29.1	19.3
Pregnancy	15.2	7.0	9.6	2.8	12.6	8.7
Injury (first)						
Severity	0.6	12.6	1.6	2.8	4.0	3.6
Body Region	1.8	11.1	1.8	2.8	3.9	3.7
Aspect	10.7	11.2	3.1	3.2	6.0	6.1
Legion	1.2	12.6	1.7	2.8	3.9	3.7
System	1.2	16.3	1.6	2.8	4.4	4.3
More than Six Injuries	0.2	10.0	0.0	2.6	2.4	2.5
AIS (derived)	0.6	12.5	1.6	2.8	4.0	3.6
Police Injury Code	2.4	0.2	10.7	4.0	2.0	4.3
Treatment Mortality	9.5	6.9	1.4	2.6	4.4	4.5
Belt Caused Injury	0.2	10.0	0.2	4.1	3.0	3.1

regarding occupant information. First, USC shows a much higher missing data rate for usage than do the other teams, and second, Miami consistently misses over 10 percent of the injury information.

It should be noted that these tables probably underestimate the missing data, since, in some cases, missing data may have been coded as one of the alternatives. For example, it appears that when an unknown type of vehicle was hit, HSRI generally recorded a standard-sized vehicle struck. Nevertheless, these data do appear to provide reasonable estimates of the extent of missing data in the Level 2 file.

A second approach to exploring the missing data problem is to determine the number or percentage of missing variables per case. Here, emphasis is placed on the 39 critical variables listed in Table 2.12. The distribution by team of the number of missing data elements for these variables is shown in Table 2.13. Note that Miami seems to have a bimodal distribution, with records being either rather incomplete or rather complete. The remaining teams seem to have distributions similar to each other, although the Calspan and USC distributions do have somewhat longer tails. In looking at the overall trend, one finds that out of the 21,829 total (weighted) cases, only 989 (4.5%) have 15 or more of the 39 critical variables missing, 2299 (10.5%) are missing ten or more, and 5805 (26.6%) are missing five or more of the critical variables.

From Table 2.14, a rough profile can be developed of those cases missing 15 or more of the 39 critical variables. A comparison of these "poor" records with the entire Level 2 file indicates that a "poor" record accident is more likely to involve striking a fixed object than another motor vehicle and more likely to involve angle or sideswipe impacts. It is also more likely to occur on a limited access road and/or during the early hours of the day. Finally, the driver is less likely to sustain any injury (according to the treatment mortality code), less likely to male, and less likely to be wearing a lap and shoulder belt.

One possible explanation for much of the missing data is suggested in a related report by O'Day, Carlson, Douglas, and Kaplan (1974). The authors claim that some 30 percent of the vehicles in their study could not be reached prior to their being repaired or abandoned. Many of the remaining problem cases may not have been true "tow-away" accidents. That is, they involved vehicles which either could have been repaired or operated at the accident site orvehicles which were towed simply because their driver was drunk or otherwise temporarily forbidden to continue driving.

In view of some of these problems, it might be recommended that a more restrictive sampling plan be imposed on subsequent studies. For example, one could redefine the sampling frame as towaway accidents where the case vehicle has an accident severity rating of one (1) or more.

In addition, a productive strategy that might be adopted would be to obtain only a small number of core variables with all teams, and in

Table 2.12. Listing of 39 critical variables for estimating missing data distribution (and variable number from Appendix A).

Type of Accident (22)

Type of Impact (24)

Number of Lanes (30)

Limited Access (31)

Time of Accident (35)

Light Condition (36)

Odometer Reading (38)

Model Year (43)

Test Buzzer (46)

Type of Front Seat (48)

Evidence of Restraint System Malfunction
- Left Front (49)
- Center Front (50)
- Right Front (51)

Evidence of Restraint System Defeat
- Left Front (52)
- Center Front (53)
- Right Front (54)

Evidence of Restraint System Maladjustment
- Left Front (55)
- Center Front (56)
- Right Front (57)

First Object Contacted (58)

Direction of Force - First Impact (59)

Vertical Distribution of Crush

Accident Severity (64)

Inches of Crush (65)

Restraint System Usage (83)

Occupant Role (122)

Seat Position (123)

Ejection (124)

Sex (125)

Age (126)

Height (127)

Weight (128)

Police Injury Code (129)

Treatment Mortality (130)

Body Region (first injury)(131)

Lesion (first injury) (133)

Injury Severity (first injury (135)

Belt Caused (first injury) (136)

Pregnancy (168)

Table 2.13. Number of cases missing data codes by team and number of codes missing.

No. of Missing Data Codes	Calspan	Miami	HSRI	SWRI	USC	Overall
	Team					
≥ 26	0	0	0	0	0	
25	2	2	0	0	2	
24	0	35	0	0	0	
23	0	41	0	0	0	
22	7	9	0	2	0	
21	3	21	0	0	8	
20	27	51	3	2	4	989
19	17	62	0	1	6	
18	18	44	0	2	40	
17	34	66	0	17	60	
16	68	33	1	11	74	
15	98	33	10	8	67	
14	135	10	4	11	85	
13	115	2	11	35	76	
12	148	3	3	27	60	
11	155	0	5	48	61	1310
10	159	3	34	72	48	
9	174	5	27	96	50	
8	227	1	124	278	73	
7	233	7	178	186	138	3516
6	243	22	214	164	164	
5	316	37	181	175	193	
4	425	44	162	312	264	
3	398	115	205	362	323	
2	464	268	497	611	326	16,024
1	487	250	1023	1613	523	
0	71	1637	1879	2684	1080	

Table 2.14. Comparison of "poor" records (missing 15 or more variables) with remaining Level 2 file.

Accident Variable	"Poor Records (%)	Overall Level 2 (%)
Accident type:		
Motor vehicle	73.4	80.1
Fixed object	21.0	18.1
Type of impact:		
Rear-end and Head-on	41.8	42.2
Angle	48.9	42.7
Sideswipe	4.4	1.9
Limited Access: Yes	29.0	14.6
Light Condition:		
Daylight	58.1	61.3
Dawn, dusk	4.0	3.2
Dark	26.7	25.2
Usage:		
None	61.3	57.9
Lap only	18.8	16.9
Lap & Shoulder	19.9	25.2
Sex:		
Male	52.3	58.0
Police Injury Code:		
Fatal	0.2	0.4
Incapacitating	3.1	4.4
Non-incapacitating	13.3	17.4
Possible	21.5	19.7
No injury	57.0	58.1
Treatment Mortality:		
Not injured	75.1	57.5
First aid	0.9	1.4
Told to consult physician	0.3	0.2
Stated would consult physician	8.3	3.1
Did consult	1.1	8.8
Emergency room	10.7	23.5
Admitted to hospital	3.0	5.0
Fatal	0.3	0.5
Time:		
Midnight-6 AM	18.9	16.4
6 AM-9 AM	10.1	7.9
9 AM-4 PM	32.6	32.5
4 PM-6 PM	14.4	15.2
6 PM-Midnight	23.6	28.1
Direction of Force (o'clock):		
(11, 12, 1), (5, 6, 7)	78.5	70.0
(2, 3, 4), (8, 9, 10)	21.5	30.0

addition, require each team to pursue one particular aspect of the data in more depth. The different in-depth variables might be assigned with regard to a particular team's strengths (e.g., basic police report, or its relationships with hospitals and other sources of information). Though this strategy would result in less data for the in-depth variables, it would not reduce the data base as severely for the more critical core variables. The obvious advantage would be to relieve a team of trying to report on all aspects of an accident by allowing it to concentrate its efforts on those aspects with which it can best deal, yielding more reliable data.

Differential coding.

A second source of inconsistent data is differential coding. If a variable's alternatives are interpreted differently by various users, than it is difficult to make generalizations about that variable.

One clear example of how this problem affected the current study concerns the coding of laceration injuries. Four of the five investigation teams apparently adopted the procedure of coding all facial lacerations as AIS=2 injuries. HSRI, however, coded a facial laceration at this level only if it was longer than three inches. Since approximately one-fourth of all AIS=2 injuries are facial lacerations, this resulted in a disproportionately lower percentage of AIS=2 injuries for HSRI. The effect of the differential coding on the effectiveness estimates is evidenced in Table 3.6, which presents injury rates and effectiveness measures by team. The HSRI estimates are, as expected, noticeably lower.

An examination of the types of cars struck reveals another example of differential coding. HSRI reports that only 2.7 percent of the cars struck were of unknown size, as opposed to 25.7 percent, 29.4 percent, and 13.8 percent, respectively, for Calspan, Miami, and USC. On the other hand, HSRI reports a much larger percentage of standard-sized cars struck. It appears then, that for whatever reason, HSRI has coded unknown cars as standard-sized cars. The result is that any analysis comparing standard-sized struck cars to other sizes of struck cars must eliminate the HSRI observations, since it cannot be determined how many of these will in fact be unknown-sized cars.

Lack of mutually exclusive coding alternatives as well as too many alternatives frequently leads to differential coding. An example of the former problem is the light condition variable with three darkness codes (dark, dark-lighted, and dark-not lighted). Here, if some teams used only dark while the others used only dark-lighted or dark-not lighted, then a comparison across the teams would be relatively simple. But when the five teams have widely different distributions over the set of alternatives (as is evident in Table 2.15), then one is not sure exactly how each team has coded the variable. This decreases the probability of providing meaningful interpretation of such data.

The second coding problem - too many alternatives - is illustrated by the object struck variable. According to the encoding instructions,

Table 2.15. Light condition distribution by team.

Light condition	Team				
	Calspan	Miami	HSRI	SWRI	USC
Daylight	53.3	70.3	60.0	63.3	60.5
Dawn	0.7	0.9	1.2	1.0	0.7
Dusk	3.0	2.1	3.3	1.4	2.1
Dark	41.5	0.3	0.0	22.6	0.4
Dark-lighted	1.2	22.0	10.6	10.5	30.2
Dark-not lighted	0.1	4.4	24.8	0.3	6.0
Not stated	0.1	0.0	0.0	0.8	0.1

there are 86 possible alternatives. In practice, many of these were used infrequently. In fact, 67 of the 86 alternatives were used less than one percent of the time. In setting up large data banks, there is often a tendency to provide for too many alternatives. It should be remembered, however, that the investigating team must be able to remember and distinguish all the alternatives. The added detail will also cause confusion in the analysis, as only relatively few alternatives can be meaningfully explored.

Knowing that these various coding problems existed in the Level 2 file, appropriate precautions and adjustments were made in interpreting the data. In future such efforts, more precise definition of relatively few easily distinguishable coding alternatives can help to keep differential coding to a minimum. Regular communication between data recorders and data users can also mitigate this problem.

Belt information source utility.

In order to maximize the reliability of the estimates of seat belt usage, up to ten different sources of belt information were investigated by the teams for each accident reported. The extent to which each of these sources was used, along with whether they supported or contradicted the teams' estimates, is presented in Table 2.16. Note that the "no information" category includes those cases where the source neither supported nor contradicted the team's estimate, where the seat position was not occupied, or where the information was not applicable or unknown.

It is not surprising to find that the different belt information sources contributed differentially to the development of belt usage

Table 2.16. Distribution of information source utility.

Source	Supported Team Estimate	Contrary to Team Estimate	No Information
Police Report	36.8	8.6	54.6
Police or Witness interview	5.9	0.7	93.4
Subject or Other interview	43.7	3.6	52.7
System Defeat	66.0	5.1	28.9
Belt Damaged by Occupant Loading	1.9	0.2	97.9
Location of Belts	36.6	0.8	62.6
Occupant Contact Points	22.1	0.7	77.2
Belt Caused Injury	4.4	0.1	95.5
Injury Pattern	23.2	1.1	76.7
Ejection	2.6	0.0	97.4

estimates. If the driver or occupant experienced no injury or perhaps just a minor injury (as was true in the vast majority of cases), then one would perhaps not expect the teams to investigate occupant contact points, belt-caused injuries, or ejection sources.

The following sources appear to have been most frequently investigated: system defeat, subject or other interview, police report, and location or condition of belt. Out of these four sources, the last one cited would clearly have the greatest tendency to provide no additional information to the belt usage judgement. The apparently low utility of the police report source is misleading, since it is primarily due to the absence of belt usage information on two of the states' police report forms (namely, Michigan and California). Similarly, the police or witness interview was not required by the contract, and thus was less frequently investigated.

A somewhat discouraging result from Table 2.16 is that 8.6 percent of the time the police report of belt usage was contrary to the team estimate. This represents almost one out of every five cases where police report information was obtainable. To a somewhat lesser extent, subject interview and system defeat sources were also relatively frequently discrepant.

Table 2.17 shows the relative usefulness of the various sources of belt information by investigation team. While the teams were fairly consistent in their use of the various sources (except for the police report, as already mentioned), there are certain notable discrepancies. For instance, Miami was much more likely to obtain police or witness interviews (even though not required) while Calspan was much less likely to obtain useful information from the system defeat source.

In way of summary, the overall quality of the Level 2 file appears fairly high, with the exception of certain vehicle damage variables and the 4.5 percent of cases ("poor" records) which account for 25.1 percent of the missing data. One would expect the seat belt estimates to be reasonably reliable, due in part to the extra effort taken to investigate several information sources.

National Representativeness

Assessment of the national representativeness of the Level 2 data file was hampered by the lack of national accident data with which comparisons could be made. Representativeness was investigated indirectly, however, by comparing certain demographic characteristics of the five sampling areas with those for the United States as a whole, and by comparing various aspects of the Level 2 accident data with comparable detailed accident data from two states -- one predominantly rural (North Carolina), the other predominantly urban (New York State). Among team differences are also explored for certain variables of interest.

Table 2.17. Information source and utility by team.

Source	Utility	Team: Calspan	Miami	HSRI	SWRI	USC
Police Report	Supported	65.0	80.0	0.0	42.6	0.1
	Contrary	8.6	18.8	0.0	15.0	1.0
	No Info.	26.4	1.2	100.0	42.4	98.9
Police or Witness Interview	Supported	0.2	39.7	0.3	0.5	0.8
	Contrary	0.0	5.1	0.0	0.0	0.1
	No Info.	99.8	55.2	99.7	99.5	99.1
Subject or Other Interview	Supported	32.2	40.9	46.6	54.9	36.9
	Contrary	0.9	4.4	1.8	7.0	3.0
	No Info.	66.9	54.7	51.6	38.1	60.1
System Defeat	Supported	44.4	78.9	66.5	72.2	65.0
	Contrary	1.3	1.7	4.1	8.1	7.5
	No Info.	54.3	19.4	29.4	19.7	27.5
Belt Damaged by Occupant Loading	Supported	0.7	0.0	0.9	4.9	0.1
	Contrary	0.0	0.0	0.0	0.4	0.2
	No Info.	99.3	100.0	99.1	94.9	99.7
Location of Belts	Supported	45.0	23.3	41.5	38.5	28.3
	Contrary	0.5	0.0	1.6	0.9	0.2
	No Info.	54.5	76.7	56.9	60.6	71.5
Occupant Contact Points	Supported	28.9	9.7	16.9	31.9	12.0
	Contrary	0.1	0.0	1.6	0.4	1.0
	No Info.	71.0	90.3	81.5	67.7	87.0
Belt Caused Injury	Supported	1.5	1.7	3.3	9.0	2.3
	Contrary	0.0	0.0	0.2	0.0	0.0
	No Info.	98.5	98.3	96.5	91.0	97.7
Injury Pattern	Supported	22.2	17.1	35.7	25.8	10.2
	Contrary	0.1	0.0	4.0	0.4	0.8
	No Info.	77.6	82.9	30.3	73.8	89.0
Ejection	Supported	0.6	0.3	0.8	7.3	0.2
	Contrary	0.0	0.2	0.0	0.0	0.0
	No Info.	99.4	99.5	99.2	92.7	99.8

Demographic comparisons.

The demographic makeup of the sampling area is of interest in part because the geographic location of the teams was not randomized. The possibility of a random selection of geographic sites was precluded by the necessity of having an established accident investigation team and the requirement of a sufficient number of accidents to be investigated within a reasonable time period. However, if it can be shown that the sampling areas approximate national estimates on various demographic and accident variables, the non-random selection of the areas will not be as crucial.

Table 2.18 reports some demographic characteristics for each of the five sampling areas as well as for the aggregated sample. The data are derived from the City and County Census Data Book (1972). Also given in the table are corresponding data for the United States and for North Carolina and New York State. The data show that, compared with the national average, the sampling areas are much more densely populated and more urban, and have a slightly higher proportion of residents over eighteen years old. In addition, a higher proportion of the sampling area residents are in the labor force, but are less likely to use public transportation or to work outside the county. Other than these differences, the aggregated sampling area and the U.S. are remarkably similar across the variables investigated.

When examining the individual sampling areas, one should note that Miami overrepresents the 65+ age group, while SWRI and HSRI overrepresent the younger age groups. Calspan area's age distribution is the most similar to the rest of the nation.

In summary, there are but three demographic concerns. First, the sampling areas are more urban (more concentrated) than is the nation. Second, questions can be raised regarding the amount of rush hour traffic (fewer people than expected use public transportation and less (except HSRI) people work outside the county). Third, there appears to be a bias toward the extremes in the age characteristics of three of the five teams. Otherwise, the sampling areas appear to be fairly representative of the nation on the demographic characteristics investigated.

Accident variable comparisons.

Since the demographic analysis indicated that there could be biases in the data based on the urban nature of the sampling areas, the possible overexposure during rush hour traffic, and the age of the population, these variables were examined further.

In exploring the urban nature of the Level 2 file, it is seen that Calspan and HSRI contribute the bulk of the rural cases and that Miami and USC contribute virtually none (see Table 2.19). The percentage of urban cases accounted for by the various teams does not vary greatly from the percentage of total cases contributed. The extreme

Table 2.18. Demographic characteristics of the five sampling areas.

Comparison Variable	TEAM						US	NC	NY
	Calspan	Miami	HSRI	SWRI	USC	All Teams			
Population/square mile	269	621	724	289	1729	674	57	104	381
Proportion female	.518	.528	.508	.507	.516	.516	.513	.510	.522
Proportion urban	.747	.984	.876	.916	.987	.935	.735	.450	.856
Proportion white	.928	.846	.955	.917	.857	.881	.876	.769	.871
Proportion under 5 years	.084	.068	.088	.091	.083	.083	.084	.085	.081
Proportion over 18 years	.653	.706	.638	.638	.677	.669	.656	.652	.678
Proportion 65 and over	.103	.137	.065	.076	.093	.095	.099	.082	.108
Median age	29.3	34.3	26.0	24.3	29.6	29.2	28.3	26.6	30.8
Proportion in labor force	.396	.428	.409	.398	.433	.422	.404	.254	.253
Proportion using public transportation	.083	.091	.019	.051	.056	.059	.089	.027	.330
Proportion working outside county	.091	.035	.290	.038	.029	.063	.178	.143	.318

Table 2.19. Team distribution within accident location.

Location	Team					Overall
	Calspan	Miami	HSRI	SWRI	USC	
Urban	16.3[1]	14.2	17.9	32.4	19.1	88.7[2]
Rural	35.1	2.1	44.1	17.7	1.0	11.3
Overall	18.4	12.8	20.9	30.8	17.1	100.0

[1]Row percent
[2]Column percent

variation of rural cases can be reconciled with the moderate variation of the urban cases by noting that the latter constitute 88.7 percent of the file.

Analysis of the time of the accident (Table 2.20) shows that USC and, to a lesser extent, Miami (the two teams with very few rural cases) report a greater proportion of their accidents occurring during the morning rush hour than do the other teams. Calspan and SWRI indicate an overrepresentation of nighttime (6 p.m. - 6 a.m.) accidents, while HSRI reports a fairly even profile across time periods.

Table 2.20. Team distribution within time period.

Time of Day	Team				
	Calspan	Miami	HSRI	SWRI	USC
Midnight - 6 AM	24.7[1]	7.5	20.5	32.4	14.9
6 AM - 9 AM	14.7	19.1	21.6	21.8	22.8
9 AM - 4 PM	15.7	16.1	22.4	28.4	17.4
4 PM - 6 PM	18.9	14.0	19.4	30.3	17.4
6 PM - Midnight	18.6	10.0	20.3	34.5	16.6
Overall	18.4	12.9	21.0	30.5	17.2

[1]Row Percent

In examining the age data (Table 2.21), one can see that Miami and Calspan have a bias toward older occupants, while HSRI and SWRI show a tendency toward younger occupants. USC remains relatively unbiased with regard to age. Noting that HSRI and SWRI account for slightly over half the total number of accidents recorded, Table 2.21 may indicate that the level 2 file is slightly biased toward younger occupants (0-25) and away from older occupants (56+).

Table 2.21. Team distribution within age groups.

Age	Team				
	Calspan	Miami	HSRI	SWRI	USC
0-16	14.5[1]	10.7	25.4	35.6	13.8
17-25	18.0	10.8	21.5	35.4	14.3
26-55	17.7	14.6	20.5	27.5	19.7
56+	23.6	15.4	19.2	25.9	15.9
Overall	18.1	13.0	21.1	30.9	16.9

[1]Row Percent

In addition to these location, time and age variables, other accident variables were examined for among-team differences. Examination of the crash configuration data (Table 2.22) reveals no consistent trends. Calspan reports a large percentage of the head-on, rollover, and fixed object categories. HSRI also shows a disproportionate number of head-on collisions, but is balanced in the other categories. SWRI reports a low incidence of head-on collisions, rollovers, sideswipes, and fixed objects struck, and a large percentage of struck in side and angle striking. Miami shows a low number of head-on and fixed object accidents, and USC a high number of rear-end accidents.

In terms of injury severity, again no consistent bias can be determined (Table 2.23). Miami shows an overrepresentation in the occupant not injured category, while Calspan is overrepresented in the severe injury levels.

Finally, the restraint system usage distribution (Table 2.24) shows considerable homogeneity among teams!

An additional comment is in order. Interactions such as between vehicle weight and location (urban-rural) can influence such an analysis as is carried out in this report. Miami, for example, is

Table 2.22. Team distribution within crash configuration.

Configuration	Team Calspan	Miami	HSRI	SWRI	USC
Head-on	31.3[1]	3.3	31.5	20.2	13.6
Rear striking	17.1	10.6	20.4	28.0	23.9
Struck in rear	16.3	13.3	18.0	25.3	27.1
Angle striking	12.5	13.5	20.2	36.4	17.4
Struck in left side	11.6	15.7	23.5	36.0	13.2
Struck in right side	11.5	13.9	19.7	40.7	14.1
Rollover & other	33.2	11.1	22.5	21.0	12.2
Sideswipe	22.8	11.0	25.7	20.3	20.1
Struck fixed object	31.1	10.0	21.0	21.5	16.5
Side of car into fixed object	31.9	5.4	21.4	28.5	12.8
Overall	18.6	11.7	21.6	30.6	17.5

[1]Row Percent

Table 2.23. Team distribution within AIS level.

AIS Level	Team Calspan	Miami	HSRI	SWRI	USC
0	19.9[1]	15.4	18.9	31.3	14.5
1	16.7	8.0	24.7	29.6	20.9
2	23.5	6.4	16.0	39.8	14.2
3	28.4	4.0	32.7	25.8	9.1
4	22.4	4.1	28.6	28.6	16.3
5	46.2	15.4	23.1	7.7	7.7
6	24.8	10.9	21.8	26.7	15.8
Overall	19.0	11.6	21.3	31.0	17.0

[1]Row Percent

Table 2.24. Team distribution within belt usage categories.

Usage	Team Calspan	Miami	HSRI	SWRI	USC
None used	19.5[1]	12.4	23.5	30.5	14.2
Lap only	18.2	14.2	19.6	33.4	14.5
Lap & shoulder	13.9	15.2	19.4	33.7	17.8
Overall	17.8	13.5	21.8	31.7	15.1

[1]Row Percent

overrepresented in terms of heavier cars (Table 2.25) and urban accidents; thus, it is not surprising to find that Miami shows a higher percentage of no injury accidents involving heavier vehicles. Such interactions have been taken into account in the estimation procedure.

Table 2.25. Team distribution within vehicle weight categories.

Vehicle Weight	Calspan	Miami	HSRI	SWRI	USC
Subcompact	14.2[1]	10.2	18.9	33.5	23.3
Compact	19.8	13.0	21.1	30.3	15.8
Intermediate	15.5	14.1	23.5	34.2	12.7
Full Sized	21.5	11.6	24.7	30.3	11.9
Overall	17.5	12.0	21.7	32.2	16.6

[1]Row Percent

National and state accident data comparisons.

There is generally a dearth of national accident information. The primary source for the national accident information that exists is the National Safety Council's publication Accident Facts (1975).

Because of the restriction to towaways in the Level 2 file, even comparisons with Accident Facts are tenuous. However, some accident factors might be relatively unaffected by these sampling differences.

Table 2.26 lists variables common to the Level 2 file and Accident Facts. The table shows a Level 2 bias toward urban accidents and female occupants. The Level 2 file also overrepresents the under 25 age group of drivers (as was suggested in the demographic and accident variable analyses) and overrepresents the midnight to 6 a.m. accidents. Finally, the Level 2 file shows an underestimate of two vehicle collisions (i.e., a bias toward single vehicle accidents) and rear-end collisions, and an overestimate of head-on and angle collisions, as compared with the national estimates.

Table 2.26. Comparison of Level 2 file with Accident Facts estimates.

Variable	Level 2 %	Accident Facts %
Location (% Urban)	88.7	71.5
Sex (% Male)	58.0	70.9
Driver age		
<25	44.5	38.6
25-54	46.0	47.4
55+	9.5	14
Time of Accident		
Midnight-6 AM	18.9	10.4
6 AM-9 AM	10.1	10.1
9 AM-4 PM	32.6	36.8
4 PM-6 PM	14.4	16.7
6 PM-Midnight	23.6	26.0
Collision Type		
Head-on	13.2	4.9
Angle	53.7	33.3
Rear-end	23.4	31.7
Two Vehicle	67.4	78.8

One can see that the restriction to towaway accidents has biased the sample in the types of accidents being analyzed. However in order to examine what biases the sampling had on accident and injury severity (and hence seat belt effectiveness), more detailed information is required.

To this end, the accident files for 1974 were obtained for North Carolina and for New York State. These files are of a Level 1 nature and hence do not contain as much information. They also have a much lower accident reporting threshold, since in both New York and North Carolina, one must report any accident which results in a fatality or injury or in which the total property damage is $200 or more. This should result in more lower severity accidents, and hence reduced seat belt effectiveness estimates.

The 1974 New York accident file was processed and an extract created which contained all towaway accidents involving 1973, 1974, and 1975 model vehicles. In North Carolina, it is not specified on the accident report form whether the vehicle was towed from the scene. Therefore, only those accidents involving a 1973, 1974, or 1975 model passenger car in which either the driver or the front seat passenger suffered a K, A, or B injury were examined. It was felt that this restriction would conform most closely to the spirit of the towaway sampling restriction.

Some comparisons of similarly coded items for the three files are shown in Table 2.27. There are several major differences. First, North Carolina contains a more male-dominated occupant population than either the New York or Level 2 file. Second, North Carolina has a much younger accident population. Third, none of the three samples have similar restraint usage distributions, with the Level 2 file indicating a lower rate of non-usage than either state file. Fourth, the New York State file contains a larger percentage of morning rush hour traffic accidents. Lastly, North Carolina accidents are much more rural than either of the other two files.

Accident and injury severities can also be compared to a limited extent, at least between the Level 2 and New York State files. Comparisons with the North Carolina file are uninformative for the most part, because of the selection rule (i.e., injuries) adopted for its processing.

Table 2.28 presents the accident severity comparisons, and Table 2.29 the injury severity comparisons. Note that the files are clearly only approximately comparable, since different damage and injury scales were used. However, it appears that the Level 2 file shows a higher percentage of low damage severity accidents than the New York State file. The files have about the same proportion of occupants suffering either no injury or only slight injury, but the New York State file shows a higher proportion of fatals.

By way of summary, it is obviously impossible to make a conclusive statement regarding the national representativeness of the Level 2 data file. The Level 2 file clearly reflects a more urban accident population, and may also have a greater proportion of females and young occupants than the national accident population. As a result of the overemphasis on urban accidents, certain collision types (e.g., head-on and angle) might be expected to be more frequently

Table 2.27. Comparison of Level 2, New York, and North Carolina files.

Accident Variable	Accident File		
	Level 2 (%)	NY (%)	NC (%)
Sex:			
Male	58.0	61.0	66.8
Female	42.0	39.0	33.2
Occupant Age:			
<25	44.5	40.8	50.3
25-54	46.0	45.6	43.3
55+	9.5	12.1	6.4
Seating Position:			
Driver	73.5	76.8	78.1
Passenger	26.5	23.2	21.9
Usage:			
None	57.9	61.9	84.6
Lap Only	16.9	29.0	10.6
Lap & Shoulder	25.2	9.1	4.8
Time of Accident:			
Midnight - 6 AM	16.4	13.7	14.0
6 AM - 9 AM	7.9	18.5	8.1
9 AM - 4 PM	32.5	26.2	30.2
4 PM - 6 PM	15.2	12.5	16.3
6 PM - Midnight	28.1	29.1	31.5
Location:			
Urban	88.7	78.6	43.7
Rural	11.3	21.4	56.3

Table 2.28. Comparison of damage severity -- Level 2 vs New York State.

Extent of Impact	Level 2 %	Damage	New York %
1	42.4		
2	33.3	None	0.3
3	17.2	Light	14.4
4	3.6	Moderate	50.1
5	1.1	Severe	31.3
6	0.7	Demolished	3.9
7	0.2		
8	0.1		
9	0.5		

Table 2.29. Comparison of injury severity -- Level 2 vs New York State.

AIS Level	Level 2 %	Injury Level	New York %
0	50.9	Normal	82.5
1	40.7	Shock	9.0
2	6.3	Incoherent	1.9
3	1.3	Semiconscious	4.1
4	0.2	Unconscious	1.5
5	0.1	Death	1.0
6	0.5		

represented on the Level 2 file. One might also expect a greater proportion of low severity accidents, which in turn would decrease the estimates of belt effectiveness. On the whole, however, the Level 2 file would appear to present a fairly reasonable basis for deriving national estimates of belt effectiveness.

Notation

Unless otherwise indicated, the following notation is used in this report:

n_{hij} = number of individuals in stratum h with belt usage i and "injury" level j

where $h = 1,2,\ldots,d$
$i = 1,2,3$
$j = 1,2$

with
$$i = \begin{cases} 1 \text{ if no belt (U)} \\ 2 \text{ if lap belt only (L)} \\ 3 \text{ if lap and shoulder belt (LS)} \end{cases}$$

$$j = \begin{cases} 1 \text{ if injured (AIS} \geq 2\text{; AIS} \geq 3\text{; AIS} = 6\text{, respectively)} \\ 2 \text{ otherwise} \end{cases}$$

$n_{hi\cdot} = \sum_j n_{hij}$ = number in stratum h with belt usage i

$n_{h\cdot j} = \sum_i n_{hij}$ = number in stratum h with injury j

$n_{\cdot ij} = \sum_h n_{hij}$ = number with belt usage i and injury level j

$n_{h\cdot\cdot} = \sum_{i,j} n_{hij}$ = number in stratum h

$n_{\cdot\cdot\cdot} = \sum_{h,i,j} n_{hij}$ = total number in sample and

$$\hat{R}_i = \sum_h w_h P_{hi1}$$

$$= \sum_h \left(\frac{n_{h\cdot\cdot}}{n_{\cdot\cdot\cdot}}\right) \cdot \left(\frac{n_{hi1}}{n_{hi\cdot}}\right)$$

= estimate overall injury rate for restraint system i, $i = 1,2,3$

$$\hat{E}_{ii'} = \frac{\hat{R}_i - \hat{R}_{i'}}{\hat{R}_i}$$

= estimated injury-reducing effect of belt system i' compared to belt system i, $i < i'$

For the investigation using direct cost of injuries, the following additional notation is required:

$c_{hi\cdot k}$ = cost for the k-th individual in the h-th stratum and in the i-th restraint system irrespective of injury condition ($h=1,\ldots,d$; $i=1,2,3$; $k=1,\ldots, n_{hi\cdot}$)

$$\bar{c}_{hi\cdot} = \frac{1}{n_{hi\cdot}} \sum_h c_{hi\cdot k}$$

= average cost for individuals in the h-th stratum using the i-th restraint system

$$\hat{C}_{i\cdot} = \sum_h w_h \bar{c}_{hi\cdot}$$

= estimated average direct injury cost for the i-th restraint system, $i=1,2,3$.

Additional notational conveniences are achieved by the following:

C = crash configuration

D = damage severity

W = vehicle weight

A = occupant age

I = injured

$\bar{I}$ = not injured

Overall Analysis Plan

The main goal of the analysis was to derive standardized injury rates, effectiveness measures and corresponding standard errors for the various belt usage categories -- both for the overall (weighted) sample and for a variety of subsets of interest (e.a., compact cars, head-on collisions). Chapter III of this report describes the estimation procedures used to accomplish this goal along with the results.

A second goal was to investigate the feasibility of deriving direct injury costs to use in the model in place of the injury information and, then, if feasible, to derive estimates of standardized injury costs, effectiveness measures and their standard errors across belt usage levels. Chapter IV describes the methodology used and describes these results.

As automobile accidents are extremely complex events involving a large number of factors, any analysis that fails to take these factors into account can be grossly misleading. Also, the variables involved are primarily categorical and thus categorical methods must be utilized. The variety of traditional Chi-square type procedures is inadequate due to the multi-dimensionality of the problem.

In recent years, considerable research has been carried out in this area of the analysis of complex contingency tables. Most of the methods use models which express functions of the observed cell frequencies (say, number of unbelted occupants with at least moderate injuries in cell (k, j, k, l, m)) in terms of combinations of a variety of independent variables (say, damage severity, car weight, crash configuration, age). The log-linear model of Goodman (1970, 1971) expresses the logarithm of the expected value of the function of the cell frequencies in terms of a linear combination of the main effects and interactions of a variety of independent variables. Maximum likelihood methods then provide estimates of the adjusted rates of interest plus tests of significance for the importance of the various main effects and interactions.

Alternatively, the weighted least aquares approach of Grizzle, Starmer, Koch (1969) expresses the expected value of either linear or log-linear functions of the observed cell proportions in terms of a linear combination of effects of a variety of independent variables. Weighted least squares methods (directly analogous to those used in the familiar general linear models procedures for continuous variables) not only provide estimates of the fit of the model but more importantly to this project estimates of the functions of interest and their corresponding standard errors.

Neither of these procedures is without its limitations. For example, the log-linear model analysis (Goodman, 1970, 1971) allows a large number of factor-level combinations but fails to provide standard errors of the derived estimates. Weighted least squares procedures (Grizzle, Starmer, and Koch, 1969; Appendix D) provide estimates and their standard errors but, as matrix inversion is required, are limited in the total number of factor-level combinations that can be considered simultaneously.

In the Interim Report (Reinfurt et al., 1975), exploration using both of these methods was presented in detail along with a sensitivity analysis (see Appendix F) investigating the relative effect on the estimates of including all possible combinations of the various post-stratifying variables. Based on this experience, an alternative procedure, more closely fitted to the characteristics of the problem at hand, was developed. It will be referred to as the Mantel - Haenszel -type estimation procedure (see Appendix E). In essence, it expresses the injury rate associated with a given restraint system as a bilinear form based on the vector of within stratum injury rates (for that particular restraint system) and the vector of stratum weights. Estimates of the standardized injury rates and their standard errors assuming random weights uncorrelated with the stratum injury weights are then derived. Finally, the effectiveness estimates and corresponding standard errors (obtained from a Taylor series approximation of the effectiveness estimates) are given.

Again, as no single procedure appeared clearly superior in all aspects, the corresponding weighted least squares (GENCAT) and Mantel-Haenszel-type estimates are presented for comparison purposes.

Figures 2.1 and 2.2 provide an overview of the steps involved in the estimation procedures. Results from both procedures along with the unadjusted estimates are presented in Chapter III.

As an alternative to the dichotomization involved in examining effectiveness through the injury description ($AIS \geq j$, $j = 2,3,6,$), a "continuous"dependent variable can be created by deriving direct injury costs for each entry on the Level 2 file. Belt effectiveness then is defined as the relative reduction in cost when comparing restraint system i' with system i.

More specifically, direct costs due to injury (medical expenses, lost wages, and funeral costs) were computed for each occupant on the file. Estimates of medical expenses for specific injuries and treatments on the file were computed using empirical Bayes estimators from a file of injury cases provided by Blue Cross Blue Shield of North Carolina. Other expenses were computed for specific treatment and injury categories from standard economic data, and all continuing expenses were discounted at a rate of 10 percent per year. These costs were then added to the Level 2 file and the revised analysis carried out. The details of the cost estimation and subsequent utilization in the effectiveness estimates are given in Chapter IV and Appendices G and H.

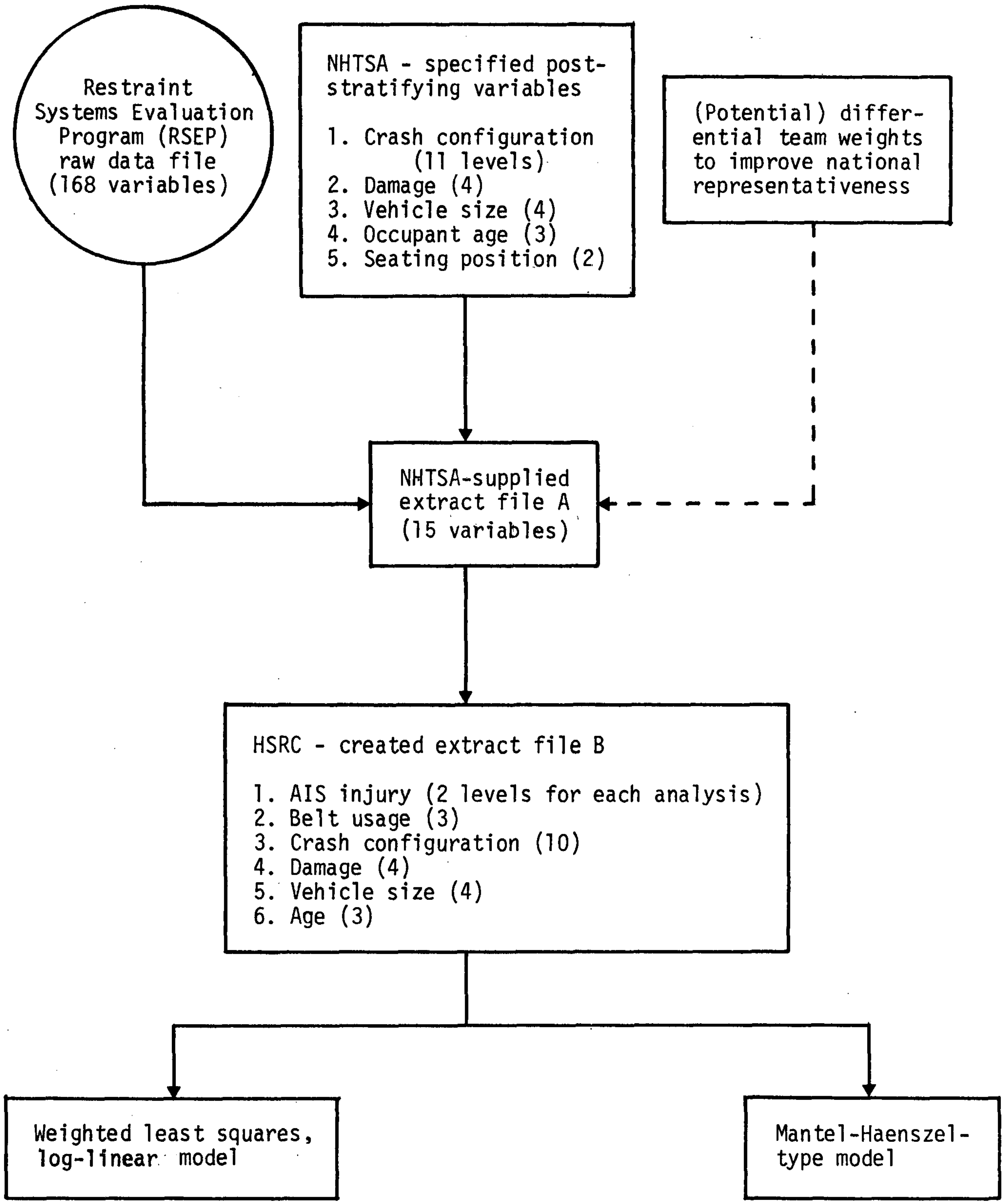

Figure 2.1. Mathematical modelling for determining true belt effectiveness.

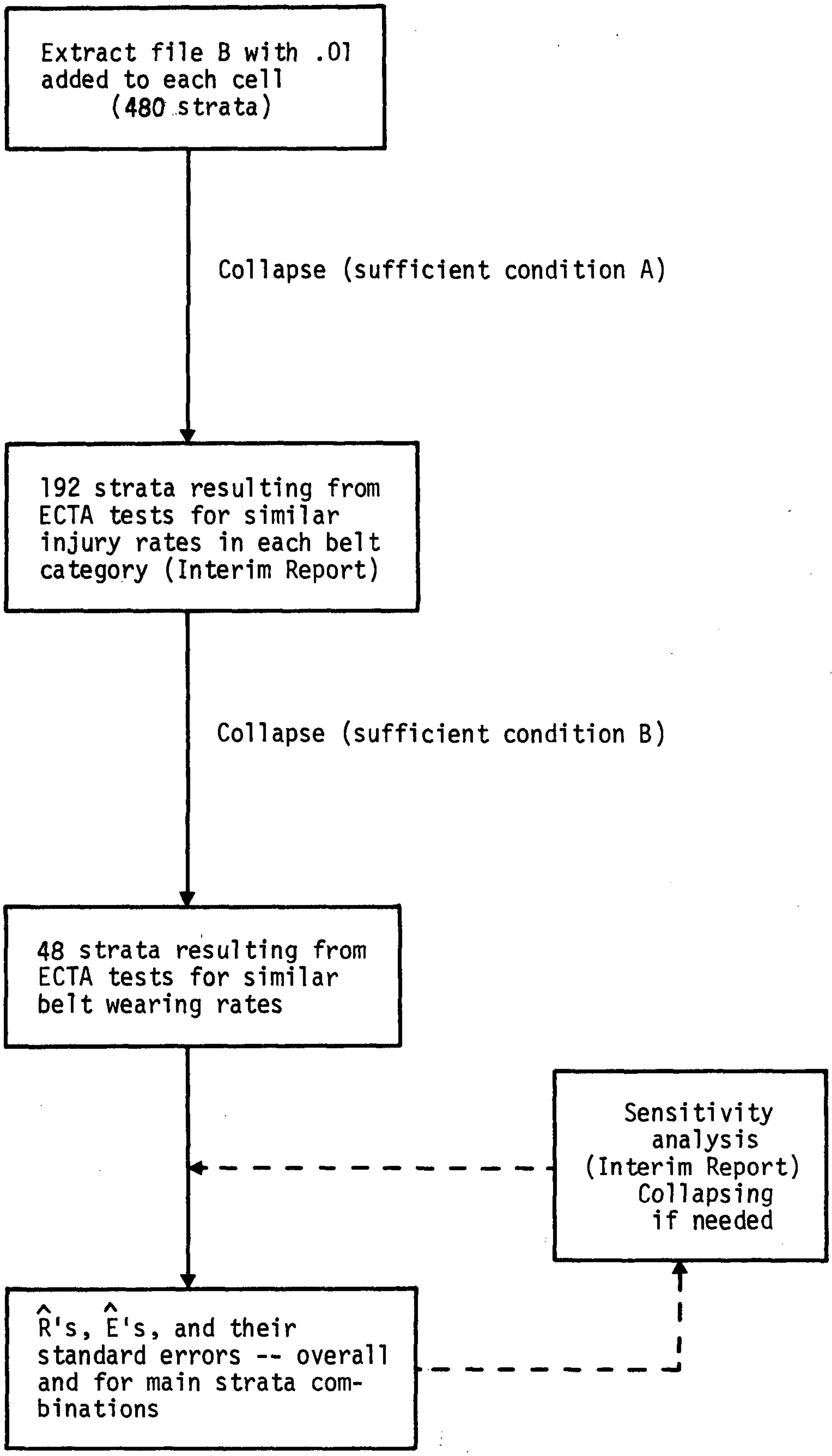

Figure 2.2. Weighted least squares, log-linear model. *(GENCAT)*

III. ESTIMATION OF STANDARDIZED INJURY RATES AND BELT EFFECTIVENESS MEASURES

Introduction

In this chapter, standardized injury rates, belt effectiveness measures, and their corresponding standard errors are derived for several levels of injury (AIS $\geq$ 2, AIS $\geq$ 3, and AIS = 6). The statistical estimation procedures utilized are essentially extensions of those described in Reinfurt *et al*. (1975) and are presented at the outset. It should be noted that primary emphasis is placed on moderate or worse injuries (AIS $\geq$ 2) since, for the other two injury groupings, the data becomes relatively thin in many of the strata.

Estimation Procedures

Weighted least squares (GENCAT).

Introduction.

The weighted least squares analysis of categorical data described in Grizzle, Starmer and Koch (1969) provides a method for estimating linear and log-linear functions of categorical data along with their corresponding standard errors. Forthofer and Koch (1973) have extended the basic approach to accommodate compounded functions of categorical data (see Appendix D) such as the standardized injury rates and belt effectiveness measures under consideration. As the computer program which derives the estimates is called the GENCAT program, for brevity the resulting estimates will be referred to as the GENCAT estimates.

It should be noted that the standard version of GENCAT cannot work with more than 80 functions of the cell proportions simultaneously. In Reinfurt *et al*. (1975) it was shown that five functions per stratum were needed to compute $\hat{R}$ and $\hat{E}$. Therefore, to use GENCAT, it was necessary to considerably reduce the number of strata by judicious collapsing.

However, from previous experience, it has been observed that the covariance between two $\hat{R}_i$'s is negligible. Under this assumption (and assuming fixed stratum weights) only two functions per stratum are required to estimate each R and its standard error. This necessitates considerably less collapsing. The results from the required (3) runs of GENCAT can then be combined to estimate the E's and their standard errors.

Collapsing criteria.

Under which conditions would it be valid to collapse various strata? That is, under which circumstances would it be algebraically equivalent (in terms of the evaluation of the R's) to treat two strata as one unique entity? The following are sufficient conditions for collapsing:

Criteria A: Collapse strata h and h' if, for each belt usage level, the "population injury rates" are equal; i.e.,

$$\frac{n_{h11}}{n_{h1\cdot}} = \frac{n_{h'11}}{n_{h'1\cdot}}, \quad \frac{n_{h21}}{n_{h2\cdot}} = \frac{n_{h'21}}{n_{h'2\cdot}} \quad \text{and} \quad \frac{n_{h31}}{n_{h3\cdot}} = \frac{n_{h'31}}{n_{h'3\cdot}} \tag{3.1}$$

Criteria B: Collapse strata h and h' if they have the same "population belt usage distribution"; i.e.,

$$\frac{n_{h1\cdot}}{n_{h\cdot\cdot}} = \frac{n_{h'1\cdot}}{n_{h'\cdot\cdot}}, \quad \frac{n_{h2\cdot}}{n_{h\cdot\cdot}} = \frac{n_{h'2\cdot}}{n_{h'\cdot\cdot}} \quad \text{and} \quad \frac{n_{h3\cdot}}{n_{h\cdot\cdot}} = \frac{n_{h'3\cdot}}{n_{h'\cdot\cdot}} \tag{3.2}$$

The sufficiency of each of these criteria can readily be seen. Under Criterion A, the "contribution" of strata h and h' to, say, R_1, is (aside from the constant $\frac{1}{n_{\cdot\cdot\cdot}}$)

$$\begin{aligned} \frac{n_{h11}}{n_{h1\cdot}}(n_{h\cdot\cdot}) + \frac{n_{h'11}}{n_{h'1\cdot}}(n_{h'\cdot\cdot}) &= \frac{n_{h11}}{n_{h1\cdot}}(n_{h\cdot\cdot} + n_{h'\cdot\cdot}) \\ &= \frac{n_{h11} + n_{h'11}}{n_{h1\cdot} + n_{h'1\cdot}}(n_{h\cdot\cdot} + n_{h'\cdot\cdot}) \end{aligned} \tag{3.3}$$

Expression (3.3) follows from Criterion A and the composition property for proportions. This equality is an identity under Criterion A and its right-hand side is the contribution of the collapsed strata (h + h') to R_1. Similarly, R_2 and R_3 would remain unchanged if we collapsed h and h' provided that Criterion A is true.

Under Criterion B, the contribution of strata h and h' to R_1 is

$$n_{h11}\left[\frac{n_{h\cdot\cdot}}{n_{h1\cdot}}\right] + n_{h'11}\left[\frac{n_{h'\cdot\cdot}}{n_{h'1\cdot}}\right] = (n_{h11} + n_{h'11})\left[\frac{n_{h\cdot\cdot}}{n_{h'\cdot\cdot}}\right]$$

since the first equality in (3.2) implies $\frac{n_{h\cdot\cdot}}{n_{h1\cdot}} = \frac{n_{h'\cdot\cdot}}{n_{h'1\cdot}}$.

Also $\frac{n_{h\cdot\cdot}}{n_{h1\cdot}} = \frac{n_{h\cdot\cdot} + n_{h'\cdot\cdot}}{n_{h1\cdot} + n_{h'1\cdot}}$. Thus

$$n_{h11}\left[\frac{n_{h\cdot\cdot}}{n_{h1\cdot}}\right] + n_{h'11}\left[\frac{n_{h'\cdot\cdot}}{n_{h'1\cdot}}\right] = (n_{h11} + n_{h'11})\,\frac{n_{h\cdot\cdot} + n_{h'\cdot\cdot}}{n_{h1\cdot} + n_{h'1\cdot}} \qquad (3.4)$$

where the right-hand side of (3.4) is the contribution of the collapsed strata (h + h') to R_1. Likewise for R_2 and R_3.

Marginal collapsing using ECTA.

Both of the collapsing criteria are "population criteria." Therefore, we cannot verify them but must resort to statistical tests using the sample information. The null hypothesis will be that the above rates have differences not significantly different from zero.

To test this hypothesis, we use the ECTA (Everyman's Contingency Table Analysis) computer program which is based on an underlying log-linear model of the table cell frequencies -- see Goodman (1970, 1971) for details. In this case, the model assumes the form

$$\xi_{\mu,\ell_1,\ell_2,\ell_3,\ell_4} = \mu + \lambda^{W}_{\ell_1} + \lambda^{C}_{\ell_2} + \lambda^{D}_{\ell_3} + \lambda^{A}_{\ell_4} + \ldots + \lambda^{WCDA}_{\ell_1\ell_2\ell_3\ell_4} \qquad (3.5)$$

where

$$\xi_{\mu,\ell_1,\ell_2,\ell_3,\ell_4} = \ln(F_{\mu,\ell_1,\ell_2,\ell_3,\ell_4})$$

$$= \ln(E[f_{\mu,\ell_1,\ell_2,\ell_3,\ell_4}])$$

With

$f_{\mu,\ell_1,\ell_2,\ell_3,\ell_4}$ = frequency in the u-th category of injury × belt usage for
W (weight) at level ℓ_1,
C (crash configuration) at level ℓ_2,
D (damage severity) at level ℓ_3, and
A (age) at level ℓ_4.

The estimation of the parameters λ and the fitted values are accomplished by ECTA using an iterative proportional fitting procedure. Basically, ECTA adjusts the table to fit certain prescribed margins preserving the interaction structure in the original table specified by these margins.

One important feature of ECTA is that, if we have an n-level factor, we can associate its (n-1) degrees of freedom with (n-1) "effects" or comparisons of interest by utilizing appropriate design matrices, $\underset{\sim}{X}$. For example, the following design matrices are useful for examining the potential for collapsing various combinations of levels of weight, of damage severity, of age, and of crash configuration:

$$\underset{\sim}{X} = \begin{bmatrix} 1 & 0 & 1 \\ -1 & 0 & 1 \\ 0 & 1 & -1 \\ 0 & -1 & -1 \end{bmatrix} \quad \text{for W, C, and D;}$$

$$\underset{\sim}{X} = \begin{bmatrix} 0 & -2 \\ 1 & 1 \\ -1 & 1 \end{bmatrix} \quad \text{for A}$$

In this way we are comparing, for example, injury rates within each belt category for level 1 vs. level 2 of W, level 3 vs. level 4 of W and levels (1 + 2) vs. levels (3 + 4) of W.

To use Criterion A, the file is divided into three subsets corresponding to the belt usage levels with a saturated model fitted to each. To use Criterion B, the injury levels are combined to test equality of the belt usage distributions. The tests corresponding to the specified design matrices are then carried out by ECTA yielding standardized λ test statistics which, under the null hypotheses, are approximately normally distributed.

Thus, if we find that the standardized λ for a given comparison is sufficiently small simultaneously for unrestrained, for lap belt, and for lap and shoulder belt users, the levels (or strata) involved in this comparison can be collapsed.

Proceeding with ECTA, the original 480 strata (4 × 10 × 4 × 3) were reduced to 192 (4 × 4 × 4 × 3) by collapsing C-levels 1, 7, 9, and 10 (head-on with vehicle, rollover, head-on with fixed object, and side of vehicle into fixed object), levels 5 and 6 (angle, struck in left side and angle, struck in right side), levels 2 and 4 (rear-end, striking and angle, striking) and levels 3 and 8 (rear-end, struck and sideswipe). Finally, they were reduced to 48 (3 × 2 × 4 × 2) strata by collapsing levels (1, 7, 9, 10) and (5, 6) of crash configuration (C); by collapsing levels 1 and 2 (subcompact and compact) and levels 3 and 4 (intermediate and full-sized) of car weight (W); and collapsing levels 1 and 2 of age (A).

Of course, as this collapsing is based on hypothesis testing, the results are subject to unknown consequences of sampling variability. Therefore, the use of the parallel Mantel-Haenszel-type estimation procedure seemed desirable for comparison purposes.

<u>Use of GENCAT to estimate the R's, E's, and their standard errors.</u>

The collapsing described previously provides 48 (=d) strata. Even using only 2 functions per stratum, d is large enough to require three separate runs of an enlarged version of GENCAT.

For a given restraint system, say "none", we will take for each stratum the following information: $[n_{h11}, n_{h12}]$, i.e., number of unbelted "injured" and number of unbelted "non-injured" occupants, respectively, in the h-th stratum. Using these 2 responses per stratum, (the set-up in the terminology of Appendix D is s = 1 population and r = 2d = 96 responses), GENCAT then divides n_{h1j} by $n_{\cdot 1 \cdot}$ (= total number of unbelted cases) to generate the vector $(\underset{\sim}{p})$ of 96 relative frequencies.

An initial linear transformation defined by the block-diagonal matrix $\underset{\sim}{A}(2d \times 2d)$ with basic blocks

$$\underset{\sim}{A}_h = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix}$$

generates a (96×1) vector with the following entries for each stratum:

$$\begin{bmatrix} n_{h11}/n_{\cdot 1 \cdot} \\ n_{h1 \cdot}/n_{\cdot 1 \cdot} \end{bmatrix} = \begin{bmatrix} p_{h11} \\ p_{h11} + p_{h12} \end{bmatrix}$$

Next, consider a block-diagonal matrix $\underset{\sim}{K}(d \times 2d)$ with basic blocks

$$\underset{\sim}{K}_h = [1 \quad -1]$$

Then $\underset{\sim}{K}' [\underset{\sim}{\ln}(\underset{\sim}{A}\underset{\sim}{p})]$ will be a (48×1) vector with entries $\ln(n_{k11}/n_{h1\cdot})$ for each stratum. Taking exponentials yields estimates of the (within stratum) injury rates for the restraint system under consideration (unbelted in this illustration). The estimate $\hat{R}_1$ is then a weighted average of these (within stratum) injury rates.

To be able to obtain not only an overall estimate (across all strata), but also estimates for some subsets (e.g., minor damage) of interest, it is convenient to define weight vectors $w^*(1 \times 48)$ with elements proportional to $n_{h..}$ for each stratum of the subset and zeros for the remaining strata. Then

$$\hat{R}_1^* = \underset{\sim}{w}^* \ \underset{\sim}{\exp}\,[\underset{\sim}{K}\ \underset{\sim}{\ln}(\underset{\sim}{Ap})] = \sum_h w_h^* \frac{n_{h11}}{n_{h1\cdot}} \qquad (3.6)$$

is the estimate of the injury rate for unbelted occupants in the subset of interest. GENCAT then provides $\hat{R}_1^*$, along with the estimate $(\hat{V}_1^*)$ of its variance, (see (D.3) of Appendix D) for each $\underset{\sim}{w}^*$.

After obtaining $\hat{R}_i^*$ and $\hat{V}_i^*$, $i = 1,2,3$, the corresponding effectiveness estimates and their variances are given by the following:

$$\hat{E}_{ii'}^* = \frac{\hat{R}_i^* - \hat{R}_{i'}^*}{\hat{R}_i^*} \qquad i < i' \qquad (3.7)$$

$$\hat{V}_{ii'}^* = \frac{(\hat{R}_{i'}^*)^2}{(\hat{R}_i^*)^4}\,\hat{V}_i^* + \frac{1}{(\hat{R}_i^*)^2}\,\hat{V}_{i'}^* \qquad (3.8)$$

See Appendix E for the case with fixed weights and uncorrelated injury rates; otherwise (i.e., random weights) additional collapsing would be required.

<u>Mantel-Haenszel-type estimates.</u>

In order to provide estimates of precision, the GENCAT approach requires a compromise between fairly stringent collapsing and assumptions like "fixed weights". After examining the special features of the estimation problems involved, a more tailor-made approach (in the spirit of Mantel-Haenszel estimation procedures) was derived. A full description of the details is given in Appendix E. In brief, for each (h,i) = (stratum, restraint system) combination (h = 1,...,192; i = 1,2,3), the injury rate p_{hi1} and an unbiased estimate of its variance were computed as follows:

$$
\begin{aligned}
p_{hi1} &= n_{hi1}/n_{hi\cdot} && \text{if } n_{hi\cdot} > 1 \\
&= 1 && \text{if } n_{hi1} = 1 \text{ and } n_{hi2} = 0 \qquad (3.9) \\
&= 0 && \text{otherwise} \\
\hat{V}(p_{hi1}) &= p_{hi1}(1-p_{hi1})/(n_{hi\cdot}-1) && \text{if } n_{hi\cdot} > 1 \qquad (3.10) \\
&= 0 && \text{otherwise}
\end{aligned}
$$

Note that, when $n_{hi\cdot} \leq 1$, (3.10) is obviously underestimating $V(p_{hi1})$. An alternative biased estimator

$$
\begin{aligned}
\tilde{V} &= p_{hi1}(1-p_{hi1})/n_{hi1} && \text{if } n_{hi\cdot} \geq 1 \\
&= 0 && \text{otherwise}
\end{aligned}
$$

presents the same drawback when $n_{hi\cdot} < 1$ (i.e., when stratum h has no occupants in the i-th belt category). In any case, these rather extreme situations ($n_{hi\cdot} \leq 1$ or $n_{hi\cdot} < 1$) generally occur in strata with correspondingly small observed sample sizes ($n_{h\cdot\cdot}$). Therefore, the underestimation of the contribution of any such cell to $\hat{V}(\hat{R}_i)$ or $\hat{V}(\hat{E}_{ii'})$ for any subset of interest would be neglibible (recall factors w_h and w_h^2 in (E.13)). In similar situations, GENCAT tends to overestimate such contributions due to the correction factor .01.

The standardized injury rates and effectiveness estimates were computed as before. For comparison purposes, standard errors for the injury rates and effectiveness measures were computed assuming fixed weights (using expressions (E.3) and (E.4) of Appendix E) and also assuming random weights (using expressions (E.13) and (E.17) with $Cov(\hat{R}_i,\hat{R}_{i'}) = 0$). Since random weights would appear to be the more valid assumption, the corresponding estimates are provided herein.

As in the GENCAT approach, in order to examine various subsets of interest, it is possible to define the corresponding weight vectors $\underset{\sim}{w}^*$ where $\underset{\sim}{w}^*$ is a (1×192) vector.

Results

At least moderate injuries (AIS $\geq$ 2).

Table 3.1 contains the results of both estimation procedures described above (along with the unadjusted or crude estimates) for "injured" corresponding to "AIS $\geq$ 2". Note that crash type has the following levels:

Table 3.1. Injury rates and effectiveness measures (AIS ≥ 2).

Population		Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
OVERALL		$\hat{R}$	U	.121	(.0034)[1]	.114	(.0033)[2]	.116	(.0035)[3]
			L	.074	(.0052)	.081	(.0058)	.080	(.0056)
			LS	.047	(.0034)	.055	(.0039)	.051	(.0040)
		$\hat{E}$	U vs L	.388	(.0466)	.294	(.0546)	.309	(.0521)
			U vs LS	.612	(.0301)	.520	(.0368)	.565	(.0364)
			L vs LS	.365	(.0641)	.320	(.0687)	.371	(.0657)
DAMAGE SEVERITY	Minor	$\hat{R}$	U	.056	(.0036)	.055	(.0035)	.055	(.0035)
			L	.040	(.0057)	.041	(.0060)	.042	(.0059)
			LS	.024	(.0035)	.026	(.0039)	.024	(.0035)
		$\hat{E}$	U vs L	.272	(.1132)	.240	(.1216)	.243	(.1182)
			U vs LS	.561	(.0687)	.530	(.0773)	.564	(.0689)
			L vs LS	.397	(.1210)	.382	(.1294)	.424	(.1167)
	Moderate	$\hat{R}$	U	.114	(.0053)	.112	(.0053)	.114	(.0053)
			L	.079	(.0085)	.083	(.0092)	.081	(.0086)
			LS	.044	(.0053)	.047	(.0061)	.045	(.0056)
		$\hat{E}$	U vs L	.305	(.0814)	.257	(.0895)	.286	(.0829)
			U vs LS	.615	(.0500)	.585	(.0580)	.602	(.0529)
			L vs LS	.446	(.0897)	.441	(.0961)	.443	(.0912)
	Moderately Severe	$\hat{R}$	U	.254	(.0128)	.250	(.0128)	.251	(.0137)
			L	.157	(.0240)	.162	(.0238)	.169	(.0252)
			LS	.105	(.0156)	.135	(.0179)	.114	(.0223)
		$\hat{E}$	U vs L	.383	(.0996)	.351	(.1010)	.329	(.1068)
			U vs LS	.586	(.0648)	.461	(.0769)	.548	(.0921)
			L vs LS	.328	(.1431)	.169	(.1647)	.326	(.1661)
	Severe	$\hat{R}$	U	.431	(.0240)	.394	(.0251)	.419	(.0371)
			L	.212	(.0386)	.249	(.0534)	.244	(.0469)
			LS	.205	(.0298)	.220	(.0333)	.206	(.0324)
		$\hat{E}$	U vs L	.508	(.0944)	.369	(.1413)	.418	(.1232)
			U vs LS	.524	(.0746)	.443	(.0915)	.508	(.0887)
			L vs LS	.033	(.2250)	.118	(.2318)	.154	(.2101)
AGE	10-25	$\hat{R}$	U	.107	(.0046)	.101	(.0044)		
			L	.075	(.0078)	.083	(.0091)		
			LS	.046	(.0049)	.052	(.0058)		
		$\hat{E}$	U vs L	.299	(.0791)	.174	(.0973)		
			U vs LS	.573	(.0491)	.480	(.0622)		
			L vs LS	.391	(.0909)	.371	(.0984)		
	26-55	$\hat{R}$	U	.126	(.0054)	.119	(.0052)		
			L	.075	(.0078)	.080	(.0084)		
			LS	.046	(.0049)	.055	(.0057)		
		$\hat{E}$	U vs L	.402	(.0672)	.324	(.0769)		
			U vs LS	.635	(.0422)	.535	(.0518)		
			L vs LS	.390	(.0911)	.312	(.1010)		
	56+	$\hat{R}$	U	.164	(.0124)	.161	(.0127)	.163	(.0191)
			L	.064	(.0150)	.071	(.0140)	.067	(.0169)
			LS	.063	(.0126)	.066	(.0133)	.071	(.0230)
		$\hat{E}$	U vs L	.610	(.0962)	.562	(.0934)	.587	(.1145)
			U vs LS	.616	(.0826)	591	(.0882)	.564	(.1499)
			L vs LS	.016	(.3107)	.067	(.2632)	-.054	(.4313)

Table 3.1. Continued.

Population		Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
CRASH TYPE	1	R̂	U	.188	(.0078)	.184	(.0076)		
			L	.120	(.0138)	.136	(.0167)		
			LS	.099	(.0110)	.112	(.0118)		
		Ê	U vs L	.363	(.0783)	.262	(.0960)		
			U vs LS	.475	(.0623)	.392	(.0688)		
			L vs LS	.176	(.1322)	.176	(.1337)		
	2	R̂	U	.114	(.0064)	.109	(.0063)		
			L	.058	(.0085)	.069	(.0093)		
			LS	.045	(.0060)	.046	(.0065)		
		Ê	U vs L	.491	(.0803)	.366	(.0932)		
			U vs LS	.605	(.0573)	.577	(.0646)		
			L vs LS	.218	(.1540)	.333	(.1302)		
	3	R̂	U	.088	(.0048)	.086	(.0047)	.086	(.0045)
			L	.068	(.0082)	.066	(.0080)	.072	(.0086)
			LS	.033	(.0045)	.033	(.0047)	.035	(.0052)
		Ê	U vs L	.227	(.1028)	.232	(.1017)	.166	(.1088)
			U vs LS	.625	(.0553)	.614	(.0587)	.592	(.0635)
			L vs LS	.522	(.0872)	.497	(.0937)	.511	(.0926)
	4	R̂	U	.067	(.0093)	.067	(.0101)	.072	(.0179)
			L	.046	(.0126)	.034	(.0106)	.038	(.0110)
			LS	.025	(.0069)	.023	(.0069)	.026	(.0189)
		Ê	U vs L	.313	(.2160)	.494	(.1760)	.467	(.2029)
			U vs LS	.627	(.1188)	.655	(.1163)	.633	(.2787)
			L vs LS	.454	(.2105)	.317	(.2963)	.312	(.5322)
VEHICLE WEIGHT	Subcompact	R̂	U	.131	(.0065)	.126	(.0063)		
			L	.094	(.0109)	.094	(.0111)		
			LS	.053	(.0059)	.061	(.0069)		
		Ê	U vs L	.282	(.0911)	.254	(.0956)		
			U vs LS	.595	(.0500)	.517	(.0597)		
			L vs LS	.433	(.0908)	.352	(.1057)		
	Compact	R̂	U	.111	(.0066)	.106	(.0064)		
			L	.082	(.0111)	.097	(.0138)		
			LS	.047	(.0062)	.051	(.0070)		
		Ê	U vs L	.259	(.1098)	.086	(.1416)		
			U vs LS	.579	(.0614)	.522	(.0721)		
			L vs LS	.431	(.1080)	.477	(.1039)		
	Intermediate	R̂	U	.118	(.0069)	.111	(.0066)		
			L	.068	(.0104)	.066	(.0101)		
			LS	.047	(.0075)	.061	(.0082)		
		Ê	U vs L	.427	(.0937)	.402	(.0984)		
			U vs LS	.602	(.0677)	.450	[illegible]		
			L vs LS	.309	(.1548)	.080	[illegible]		
	Full-Sized	R̂	U	.120	(.0070)	.111	(.0069)		
			L	.048	(.0086)	.058	(.0099)		
			LS	.035	(.0074)	.045	(.0096)		
		Ê	U vs L	.600	(.0760)	.480	(.0947)		
			U vs LS	.708	(.0646)	.597	(.0893)		
			L vs LS	.267	(.2018)	.226	(.2116)		

[1] Standard error calculated using Taylor series expansion.

[2] Standard error calculated using formula described in text.

[3] Standard error calculated using GENCAT program.

1. Head-on, vehicle + rollover + head-on with fixed object + skidded sideways into fixed object

2. Rear-end, striking + angle, striking

3. Angle, struck in left side + angle, struck in right side

4. Rear-end, struck + sideswipe

In general, the Mantel-Haenszel-type estimates are farther away from the unadjusted estimates than the GENCAT estimates. These differences are, for the most part, not great. That there should be such differences should be expected since the Mantel-Haenszel-type estimation involves a finer stratification than GENCAT (overall, 192 strata for M-H vs. 48 strata for GENCAT vs. 1 stratum for each unadjusted estimate). Also the estimates of the standard errors given by the M-H type procedure are usually larger than those provided by the other procedures; this can at least partially be attributed to the the assumption of random stratum weights.

Estimates of the true overall injury rates are given by 11.6 percent, 8.0 percent and 5.1 percent for U, L, and LS, respectively, with corresponding effectiveness estimates of 30.9 percent, 56.5 percent, and 37.1 percent for U vs. L, U vs. LS, and L vs. LS. Their standard errors are naturally smaller than those associated with the "subsets" of interest.

For <u>each</u> restraint system, the injury rate increases with damage severity. The same trend is observed for the U vs. L effectiveness estimate; the other effectiveness estimates (U vs. LS) and (L vs. LS) are at least as high as the overall estimate for damage levels 1 and 2 and below the overall estimate for damage levels 3 and 4. The effectiveness estimates for (U vs. L) and (U vs. LS) generally increase with crash type level and with age.

On the average, belt effectiveness is greater for intermediate and full-sized cars than for compact and subcompact cars.

It should be noted that the single negative estimate for L vs. LS effectiveness has a large standard error indicating nonsignificant differences between the corresponding injury rates.

For the sake of brevity, estimates corresponding to certain categories (e.g., subcompact + compact) created by the collapsing required by GENCAT were computed but are not reported.

As there is special interest in belt effectiveness by area of the car impacted (e.g., front, side), the crash configuration variable was re-grouped into an "impact site" variable with levels defined as follows:

1. Front = Head-on with vehicle + rear-end, striking + angle striking + head-on with fixed object

2. Side = Angle, struck in left side + angle, struck in right side + sideswipe + skidded sideways into fixed object

3. Rear = Rear-end, struck

4. Rollover = Rollover.

For convenience, the resulting estimates are displayed in Table 3.2 for AIS ≥ 2. The 15,818 weighted observations break down into 8852 front impacts, 5673 side impacts, 1028 rear impacts and 265 rollovers. For AIS ≥ 2, the effectiveness increases from 23 percent for L to 53 percent for LS in front impacts. Similar results obtain in side and rear impacts. Adjusted estimates for rollover are not presented due to severe sample size limitations.

Table 3.3 presents the belt usage distributions for the three model years. As might be expected, the distributions are vastly different. In examining injury rates and effectiveness estimates by model year (see Table 3.4), no consistent trend is indicated. However, when analyzing these figures, one must recall the varying belt usage rates and the relatively small subsample of '75 vehicles (1744 compared to 7219 for '73 vehicles and 6833 for '74 vehicles; 22 '76 vehicles are included in the "pooled" estimates). These factors evidently cause the standardization procedure to differentially affect the three sets of estimates.

As indicated in Chapter II, there are differences (and inconsistencies) among the teams on such variables as belt usage (see Table 3.5) and object struck. If these are only differences related to region and if the composite of the regions represents the nation, there would be no problems pooling the data from the five teams. This, however, is perhaps too optimistic. Very likely the estimates should be carried out on a team-by-team basis. The trade-off is an obvious inability to control for more than one or at most two variables at a time (see Scott, Marsh, and Flora, 1976). This approach severely limits taking into account important interactions among the variables.

For the major portion of this report, it has been assumed that it is most important to control for a variety of interacting variables and hence the team data is pooled. However, an attempt was made to examine the within team estimates.

As shown in Table 3.6, the estimates for injury rates and effectiveness by team vary considerably. For example, for Calspan and Miami all the injury rates are slightly reduced by the standardization, for HSRI two of them are reduced, and for SWRI and USC only one injury rate is reduced.

Table 3.2 Injury rates and effectiveness measures by impact site (AIS $\geq$ 2).

Impact Site[2]	Estimate	Restraint System	Estimation Procedure: Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
Front	$\hat{R}$	U	.122	(.0045)[1]	.119	(.0043)	.118	(.0042)
		L	.085	(.0075)	.088	(.0078)	.091	(.0077)
		LS	.050	(.0048)	.055	(.0057)	.055	(.0053)
	$\hat{E}$	U vs L	.307	(.0668)	.258	(.0713)	.231	(.0710)
		U vs LS	.587	(.0421)	.532	(.0508)	.530	(.0478)
		L vs LS	.404	(.0778)	.370	(.0854)	.389	(.0781)
Side	$\hat{R}$	U	.123	(.0058)	.118	(.0057)	.118	(.0054)
		L	.061	(.0077)	.075	(.0089)	.071	(.0086)
		LS	.048	(.0054)	.049	(.0058)	.049	(.0055)
	$\hat{E}$	U vs L	.508	(.0668)	.364	(.0809)	.403	(.0776)
		U vs LS	.613	(.0478)	.590	(.0530)	.589	(.0503)
		L vs LS	.214	(.1345)	.355	(.1084)	.311	(.1145)
Rear	$\hat{R}$	U	.053	(.0105)	.054	(.0110)	.062	(.0229)
		L	.056	(.0158)	.037	(.0124)	.048	(.0195)
		LS	.031	(.0091)	.025	(.0078)	.033	(.0245)
	$\hat{E}$	U vs L	-.070	(.3686)	.323	(.2665)	.233	(.4204)
		U vs LS	.416	(.2088)	.539	(.1709)	.478	(.4376)
		L vs LS	.455	(.2231)	.319	(.3128)	.319	(.5832)

[1]Standard error.

[2]Adjusted estimates for ROLLOVER are not presented due to severe sample size limitations (190 unbelted, 14 lap belted, and 61 lap and shoulder belted). The unadjusted injury rates (see Table 2.3) are .174, .214, and .049 for U, L and LS, respectively; the unadjusted effectiveness estimates are -.234 for U vs L, .717 for U vs LS and .770 for L vs LS.

Table 3.3. Belt usage distribution by model year.

Model Year	None	Lap	Lap-Shoulder	Total
1973	4646 (64.4%)[1]	2143 (29.7%)	430 (6.0%)	7219 (45.7%)[2]
1974	3615 (52.9%)	317 (4.6%)	2901 (42.5%)	6833 (43.3%)
1975	973 (55.8%)	84 (4.8%)	687 (39.4%)	1744 (11.0%)
Total	9234 (58.5%)	2544 (16.1%)	4018 (25.4%)	15796[3]

[1]Row percent
[2]Column percent
[3]Excludes 22 1976 models

Table 3.4. Injury rates and effectiveness measures by model year (AIS ≥ 2).

Model Year	Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate	
1973	$\hat{R}$	U	.120	(.0048)[1]	.113	(.0042)
		L	.067	(.0054)	.071	(.0056)
		LS	.044	(.0099)	.034	(.0060)
	$\hat{E}$	U vs L	.438	(.0505)	.375	(.0550)
		U vs LS	.630	(.0843)	.698	(.0544)
		L vs LS	.342	(.1569)	.516	(.0935)
1974	$\hat{R}$	U	.124	(.0055)	.118	(.0050)
		L	.117	(.0181)	.098	(.0182)
		LS	.058	(.0042)	.061	(.0045)
	$\hat{E}$	U vs L	.059	(.1515)	.170	(.1582)
		U vs LS	.572	(.0385)	.487	(.0438)
		L vs LS	.545	(.0789)	.382	(.1238)
1975	$\hat{R}$	U	.109	(.0100)	.104	(.0091)
		L	.083	(.0303)	.049	(.0140)
		LS	.028	(.0063)	.037	(.0101)
	$\hat{E}$	U vs L	.235	(.2872)	.531	(.1407)
		U vs LS	.747	(.0619)	.647	(.1020)
		L vs LS	.669	(.1421)	.248	(.2988)
Pooled[2]	$\hat{R}$	U	.120	(.0034)	.114	(.0031)
		L	.074	(.0052)	.081	(.0057)
		LS	.048	(.0034)	.055	(.0038)
	$\hat{E}$	U vs L	.384	(.0466)	.294	(.0535)
		U vs LS	.603	(.0301)	.520	(.0359)
		L vs LS	.356	(.0641)	.320	(.0677)

[1]Standard error

[2]Includes 22 (weighted) observations on 1976 models.

Table 3.5 Belt usage by team.

Team	Belt Usage			Total
	None	Lap	Lap-Shoulder	
Calspan	1402 (65.9%)[1]	283 (13.3%)	444 (20.9%)	2129 (13.5%)[2]
Miami	1001 (54.9%)	302 (16.6%)	519 (28.5%)	1822 (11.5%)
HSRI	2526 (61.9%)	624 (15.3%)	933 (22.9%)	4083 (25.8%)
SWRI	3206 (55.6%)	1030 (17.9%)	1530 (26.5%)	5766 (36.5%)
USC	1107 (54.9%)	305 (15.1%)	606 (30.0%)	2018 (12.8%)
Total	9242	2544	4032	15818

[1] Row percent

[2] Column percent

Table 3.6 Injury rates and effectiveness measures by team (AIS≥2).

Team	Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate	
Calspan	$\hat{R}$	U	.180	(.0103)	.167	(.0091)
		L	.113	(.0189)	.096	(.0165)
		LS	.092	(.0138)	.081	(.0109)
	$\hat{E}$	U vs L	.371	(.1109)	.424	(.1036)
		U vs LS	.486	(.0820)	.518	(.0701)
		L vs LS	.183	(.1826)	.162	(.1828)
Miami	$\hat{R}$	U	.068	(.0080)	.064	(.0073)
		L	.050	(.0125)	.036	(.0083)
		LS	.021	(.0063)	.018	(.0052)
	$\hat{E}$	U vs L	.270	(.2031)	.434	(.1446)
		U vs LS	.689	(.0998)	.712	(.0879)
		L vs LS	.574	(.1664)	.491	(.1851)
HSRI	$\hat{R}$	U	.095	(.0058)	.088	(.0053)
		L	.056	(.0092)	.055	(.0080)
		LS	.049	(.0071)	.059	(.0071)
	$\hat{E}$	U vs L	.407	(.1040)	.371	(.0986)
		U vs LS	.479	(.0815)	.332	(.0902)
		L vs LS	.121	(.1920)	-.062	(.2006)
SWRI	$\hat{R}$	U	.135	(.0060)	.126	(.0054)
		L	.078	(.0083)	.088	(.0078)
		LS	.042	(.0052)	.046	(.0054)
	$\hat{E}$	U vs L	.424	(.0670)	.308	(.0686)
		U vs LS	.685	(.0408)	.637	(.0456)
		L vs LS	.453	(.0887)	.476	(.0775)
USC	$\hat{R}$	U	.107	(.0093)	.105	(.0088)
		L	.085	(.0160)	.089	(.0156)
		LS	.048	(.0087)	.045	(.0095)
	$\hat{E}$	U vs L	.200	(.1656)	.152	(.1640)
		U vs LS	.551	(.0903)	.576	(.0970)
		L vs LS	.439	(.1466)	.500	(.1376)
Pooled	$\hat{R}$	U	.120	(.0034)	.114	(.0031)
		L	.074	(.0052)	.081	(.0057)
		LS	.048	(.0034)	.055	(.0038)
	$\hat{E}$	U vs L	.384	(.0466)	.294	(.0535)
		U vs LS	.612	(.0301)	.520	(.0359)
		L vs LS	.356	(.0641)	.320	(.0677)

With respect to the effectiveness estimates, there would appear to be four outliers (three of which have relatively large standard errors). Specifically, these deviant estimates derive from USC for U vs. L, HSRI for U vs. LS, and from Calspan and HSRI for L vs LS.

At least severe injuries (AIS ≥ 3).

Because these injuries are naturally considerably less common than those classified as AIS ≥ 2, (2.4% vs. 9.4% in the Level 2 file), analysis of this information will be less detailed. Generally, larger standard errors, more cases of negative estimates of effectiveness, etc., are to be anticipated.

Table 3.7 presents results for the different estimation procedures when "injured" is defined to be "AIS ≥ 3". Here, the overall injury rates are 3.1 percent, 1.7 percent, and 1.3 percent for U, L, and LS, respectively; effectiveness measures for U vs. L, U vs. LS, and L vs. LS are 46.3 percent, 56.8 percent, and 19.6 percent, respectively. As observed previously for AIS ≥ 2, the GENCAT estimates are closer to the unadjusted estimates than are the Mantel-Haenszel-type estimates.

As expected, for each restraint system, the injury rate increases with damage severity. Since, in most cases there are changes in the second or third decimal place, the corresponding changes in effectiveness are less predictable. Similarly, the injury rates for the U and LS restraint systems increase with age while being stationary for L.

AIS ≥ 3 injury rates and effectiveness measures by impact site are given in Table 3.8. Compared with the corresponding estimates for AIS ≥ 2 injuries (see Table 3.2), the effectiveness estimates for AIS ≥ 3 injuries increase for U vs. L and U vs. LS in frontal impacts, and for U vs. L in side and rear impacts. Again, the negative estimate for L vs. LS effectiveness in rear impacts is associated with a large standard error, implying a nonsignificant difference between the corresponding injury rates.

Fatalities.

Only .54 percent (86 out of 15818) of the observations in the extract file (see Appendix B) correspond to fatalities. Therefore, the adjusted estimates appear to be appropriate for the overall sample, at most. Table 3.9 shows effectiveness estimates for U vs. L of 71.4 percent, for U vs. LS of 54.6 percent, and for L vs. LS not significantly different from zero. For reference, unadjusted values of the injury rates and effectiveness measures are displayed in Table 3.10 for various subsets of interest.

All of these estimates must be regarded with caution since they derive from very small numbers:

70 fatalities out of 9242 unbelted occupants,

4 fatalities out of 2544 lap-belted occupants, and

12 fatalities out of 4032 lap and shoulder belt users.

Table 3.7. Injury rates and effectiveness measures (AIS ≥ 3).

Population		Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
DAMAGE SEVERITY	OVERALL	$\hat{R}$	U	.032	(.0018)[1]	.030	(.0018)[2]	.031	(.0022)[3]
			L	.015	(.0024)	.017	(.0029)	.017	(.0027)
			LS	.012	(.0017)	.016	(.0021)	.013	(.0026)
		$\hat{E}$	U vs L	.531	(.0802)	.426	(.1007)	.463	(.0970)
			U vs LS	.618	(.0585)	.465	(.0774)	.568	(.0899)
			L vs LS	.187	(.1746)	.072	(.1971)	.196	(.2054)
	Minor	$\hat{R}$	U	.010	(.0016)	.010	(.0016)	.010	(.0016)
			L	.006	(.0022)	.006	(.0022)	.005	(.0020)
			LS	.005	(.0017)	.006	(.0018)	.005	(.0017)
		$\hat{E}$	U vs L	.415	(.2386)	.430	(.2345)	.461	(.2175)
			U vs LS	.500	(.1875)	.428	(.2035)	.498	(.1817)
			L vs LS	.167	(.4567)	-.004	(.4983)	.068	(.4617)
	Moderate	$\hat{R}$	U	.022	(.0024)	.023	(.0025)	.022	(.0025)
			L	.014	(.0037)	.016	(.0046)	.014	(.0038)
			LS	.007	(.0021)	.008	(.0026)	.008	(.0024)
		$\hat{E}$	U vs L	.365	(.1829)	.275	(.2187)	.344	(.1888)
			U vs LS	.691	(.1034)	.662	(.1189)	.653	(.1180)
			L vs LS	.513	(.2006)	.534	(.2035)	.471	(.2199)
	Moderately Severe	$\hat{R}$	U	.075	(.0077)	.071	(.0076)	.074	(.0095)
			L	.030	(.0114)	.033	(.0129)	.033	(.0121)
			LS	.023	(.0076)	.046	(.0093)	.028	(.0172)
		$\hat{E}$	U vs L	.600	(.1588)	.545	(.1873)	.549	(.1739)
			U vs LS	.693	(.1076)	.358	(.1465)	.623	(.2376)
			L vs LS	.242	(.3776)	-.412	(.6304)	.164	(.5988)
	Severe	$\hat{R}$	U	.213	(.0198)	.190	(.0195)	.204	(.0343)
			L	.088	(.0268)	.102	(.0298)	.103	(.0349)
			LS	.103	(.0224)	.115	(.0287)	.104	(.0267)
		$\hat{E}$	U vs L	.587	(.1342)	.465	(.1661)	.494	(.1911)
			U vs LS	.516	(.1165)	.394	(.1655)	.489	(.1562)
			L vs LS	-.161	(.4334)	-.133	(.4360)	-.010	(.4283)
AGE	10-25	$\hat{R}$	U	.025	(.0023)	.023	(.0022)		
			L	.016	(.0037)	.017	(.0043)		
			LS	.010	(.0023)	.011	(.0027)		
		$\hat{E}$	U vs L	.360	(.1649)	.241	(.2044)		
			U vs LS	.600	(.1019)	.505	(.1309)		
			L vs LS	.384	(.2042)	.348	(.2292)		
	26-55	$\hat{R}$	U	.036	(.0030)	.032	(.0028)		
			L	.015	(.0036)	.019	(.0044)		
			LS	.012	(.0025)	.019	(.0035)		
		$\hat{E}$	U vs L	.583	(.1079)	.416	(.1466)		
			U vs LS	.667	(.0769)	.412	(.1200)		
			L vs LS	.219	(.2532)	-.006	(.3004)		
	56+	$\hat{R}$	U	.057	(.0077)	.057	(.0074)	.059	(.0169)
			L	.011	(.0065)	.011	(.0064)	.015	(.0104)
			LS	.023	(.0081)	.027	(.0079)	.030	(.0207)
		$\hat{E}$	U vs L	.807	(.1179)	.811	(.1146)	.743	(.1921)
			U vs LS	.596	(.1573)	.533	(.1520)	.483	(.3824)
			L vs LS	-1.091	(1.5132)	-.147	(1.6423)	-1.010	(1.9519)

Table 3.7. Continued

Population		Estimate	Restraint System	Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
CRASH TYPE	1	R̂	U	.061	(.0048)	.061	(.0047)		
			L	.038	(.0081)	.043	(.0097)		
			LS	.032	(.0065)	.043	(.0072)		
		Ê	U vs L	.380	(.1414)	.298	(.1679)		
			U vs LS	.472	(.1138)	.290	(.1296)		
			L vs LS	.149	(.2501)	-.011	(.2839)		
	2	R̂	U	.031	(.0034)	.127	(.0032)		
			L	.013	(.0041)	.018	(.0052)		
			LS	.012	(.0032)	.013	(.0036)		
		Ê	U vs L	.581	(.1499)	.326	(.2071)		
			U vs LS	.613	(.1182)	.534	(.1445)		
			L vs LS	.062	(.3806)	.309	(.2788)		
	3	R̂	U	.015	(.0020)	.015	(.0021)	.014	(.0020)
			L	.004	(.0021)	.003	(.0016)	.004	(.0016)
			LS	.004	(.0016)	.004	(.0015)	.005	(.0026)
		Ê	U vs L	.711	(.1499)	.783	(.1156)	.703	(.1871)
			U vs LS	.736	(.1138)	.752	(.1123)	.676	(.1827)
			L vs LS	.087	(.5887)	-.140	(.7624)	-.089	(.8963)
	4	R̂	U	.022	(.0054)	.022	(.0061)	.026	(.0164)
			L	.011	(.0062)	.005	(.0031)	.007	(.0038)
			LS	.008	(.0039)	.006	(.0033)	.010	(.0181)
		Ê	U vs L	.500	(.3215)	.755	(.1584)	.742	(.2170)
			U vs LS	.636	(.2082)	.720	(.1703)	.636	(.7239)
			L vs LS	.272	(.5540)	-.143	(.9077)	-.408	(2.7789)
VEHICLE WEIGHT	Subcompact	R̂	U	.033	(.0034)	.032	(.0033)		
			L	.022	(.0055)	.022	(.0058)		
			LS	.012	(.0028)	.013	(.0033)		
		Ê	U vs L	.320	(.1827)	.325	(.1935)		
			U vs LS	.639	(.0952)	.599	(.1094)		
			L vs LS	.468	(.1838)	.406	(.2183)		
	Compact	R̂	U	.029	(.0035)	.028	(.0034)		
			L	.010	(.0040)	.012	(.0051)		
			LS	.013	(.0033)	.014	(.0042)		
		Ê	U vs L	.656	(.1463)	.580	(.1927)		
			U vs LS	.546	(.1291)	.480	(.1655)		
			L vs LS	-.317	(.6332)	-.238	(.6565)		
	Intermediate	R̂	U	.032	(.0038)	.030	(.0036)		
			L	.014	(.0048)	.016	(.0056)		
			LS	.015	(.0044)	.028	(.0053)		
		Ê	U vs L	.531	(.1550)	.478	(.1974)		
			U vs LS	.506	(.1476)	.066	(.2099)		
			L vs LS	-.071	(.5269)	-.789	(.7244)		
	Full-sized	R̂	U	.035	(.0039)	.030	(.0036)		
			L	.013	(.0045)	.019	(.0061)		
			LS	.006	(.0032)	.010	(.0046)		
		Ê	U vs L	.629	(.1413)	.358	(.2177)		
			U vs LS	.829	(.0977)	.680	(.1570)		
			L vs LS	.500	(.3051)	.502	(.2845)		

[1] Standard error calculated using Taylor series expansion

[2] Standard error calculated using formula described in test.

[3] Standard err~r calculated using GENCAT program.

Table 3.8. Injury rates and effectiveness measures by impact site (AIS ≥ 3).

Impact Site[2]	Estimate	Restraint System	Estimation Procedure: Unadjusted		Mantel-Haenszel-type estimate		GENCAT and log-linear model	
Front	$\hat{R}$	U	.029	(.0023)[1]	.028	(.0023)	.028	(.0023)
		L	.013	(.0031)	.014	(.0034)	.014	(.0033)
		LS	.011	(.0023)	.013	(.0028)	.013	(.0028)
	$\hat{E}$	U vs L	.544	(.1127)	.511	(.1276)	.494	(.1241)
		U vs LS	.619	(.0844)	.551	(.1044)	.539	(.1067)
		L vs LS	.165	(.2611)	.083	(.3030)	.089	(.2889)
Side	$\hat{R}$	U	.037	(.0034)	.035	(.0032)	.035	(.0030)
		L	.017	(.0041)	.023	(.0052)	.021	(.0050)
		LS	.015	(.0031)	.015	(.0033)	.015	(.0030)
	$\hat{E}$	U vs L	.549	(.1190)	.330	(.1613)	.413	(.1513)
		U vs LS	.595	(.0914)	.569	(.1026)	.582	(.0931)
		L vs LS	.102	(.2901)	.358	(.2008)	.288	(.2262)
Rear	$\hat{R}$	U	.011	(.0049)	.011	(.0053)	.018	(.0208)
		L	.014	(.0081)	.007	(.0040)	.011	(.0147)
		LS	.008	(.0048)	.006	(.0037)	.011	(.0234)
	$\hat{E}$	U vs L	-.285	(.9338)	.398	(.4515)	.385	(1.1110)
		U vs LS	.236	(.5562)	.461	(.4113)	.355	(1.5388)
		L vs LS	.405	(.4840)	.106	(.7524)	-.048	(2.5397)

[1]Standard error.

[2]Adjusted estimates for ROLLOVER are not presented due to severe sample size limitations (190 unbelted, 14 lap belted, and 61 lap and shoulder belted). The unadjusted injury rates (see Table 2.3) are .074, .071 and .000 for U, L and LS, respectively; the unadjusted effectiveness estimates are .031 for U vs L, 1.000 for U vs LS and 1.000 for L vs LS.

Table 3.9. Overall estimates of injury rates and effectiveness measures (AIS=6).

Estimate	Restraint System	Estimation Procedure					
		Unadjusted		Mantel-Haenzel-type estimate		GENCAT	
$\hat{R}$	U	.0076	(.0009)	.0067	(.0008)	.0074	(.0017)
	L	.0016	(.0008)	.0025	(.0009)	.0021	(.0012)
	LS	.0030	(.0009)	.0030	(.0009)	.0034	(.0020)
$\hat{E}$	U vs L	.7924	(.1066)	.6299	(.1433)	.7142	(.1687)
	U vs LS	.6071	(.1226)	.5584	(.1442)	.5459	(.2902)
	L vs LS	-.8929	(1.0920)	-.1929	(.5669)	-.5889	(1.1284)

One misclassified observation (especially with respect to lap belts) can produce sizable consequences!

Finally, it should be mentioned that only 86 out of a total of 96 fatalities were included in the extract file because of incomplete information on the other 10. Three of these cases provide no information on crash type; an additional three lack information on car weight and damage severity (investigators evidently were not able to examine the vehicle); two others lacked age; and belt status was not reported for the remaining case. The unusable cases were distributed among the five teams approximately proportional to their sample sizes. In addition, at least in terms of belt usage, both groups look similar (4 unbelted out of 6 "non-included" fatalities (for which belt status was known) versus 70 out of 86 "usable" fatalities; i.e., 67% vs. 81%). Thus, the usable fatals do not appear to be a seriously biased subsample of the fatal cases.

Smoothing the data.

Throughout the analysis phases, various attempts were made to fit various GENCAT and ECTA models to the data in an attempt to smooth the data prior to deriving the belt-specific injury rates and effectiveness estimates. Generally, it was to no avail due to the highly skewed distribution of the data across the various strata. The data is particularly thin for belted occupants in the highest damage category (severe), in rollovers, and in the oldest age category (>55 years of age). This made adequate model fitting most tenuous (for example in Appendix C) without further collapsing.

Table 3.10. Injury rates and effectiveness measures for AIS = 6.

Population		Frequency of AIS = 6			Unadjusted injury rate			Unadjusted effectiveness estimate		
		U	L	LS	U	L	LS	U vs L	U vs LS	L vs LS
Overall		70	4	12	.0076	.0016	.0030	.7924	.6071	-.8929
Crash Type	1	44	2	7	.0174	.0036	.0094	.7919	.4575	-1.6073
	2	20	1	4	.0081	.0013	.0033	.8364	.5904	-1.5029
	3	4	0	0	.0011	.0000	.0000	1.0000	1.0000	--[1]
	4	2	1	1	.0028	.0036	.0019	-.2786	.3021	.4542
Car Weight	Sub-compact	19	1	7	.0071	.0014	.0049	.8055	.3182	-2.5049
	Compact	14	0	4	.0062	.0000	.0035	1.0000	.4468	--
	Intermediate	17	1	1	.0077	.0017	.0012	.7783	.8388	.2728
	Full-sized	20	2	0	.0095	.0032	.0000	.6611	1.0000	1.0000
Damage Severity	Minor	4	0	2	.0010	.0000	.0010	1.0000	-.0332	--
	Moderate	16	0	2	.0045	.0000	.0013	1.0000	.6987	--
	Mod. severe	15	0	1	.0129	.0000	.0026	1.0000	.8017	--
	Severe	35	4	7	.0820	.0354	.0378	.5681	.5384	-.0689
Age	10-25	28	1	6	.0061	.0009	.0033	.8559	.4670	-2.6973
	26-55	29	3	4	.0077	.0026	.0022	.6580	.7117	.1570
	56 +	13	0	2	.0146	.0000	.0052	1.0000	.6442	--
Impact Site	Front	33	2	4	.0061	.0015	.0019	.7589	.6850	-.3064
	Side	31	1	8	.0097	.0010	.0052	.8926	.4631	-4.0006
	Rear	1	1	0	.0022	.0047	.0000	-1.1455	1.0000	1.0000
	Rollover	5	0	0	.0263	.0000	.0000	1.0000	1.0000	--
Model Year	1973	44	2	1	.0095	.0009	.0023	.9015	.7544	-1.4919
	1974	23	2	9	.0064	.0063	.0031	.0084	.5124	.5083
	1975	3	0	2	.0031	.0000	.0029	1.0000	.0558	--

[1]The value of this ratio is undefined (zero denominator)

In a final attempt to derive smoothed stratum injury rates (i.e., to fit GENCAT linear models with satisfactory lack-of-fit statistics), it was necessary to collapse into two impact sites -- front vs. others. Relatively simple models sufficed for unbelted (U) and for lap and shoulder-belted (LS) occupants (p=.48 and p=.35, respectively) but the opposite occurred with lap (L) belted occupants (p=.00).

After combining L and LS into a single belt category (B), a linear model which included all second order interactions and two third order interactions, (D x I x A) and (D x W x A), provided an adequate fit to the data (p=.30 for U and p=.27 for B). The resulting cell estimates are given in Table 3.11 with the corresponding standard errors of these injury rate estimates. Note that one stratum (front impact, damage 2, weight 1, over 55) was excluded due to lack of information: 0 unbelted cases, 2 belted. Comparing similar strata, it can be noted that these smoothed injury rates are higher for unbelted occupants in every situation than for belted; generally higher for frontal collisions than for others; and clearly increasing with damage severity for unbelted occupants (no clear pattern for belted occupants). In addition, for about 60 percent of the comparisons between levels of vehicle weight, the injury rate is higher for the smaller cars. For most age comparisons, the higher injury rate corresponds to older people.

Proceeding as before, these smoothed estimates are used as input in the calculation of adjusted injury rates and corresponding effectiveness estimates (see Table 3.12). The estimates for "unbelted" occupants are very close to the corresponding entries in Table 3.1 and 3.2; on the other hand, the estimates for "belted" lie between the values corresponding to L and LS -- closer to those for LS.

As considerably further collapsing was inquired in order to smooth the data (e.g., belt status, impact site), the analyses were generally applied to the raw data. It is useful to note that, where comparisons could be made, the results were quite similar.

Table 3.11. Smoothed (GENCAT) stratum injury rates and their standard errors.

Stratum*				Belt Status			
				Unbelted		Belted	
I	D	W	A	Injury Rate	(Standard Error)	Injury Rate	(Standard Error)
1	1	1	1	.049	(.0054)	.035	(.0052)
1	1	1	2	.113	(.0282)	.031	(.0168)
1	1	2	1	.059	(.0065)	.025	(.0055)
1	1	2	2	.075	(.0187)	.048	(.0202)
1	2	1	1	.155	(.0105)	.088	(.0101)
1	2	1	2	.247	(.0477)	.030	(.0194)
1	2	2	1	.124	(.0105)	.081	(.0113)
1	2	2	2	.251	(.0391)	.076	(.0297)
1	3	1	1	.390	(.0293)	.216	(.0364)
1	3	1	2	.473	(.1238)	.005	(.0165)
1	3	2	1	.367	(.0308)	.205	(.0397)
1	3	2	2	.452	(.1059)	.021	(.0827)
1	4	1	1	.400	(.0447)	.350	(.0516)
1	4	2	1	.483	(.0492)	.212	(.0510)
1	4	2	2	.643	(.1281)	.333	(.2722)
2	1	1	1	.045	(.0081)	.026	(.0064)
2	1	1	2	.085	(.0335)	.040	(.0251)
2	1	2	1	.058	(.0106)	.016	(.0062)
2	1	2	2	.051	(.0219)	.057	(.0222)
2	2	1	1	.083	(.0096)	.040	(.0068)
2	2	1	2	.109	(.0310)	.021	(.0200)
2	2	2	1	.055	(.0077)	.033	(.0075)
2	2	2	2	.117	(.0270)	.067	(.0219)
2	3	1	1	.187	(.0178)	.097	(.0174)
2	3	1	2	.369	(.0840)	.113	(.0775)
2	3	2	1	.167	(.0205)	.085	(.0224)
2	3	2	2	.352	(.0636)	.128	(.0504)
2	4	1	1	.386	(.0368)	.207	(.0325)
2	4	1	2	.333	(.1924)	.429	(.1870)
2	4	2	1	.473	(.0460)	.069	(.0382)
2	4	2	2	.417	(.1432)	.001	(.0062)

* I: 1 = front
2 = others

D: 1 = minor
2 = moderate
3 = moderately severe
4 = severe

W: 1 = less than 3600 lbs.
2 = 3600+ lbs.

A: 1 = 10-55
2 = 56+

Table 3.12 GENCAT adjusted injury rates (AIS ≥ 2) and effectiveness estimates based on smoothed stratum-injury rates

	Population	Injury Rate: Unbelted	Injury Rate: Belted	Effectiveness Estimates
	Overall	.116 (.0031)[1]	.060 (.0030)	.478 (.0294)[1]
Impact Site	Front	.118 (.0041)	.066 (.0043)	.438 (.0411)
	Others	.113 (.0408)	.053 (.0040)	.532 (.0408)
Damage Severity	Minor	.055 (.0036)	.030 (.0031	.456 (.0658)
	Moderate	.112 (.0052)	.060 (.0049)	.462 (.0504)
	Mod. Severe	.251 (.0124)	.124 (.0134)	.506 (.0585)
	Severe	.425 (.0239)	.211 (.0234)	.503 (.0619)
Vehicle Weight	<3600 lbs.	.118 (.0043)	.066 (.0039)	.441 (.0391)
	3600 + lbs.	.113 (.0045)	.053 (.0044)	.528 (.0434)
Occupant Age	≤ 55	.111 (.0032)	.061 (.0031)	.454 (.0325)
	56+	.162 (.0117)	.059 (.0095)	.634 (.0643)

[1]Standard error.

IV. ESTIMATION OF BELT EFFECTIVENESS USING DIRECT INJURY COSTS.

In order to estimate belt effectiveness using the continuous variable cost, it is necessary to estimate for each occupant on the Level 2 file, the direct cost due to the injuries sustained. This task consists of two phases: Phase I, in which a literature search and search for data is used to determine the feasibility of obtaining cost information that is relevant and usable in this task, and Phase II, in which the required data gathering and analysis is carried out, since the results of Phase I are favorable.

Feasibility of Obtaining Data

Phase I has been successfully completed and sufficient data has been obtained to allow computing costs on a limited but perhaps adequate basis. A number of publications from the National Center for Health Statistics, as well as Marsh (1973), Flora et al., (1975), U.S. Vital Statistics (1973), U.S. Bureau of the Census (1973), and the U.S. Department of Commerce (1974), were searched for either clues to the existence of injury - specific treatment cost data or tables that contained usable data. Many of the publications contained data and reference to data sources; however, due to the fact that all of the publications were concerned with cost comparisons over broad classes of injuries, it became readily apparent that data which would be specific enough for the present purposes would be unlikely to be found. Thus, it was determined that other data sources would have to be investigated.

A number of persons were contacted in order to determine if appropriate data could be obtained. The data being sought would need to provide some estimate of hospital days, mean hospital cost and mean professional cost (physician, anesthesiology, surgery, etc.) for each class of injury defined by the OIC (Occupant Injury Code) on the Level 2 file. (See Marsh, 1973 for a description of the OIC.) The data would also need to distinguish between persons being admitted, persons treated and released, and persons fatally injured. In addition, it was desirable to determine an estimate of disability days for each injury class on the Level 2 file. Age and sex specific data would also be helpful since these two variables are highly correlated with length of stay in hospital and therefore cost.

Inquiries made of Richmond Blue Cross in Richmond, Virginia, indicated that a listing of the ICDA (diagnosis) code, along with total number of cases, total hospital days, and total cost for the code for their files had been requested by and sent to Technology & Economics, Inc. in Cambridge, Massachusetts. In turn, a copy of this report was sent to HSRC. It proved to be quite useful; however, it contained only hospital data, not professional or disability data. NHTSA was also contacted and it was determined that data in their possession was not useful for our purposes because it was aggregated by AIS levels. The Research Resources Center of the Illinois Department of Public Health in Chicago maintains a "trauma registry" which contains detailed medical and other data on accident cases. However, the cases in the file are serious injury cases only, and no cost data is contained in the file. Thus, this data source was also judged to be inadequate for our purposes. Other potential data sources were considered and abandoned because the data were not sufficiently specific or comprehensive. These sources included INS America, the Health Insurance Association, and the Commission on Professional and Hospital Activities.

Toward the end of August 1975, a request was made of Blue Cross Blue Shield (BCBS) of North Carolina for the Plan's assistance in obtaining hospital and professional cost data for specific injuries. BCBS responded favorably to the inquiry by extracting the needed data from their files and allowing HSRC to use the data for analysis purposes. A description of the extracted file will be given in another section. The data from BCBS of North Carolina appears to be adequate to estimate days of hospitalization and cost to the specific injury classification level desired, and thus it was used for this purpose.

Estimates of the number of days of restricted activity for specific age/sex/injury categories were found to be available from the National Center for Health Statistics (National Center for Health Statistics, 1969), and estimates of mean yearly wages for specific age/sex categories were available from the 1970 census data (U.S. Bureau of the Census, 1973). Based upon the data obtained from BCBS and the availability of data on disabilities and wages, it was determined that it was feasible to estimate injury costs based upon direct medical expenditures, lost wages, and funeral costs (for victims that were fatally injured). Other cost components, such as insurance administration costs, legal fees, pain and suffering, and property repair costs were not pursued because of the likelihood that the data were not available and because of the limited time frame of this project.

Data

The data which BCBS extracted for our use consists of approximately 600,000 claims records which were identified as referring to claims that were filed for treatment of injuries. The extracted file, which will be referred to as the BCBS file, did not contain all of the variables that were recorded in each record of the original file. Rather, only the following 11 items, which were considered necessary for the present effort, were obtained:

1. Identification key - contains an 8-digit number which identifies the patient uniquely and is useful for matching purposes. (This is always present.)
   Note: To prohibit actual identification of the person involved, only the final five digits of

the ten digit identification key were extracted. Since the file was sorted by the entire identification key, this allowed all records having the same identification key to be identified.

2. Benefit code - a 1 digit code which gives the type of services required. It has the following possible values:
   0 - hospital inpatient services
   1 - hospital outpatient services
   2 - professional surgical services
   3 - professional medical services
   (This code is always available.)

3. Birth year - a two digit code giving the year of birth of the victim (00 through 75 for 1900 through 1975 and 99 for years prior to 1900). (This code is occasionally missing.)

4. Sex/Relationship - a 1 digit code giving the sex of the victim and his relationship to the insurance policy holder. It takes the following values:
   1 - male BCBS subscriber
   2 - female BCBS subscriber
   3 - male spouse of BCBS subscriber
   4 - female spouse of BCBS subscriber
   5 - male child of BCBS subscriber
   6 - female child of BCBS subscriber
   7 - male handicapped dependent of BCBS subscriber
   8 - female handicapped dependent of BCBS subscriber

   (This code is always available; however, it will not distinguish between brothers or sisters.)

5. Days of service paid - a three digit number giving the number of days of hospital care that were paid by BCBS. (This can be useful for eliminating nonvalid cases.)

6. Beginning date of service - a two byte code containing, in packed bit representation, the first day that treatment was rendered. This must be recoded before it is usable.

7. Ending date of service - same as 6., but contains the last date that service was provided. These two dates are useful for determining the number of days of hospital care that was provided.

8. Total charge - the total amount charged the patient for services represented on the record. This generally includes all necessary hospital services. Supplementary services, such as television charges, may possibly be included but usually are not.

9. Treatment code - a two digit code giving the nature of services provided. Some relevant examples are:

   02 - surgery
   04 - anesthesia
   06 - medical care in hospital
   07 - dental care
   08 - laboratory services
   09 - consultation
   20 - accident
   21 - medical emergency
   22 - diagnostic x-ray
   34 - laboratory services and x-ray

10. Diagnosis code - a four digit number giving either the 3 digit ICDA code for hospital inpatient cases, the 4 digit procedure code for professional services, or nothing for hospital outpatient services

11. Type record - a one digit code having the following meaning:

   5 - indicates hospital services were provided and diagnosis code contains an ICDA code.

   7 - indicates professional services were provided and diagnosis code contains a procedure code.

The National Center for Health Statistics publication Types of Injuries: Incidence and Associated Disability (NCHS, 1969) contains tables giving the average annual number of days of restricted activity due to current injuries by age, sex, and type of injury (Table 16) and the average annual number of current injuries by age, sex, and type of injury. The mean number of days of restricted activity per injury was computed by dividing each entry in Table 16 by the corresponding entry in Table 5. (See Table 4.1).

Wage data was obtained from the publication by the U.S. Bureau of the Census (1970). This data is given in Table 4.2. These figures refer to 1969 wages, rather than 1974 wages. To adjust for the effects of wage inflation, the figures in Table 4.2 were increased by 32 percent when costs due to lost wages were computed.

The life table, given in National Center for Health Statistics (1971), was used to estimate the expected number of years of life remaining for a person with a specified age and sex. For example, the table shows that at birth life expectancies are 67.0, 74.6 years for males, females, respectively. At age 10, the corresponding expectancies of remaining years of life are 59.0 and 66.3 while at age 40 they are 31.5 and 37.6.

Table 4.1. Mean days of restricted activity by sex.

	< 17			17-24			25-44			45-64			> 64			All Ages		
	M	F	Both	M	F	Both	M	F	Both	M	F	Both	M	F	Both	M	F	Both
1. Skull fractures	1.3	4.1	2.3	5.7	2.2	3.4	7.3	8.6	7.7	11.1	10.2	10.7	10.1	6.8	8.9	4.0	5.1	4.4
2. Other fractures	14.0	11.3	12.9	20.6	9.4	16.4	21.4	21.7	21.5	25.1	33.0	28.1	39.3	49.9	47.0	20.3	22.8	21.3
3. Sprains of back	6.9	1.6	3.8	7.0	6.8	6.9	11.4	12.4	11.8	6.7	15.8	10.2	25.4	16.1	20.2	9.7	10.9	10.2
4. Other sprains	4.4	3.7	4.1	7.1	4.2	5.8	5.2	5.9	5.4	8.8	6.7	7.9	26.4	7.6	10.8	6.4	5.4	5.9
5. Lacerations & abrasions	1.7	2.0	1.8	3.5	3.3	3.4	4.7	2.7	3.9	6.1	4.3	5.2	9.5	7.3	7.6	3.2	2.9	3.0
6. Contusions	1.9	2.8	2.2	3.2	3.2	3.2	6.8	7.3	7.0	7.2	10.0	8.5	9.1	10.8	10.3	4.6	7.0	5.7
7. Burns	4.5	3.6	4.1	4.1	2.2	2.8	4.4	4.0	4.2	2.2	4.4	3.0	[1]	9.0	[1]	4.2	3.7	4.0
8. Other	2.0	2.4	2.1	1.6	3.0	2.2	5.6	8.7	6.6	8.5	9.1	8.7	38.8	8.4	13.3	4.3	5.6	4.8
9. All	3.1	3.3	3.2	6.0	3.9	5.1	7.6	7.1	7.4	9.9	10.8	10.3	15.5	14.8	15.0	6.1	6.6	6.3

[1] Data not available.

Table 4.2. Mean per capita income - 1969 - N.C. workers (dollars).

Ages	Male	Female	Total
14-19	$1465	$1139	$1334
20-24	3557	2635	3148
25-29	6141	3308	4947
30-34	7131	3340	5531
35-39	7804	3413	5906
40-44	7924	3485	5981
45-49	7868	3458	5952
50-54	7180	3353	5526
55-59	6509	3197	5061
60-64	5816	2691	4314
65-69	3997	1878	2855
70-74	3290	1665	2390
75+	2550	1488	1911

The assumption that was implicitly made with all the data is that the population for which the quantities were estimates is the same as the population for which the estimates were used to compute costs, i.e., the population of persons injured in automobile crashes. The question of the comparability of these populations is a complex and difficult one, and the task of comparing the populations is outside the scope of this project.

Method of Analysis of Blue Cross Blue Shield Injury Data

The processing of the file consisted of the following steps:

1. Recode the data.
2. Match records referring to the same injury for each individual to form cases for that individual.
3. Group injuries into classes and subclasses for estimation purposes.
4. Separate cases by place of treatment:
   a. Hospital admission
   b. Emergency room
   c. Doctor's office

   and classify cases according to injury class and subclass.
5. Compute estimates for:
   a. Hospital costs
   b. Professional costs
   c. Hospital days

   classified by age/sex of the individual, and subclass of injury.

Each step will be considered individually.

Recoding of data.

The raw data was recoded in order to create a file containing data which is relevant to the present needs. The recoded file consisted of the following 13 items:

1. Identification key
2. Type record
3. Benefit code
4. Birth year
5. Age
6. Sex

7. Relationship to certificate holder
8. Diagnosis code
9. Treatment code
10. Number of days treatment
11. Beginning date of treatment
12. Ending date of treatment
13. Total charge

The Age (Item 5) was computed from the year of birth as the age at the time of treatment (i.e., at the date given by Item 11), and rounded up to the next integer. No ages of 0 were used. The sex and relationship codes were separated for accessibility and usability. The number of days of treatment was computed as the number of days between the beginning date of service (Item 11) and the ending date of service (Item 12) including the first day but not including the last. The variable, "Days of service paid", provided no additional information. All other items of data were left intact. Part of the effort in this step of processing was to change the machine representation of certain dates so that these dates would be accessible by other programs.

Matching records to form cases.

Each record in the BCBS file refers to one claim that was submitted to North Carolina Blue Cross Blue Shield for charges incurred for the treatment of an injury. As the insurance system is established, each claim represents an aspect of the treatment of the injury. Separate claims are submitted for hospital costs and professional fees. In addition, if a victim is treated by the physician several times over a period of days or weeks, then several claims can be generated.

A case is defined to be the occurrence of an injury. From the above description, one can see that a number of claims may refer to the same injury. Therefore, claims must be matched in order to compute costs for the entire case.

The algorithm which was used to match claims was an adaptive, heuristic procedure, which was developed and tested on the first 1000 records on the file. Originally, the BCBS file was in the order of the identification key, i.e., all records with the same identification key (i.e., members covered under an individual Blue Cross Blue Shield certificate) were located together on the file. Thus, two records with the same identification key could refer to the same case (i.e., the same injury and the same person), to different injuries for the same person, or to different persons. To determine which of these possibilities was indeed the case, the following procedure was followed:

a. If three of the following items--birth year, sex, relationship, name--match for two records, then the two records are considered to refer to the same person;

b. If the beginning dates of service for the two records are within six weeks of one another, then the records are considered to refer to the same injury.

The justification of this procedure is that it is unlikely that two different family members would have three out of the four variables identical, and it is also unlikely that the same person would suffer two different injuries requiring treatment by a doctor or hospital within six weeks.

The two possible errors that could occur in the matching process are: 1) To match records that refer to distinct persons or injuries, and 2) not to match records that refer to the same person and the same injury. There is no way, short of conducting a large scale investigation, to determine the extent of these errors; however, the authors feel that the reasonableness of the matching criteria and the nature of the estimates of costs and days of treatment provide evidence that the matching process was substantially correct.

Grouping injuries for estimation.

The nature of the injury in the BCBS file was given by the diagnosis code (Item 10 in the file description). This code has one of two definitions depending upon the type of record (Item 11 in the file description). If the record was a hospital record, then the diagnosis code referred to the ICDA hospital codes. Alternatively, if the record was a professional record, then the diagnosis code referred to the set of procedure codes used by the BCBS system to specify the type of service administered by the physician. The ICDA codes are specific to the type of injury, whereas, the procedure codes are specific to the type of treatment.

In the Level 2 data file, injuries are characterized by region (R), lesion (L), system (S), aspect and AIS level codes (referred subsequently to as RLS codes). Thus, in order to use the Blue Cross Blue Shield cost data to estimate costs for the injuries on the Level 2 file, it was necessary to determine the correspondence between the RLS codes and the two coding systems on the BCBS file. Moreover, it became apparent that some injuries may not be represented on the BCBS file, and that others would be represented only infrequently. Thus, in order to overcome the problem of nonrepresentation, it was necessary to group injuries into groups that are as homogeneous as possible with respect to treatment costs.

A simple correspondence between the procedure and ICDA codes could not be specified. Therefore, two systems of classification were used: one which utilizes the correspondence between the ICDA codes and the RLS codes, and one which utilizes the correspondence between the RLS codes and the procedure codes. These systems are given in Tables 4.3

and 4.4 and will be referred to as the I system (for ICDA) and the P system (for procedure). The I system is primarily a matching between ICDA codes on the BCBS file and region and lesion codes on the Level 2 file, whereas the P system is a matching between the procedure codes on the BCBS file and the lesion and system codes on the Level 2 file. These systems will be considered further in the next sextion.

Separate cases by place of treatment.

Once the records were matched to form the cases and the injury classification systems were defined, the following three procedures were carried out:

1. The place of treatment was determined;
2. The appropriate injury class and subclass were determined;
3. A new record was formed for use in estimating costs.

The following procedure was used to determine the place of treatment:

If a hospital inpatient record was present in the group of claims forming a case, then the place of treatment is hospital inpatient (HI); otherwise, if a hospital outpatient record was present in the group, then the place of treatment is emergency room (ER).
Otherwise, if only professional claims are present in the group, then the place of treatment is doctor's office (DO).

One difficulty with the BCBS file is that, for hospital records referring to emergency room treatment, the ICDA code is not given for the specific injury. Rather, a code is given which refers to "unspecified injuries." Thus, in order to be specific about the nature and extent of injuries treated in the emergency room, the procedure code on any professional records that belong to the same case as the emergency room record is used. For HI cases, the ICDA code is used to determine the injuries, and, for the DO cases, the procedure code is used. Once the appropriate ICDA code (for HI cases) or procedure code (for ER and DO cases) is determined, the I system (for HI cases) or the P system (for ER and DO cases) is used to determine the appropriate injury class and subclass.

The new record which is created refers to the case, rather than an individual claim. This record contains the following data:

Age
Sex
Injury class, subclass
Total days of treatment
Total hospital cost
Total professional cost.

Table 4.3. Hospital inpatient injury classification system (I system)

Class	Subclasses	Lesions	Regions (Systems)
Lacerations		V, R, L, H	
	Head - eyes, ears		H (E)
	Head, face		H, F
	Neck		N
	Chest		C, Y
	Back		B
	Thigh, Pelvis		T, P
	Abdomen		M
	Shoulder, upper arm		S, A
	Elbow, forearm, wrist		E, R, W
	Knee, leg, ankle		K, L, Q
	Extremities		X
	Unknown, other		U, O
General Injuries		P, C, A, B, U	
	Head, face, neck		H, F, N
	Chest, back		C, Y, B
	Legs		P, T, K, L, Q, X
	Arms		S, A, E, R, W
	Unknown		U
Dislocations & Sprains		D, S	
	Head, face		H, F
	Back, neck		B, N
	Chest, abdomen		C, Y, M
	Shoulder		S
	Elbow		E
	Wrist		W
	Thigh, pelvis		T, P
	Knee		K
	Ankle		Q
	Unknown, other		U
Fractures		F, N	
	Arm		W, R, E, A
	Thigh		T
	Knee		K
	Leg, ankle		Q, L
	Pelvis		P
	Head		H
	Face		F
	Chest		C, Y, M, S
	Back, neck		B, N
	Extremities		X
	Other		U
Concussion		K	

Table 4.4. Injury classification system for doctor's office and emergency room treatment (P system)

Class		Lesions	
	Subclass		Regions (Systems)
Lacerations		V, R, L, H	
	Integumentary		(I)
	Muscles & Skeleton		(M, S)
	Respiratory		(R)
	Arteries, Spleen, Liver		(A, Q, L)
	Digestive		(D)
	Kidneys, Urogenital		(G, K)
	Eyes, Ears		(E)
General & Unknown		P, C, A, B, U	
Dislocations & Sprains		D, S	
	Head & face		H, F
	Back & neck		B, N
	Chest & upper body		C, Y, M
	Shoulder		S
	Elbow		E
	Wrist		W
	Thigh, Pelvis		T, P
	Knee		K
	Ankle		Q
	Other & Unknown		U & all other
Fractures		F, N	
	Arm		W, R, E, A
	Thigh		T
	Knee		K
	Lower leg		Q, L
	Pelvis		P
	Head		H
	Face		F
	Chest, Upper body		C, Y, M, S
	Back, Neck		B, N
	Arms & Legs		X

The total days of treatment was taken from the hospital inpatient record if the case is an HI case. Otherwise, this element was set equal to 0. Total hospital cost was computed as the sum of total charges on hospital claims if the case is either an HI or an ER case. Otherwise, this element is set equal to 0. Total professional cost is the sum of all charges on professional claims. Thus, only HI cases will have a days of treatment cost; HI and ER cases will have hospital costs; and all cases will have professional costs.

Compute cost estimates.

Cost estimates for each age (<26, 26-55, >55), sex (M,F), treatment (HI,ER,DO), and injury class and subclass category are computed from the mean hospital days, mean hospital cost and mean professional cost estimates. For a given age/sex/treatment/injury class category, the empirical Bayes estimator (see Appendix G) was used to estimate mean hospital days, mean hospital cost and mean professional cost for the injury subclasses within the given injury class. The empirical Bayes estimator has the effect of reducing the variance within subclasses. The objective of the estimation is to retain as much variance between age/sex/treatment/injury class/injury subclass categories, while minimizing the variance within these categories. However, injury classes and subclasses were defined such that most of the overall between-category variance is accounted for by age, sex, treatment and injury class, and that, within injury classes, mean costs and days for subclasses should be comparable. Thus, it is reasonable that an estimation method be used which utilizes the comparability of subclass means to improve estimation efficiency. Moreover, when there are no observations for a subclass, it is justifiable to use the class mean as the subclass estimate.

The particular implementation that was used is described in Appendix G. This procedure consists of two steps:

1. Computing estimates of class and subclass means and variances;

2. Combining these estimates to form empirical Bayes estimates.

The resulting estimates are available from HSRC.

Method of Computation of Injury Costs

Once the estimates of hospital costs, professional fees, and days of hospital treatment were available, injury costs could be computed for each occupant on the Level 2 file. The direct injury cost is the sum of the following four cost components:

1. Hospital costs
2. Professional fees
3. Lost wages
4. Funeral expenses

The way in which these components were computed was dependent upon the degree of injury and the type of treatment that was received by the victim. Therefore, the description of the methodology used will be considered separately for the following different treatment categories.

Unknown injuries.

If the treatment/mortality code on the file is 9, and the overall AIS code is 9, then the nature and extent of injuries to the victim are unknown. Since there is no reasonable basis for estimating injury costs when the injuries are unknown, these cases are given a cost of -1, and in the later analysis all cases with negative costs are deleted.

No or slight injuries.

Victims having treatment/mortality codes 0, 1, 2, 3, or 8, or having a treatment/mortality code 9 with AIS not 6 or 9, were either uninjured, or injured so slightly that medical attention at a hospital or doctor's office was not considered mandatory. For this reason, these cases were given a cost of 0.

Cases treated in the doctor's office.

For those cases on the Level 2 file with treatment/mortality code 4, the following procedure was used to compute professional fees: Hospital costs and funeral expenses are zero; professional fees are obtained from the appropriate age/sex/injury subclass entry in the table of professional fees; lost wages are computed as the product of the mean daily wage for the appropriate age/sex class and the number of days of restricted activity for the appropriate age/sex/injury class.

Cases treated in the emergency room.

Cases in the Level 2 file with treatment/mortality code 5 refer to injuries that received treatment in the emergency room. For these cases, professional fees and lost wages are computed in the same way that was used for DO cases; hospital costs are obtained from the appropriate entry in the table of hospital costs; and funeral expenses are still 0.

Cases treated by admission to the hospital.

If the treatment/mortality code on the Level 2 file is 6, then the victim was admitted to the hospital for treatment. For these cases, hospital costs and professional fees were obtained from the tables of hospital costs and professional fees. Funeral expenses are zero. The number of days of disability is the maximum of the number of days of hospital treatment (given in the appropriate entry in the table of hospital treatment days) and the number of days of restricted activity (given in Table 4.1). Then, the lost wages is computed as the product of the mean daily wage and the number of days of disability.

<u>Fatal cases</u>.

For fatalities (treatment/mortality code 7), a fixed hospital and professional cost of $1216.34 is assigned. This amount is the mean cost for nine days of hospitalization. Funeral expenses are computed from the following formula:

$$f = \$2000 - \$2000\ d^{Y},$$

where

$$d = \frac{1}{1.10}$$

= discount factor corresponding to an interest rate of 10 percent

Y = expected number of years of remaining life corresponding to the given age of the victim.

This quantity is the difference between $2000 and $2000 discounted at 10 percent per year for Y years. It is assumed that the victim would be required to pay for a funeral at some point, and f is the marginal cost of paying for the funeral at present, rather than waiting Y years into the future.

Lost wages are computed as the sum of discounted yearly wages:

$$W = \sum_{i=0}^{Y} W_{A+i} d^{i} ,$$

where

A = victim's present age

Y = expected number of years of life remaining for the victim's age/sex category,

W_{A+i} = mean annual wages for a person of the victim's sex and age A+i

$d = \frac{1}{1.10}$

W = total lost wages.

Note that W_{A+i} is taken from Table 4.2, where the entry is multiplied by 1.32 to account for the mean wage inflation of 32 percent in North Carolina between 1969 and 1974.

Finally, after the direct injury cost was computed for the reported treatment/mortality code, age, sex, and OIC code, this cost was assigned to the record on the file.

Belt Effectiveness Methodology Utilizing Direct Costs

Not all of the observations in the Level 2 file had all the information required for deriving estimated direct injury costs by the procedure described above. For example, the treatment mortality code was missing in some of the 15,818 cases. Consequently, in the following analysis, the total number of weighted observations is 15,580 instead of the 15,818 considered in Chapter III.

Using the estimated direct injury costs ($c_{hi\cdot k}$, h=1,...,192; i=1,2,3; k=1,...,$n_{hi\cdot}$), the estimation procedure obtains for each (h,i) = (stratum, restraint system) combination an estimated average cost ($\bar{c}_{hi\cdot}$) and the corresponding standard error ($s_{hi\cdot}$) as defined in Appendix H. The corresponding effectiveness measures and their standard errors are then derived as in Chapter III which used the proportion injured.

Specifically, if $w_h = \frac{n_{h\cdot\cdot}}{n_{\cdot\cdot\cdot}}$ is the sample weight for the h-th stratum, the estimated average direct injury cost for a given restraint system i, i=1,2,3, is given by

$$\hat{C}_{i\cdot} = \sum_h w_h \bar{c}_{hi\cdot}$$

with estimated variance from (H.9)

$$V_{i\cdot} = \sum_h w_h^2 s_{hi\cdot}^2 + \frac{1}{n_{\cdot\cdot\cdot}} \left[\sum_h w_h s_{hi\cdot}^2 - \sum_h w_h^2 s_{hi\cdot}^2 + \sum_h w_h \bar{c}_{hi\cdot}^2 - \left(\sum_h w_h \bar{c}_{hi\cdot}\right)^2 \right].$$

Then the estimated effectiveness is given by

$$\hat{E}_{ii'} = \frac{(\hat{C}_{i\cdot} - \hat{C}_{i'\cdot})}{\hat{C}_{i\cdot}}$$

with estimated variance

$$\hat{V}\left[\hat{E}_{ii'}\right] = \frac{\hat{C}_{i'\cdot}^2}{\hat{C}_{i\cdot}^4} V_{i\cdot} + \frac{1}{\hat{C}_{i\cdot}^2} V_{i'\cdot}.$$

This set-up corresponds, in the context of Appendix H, to considering the weights w_h as random variables uncorrelated with the average costs $\bar{c}_{hi\cdot}$.

Estimates for various subsets of interest ("minor damage" for example) are obtained using different weight vectors w* with entries proportional to the sample size for each stratum in the subset under consideration and zero entries for the other strata.

Results

Overall estimates obtained using this procedure are presented in Table 4.5, along with the unadjusted or crude estimates. As expected, the average direct injury cost for unbelted occupants is higher than for lap or lap and shoulder-belted occupants. However, the cost for lap-belted occupants is lower than the cost for lap and shoulder-belted occupants ($267 for L, $281 for LS)!

Table 4.5. Average direct injury costs and effectiveness measures.

Population	Estimate	Restraint System	Estimation Procedure: Unadjusted		Mantel-Haenszel-Type Estimate	
Overall	$\hat{C}$	U	$ 674	($68.11)[1]	$ 588	($49.64)[2]
		L	230	(68.69)	267	(29.87)
		LS	276	(59.66)	281	(44.88)
	$\hat{E}$	U vs L	.658	(.1177)	.546	(.0636)
		U vs LS	.591	(.1190)	.522	(.0863)
		L vs LS	-.198	(.4411)	-.053	(.2054)

A major factor which certainly contributes to this unexpected result is suggested by Table 4.6, which presents the mean cost of injury by AIS level. The cost of an AIS=6 injury (i.e., fatal) is almost 24 times that of an AIS=5 injury. Clearly, the number of fatalities at each level of belt usage will greatly affect the overall cost estimates. In the Level 2 file, there are overall fewer lap-belted than lap and shoulder-belted occupants (see Table 2.1). Correspondingly there are only four lap-belted fatalities, but 12 lap and shoulder-belted fatalities.

In order to obtain more representative estimates of direct injury costs and effectiveness measures, the overall analysis summarized in Table 4.5 as well as a more detailed analysis was carried out on occupants with AIS<6 injuries. The results for these non-fatal cases are presented in Table 4.7. Note that the overall injury costs now decrease as one becomes progressively more restrained. The effectiveness estimates reflect this trend--.239 for U vs L, .377 for U vs LS, and .181 for L vs LS.

Table 4.7 Average direct injury costs and effectiveness measures (non-fatals).

	Population	Estimate	Restraint System	Estimation Procedure: Unadjusted		Mantel-Haenszel-Type Estimate	
	Overall	$\hat{C}$	U	$ 147	($ 3.78)[1]	$ 144	($ 3.68)
			L	100	(5.79)	109	(5.94)
			LS	83	(3.91)	90	(4.76)
		$\hat{E}$	U vs L	.316	(.0449)	.239	(.0457)
			U vs LS	.434	(.0367)	.377	(.0368)
			L vs LS	.173	(.0616)	.181	(.0623)
DAMAGE SEVERITY	Minor	$\hat{C}$	U	$ 74	($ 3.44)	$ 75	($ 3.47)
			L	76	(8.03)	75	(8.03)
			LS	52	(3.88)	51	(3.90)
		$\hat{E}$	U vs L	-.032	(.1184)	-.001	(.1168)
			U vs LS	.299	(.0752)	.323	(.0608)
			L vs LS	.321	(.0877)	.323	(.0892)
	Moderate	$\hat{C}$	U	$ 147	($ 5.65)	$ 149	($ 5.79)
			L	96	(8.25)	99	(8.97)
			LS	79	(5.91)	80	(7.68)
		$\hat{E}$	U vs L	.344	(.0642)	.333	(.0658)
			U vs LS	.463	(.0530)	.464	(.0558)
			L vs LS	.181	(.0931)	.196	(.1063)
	Moderately Severe	$\hat{C}$	U	$ 290	($15.53)	$ 288	($15.36)
			L	172	(23.48)	229	(21.06)
			LS	191	(21.07)	220	(23.67)
		$\hat{E}$	U vs L	.406	(.0909)	.205	(.0846)
			U vs LS	.342	(.1015)	.263	(.0918)
			L vs LS	-.108	(.1944)	.039	(.1361)
	Severe	$\hat{C}$	U	$ 476	($35.56)	$ 456	($36.25)
			L	242	(42.85)	256	(45.56)
			LS	229	(34.02)	253	(43.00)
		$\hat{E}$	U vs L	.492	(.1046)	.439	(.1094)
			U vs LS	.518	(.0954)	.477	(.1040)
			L vs LS	.050	(.2196)	.013	(.2431)
AGE	10-25	$\hat{C}$	U	$ 87	($ 3.66)	$ 83	($ 3.52)
			L	64	(6.01)	67	(6.48)
			LS	48	(3.88)	52	(4.61)
		$\hat{E}$	U vs L	.263	(.0783)	.191	(.0856)
			U vs LS	.443	(.0620)	.369	(.0619)
			L vs LS	.244	(.0936)	.220	(.1023)
	26-55	$\hat{C}$	U	$ 197	($ 7.07)	$ 190	($ 6.66)
			L	132	(10.38)	154	(11.11)
			LS	109	(6.94)	121	(8.30)
		$\hat{E}$	U vs L	.331	(.0602)	.188	(.0650)
			U vs LS	.447	(.0485)	.365	(.0490)
			L vs LS	.173	(.0836)	.218	(.0779)
	56+	$\hat{C}$	U	$ 241	($15.73)	$ 241	($16.08)
			L	120	(19.56)	121	(18.59)
			LS	127	(15.76)	137	(23.79)
		$\hat{E}$	U vs L	.504	(.0933)	.497	(.0841)
			U vs LS	.474	(.0855)	.430	(.1058)
			L vs LS	-.059	(.2177)	-.132	(.2617)

Table 4.7 (continued)

	Population	Estimate	Restraint System	Estimation Procedure: Unadjusted		Estimation Procedure: Mantel-Haenszel-Type Estimate	
Crash Type	1	$\hat{C}$	U	$ 216	($ 9.59)	$ 214	($ 9.55)
			L	157	(18.07)	166	(18.66)
			LS	121	(12.98)	142	(14.15)
		$\hat{E}$	U vs L	.276	(.0916)	.227	(.0936)
			U vs LS	.440	(.0744)	.339	(.0723)
			L vs LS	.227	(.1217)	.144	(.1288)
	2	$\hat{C}$	U	$ 145	($ 6.97)	$ 145	($ 6.98)
			L	86	(9.08)	118	(9.45)
			LS	88	(7.29)	90	(9.48)
		$\hat{E}$	U vs L	.408	(.0728)	.182	(.0764)
			U vs LS	.390	(.0700)	.377	(.0721)
			L vs LS	-.030	(.1382)	.239	(.1007)
	3	$\hat{C}$	U	$ 100	($ 4.64)	$ 100	($ 4.71)
			L	74	(7.50)	69	(6.69)
			LS	55	(4.63)	55	(4.76)
		$\hat{E}$	U vs L	.257	(.0854)	.310	(.0742)
			U vs LS	.448	(.0648)	.456	(.0540)
			L vs LS	.257	(.0980)	.211	(.1029)
	4	$\hat{C}$	U	$ 140	($10.78)	$ 139	($10.78)
			L	121	(16.04)	103	(14.24)
			LS	99	(9.50)	97	(9.41)
		$\hat{E}$	U vs L	.138	(.1346)	.256	(.1179)
			U vs LS	.292	(.1064)	.298	(.0871)
			L vs LS	.179	(.1342)	.058	(.1589)
Weight	Subcompact	$\hat{C}$	U	$ 145	($ 6.94)	$ 146	($ 6.94)
			L	117	(12.34)	119	(11.86)
			LS	86	(6.61)	91	(8.95)
		$\hat{E}$	U vs L	.196	(.0953)	.184	(.0899)
			U vs LS	.409	(.0704)	.375	(.0680)
			L vs LS	.265	(.0963)	.234	(.1069)
	Compact	$\hat{C}$	U	$ 132	($ 7.09)	$ 130	($ 6.91)
			L	86	(10.16)	88	(10.63)
			LS	77	(6.82)	78	(7.42)
		$\hat{E}$	U vs L	.348	(.0885)	.325	(.0889)
			U vs LS	.418	(.0779)	.403	(.0651)
			L vs LS	.108	(.1320)	.115	(.1361)
	Intermediate	$\hat{C}$	U	$ 145	($ 7.68)	$ 139	($ 7.26)
			L	107	(13.49)	135	(13.64)
			LS	87	(9.33)	104	(11.02)
		$\hat{E}$	U vs L	.265	(.1032)	.028	(.1105)
			U vs LS	.399	(.0818)	.255	(.0883)
			L vs LS	.182	(.1352)	.234	(.1124)
	Full-sized	$\hat{C}$	U	$ 165	($ 8.65)	$ 161	($ 8.40)
			L	90	(9.70)	93	(10.67)
			LS	82	(9.97)	86	(10.88)
		$\hat{E}$	U vs L	.458	(.0702)	.423	(.0728)
			U vs LS	.502	(.0659)	.467	(.0732)
			L vs LS	.082	(.1493)	.075	(.1583)

Table 4.6. Cost of injury by AIS level.

		Mean	S.D.	N
AIS Level	1	$130.56	$211.03	8100
	2	548.30	565.54	1317
	3	1340.18	734.89	273
	4	1688.79	840.76	48
	5	2893.23	6661.71	13
	6	68516.68	29137.10	96

Looking at the remaining sections of the table, for each restraint system, the average cost increases with damage severity. Also, within each damage category the injury cost decreases as level of restraint increases. The effectiveness of lap and shoulder belts relative to lap belts alone, however, decreases as damage severity increases.

A similar pattern is shown by the average costs across levels of age, with the exception of the oldest age group where the cost of injuries to lap and shoulder-belted occupants is slightly more than the cost to lap-belted occupants. Thus, there would appear to be no appreciable difference in the effectiveness of the two belt systems for this age group. It should be noted that this lack of differentiation is due more to an unusually high level of effectiveness for U vs L, rather than a decrease in effectiveness at the L vs LS level. The 50 percent level of effectiveness for U vs L for the oldest age group is much higher than for the other two age groups, which average about 20 percent effectiveness for U vs L and 37 percent effectiveness for U vs LS.

Finally, average injury costs were found lowest for occupants of compact cars, within each level of belt usage! Belted occupants consistently fared better than their unbelted counterparts in similar-sized cars, with those wearing both lap and shoulder belts sustaining the least costly injuries.

The estimates for non-fatals corresponding to the different impact site categories are presented in Table 4.8. According to the adjusted estimates, belts are slightly more effeceive in frontal impact crashes than in side impact crashes; they are somewhat less effective in rear crashes. Severe sample size limitations prohibit conclusive comments regarding belt effectiveness in rollover crashes.

When analyzing the results contained in Tables 4.5, 4.6, 4.7 and 4.8, differences between the two types of estimates (especially with respect to the standard errors) are evident. To some extent, this is to be expected if the standarization is based on a reasonable stratification. However,

Table 4.8 Average direct injury costs and effectiveness measures by impact site (non-fatals).

Impact Site[2]	Estimate	Restraint System	Estimation Procedure: Unadjusted		Estimation Procedure: Mantel-Haenszel-type estimate	
Front	$\hat{C}$	U	$143	($ 5.07)[1]	$141	($ 4.98)
		L	96	(8.03)	99	(8.18)
		LS	73	(5.28)	77	(6.06)
	$\hat{E}$	U vs L	.326	(.0633)	.298	(.0631)
		U vs LS	.488	(.0493)	.454	(.0471)
		L vs LS	.240	(.0837)	.222	(.0888)
Side	$\hat{C}$	U	$148	($ 6.23)	$147	($ 6.16)
		L	91	(8.96)	107	(12.83)
		LS	88	(6.83)	89	(7.56)
	$\hat{E}$	U vs L	.382	(.0691)	.271	(.0924)
		U vs LS	.403	(.0634)	.394	(.0573)
		L vs LS	.035	(.1205)	.169	(.1219)
Rear	$\hat{C}$	U	$154	($13.04)	$147	($12.97)
		L	140	(19.69)	125	(19.17)
		LS	118	(11.20)	123	(11.24)
	$\hat{E}$	U vs L	.094	(.1520)	.149	(.1504)
		U vs LS	.237	(.1152)	.165	(.1061)
		L vs LS	.159	(.1431)	.019	(.1750)

[1]Standard error.

[2]Adjusted estimates for ROLLOVER are not presented due to severe sample size limitations (181 unbelted, 13 lap belted, and 58 lap and shoulder belted). The unadjusted average direct injury costs are $208, $500, and $64 for U, L and LS, respectively; the unadjusted effectiveness estimates are -1.404 for U vs L, .693 for U vs LS and .872 for L vs LS.

another possible source of the differences should be noted. The distribution of the (individual) direct injury costs is extremely skewed. Although the Central Limit theorem was appealed to in treating the average costs, it would appear that, with such a skewed distribution and such a large number of strata, the rate of convergence may not have been satisfactory. Alternatives such as different collapsing, transformation of the $c_{hi\cdot k}$ (e.g., $\ln(1+c_{hi\cdot k})$) or even redefinition of $c_{hi\cdot k}$ might be considered in the future.

Finally, with respect to a possible redefinition of $c_{hi\cdot k}$ it should be noted that information about age, sex, treatment, and specific injury was used to derive the estimated direct injury costs. How sensitive are the derived injury costs and corresponding effectiveness estimates to utilizing this information? What if only the AIS information were available plus a table listing average cost for each AIS level?

These questions were examined by assigning to each case on the Level 2 file the average cost from Table 4.6.for the corresponding AIS indicated for that case. The resulting estimates are displayed in Tables 4.9 and 4.10. A comparison with the corresponding results given in Tables 4.7 and 4.8 shows no major effects (or differences) obtained by the two different methods with the exception of age. Here the $\hat{c}_i$'s showed increases for the first two age groups and a decrease for the oldest occupants.

Nevertheless, for this data, the additional adjustments carried out in the basic analysis do not have major consequences on the resulting cost estimates and effectiveness measures.

Table 4.9 Average direct injury costs (by AIS)* and effectiveness measures (non-fatals).

Population		Estimate	Restraint System	Unadjusted		Mantel-Haenszel-Type Estimate	
Overall		Ĉ	U	$ 144	($ 2.73)[1]	$ 147	($ 2.67)
			L	107	(4.34)	112	(5.06)
			LS	85	(2.73)	91	(3.40)
		Ê	U vs L	.255	(.0343)	.203	(.0389)
			U vs LS	.409	(.0264)	.355	(.0270)
			L vs LS	.206	(.0410)	.191	(.0474)
DAMAGE SEVERITY	Minor	Ĉ	U	$ 90	($ 2.75)	$ 90	($ 2.80)
			L	75	(4.94)	76	(4.84)
			LS	60	(2.86)	60	(3.02)
		Ê	U vs L	.159	(.0619)	.154	(.0598)
			U vs LS	.334	(.0461)	.337	(.0394)
			L vs LS	.208	(.0643)	.216	(.0637)
	Moderate	Ĉ	U	$ 141	($ 3.90)	$ 142	($ 4.03)
			L	115	(7.08)	122	(9.46)
			LS	84	(3.88)	84	(4.55)
		Ê	U vs L	.188	(.0559)	.141	(.0708)
			U vs LS	.410	(.0371)	.409	(.0361)
			L vs LS	.273	(.0561)	.312	(.0649)
	Moderately Severe	Ĉ	U	$ 255	($10.97)	$ 253	($10.87)
			L	185	(18.82)	189	(20.61)
			LS	151	(11.52)	173	(12.43)
		Ê	U vs L	.276	(.0823)	.254	(.0876)
			U vs LS	.408	(.0643)	.317	(.0572)
			L vs LS	.182	(.1041)	.085	(.1197)
	Severe	Ĉ	U	$ 401	($24.85)	$ 381	($25.86)
			L	213	(32.60)	210	(32.52)
			LS	239	(30.65)	271	(48.39)
		Ê	U vs L	.468	(.0930)	.448	(.0933)
			U vs LS	.404	(.1015)	.289	(.1360)
			L vs LS	-.120	(.2236)	-.289	(.3048)
AGE	10-25	Ĉ	U	$ 131	($ 3.56)	$ 127	($ 3.44)
			L	111	(6.78)	118	(8.44)
			LS	82	(3.90)	89	(5.36)
		Ê	U vs L	.156	(.0574)	.073	(.0709)
			U vs LS	.374	(.0417)	.301	(.0462)
			L vs LS	.258	(.0576)	.246	(.0706)
	26-55	Ĉ	U	$ 151	($ 4.46)	$ 148	($ 4.34)
			L	105	(6.01)	109	(6.51)
			LS	86	(3.98)	94	(4.70)
		Ê	U vs L	.305	(.0467)	.263	(.0491)
			U vs LS	.429	(.0371)	.365	(.0369)
			L vs LS	.179	(.0603)	.138	(.0672)
	56+	Ĉ	U	$ 178	($10.35)	$ 180	($10.34)
			L	101	(14.97)	100	(13.52)
			LS	93	(11.07)	88	(10.23)
		Ê	U vs L	.432	(.0947)	.445	(.0817)
			U vs LS	.476	(.0803)	.511	(.0635)
			L vs LS	.078	(.1747)	.113	(.1576)

Table 4.9 Continued.

Population		Estimate	Restraint System	Estimation Procedure: Unadjusted		Estimation Procedure: Mantel-Haenszel-Type Estimate	
CRASH TYPE	1	Ĉ	U	$ 193	($ 6.48)	$ 192	($ 6.38)
			L	153	(14.37)	166	(16.97)
			LS	121	(9.71)	140	(11.51)
		Ê	U vs L	.207	(.0801)	.134	(.0930)
			U vs LS	.373	(.0624)	.271	(.0647)
			L vs LS	.209	(.0974)	.158	(.1104)
	2	Ĉ	U	$ 145	($ 5.40)	$ 142	($ 5.36)
			L	93	(7.08)	104	(8.41)
			LS	84	(4.66)	83	(5.10)
		Ê	U vs L	.359	(.0572)	.267	(.0652)
			U vs LS	.421	(.0460)	.416	(.0420)
			L vs LS	.097	(.0852)	.204	(.0806)
	3	Ĉ	U	$ 113	($ 3.50)	$ 113	($ 3.51)
			L	94	(5.15)	90	(4.71)
			LS	66	(3.36)	67	(3.45)
		Ê	U vs L	.165	(.0537)	.200	(.0486)
			U vs LS	.417	(.0422)	.408	(.0357)
			L vs LS	.302	(.0522)	.261	(.0543)
	4	Ĉ	U	$ 121	($ 7.73)	$ 123	($ 8.40)
			L	102	(9.73)	91	(7.42)
			LS	94	(5.84)	89	(5.20)
		Ê	U vs L	.160	(.0993)	.265	(.0782)
			U vs LS	.224	(.0818)	.282	(.0645)
			L vs LS	.076	(.1053)	.023	(.0984)
WEIGHT	Subcompact	Ĉ	U	$ 155	($ 5.16)	$ 154	($ 5.10)
			L	137	(9.88)	139	(11.87)
			LS	91	(4.30)	96	(4.94)
		Ê	U vs L	.115	(.0711)	.097	(.0828)
			U vs LS	.411	(.0439)	.373	(.0383)
			L vs LS	.334	(.0574)	.306	(.0692)
	Compact	Ĉ	U	$ 138	($ 5.60)	$ 135	($ 5.41)
			L	101	(7.73)	108	(8.71)
			LS	83	(4.96)	86	(5.72)
		Ê	U vs L	.266	(.0660)	.199	(.0718)
			U vs LS	.396	(.0554)	.368	(.0492)
			L vs LS	.177	(.0798)	.211	(.0825)
	Intermediate	Ĉ	U	$ 141	($ 5.34)	$ 136	($ 5.22)
			L	97	(8.39)	101	(9.22)
			LS	90	(7.39)	105	(9.67)
		Ê	U vs L	.316	(.0670)	.260	(.0734)
			U vs LS	.366	(.0660)	.232	(.0769)
			L vs LS	.073	(.1110)	-.039	(.1351)
	Full-sized	Ĉ	U	$ 139	($ 5.74)	$ 135	($ 5.57)
			L	89	(7.90)	91	(8.40)
			LS	69	(5.90)	75	(7.06)
		Ê	U vs L	.360	(.0657)	.321	(.0685)
			U vs LS	.506	(.0472)	.446	(.0573)
			L vs LS	.228	(.0953)	.184	(.1077)

*See text

[1]Standard error

Table 4.10. Average direct injury costs (by AIS)* and effectiveness measures by impact site (non-fatals).

Impact Site[2]	Estimate	Restraint System	Estimation Procedure: Unadjusted		Estimation Procedure: Mantel-Haenszel-type estimate	
Front	Ĉ	U	$142	($ 3.45)[1]	$140	($ 3.40)
		L	111	(5.86)	112	(5.91)
		LS	81	(3.99)	87	(4.95)
	Ê	U vs L	.213	(.0468)	.201	(.0465)
		U vs LS	.425	(.0377)	.381	(.0385)
		L vs LS	.270	(.0525)	.225	(.0604)
Side	Ĉ	U	$149	($ 5.01)	$146	($ 4.94)
		L	96	(7.29)	109	(8.67)
		LS	83	(4.33)	84	(4.48)
	Ê	U vs L	.354	(.0560)	.252	(.0646)
		U vs LS	.440	(.0413)	.427	(.0363)
		L vs LS	.134	(.0797)	.234	(.0734)
Rear	Ĉ	U	$124	($ 7.59)	$123	($ 7.90)
		L	.119	(12.19)	105	(9.02)
		LS	.112	(7.49)	108	(6.44)
	Ê	U vs L	.041	(.1149)	.148	(.0912)
		U vs LS	.097	(.0965)	.129	(.0764)
		L vs LS	.059	(.1150)	-.023	(.1070)

*See text

[1]Standard error

[2]Adjusted estimates for ROLLOVER are not presented due to severe sample size limitations (181 unbelted, 13 lap belted, and 58 lap and shoulder belted). The unadjusted average direct injury costs (by AIS) are $180, $285 and $89 for U, L and LS, respectively; the unadjusted effectiveness estimates are -.581 for U vs L, .505 for U vs LS and .687 for L vs LS.

V. DISCUSSION AND RECOMMENDATIONS

In this report, standardized injury rates (AIS≥2, AIS≥3) and effectiveness measures along with estimates of their precision are derived for three belt levels (unrestrained, lap only, and lap and shoulder) for the overall population (see Table 5.1) as well as a variety of subsets of interest (e.g., model year; impact site; crash type; vehicle weight; vehicle damage severity; occupant age). For AIS=6 (fatals), only a limited degree of standardization could be effected due to sample size limitations. As the results are given in detail in Chapter III and summarized in the Technical Summary, only some of the highlights will be repeated in this section.

Table 5.1. Injury (cost) rates and effectiveness estimates by belt usage.

Estimate[1]	Restraint System[2]	Injury				Average Cost (Non-fatals)	
		AIS≥2		AIS≥3			
		Unadj.	GENCAT	Unadj.	GENCAT	Unadj.	Mantel-Haenszel
$\hat{R}$	U	.121	.116	.032	.031	$147	$144
	L	.074	.080	.015	.017	100	109
	LS	.047	.051	.012	.013	83	90
$\hat{E}$	U vs L	.388	.309	.531	.463	.316[3]	.239
	U vs LS	.612	.565	.618	.568	.434	.377
	L vs LS	.365	.371	.187	.196	.173	.181

[1] $\hat{R}$ = injury (cost) rate
$\hat{E}$ = effectiveness estimate

[2] U = unrestrained
L = lap belted
LS = lap and shoulder belted

[3] Proportionate reduction in cost

The limitations and/or advantages of the competing categorical data estimation procedures (Mantel-Haenszel-type vs weighted least squares) are pointed out while describing the methods in Chapter III and Appendices D and E. Likewise, the effect on the estimates of deleting various subsets of the control variables is discussed in the Technical Summary and detailed in Appendix F.

The procedure utilized for deriving direct injury costs (medical, lost wages, funeral) for each occupant on the file is indicated in Chapter IV. And, finally, the process of utilizing these estimated costs in deriving standardized injury costs for alternatively investigating belt effectiveness is presented along with a variety of results (primarily limited to non-fatal injuries).

In a nutshell, both standardization methods generally lower the estimated injury (AIS $\geq$ 2) rate for unrestrained occupants while fairly substantially raising the corresponding rates for the lap-belted and lap and shoulder-belted occupants. This results in lowered estimates of belt effectiveness for U vs L and U vs LS. For the overall file (see Table 5.1), the effectiveness estimates are 30.9 percent, 56.5 percent, and 37.1 percent for U vs L, U vs LS, and L vs LS, respectively.

The effect of standardizing for "at least serious" injuries (AIS $\geq$ 3) is similar to that for the "moderate or worse" injuries. Interestingly, lap and lap and shoulder belts appear more nearly equally as effective (compared with being unrestrained) in this worst 2.4 percent of the injuries (46.3% vs 56.8%, respectively).

For fatal (AIS = 6) injuries, the sample size (namely 86 with complete information) precludes much, if any, adjustment. Only 4 fatally injured occupants wearing lap belts makes any corresponding estimates tenuous.

In their proposal for a study of active restraint system performance in accidents, Kahane et al (1975) suggested various commonly accepted hypotheses concerning seat belt effectiveness which the current project has been able to examine. A review of some of these hypotheses, along with the evidence provided by this study, is indicated in the following discussion.

One widely accepted hypothesis concerning seat belts is that the lap and shoulder belt provides at least 10 percent more protection than the lap belt alone. This statement is indeed upheld (in fact, exceeded) by the results of the current study. Overall ,lap belts were found to reduce the likelihood of moderate or worse injury by 31 percent -- lap and shoulder belts by nearly 57 percent. This represents a 45 percent increase in effectiveness for lap and shoulder belts. In reducing the likelihood of "at least serious" injury, lap and shoulder belts are nearly 20 percent more effective than lap belts (57 percent for LS compared with 46 percent for L).

Another hypothesis advocated by some people is that belts have little effect in rear impact crashes, and that lap belts are particularly ineffective in frontal impacts. The Level 2 results indicate that, while belts are less effective in rear crashes than in frontal or side crashes, they still substantially reduce the likelihood of injury in rear impact crashes (23 percent for L, 48 percent for LS, at the AIS$\geq$2 level). In frontal crashes, lap belts alone were found to prevent "moderate or worse" injury with 23 percent effectiveness, and "serious or worse" injury with 49 percent effectiveness.

The opinion is frequently expressed that belts are less effective in subcompacts than in larger cars. The Level 2 results show that this is generally true at both the AIS $\geq$ 2 and AIS $\geq$ 3 injury levels for lap belts only. However, lap and shoulder belts are about as effective in reducing injuries at these levels in the subcompact cars as in the larger-sized cars.

Another hypothesis is that belt effectiveness decreases as crash severity increases. According to the Level 2 file, however, quite the opposite appears to be true of lap belts in preventing AIS $\geq$ 2 injuries. In this case, effectiveness estimates increased from 24 percent for minor damage to 42 percent for severe damage. For other levels of belt usage and injury, there was no consistent trend across the damage levels.

Finally, it is often held that belts are most effective for young and middle-aged adults. The Level 2 results, however, indicate that it is the older people who stand to benefit most from wearing seat belts. Effectiveness estimates for the 56+ age group were 56 percent and 59 percent for L and LS, respectively, at the AIS $\geq$ 2 level, and 81 percent and 53 percent at the AIS $\geq$ 3 level. Belt effectiveness for the two younger age groups was lower in every category. (Note should be made of possible sample size limitations for the older group,especially in the case of serious injuries.)

It should be pointed out that many additional results derived from the Level 2 file are contained in the "Fact Book" volume of this report (Hall, 1976). Topics covered in this rather extensive compilation of results include make and model year effects; costs of injuries; belt-caused injuries; malfunction, defeat or maladjustment of belts; ejections; and belt usage by various subpopulations of interest.

Virtually every study that treats accident costs seems to have problems. This investigation is no exception. The overall estimates (see Table 5.1) are quite similar to those for "at least serious" injuries. Beyond that, although the standardized costs have generally the same trends as the unadjusted costs, some unusual estimates arise (e.g., unusually high costs and generally lower lap belt and lap and shoulder belt effectiveness for intermediate-sized cars). One possible source of this problem is that a large proportion of the sample is assigned zero costs resulting in a most skewed distribution. Likewise, the 11.7 percent of the sample where treatment mortality was coded as "other" (and hence unknown for the analysis) might have come primarily from one segment of the injury distribution rather than throughout the range of injuries.

Recommendations fall into at least the following categories: investigation procedures; structure of the data elements; quality control efforts; and additional analysis concerns. With respect to investigation procedures, for example, the fact that nearly 20 percent of the cases on the file lacked vehicle damage information suggests that all too often the team members were not able to examine the vehicle. Probably the procedure by which the team was notified that a towaway crash occurred which involved a

1973-75 model car could be improved. It must be possible if the National Crash Severity Study (NCSS) is to have any chance for success.

With respect to structure of the data elements, levels of any variable must be mutually exclusive and exhaustive (cf. "light condition" comments rendered in Chapter II). Some data elements clearly had too many levels (e.g., "object contacted" with 86 codes) whereas others appeared to contain too few (e.g., "treatment mortality" since 11.7% of the occupants were classified as "other"). For the latter example, perhaps the following levels would reduce this problem:

0 not injured
1 injured (slightly) - not treated
2 first aid at scene - no further treatment
3 treated in doctor's office
4 treated in emergency room and released
5 admitted to hospital - nonfatal
6 admitted to hospital - fatal (died later)
7 fatal at scene - no hospital treatment
9 unknown injuries/treatment

In addition, the "police report" coding should have had levels similar to those found on the team accident report forms. Determining the utility of this data source (e.g., "supported evaluation", "contrary to evaluation"; see Appendix A) is a trivial exercise on the computer.

In the quality control area, it seems clear that all five teams did not always consistently code the same information. Perhaps more periodic on-sight observation would help alleviate this problem. Then, again, available automatic editing programs might be utilized to resolve some inconsistencies in the data such as the o'clock direction of force showing an eight o'clock whereas the corresponding damage is on the door on the right side of the vehicle.

Finally, time constraints precluded additional refinements on the analysis procedures. The obvious skewness of the cost data would suggest perhaps a log transformation to at least assist with the normality assumptions. Somehow, even if repair costs to the vehicle were needed, there should be a much smaller proportion of cases in the zero cost category or else the estimation might be restricted to the non-zero cases.

Perhaps stratifying to a total of 192 levels is too ambitious for the quantity of data and the corresponding non-uniform distribution (e.g., occupants 56+ years of age). Without more data, the ideal number of factor level distributions would probably have been somewhat lower but in excess of the 48 used with the GENCAT estimates.

Another manner in which stratification came into play was in the basic sampling scheme. Originally (and ideally) occupants of vehicles in which at least one outboard front seat occupant was transported to a treatment facility were to be sampled at 100 percent. Otherwise, vehicles were to be selected basically at a 50 percent rate using the odd/even status of the terminal digit of the license plate as the randomizing mechanism. Appendix B details the actual sampling plan which results in a set of 5, rather than 2, different case weights.

To best estimate the precision of each of the estimates, it is necessary to account for yet one additional stratifying variable: case weight. This results in an even less acceptable distribution of the data, with many empty cells inducing additional instability in the primary estimates of interest.

With these considerations in mind and some idea of the appropriate underestimation of the variances involved (Kish, 1965, p. 430-431) -- namely, a maximum of 12.8 percent for the present setup -- it was decided to treat the weighted sample of 15,818 observations as a simple random sample of towaway crashes from five regions of the U.S. (post-stratified according to damage severity, crash configuration, vehicle weight and age of occupant). As the calculated standard errors are generally quite small, this assumption appears tolerable in this situation.

With larger samples, the data is likely to be less ill-conditioned and techniques like "balanced repeated replications" (Kish and Frankel, 1970) or "paired selection algorithms for multiple subclasses" (O'Day, Wolfe, and Kaplan, 1975) would be excellent options to be considered in overcoming these sampling design complications.

It has been indicated (Chapter II) that there are not only team differences but also differences between the composite of the teams and the nation, such as by population density where the U.S. is less urban than the sampling frame. To the extent to which this could be quantified, the data from the more urban teams (Miami and USC) could be weighted (by a factor less than unity) prior to the estimation procedures.

Finally, Campbell (1970) utilizes a methodology ideal for this study, except that the parameters estimated differ from those required herein. In essence, the program estimates the ratio of observed number of injuries to, say, unbelted occupants vs the number that would be expected had they had the stratum injury rates of the overall population. A standard error for this ratio is calculated and the comparison among belt systems is immediate. This effort will subsequently be carried out in HSRC's continuing analysis of this RSEP data.

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APPENDIX A

Occupant Restraint System Summary Form

DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Occupant Restraint System Summary Form

Part 1: — General Information —

Card 1/1

REPORT NO.

Team	Accident Date yr	mo	day	Sequence No.
1	2	3	4	5
2	3 4	5 6	7 8	9 10 11

Prepared By:
Yr. 7 6 Mo. 7 Day 8
12-13 14-15 16-17

Vehicle Category [9] 18
1. Control Vehicle
2. ACRS Vehicle

Hospitalized Sample Vehicle (Front Seat Occupants) [10] 19
1. Yes
2. No

Occupants
1 - 8 Actual Number
9 - Unknown
Front Seat [11] 20 Total [12] 21

Accident Location
State [1 | 3] 22 23
County [| 14 |] 24 25 26
Municipality [| 15 |] 27 28 29 30

Reporting Jurisdiction [16] 31
1. Local/Municipal
2. County
3. State
4. Federal

Check Items Submitted (1. Yes; 2. No)
Medical Form [17] 32
Vehicle Form [18] 33
Photographs [19] 34
Driver Interview [20] 35
Police Report [21] 36

Type of Accident (First Harmful Event) [22] 37
Collision With
1. Pedestrain
2. Pedalcycle
3. RR Train
4. Other Collision
5. Motor Vehicle
6. Fixed Object
Non-Collision
7. Overturn
8. Other Non-Coll.
9. Unknown

Area [23] 38
1. Urban
2. Rural

Type of Impact [24] 39
1. Head On
2. Rear end
3. Angle
4. Side Swipe
5. Rollover
6. Other
7. Not Applicable
9. Unknown

Number of Vehicles
Total [25] 40 Case [26] 41
1-7 Actual No.
8. Eight (8) or More
9. Unknown

Total Number
Killed [2 | 7] 42 43 Injured [2 | 8] 44 45
00-98 Actual No.
99 Unknown
To include the Total Killed/Injured in the Accident.

Occupant Ejected [29] 46
1. Yes
2. No
3. Not Stated
9. Unknown

Number of Lanes
Trafficway [3 | 0] 47 48
01-98 Actual No.
99- Unknown/Not Stated

Limited Access [31] 49
1. Yes
2. No
3. Not Applicable
9. Unknown

Road Surface [32] 50
1. Paved
2. Unpaved
3. Not Applicable
9. Unknown

Surface Condition [33] 51
1. Dry
2. Wet
3. Snow
4. Ice
5. N/A
6. Other:
9. Unknown

Day of Week [34] 52
1. Mon
2. Tue
3. Wed
4. Thu
5. Fri
6. Sat
7. Sun
9. Unk

Time of Accident [| 3 | 5 |] 53 54 55 56
0000-Midnight
0615-6:15 am
1200-Noon
1815-6:15 pm
2359-11:59 pm
9999-Unknown

Light Condition [36] 57
1. Daylight
2. Dawn
3. Dusk
4. Dark
5. Dark-Lighted
6. Dark-Not Lighted
7. Not Stated
9. Unknown

ATTACHMENT F

DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Occupant Restraint System Summary Form

Part 2: —Vehicle Information— Card 2/1

Prepared By: ____________

Date: Yr. 7__ Mo. ____

REPORT NO.

Team	Accident Date yr		mo		day		Sequence No.		
2	3	4	5	6	7	8	9	10	11

Vehicle Identification Number (Left Justify) Omit Production Nos. [37] 12 13 14 15 16 17 18

Odometer Reading [38] 19 20 21 22 23 24

Vehicle Make/Model Code (Make: ____________) [39 | 40] 25 26 27 28 29

The five digit Make/Model code to be extrapolated from SECTION 5-1973 Editing Manual and Reference Information-MDAI Rpt. Automation & Utilization:

Body Style [41] 30
1. 2dr. Hardtop
2. 2dr. Sedan/Coupe
3. 4dr. Hardtop
4. 4dr. Sedan
5. Stationwagon
8. Other
9. Unknown

Number of Cylinders [42] 31
1. Rotary
2. 2-cyl.
4. 4-cyl.
6. 6-cyl.
8. 8-cyl.
9. Unknown.

Model Year [7 | 43] 32
3. 1973
4. 1974
5. 1975
9. Unknown

Transmission [44] 33
1. Automatic
2. Standard
9. Unknown

Air/Conditioned [45] 34
1. Yes
2. No
9. Unknown

Test Buzzer/Warning Light-Ignition Interlock (Explain Details on Vehicle Field Form) [46] 35
1. System Tested NORMAL
2. System Tested ABNORMAL
3. Unable to Test-Damage
4. Not Applicable
9. Unknown

Vehicle Towing Another Vehicle [47] 36
1. Yes
2. No
9. Unknown

Type of Front Seat [48] 37
1. Bench
2. Bucket
9. Unknown

Evidence of Restraint System (Details on Veh. Field Form)

	Malfunction LF	Malfunction CF	Malfunction RF	Defeat LF	Defeat CF	Defeat RF	Maladjustment LF	Maladjustment CF	Maladjustment RF
Box	49	50	51	52	53	54	55	56	57
Column	38	39	40	41	42	43	44	45	46

CODES: (1. Yes; 2. No; 3. N/A; 9. Unk:)- Code Each of the Nine Blocks.

OBJECTS CONTACTED & C.D.C.

Chronological Order	Object Contacted	Collision Deformation Classification						Inches Crush
1	58 (47 48)	59 (49 50)	60 (51)	61 (52)	62 (53)	63 (54)	64 (55)	65 (56 57)
2	66 (58 59)	67 (60 61)	68 (62)	69 (63)	70 (64)	71 (65)	72 (66)	73 (67 68)
3	74 (69 70)	75 (71 72)	76 (73)	77 (74)	78 (75)	79 (76)	80 (77)	81 (78 79)

Number of Event Producing Most Severe Injury [82] 80

0- No Injury
1-7 Event No.
8- Pre-Crash Event
9- Unknown

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION

Occupant Restraint System Summary Form

Part 3: —Restraint Usage Information Card 3/T

Prepared By: ____________

Date: Yr. 7__ Mo. ____

REPORT NO.									
Team	Accident Date yr		mo		day		Sequence No.		
2	3	4	5	6	7	8	9	10	11

Active Restraint System Usage

Left Front	Center Front	Right Front
83	84	85
12	13	14

1. No Occupant
2. None Used
3. Lap & Torso
4. Lap Only
5. Torso Only
6. Child Seat
7. Other (Desc. on Veh. Form)
8. Not Known if Occupied
9. Unknown if Restraint Used

FACTORS DETERMINING USAGE CLASSIFICATION

	Belt/Fittings Damaged by Occupant Load	Location or Condition of Belts	System Defeated	Ext. Veh. Damage or Occupant Contact Points	Police Report	Police or Witness Observation	Subject Interview	Other Interview	Occupant Injury Pattern	Belt Caused Injury	Occupant Ejected
Left Front	86	87	88	89	90	91	92	93	94	95	96
	15	16	17	18	19	20	21	22	23	24	25
Center Front	97	98	99	100	101	102	103	104	105	106	107
	26	27	28	29	30	31	32	33	34	35	36
Right Front	108	109	110	111	112	113	114	115	116	117	118
	37	38	39	40	41	42	43	44	45	46	47

1. Supported Evaluation
2. Contrary to Evaluation
3. Neither Supported or Contradicted Evaluation
4. Position Not Occupied
5. Not Applicable
9. Unknown

Reliability of Information

Left Front	Center Front	Right Front
119	120	121
48	49	50

1. Certain
2. Reliable
3. Unreliable
4. Unable to Estimate

Occupant Restraint System Summary Form

Part 4: Occupant Information

Card N/T

Complete one card for each Front Seat Occupant (N=3+Occupant No.)

REPORT NO.

Team	Accident Date yr		mo		day		Sequence No.		
2	3	4	5	6	7	8	9	10	11

Occupant Role — 122 (12)
1. Driver
2. Passenger
9. Unknown

Seat Position — 123 (13)
1. Left Front
2. Center Front
3. Right Front
4. Other
9. Unknown

Ejection or Entrapment — 124 (14)
1. Not Ejected/ Not Trapped
2. Ejected (Degree Not Stated)
3. Partial Eject and Trapped
4. Partial Ejection
5. Total Ejection
6. Trapped
9. Unknown

Sex — 125 (15)
1. Male
2. Female
9. Unknown

Age (Years) — 126 (16 17)
00-97 Actual
98 - 98yrs. or Over
99 - Unknown

Height (Inches) — 127 (18 19)
01-98 Inches
99- Unknown

Weight (Pounds) — 128 (20 21 22)
001-998 Pounds
999- Unknown

Police Injury Code — 129 (23)
1. (K) (Fatal)
2. (A) (Incapacitating)
3. (B) (Non-incapt'g)
4. (C) Possible)
5. (O) No-Injury)
9. (U) Unknown

Treatment — Mortality — 130 (24)
0. Not Injured
1. First Aid at Scene
2. Stated-would consult MD
3. Directed to Consult MD
4. Did consult MD
5. Emer. Rm. Treatment-Rel.
6. Admitted to Hosp.-Non Fatal
7. Fatal
8. Other
9. Unknown

OCCUPANT INJURY CLASSIFICATION—Injury Detail—Use O.I.C. Code

Coding for Belt Caused Category ONLY:
0. No
1. Possible
2. Probable
3. Definite
9. Unknown

Injury Number	Body Region	Aspect	Lesion	Sys/Organ	Severity	Belt Caused
1	131 (25)	132 (26)	133 (27)	134 (28)	135 (29)	136 (30)
2	137 (31)	138 (32)	139 (33)	140 (34)	141 (35)	142 (36)
3	143 (37)	144 (38)	145 (39)	146 (40)	147 (41)	148 (42)
4	149 (43)	150 (44)	151 (45)	152 (46)	153 (47)	154 (48)
5	155 (49)	156 (50)	157 (51)	158 (52)	159 (53)	160 (54)
6	161 (55)	162 (56)	163 (57)	164 (58)	165 (59)	166 (60)

More Than Six Injuries ? — 167 (61)
1. Yes -Note Details on Med. form
2. No
9. Unknown

Occupant Pregnant ? — 168 (62)
1. Yes
2. No
3. N/A (Male)
9. Unknown

APPENDIX B

Codebook for Extract File

Var. 1: Team (Var. 1 on Occupant Restraint System Summary Form)

1. CALSPAN (W. New York)
2. U. of Miami
3. HSRI (S.E. Michigan)
4. SWRI (S. Texas)
5. UDC (Los Angeles)

Var. 2: Accident year (2)

4. 1974
5. 1975

Var. 3: Accident month (3)

1.	January	7.	July
2.	February	8.	August
3.	March	9.	September
4.	April	10.	October
5.	May	11.	November
6.	June	12.	December

Var. 4: Sequential number (5)

(3 digit numeric)

Var. 5: Case weight factor (Function of 1, 2, 3, 10)[1]

1. Sampled at 100%
2. Sampled at 50%
3. Sampled at 33%
4. Sampled at 10%
5. Sampled at 80%

Var. 6: Restraint system usage (83, 85)

2. No restraints used
3. Lap and shoulder belts
4. Lap belt only
9. Unknown

Var. 7: AIS injury (129, 130, 135)

0.	Not injured	4.	Serious nonfatal
1.	Minor	5.	Critical nonfatal
2.	Moderate	6.	Fatal
3.	Severe	9.	Unknown

Var. 8: Crash configuration (22, 24, 58-63)

0. Unknown
1. Head-on with veh
2. Rear end, striking
3. Rear end, struck
4. Angle, striking
5. Angle, struck in left side
6. Angle, struck in right side
7. Rollover
8. Other noncollision
9. Sideswipe
10. Head-on with fixed object
11. Side of vehicle into fixed object

Var. 9: Case vehicle weight (37, 39, 40)

0. Unknown
1. Subcompact
2. Compact
3. Intermediate
4. Full-sized

Var. 10: Damage severity (24, 58-64)

0. Unknown
1. Minor (e.g., 12-FDEW-1, 12-FYEW-1, 12-FLEW-1, 12-FLEE-1, 12-FLEE-2)
2. Moderate (e.g., 12-FDEW-2, 12-FYEW-2, 12-FLEW-2, 12-FLEW-3, 12-FLEE-3, 12-FLEE-4)
3. Moderately severe (e.g., 12-FDEW-3, 12-FYEW-3, 12-FLEW-4, 12-FLEE-5)
4. Severe (e.g., 12-FDEW-4, 12-FYEW-4, 12-FLEW-5, 12-FLEE-6)

Var. 11: Occupant age group (126)

0. Unknown
1. Under 10
2. 10 - 25
3. 26 - 55
4. 56 +

Var. 12: Occupant position (122, 123)

1. Driver
2. Passenger

Var. 13: Occupant sex (125)

1. Male
2. Female
3. Unknown

Var. 14: Vehicle model year (43)

3. 1973
4. 1974
5. 1975

Var. 15: Exact occupant age (126)

0. Less than 1 year
1 - 97. Exact age in years
98. 98 years or more
99. Unknown

---

[1] As this study was initiated under the auspices of the Motor Vehicle Manufacturers' Association and later sponsored by the National Highway Traffic Safety Administration, the sampling schemes and starting dates for the five teams differed somewhat. The weighting of the cases on the Level 2 file takes into account these differences. Specifically, the teams operated as follows:

Team	Time	Deviations from Basic Sampling Scheme
Calspan	6/74 - 3/75	100% (regardless of H)
	9/75 - end	10% N-H
Miami	10/75 - end	80% H 33 1/3% N-H
HSRI	1/74 - end	33 1/3% - 1973 models - N-H
		50% - 1974 models - N-H
		50% - 1975 models - N-H (after 6/75)

H = hospitalized
N-H = non-hospitalized

APPENDIX C

Contingency Table Screening Analyses

Introduction

This Appendix presents descriptive analyses for the evaluation of the effects of certain accident variables on the occurrence of serious injury. For this purpose, the following six variables are under investigation: belt usage, vehicle damage severity, crash configuration, vehicle weight, occupant age, and seat position.

The original analysis strategy for these data was to involve two basic phases:

Phase 1: A variable screening phase to identify which variables tended to be responsible for the greatest amount of variation among the respective estimated rates for moderate or worse injury (AIS $\geq$ 2).

Phase 2: A statistical modeling phase to produce a framework which efficiently characterizes the manner in which the variables identified in Phase 1 affected the estimated injury rates in the sense of explaining the variation among them in terms of a minimum number of underlying parameters.

The objectives of Phase 1 are directly analogous to those of "forward stepwise regression." However, here Pearson Chi-square statistics (divided by their degrees of freedom) were used like the "F to enter" statistics in multiple regression as a measure of the relative importance of certain combinations of variables in accounting for the variation among the estimated injury rates. According to this criterion, vehicle damage severity was by far the most important variable.

This variable selection process can be continued by considering the combined set of Pearson Chi-square statistics within the respective categories of the previously selected variable (i.e., vehicle damage severity). At this stage of the analysis, belt usage represented the second most important variable. However, belt usage was not included here since a major objective of this investigation was the comparison of different usage groups after controlling for the other important variables. Hence, crash configuration was the second variable which was taken into account in the analysis.

When the selection process was extended to the third stage, belt usage again represented the most important of the remaining variables under consideration. However, the belt usage effects were somewhat diminished with statistical significance occurring for many but not all crash configuration x damage severity combinations. The effects of vehicle weight and occupant age appeared to be of considerably lesser importance and the effects of seat position were virtually negligible. Finally, if either vehicle weight or occupant age were included at the third stage, the statistical significance of belt usage effects were further reduced, although this fact may be largely due to sample size attrition.

Given the previously described results, several attempts were made to fit log-linear models to the observed injury rates with a minimum number of parameters which reflected the relative importance of the respective variables. However, because of the general tendency for belt usage effects to interact with both crash configuration and damage severity (i.e., usage effects showed substantial variation across crash configuration x damage severity combinations), such efforts were largely unsuccessful. In addition, the relatively small sample sizes (for model fitting purposes) for many of the damage severity x crash configuration combinations further restricted the extent to which the effects of vehicle weight, occupant age, seat position and belt usage could be simultaneously investigated within such sub-populations. For these reasons, any further attempts at model fitting were regarded as potentially misleading in the sense of either possibly inducing apparent differences for certain variables which were not directly supported by the data and/or possibly suppressing real differences which were to some extent evident from more simplistic analyses. Thus, model fitting was concluded to be inappropriate for these data.

Accordingly, the remainder of this Appendix descriptively characterizes the effects of belt usage in terms of simple Pearson Chi-square tests (or alternativley Fisher's exact tests and rank correlation coefficients where sample sizes are small) for each crash configuration x damage severity combination, both in an overall sense as well as for specific occupant age and vehicle weight groups. In addition, the specific observed rates for serious injury are given for each belt usage group within each crash configuration x damage severity sub-population. Finally, other tests of significance pertaining to occupant age, vehicle weight, and seat position effects in their own right are given as general background information.

Methodology

Pearson Chi square tests of association between each of the variables under question as well as specific combinations of these variables and the resultant injury level are included in the summary tables of this Appendix. For those particular combinations of accident type variables which have an incidence level of less than 5, adjacent rows are combined to form 2 by 2 contingency tables in order that Fisher's exact tests can be applied. Finally, rank correlation coefficients are used to supplement the evaluation of the restraint system to take into account the natural ordering of the categories for this variable.

Results

In Tables C.1-C.6 the Pearson Chi-square test statistics and the estimated injury associated with each variable are shown. Belt usage, vehicle damage severity, crash configuration and occupant age each have a highly significant effect upon injury level (α = .01); vehicle weight is of lesser importance (α = .05); seat position is non-significant. The high Chi-square value corresponding to vehicle damage severity (χ_p^2 = 1222.1, df = 4) gives rise to a separate evaluation of the five remaining variables which controls for vehicle damage severity. Table C.7 presents the threshold levels of significance attained by the individual Pearson Chi-square tests of association within each of five levels of damage severity (minor, moderate, moderately severe, severe, unknown). Again, the specific belt usage system which is employed, as well as the crash configuration, both have a highly significant relationship with injury level (α = .01). For the most part, occupant age is also a significant factor, although it is non-significant for the severe damage category. When vehicle damage severity is controlled for, vehicle weight and seat position do not have a statistically significant relationship with the resulting injuries.

Since crash configuration continues to be a statistically significant factor when vehicle damage severity is controlled for, an examination of each of the four additional investigative variables within all combinations of vehicle damage severity and crash configuration is given in Tables C.8-C.11. Belt usage (C.8) has a generally statistically significant effect on accident injury for all levels of vehicle damage severity for the following five crash configurations: rear-end striking, angle striking, angle struck in left and right sides, head-on with fixed object. For the remaining combinations of vehicle damage severity and crash configuration, the restraint system effect is principally non-significant. Table C.12 enumerates the corresponding injury percentages for each combination of belt usage, vehicle damage severity, and crash configuration.

The vehicle weight effects (C.9) associated with injury level are primarily non-significant after vehicle damage severity and crash configuration are taken into account. However, those cases in which vehicle weight is significantly important occur more frequently in the moderate and moderately severe damage severity accidents than in the minor or severe accidents.

The occupant age effects (C.10) are non-significant for most vehicle damage severity x crash configuration combinations. In addition, those combinations for which age does have a significant influence upon injury level do not consistently fall within certain crash configuration or vehicle damage severity levels, but are instead scattered throughout all possible combinations. This dispersion tends to weaken whatever importance may be associated with this variable. When vehicle damage severity and crash configuration are taken into account, seat position (C.11) is clearly a non-significant factor with respect to injury level.

The results of the evaluation of belt usage, occupant age and seat position effects upon injury level within all combinations of damage severity, crash configuration, and vehicle weight are shown in Tables C.13-C.15. Belt usage (C.13) is an equally significant factor for all levels of vehicle weight as well as vehicle damage severity. However, there are four crash configurations for which belt usage has greater importance with regard to injury: angle striking, angle struck in left and right sides, head-on with fixed object. The occupant age and seat position effects (C.14 and C.15, respectively) are again generally non-significant.

Tables C.16-C.18 summarize the tests of association within each combination of vehicle damage severity by crash configuration by occupant age. Belt usage has a significant effect upon injury level most frequently among the 26-55 age group (C.16). (For the other age groups, belt usage does not appear to have any consistently significant effect.) The vehicle weight effects (C.17) are somewhat less significant for the oldest age category, which may be partially due to sample size attrition. The heavier concentration of significant vehicle weight effects in the moderate and moderately severe damage levels is again discernable. Finally, Table C.18 clearly displays the lack of association between seat position and injury level when vehicle damage severity, crash configuration and occupant age are under consideration.

Table C.1. Injury percentage by belt usage.

Belt Usage	Number Occupants	Number Injured	Percent Injured
None	11451	1279	11.2
Lap	3379	205	6.1
Lap + Shoulder	5048	227	4.5
	χ^2_p (df=2) = 231.7		
Combined	19878[1]	1711	8.6

[1]All cases on the file for which belt usage and injury information is available.

Table C.2. Injury percentage by damage.

Damage	Number Occupants	Number Injured	Percent Injured
Unknown	4137	187	4.5
Minor	7779	337	4.3
Moderate	6426	588	9.2
Moderately Severe	1911	382	20.0
Severe	791	262	33.1
χ^2_p (df=4) = 1222.1			
Combined	21044	1756	8.3

Table C.3. Injury percentage by crash configuration.

Crash Configuration	Number Occupants	Number Injured	Percent Injured
Head-on with vehicle	1299	200	15.4
Rear-end, striking	3216	188	5.8
Rear-end, struck	1283	51	4.0
Angle, striking	4397	296	6.7
Angle, struck in left side	2613	201	7.7
Angle, struck in right side	2594	218	8.4
Rollover	333	45	13.5
Sideswipe	652	30	4.6
Head-on with fixed object	2635	333	12.6
Side of vehicle into fixed object	933	129	13.8
χ^2_p (df=9) = 278.5			
Combined	19955	1691	8.5

Table C.4. Injury percentage by vehicle weight.

Vehicle Weight	Number Occupants	Number Injured	Percent Injured
Subcompact	6302	577	9.2
Compact	5025	405	8.1
Intermediate	4497	393	8.7
Full-sized	4350	346	8.0
χ^2_p (df=3) = 6.69			
Combined	20174	1721	8.5

Table C.5. Injury percentage by age.

Age	Number Occupants	Number Injured	Percent Injured
10-25	9516	758	8.0
26-55	8798	746	8.5
56+	1991	216	10.8
χ^2_p (df=2) = 17.7			
Combined	20305	1720	8.5

Table C.6. Injury percentage by seat position.

Occupant Position	Number Occupants	Number Injured	Percent Injured
Driver	15474	1285	8.3
Passenger	5570	471	8.5
χ^2_p (df=1) = 0.10			
Combined	21044	1756	8.3

Table C.7. P-values for usage, crash configuration, vehicle weight, age, seat position within damage.

	Minor	Moderate	Moderate Severe	Severe	Unknown
Usage	.01	.01	.01	.01	.01
Crash Configuration	.01	.01	.01	.01	.01
Vehicle Weight	NS*	.10	NS	NS	NS
Age	.05	.01	.01	NS	NS
Seat Position	NS	NS	NS	NS	NS

* NS = Non-significant

Table C.8 . P-values for usage effects within damage severity by crash configuration.*

Crash Configuration	Damage Severity				
	Minor	Moderate	Moderately Severe	Severe	Unknown
Head-on with vehicle	NS'	NS	NS	NS	NS
Rear-end, striking	.01	NS	.05/.05	NS	.05/.05
Rear-end, struck	NS	NS	NS	.10/.01	NS
Angle, striking	.01	.01	NS	.01	.01
Angle, struck in left side	.05/.01	.01	.05/.05	NS	.10/WD
Angle, struck in right side	.05/.05	NS	.01	.01	NS
Rollover	NS	NS	NS/.10	NS	NS
Sideswipe	NS	NS	NS	.05/.05	NS
Head-on with fixed object	.05/.05	.01	.01	NS	.01
Side of vehicle into fixed object	.10/NS	.10/.10	NS/.10	NS	NS

Table C.9 . P-values for vehicle weight effects within damage severity by crash configuration.

Crash Configuration	Damage Severity				
	Minor	Moderate	Moderately Severe	Severe	Unknown
Head-on with vehicle	NS	.10	.01	.05	NS
Rear-end, striking	NS	NS	NS	NS	NS
Rear-end, struck	NS	NS	.05	NS	NS
Angle, striking	.10	.01	NS	NS	NS
Angle, struck in left side	NS	NS	NS	NS	NS
Angle, struck in right side	NS	NS	NS	NS	NS
Rollover	NS	.05	.10	NS	NS
Sideswipe	NS	NS	NS	NS	NS
Head-on with fixed object	NS	.01	NS	NS	NS
Side of vehicle into fixed object	.10	NS	.05	NS	NS

* NS = Non-significant
Fisher's Exact Test/Rank Correlation Coefficient
WD = Rank Correlation in Wrong Direction

Table C.10. P-values for age effects within damage severity by crash configuration.*

Crash Configuration	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Unknown
Head-on with vehicle	NS	.01	.01	.05	NS
Rear-end, striking	NS	.05	NS	NS	NS
Rear-end, struck	NS	NS	NS	NS	NS
Angle, striking	.05	NS	NS	NS	NS
Angle, struck in left side	NS	NS	.01	NS	.05
Angle, struck in right side	.01	NS	NS	NS	NS
Rollover	NS	NS	.01	.05	NS
Sideswipe	.05	.10	NS	NS	NS
Head-on with fixed object	NS	.01	NS	.10	NS
Side of vehicle into fixed object	NS	.10	NS	NS	NS

Table C.11. P-values for occupant position effects within damage severity by crash configuration.

Crash Configuration	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Unknown
Head-on with vehicle	NS	NS	NS	NS	NS
Rear-end, striking	NS	NS	NS	NS	NS
Rear-end, struck	NS	NS	NS	NS	NS
Angle, striking	.10	NS	NS	NS	NS
Angle, struck in left side	NS	NS	NS	NS	NS
Angle, struck in right side	NS	.10	NS	NS	NS
Rollover	NS	NS	NS	NS	NS
Sideswipe	NS	NS	NS	NS	NS
Head-on with fixed object	NS	NS	NS	NS	NS
Side of vehicle into fixed object	NS	NS	NS	.05	NS

* NS = Non-significant

Table C.12. Injury rates within usage × crash configuration × damage severity.

Severity	Belt Usage	Head-On With Vehicle	Rear-End Striking	Rear-End Struck	Angle Striking	Angle Struck Left Side	Angle Struck Right Side	Rollover	Sideswipe	Head-On With Fixed Object	Side of Vehicle Into Fixed Object
		Crash Configuration									
Unknown	U	13.6	7.5	3.8	6.2	1.5	3.8	10.3	4.8	10.2	7.2
	L	4.4	2.6	0.0	0.0	6.1	3.6	0.0	0.0	0.0	0.0
	LS	7.1	2.5	0.0	0.8	8.9	1.7	16.7	12.5	1.4	6.5
Minor	U	7.4	4.2	3.2	4.1	5.1	4.8	2.5	4.5	9.9	10.9
	L	1.6	7.2	4.7	3.0	2.4	0.0	33.3	0.0	7.0	4.2
	LS	8.5	1.8	3.4	1.5	0.6	1.8	7.1	1.1	4.8	6.0
Moderate	U	14.1	8.5	3.9	13.9	7.9	6.4	11.1	5.1	20.9	15.0
	L	15.2	7.1	0.0	10.2	3.4	7.1	100.0	3.4	15.9	8.1
	LS	8.5	5.3	4.0	6.0	1.8	3.9	4.2	0.0	7.6	6.0
Moderately Severe	U	42.5	30.9	2.3	35.5	18.2	22.8	17.3	18.4	41.9	29.5
	L	45.5	13.3	7.4	21.1	8.5	25.7	12.5	0.0	13.6	21.1
	LS	23.5	14.3	0.0	21.7	11.2	8.4	0.0	10.0	23.1	12.0
Severe	U	64.0	36.8	23.8	70.0	50.0	35.5	35.7	42.9	29.5	63.9
	L	42.9	33.3	14.6	25.0	100.0	3.7	0.0	0.0	30.0	60.0
	LS	73.3	0.0	2.9	9.1	40.9	12.8	14.3	0.0	20.0	45.5

Table C.13. P-values for usage effects within damage severity by crash configuration by vehicle weight.

Vehicle Weight	Crash Configuration	Damage Severity Minor	Moderate	Moderately Severe	Severe	Unknown
Subcompact	1	.05/.05	NS/.10	NS	NS	NS
	2	NS	NS/.	NS	NS	NS
	3	NS	.10	--	NS	--
	4	.05/.05	.05/.01	NS	.10/.05	.05/.05
	5	NS	.01	NS	NS	NS
	6	.05/.05	NS	.01	NS	NS
	7	NS	NS	NS	NS	--
	8	--	.05/.05	NS	--	--
	9	NS	NS	NS	NS	.01
	10	NS	NS	NS	NS	NS/.10
Compact	1	NS	NS	NS/.10	NS	NS
	2	NS	NS	NS/.10	NS	NS
	3	NS	NS	--	.05/.05	NS
	4	NS	NS/.10	NS	NS	NS
	5	NS	NS/.05	NS	NS	--
	6	.10/.10	NS	NS	.10/.10	--
	7	NS	NS	NS	NS	NS
	8	NS	NS	NS	NS	NS
	9	NS	NS/.10	.05/.05	NS	.05/.05
	10	NS	NS	NS	NS	NS
Intermediate	1	NS	NS	NS	NS	.05/.05
	2	NS	NS	NS	--	NS
	3	NS	NS	NS	NS/.05	--
	4	NS	NS/.10	NS	.05/.05	.01
	5	NS	NS	NS	NS	NS
	6	NS	NS	NS	NS/.10	NS
	7	--	NS	NS	--	--
	8	NS	--	--	NS	NS
	9	.01	.10/.05	NS	NS	.01
	10	NS	NS	NS	--	NS
Full-Sized	1	NS	NS	NS	NS	NS
	2	NS/.10	NS	NS	NS	.05/.05
	3	NS	NS	NS	NS	NS
	4	NS	NS	NS	.10	--
	5	.05/.05	NS	.01	NS	.01/WD
	6	NS	NS/.10	NS	.01	--
	7	--	--	--	--	--
	8	NS	NS	NS	--	--
	9	NS	NS	NS	NS	NS
	10	.10/.10	NS	NS	NS	--

Table C.14. P-values for age effects within damage severity by crash configuration by vehicle weight.

Vehicle Weight	Crash Configuration	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Unknown
Subcompact	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	NS	NS
	3	NS	NS	--	NS	--
	4	NS	NS	NS	NS	NS
	5	NS	NS	NS	NS	NS
	6	.01	NS	.05	NS	NS
	7	NS	NS	.10	NS	--
	8	--	.10	NS	--	--
	9	NS	.01	NS	.01	.05
	10	NS	NS	NS	NS	NS
Compact	1	NS	NS	NS	NS	NS
	2	NS	.05	NS	NS	NS
	3	.01	NS	--	.10	NS
	4	NS	NS	.01	NS	NS
	5	NS	NS	NS	NS	NS
	6	.10	NS	NS	N6	--
	7	NS	NS	NS	.01	NS
	8	NS	NS	NS	NS	NS
	9	.05	NS	NS	NS	NS
	10	NS	NS	NS	NS	NS
Intermediate	1	NS	.05	NS	NS	NS
	2	NS	.10	NS	--	NS
	3	NS	NS	NS	NS	--
	4	NS	.05	NS	NS	NS
	5	NS	NS	.01	.05	NS
	6	.05	NS	NS	NS	NS
	7	--	NS	NS	NS	NS
	8	NS	--	NS	NS	NS
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	NS	NS
Full-Sized	1	NS	NS	NS	NS	NS
	2	NS	.05	NS	NS	NS
	3	NS	NS	NS	NS	NS
	4	.05	NS	NS	NS	--
	5	.05	NS	NS	.10	NS
	6	.05	.01	NS	NS	--
	7	--	--	NS	--	--
	8	NS	NS	NS	--	--
	9	NS	.01	.10	NS	NS
	10	NS	.10	NS	NS	--

Table C.15. P-values for seat position effects within damage severity by crash configuration by vehicle weight.

Vehicle Weight	Crash Configuration	Damage Severity				
		Minor	Moderate	Moderately Severe	Severe	Unknown
Subcompact	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	NS	NS
	3	NS	NS	--	NS	--
	4	.05	NS	NS	NS	NS
	5	NS	.10	NS	NS	NS
	6	NS	NS	NS	NS	NS
	7	NS	NS	NS	NS	--
	8	--	NS	NS	--	--
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	.01	NS
Compact	1	NS	NS	NS	.10	NS
	2	NS	NS	NS	NS	NS
	3	NS	NS	--	NS	NS
	4	NS	NS	NS	NS	NS
	5	NS	NS	NS	NS	NS
	6	.01	NS	NS	NS	--
	7	NS	NS	NS	NS	NS
	8	NS	NS	NS	NS	NS
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	NS	NS
Intermediate	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	--	NS
	3	NS	.05	NS	NS	--
	4	NS	NS	NS	NS	NS
	5	NS	NS	.10	NS	NS
	6	NS	.10	.05	NS	NS
	7	--	--	NS	NS	NS
	8	NS	--	NS	NS	NS
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	NS	NS
Full-Sized	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	--	NS
	3	NS	NS	NS	NS	NS
	4	NS	NS	NS	--	--
	5	.01	NS	NS	NS	NS
	6	NS	NS	NS	.05	--
	7	--	--	NS	NS	--
	8	NS	NS	NS	--	--
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	NS	--

Table C.16. P-values for usage effects within damage severity by crash configuration by age.*

Age	Crash Configuration**	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Unknown
10-25	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	NS	NS/.10
	3	NS	NS	NS	NS	--
	4	.01	.01	NS	.01	.10/.10
	5	.10/.05	.05/.01	NS	NS	NS
	6	--	NS	NS/.05	NS	NS
	7	NS	NS	NS	NS	NS
	8	--	--	NS	NS	NS
	9	NS	NS	.05/.05	NS	.01
	10	NS	NS	NS	NS	NS
26-55	1	NS	NS	NS	NS	.01
	2	NS	NS	.05/.01	.10/.10	.05/.05
	3	NS	NS	NS	.01	.10/.10
	4	NS	NS	NS	.05/.05	.01
	5	NS	.05/.10	.05/.05	NS	NS
	6	.01	NS	NS	.01	NS
	7	NS	NS	NS/.10	NS	--
	8	NS	NS	NS	NS/.10	NS
	9	.05/.05	.05/.05	NS	NS	.05/.05
	10	.05/.05	NS	NS	NS	NS
56+	1	NS	.10/.10	NS	--	NS
	2	.05/.05	NS	NS	--	NS
	3	NS	NS	NS	NS	--
	4	NS	.05/.05	NS	--	--
	5	NS	.05/.05	.01	NS	.05/WD
	6	NS	NS	NS	NS	NS
	7	--	--	--	--	--
	8	--	NS	--	--	NS
	9	NS	NS	.10	NS	NS/.10
	10	NS	NS	--	--	--

* NS = Non-significant
-- = Non-applicable
Fisher's Exact Test/Rank Correlation Coefficient
WD = Rank Correlation in Wrong Direction

** Crash Configuration Levels:

1. Head-on with vehicle
2. Rear-end, striking
3. Rear-end, struck
4. Angle, striking
5. Angle struck in left side
6. Angle struck in right side
7. Rollover
8. Sideswipe
9. Head-on with fixed object
10. Side of vehicle into fixed object

Table C.17. P-values for vehicle weight effects within damage severity by crash configuration by age.

Age	Crash Configuration	Damage Severity				
		Minor	Moderate	Moderately Severe	Severe	Unknown
10-25	1	NS	NS	NS	NS	NS
	2	NS	.10	NS	NS	NS
	3	NS	NS	NS	NS	--
	4	NS	.01	NS	NS	NS
	5	NS	NS	.10	NS	NS
	6	NS	NS	NS	NS	NS
	7	NS	NS	NS	.05	NS
	8	--	--	.10	NS	--
	9	NS	.01	NS	.01	NS
	10	.10	NS	.05	NS	NS
26-55	1	.10	NS	NS	.01	NS
	2	NS	.10	.05	NS	NS
	3	NS	NS	NS	NS	NS
	4	.10	NS	NS	NS	NS
	5	NS	NS	NS	NS	NS
	6	NS	.01	NS	NS	NS
	7	NS	.05	NS	NS	NS
	8	NS	NS	NS	NS	NS
	9	NS	NS	.10	.05	NS
	10	NS	NS	NS	NS	NS
56+	1	NS	NS	.10	--	NS
	2	NS	NS	NS	--	NS
	3	NS	NS	NS	NS	--
	4	NS	NS	NS	--	--
	5	NS	NS	NS	NS	NS
	6	NS	.10	.10	NS	NS
	7	--	--	--	--	--
	8	--	NS	NS	--	NS
	9	NS	NS	.10	NS	NS
	10	NS	NS	--	--	--

Table C.18. P-values for seat position within damage severity by crash configuration by age.

Age	Crash Configuration	Damage Severity: Minor	Moderate	Moderately Severe	Severe	Unknown
10-25	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	NS	NS
	3	NS	NS	NS	NS	--
	4	NS	NS	NS	NS	NS
	5	NS	NS	NS	NS	NS
	6	NS	NS	NS	NS	NS
	7	NS	NS	NS	NS	NS
	8	--	--	NS	NS	NS
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	.05	NS
26-55	1	NS	NS	NS	NS	NS
	2	NS	NS	NS	NS	NS
	3	NS	NS	NS	NS	NS
	4	NS	NS	NS	NS	NS
	5	NS	NS	NS	NS	NS
	6	NS	NS	NS	NS	NS
	7	NS	NS	.10	NS	NS
	8	NS	NS	NS	.10	NS
	9	NS	NS	NS	NS	NS
	10	NS	NS	NS	--	NS
56+	1	NS	NS	NS	--	NS
	2	NS	NS	--	--	NS
	3	NS	NS	NS	NS	--
	4	NS	.05	NS	--	--
	5	NS	NS	NS	NS	NS
	6	NS	NS	NS	NS	NS
	7	--	--	--	--	--
	8	--	NS	NS	--	--
	9	NS	NS	NS	--	NS
	10	NS	NS	--	--	--

APPENDIX D

Contingency Table Analysis for Compounded Logarithmic - Exponential - Linear Functions

Grizzle, Starmer and Koch (1969) describe how linear regression models and weighted least squares can be used to either test hypotheses or fit simplified models to multi-dimensional contingency tables which arise when frequency counts are obtained for respective cross-classifications of specific qualitative variables. Briefly, assuming an underlying product multinomial model for the cell frequencies and certain regularity conditions on $\underline{F}(\underline{p}) = (F_1(\underline{p}),\ldots,F_u(\underline{p}))$, a set of functions of the cell proportions, attention is directed at fitting a linear model

$$E(\underline{F}(\underline{p})) = \underline{X}\underline{\beta} \tag{D.1}$$

where $\underline{X}$ is a known (u×t) coefficient matrix of full rank $t \leq u$ and $\underline{\beta}$ is an unknown (t×1) parameter vector. Weighted least squares provides the BAN estimator

$$\underline{b} = \hat{\underline{\beta}} = (\underline{X}'\underline{V}_F^{-1}\underline{X})^{-1}\underline{X}'\underline{V}_F^{-1}\underline{F} \tag{D.2}$$

where

$$\underline{V}_F = \underline{H}\underline{V}(\underline{p})H' \tag{D.3}$$

with

$\underline{H} = \left[\underline{dF}(\underline{x})/\underline{dx}\,|\,\underline{x}=\underline{p}\right]$

$\underline{V}(\underline{p})$ is block-diagonal with matrices

$\underline{V}_i(\underline{p}_i) = (\underline{D}_{\underline{p}_i} - \underline{p}_i\underline{p}_i')/n_i$ on the main diagonal

with $\underline{D}_{p_i}$ a diagonal matrix with $\underline{p}_i$ on the main diagonal, i = 1, s,....,s = number of populations.

Also

$$\underline{V}_b = \text{var}(\underline{b}) = (\underline{X}'\underline{V}_F^{-1}\underline{X})^{-1} \tag{D.4}$$

A goodness of fit test statistic is given by

$$X_F^2 = SS(E(\underline{F}) = \underline{X}\underline{\beta}) = \underline{F}'\underline{V}_F^{-1}\underline{F} - \underline{b}'(\underline{X}'\underline{V}_F^{-1}\underline{X})\underline{b} \tag{D.5}$$

which, under the null hypothesis that the model fits, is approximately χ^2(df=u-t). Given an adequate fit, general linear hypotheses H_c: $\underline{C}\underline{\beta} = \underline{0}$, where $\underset{\sim}{C}$ is a known (d×t) matrix of full rank d≤t, can be tested using

$$X_c^2 = SS(\underline{C}\underline{\beta} = \underline{0}) = \underline{b}'\underline{C}'\left[\underline{C}(\underline{X}'\underline{V}_F^{-1}\underline{X})^{-1}\underline{C}'\right]^{-1}\underline{C}\underline{b} \qquad (D.6)$$

which, under H_c, is approximately $\chi^2(df = d)$.

Grizzle, Starmer, and Koch (1969) restrict attention to linear functions $\underline{F}(\underline{p}) = \underline{A}\underline{p} = \underline{a}$ and log-linear funcitons

$$\underline{F}(\underline{p}) = \underline{K}\left[\underline{\ln}(\underline{A}\underline{p})\right] = \underline{f} \qquad (D.7)$$

where $\underline{A}$ and $\underline{K}$ are known matrices and $\underline{\ln}$ transforms a vector to the corresponding vector of natural logarithms.

Forthofer and Koch (1973) extend the previous work to exponential functions of the type

$$\underline{F}(\underline{p}) = \underline{Q}(\underline{\exp}\{\underline{K}\left[\underline{\ln}(\underline{A}\underline{p})\right]\}) = \underline{g} \qquad (D.8)$$

and compounded logarithmic functions of the type

$$\underline{F}(\underline{p}) = \underline{L}\{\underline{\ln}\left[\underline{Q}(\underline{\exp}\{\underline{K}\left[\underline{\ln}(\underline{A}\underline{p})\right]\})\right]\} = \underline{h} \qquad (D.9)$$

where $\underline{Q}$ and $\underline{L}$ are known matrices and $\underline{\exp}$ transforms a vector to the corresponding vector of exponential functions (i.e., of anti-logarithms). Forthofer and Koch (1973) illustrate this extension with four examples, two of which deal with problems in highway safety - relationship between car size and accident injuries for accompanied and for unaccompanied drivers.

The Level 2 study has extended Forthofer and Koch (1973) to handle functions of the form

$$\underline{F}(\underline{p}) = \underline{\exp}(\underline{L}\{\underline{\ln}\left[\underline{Q}\underline{\exp}\{\underline{K}\left[\underline{\ln}(\underline{A}\underline{p})\right]\})\right]\}) = \underline{k} = \frac{R_2}{R_1} \qquad (D.10)$$

the ratio of standardized injury rates for lap belted and unrestrained occupants respectively, for example. A consistent estimate for the covariance matrix of $\underline{F}(\underline{p})$ is given by

$$\text{var}(\underline{F}(\underline{p})) = \underline{D}_{\underline{z}}\underline{L}\underline{D}_{\underline{g}}^{-1}\underline{Q}\underline{D}_{\underline{y}}\underline{K}\underline{D}_{\underline{a}}^{-1}\underline{A}\left[\underline{V}(\underline{p})\right]\underline{A}'\underline{D}_{\underline{a}}^{-1}\underline{K}'\underline{D}_{\underline{y}}\underline{Q}'\underline{D}_{\underline{g}}^{-1}\underline{L}'\underline{D}_{\underline{z}} \qquad (D.11)$$

where

$$\underline{y} = \underline{\exp}(\underline{f}), \qquad \underline{z} = \underline{\exp}(\underline{h}).$$

Hypothesis testing and model fitting for this complex situation is carried out using a computer program for generalized categorical data models called GENCAT (see Landis et. al., 1976), which is an extension of the previous LINCAT and MODCAT programs developed by the Department of Biostatistics, University of North Carolina at Chapel Hill.

APPENDIX E

Mantel-Haenszel-Type Estimation

Using the notation of Chapter II, the overall injury rate for restraint system i, i=1,2,3, is estimated by

$$\hat{R}_i = \sum_h w_h p_{hi1} = \sum_h \left(\frac{n_{h\cdot\cdot}}{n_{\cdot\cdot\cdot}}\right)\left(\frac{n_{hi1}}{n_{hi\cdot}}\right) \tag{E.1}$$

and the injury-reducing effectiveness of belt system i' compared to belt system i (i<i') is then estimated by

$$\hat{E}_{ii'} = \frac{\hat{R}_i - \hat{R}_{i'}}{\hat{R}_i} \tag{E.2}$$

If it is assumed that the w_h are non-random or fixed (and equal to the population strata weights), then the variance of $\hat{R}_i$ can be estimated by

$$V_i = \hat{V}(\hat{R}_i) = \sum_h w_h^2 \frac{p_{hi1}(1-p_{hi1})}{n_{hi\cdot}-1}, \quad n_{hi\cdot}>1 \tag{E.3}$$

If, in addition, it is also assumed that the $\hat{R}_i$'s are uncorrelated, the variance of $\hat{E}_{ii'}$ can be estimated as in Reinfurt et al. (1975) by

$$\hat{V}(\hat{E}_{ii'}) = \left(\frac{\hat{R}_i - \hat{R}_{i'}}{\hat{R}_i}\right)^2 \left[\frac{V_i + V_{i'}}{(\hat{R}_i - \hat{R}_{i'})^2} - \frac{2V_i}{\hat{R}_i(\hat{R}_i - \hat{R}_{i'})} + \frac{V_i}{\hat{R}_i^2}\right]$$

$$= \frac{\hat{R}_{i'}^2}{\hat{R}_i^4} V_i + \frac{1}{\hat{R}_i^2} V_{i'} \tag{E.4}$$

Suppose, as is more reasonable in the present application, that the weights w_h are random. Let

$\underset{\sim}{w} = (w_1 \cdots w_h \cdots w_d)'$ be the vector of sample stratum weights

$\underset{\sim}{p}_i = (p_{1i1} \cdots p_{hi1} \cdots p_{di1})'$ be the vector of injury rates for the i-th restraint system.

Assume $\underset{\sim}{w} \mathrel{\dot{\sim}} N(\underset{\sim}{\mu},\underset{\sim}{V})$ and $\underset{\sim}{p}_i \mathrel{\dot{\sim}} N(\underset{\sim}{\pi}_i,\underset{\sim}{\Sigma}_i)$.

Then
$$\hat{\underset{\sim}{\mu}} = \left(\frac{n_{1\cdot\cdot}}{n_{\cdot\cdot\cdot}} \cdots \frac{n_{h\cdot\cdot}}{n_{\cdot\cdot\cdot}} \cdots \frac{n_{d\cdot\cdot}}{n_{\cdot\cdot\cdot}} \right)' \tag{E.5}$$

$$\hat{\underset{\sim}{\pi}}_i = \left(\frac{n_{1i1}}{n_{1i\cdot}} \cdots \frac{n_{hi1}}{n_{hi\cdot}} \cdots \frac{n_{di1}}{n_{di\cdot}} \right)' \qquad i=1,2,3 \tag{E.6}$$

and
$$\hat{\underset{\sim}{V}} = \frac{1}{n_{\cdot\cdot\cdot}} (\underset{\sim}{\text{Diag}}\ (\underset{\sim}{w}) - \underset{\sim}{w}\underset{\sim}{w}') \tag{E.7}$$

$$\hat{\underset{\sim}{\Sigma}}_i = \underset{\sim}{\text{Diag}}\ (v_{hi}) = \underset{\sim}{\text{Diag}} \left(\frac{p_{hi1}(1-p_{hi1})}{n_{hi\cdot}-1} \right) \qquad n_{hi\cdot}>1 \tag{E.8}$$

For convenience, express $\hat{R}_i$ as a bilinear form as follows:

$$\hat{R}_i = \sum_h w_h p_{hi1} = \underset{\sim}{w}' I_d \underset{\sim}{p}_i = \underset{\sim}{w}' \underset{\sim}{p}_i \tag{E.9}$$

Then, it can be shown (Searle, 1971, p. 65) that

$$E(\underset{\sim}{w}'\underset{\sim}{p}_i) = tr(\underset{\sim}{B}_{wi}) + \underset{\sim}{\mu}'\underset{\sim}{\pi}_i \tag{E.10}$$

$$V(\underset{\sim}{w}'\underset{\sim}{p}_i) = tr(\underset{\sim}{B}_{wi})^2 + tr(\underset{\sim}{\Sigma}_i\underset{\sim}{V}) + \underset{\sim}{\mu}'\underset{\sim}{\Sigma}_i\underset{\sim}{\mu} + \underset{\sim}{\pi}_i'\underset{\sim}{V}\underset{\sim}{\pi}_i + 2\underset{\sim}{\mu}'\underset{\sim}{B}_{wi}\underset{\sim}{\pi}_i \qquad (E.11)$$

where

$tr(\underset{\sim}{B}_{wi}) = trace\ (\underset{\sim}{B}_{wi})$

$\underset{\sim}{B}_{wi} = Cov(\underset{\sim}{w},\underset{\sim}{p}_i) = E\left[(\underset{\sim}{w}-\underset{\sim}{\mu})(\underset{\sim}{p}_i-\underset{\sim}{\pi}_i)'\right]$ with off-diagonal elements zero assuming independence between strata; diagonal elements zero if w_h and p_{hi1} are assumed stochastically independent.

The following cases are of interest:

a) w_h and p_{hi1} <u>independent</u> random variables. From (E.10) and (E.11) it follows that

$E(\hat{R}_i) = E(\underset{\sim}{w}'\underset{\sim}{p}_i) = \underset{\sim}{\mu}'\underset{\sim}{\pi}_i = R_i$, true injury rate for the i-th restraint system.

(E.12)

$$\hat{V}(\hat{R}_i) = \hat{V}(\underset{\sim}{w}'\underset{\sim}{p}_i)$$

$$= \frac{1}{n_{\cdots}}\left[\sum_h w_h v_{hi} - \sum_h w_h^2 v_{hi}\right] + \sum_h w_h^2 v_{hi} + \frac{1}{n_{\cdots}}\left[\sum_h w_h p_{hi1}^2 - \left(\sum_h w_h p_{hi1}\right)^2\right]$$

$$\doteq \sum_h w_h^2 \frac{p_{hi1}(1-p_{hi1})}{n_{hi\cdot}-1} + \frac{1}{n_{\cdots}}\left[\sum_h \frac{w_h p_{hi1}}{n_{hi\cdot}-1} + \sum_h \left(\frac{n_{hi\cdot}-2}{n_{hi\cdot}-1}\right) w_h p_{hi1}^2 - \left(\sum_h w_h p_{hi1}\right)^2\right],$$

$$n_{hi\cdot} > 1 \qquad (E.13)$$

which contains the basic estimator given in (E.3) plus a correction factor arising from the assumption of random weights.

b) w_h and p_{hil} correlated random variables

$$E(\hat{R}_i) = E(\underset{\sim}{w}'\underset{\sim}{p}_i) = \sum_h b_{wi}^{(h)} + \underset{\sim}{\mu}'\underset{\sim}{\pi}_i$$

$$\text{where } \underset{\sim}{\hat{B}}_{wi} = \underset{\sim}{\text{Diag}}\left(\hat{b}_{wi}^{(h)}\right) \qquad h=1,2,\ldots,d \tag{E.14}$$

$$\hat{V}(\hat{R}_i) = \hat{V}(\underset{\sim}{w}'\underset{\sim}{p}_i)$$

$$= \sum_h \left(b_{wi}^{(h)}\right)^2 + \sum_h w_h^2 v_{hi} + \frac{1}{n_{\cdots}}\left[\sum_h w_h v_{hi} - \sum_h w_h^2 v_{hi} + \sum_h w_h p_{hil}^2 - \left(\sum_h w_h p_{hil}\right)^2\right]$$

$$+ 2\sum_h w_h b_{wi}^{(h)} p_{hil}$$

$$\doteq \sum_h w_h^2 \frac{p_{hil}(1-p_{hil})}{n_{hi\cdot}-1} + \frac{1}{n_{\cdots}}\left[\sum_h \frac{w_h p_{hil}}{n_{hi\cdot}-1} + \sum_h\left(\frac{n_{hi\cdot}-2}{n_{hi\cdot}-1}\right) w_h p_{hil}^2 - \left(\sum_h w_h p_{hil}\right)^2\right]$$

$$+ \left[\sum_h \left(b_{wi}^{(h)}\right)^2 + 2\sum_h w_h b_{wi}^{(h)} p_{hil}\right], \qquad n_{hi\cdot}>1 \tag{E.15}$$

where the last term in (E.15) represents an additional correction between $\underset{\sim}{w}$ and $\underset{\sim}{p}_i$. Note that (E.14) contains a bias term $\left(\sum_h b_{wi}^{(h)}\right)$ due to this dependence. These covariances $b_{wi}^{(h)}$ can be assumed negligible as they appear to be of order 10^{-10} for the Level 2 data.

In order to estimate the standard error of $\hat{E}_{ii'}$, we utilize the Taylor series expansion of $\hat{E}_{ii'}$ around $(R_i, R_{i'})$, namely

$$\hat{E}_{ii'} = \frac{\hat{R}_i - \hat{R}_{i'}}{\hat{R}_i} = f(\hat{R}_i, \hat{R}_{i'})$$

$$\doteq f(R_i,R_{i'}) + \left.\frac{\partial f}{\partial \hat{R}_i}\right|_{(R_i,R_{i'})} (\hat{R}_i - R_i) + \left.\frac{\partial f}{\partial \hat{R}_{i'}}\right|_{(R_i,R_{i'})} (\hat{R}_{i'} - R_{i'})$$

$$+ \tfrac{1}{2}\left[\left.\frac{\partial^2 f}{\partial \hat{R}_i^2}\right|_{(R_i,R_{i'})} (\hat{R}_i - R_i)^2 + 2\left.\frac{\partial^2 f}{\partial \hat{R}_i \partial \hat{R}_{i'}}\right|_{(R_i,R_{i'})} (\hat{R}_i - R_i)(\hat{R}_{i'} - R_{i'})\right.$$

$$\left. + \left.\frac{\partial^2 f}{\partial \hat{R}_{i'}^2}\right|_{(R_i,R_{i'})} (\hat{R}_{i'} - R_{i'})^2\right] + \cdots$$

$$\doteq \frac{R_i - R_{i'}}{R_i} + \left[\frac{R_{i'}}{R_i^2}(\hat{R}_i - R_i) - \frac{1}{R_i}(\hat{R}_{i'} - R_{i'})\right]$$

$$- \left[\frac{R_{i'}}{R_i^3}(\hat{R}_i - R_i)^2 - \frac{1}{R_i^2}(\hat{R}_i - R_i)(\hat{R}_{i'} - R_{i'})\right] + \cdots$$

Linear approximations to the mean and variance of $f(\hat{R}_i,\hat{R}_{i'})$ are given by

$$E\left[f(\hat{R}_i,\hat{R}_{i'})\right] = \frac{R_i - R_{i'}}{R_i} \tag{E.16}$$

$$V\left[f(\hat{R}_i,\hat{R}_{i'})\right] = \frac{R_{i'}^2}{R_i^4} V(\hat{R}_i) + \frac{1}{R_i^2} V(\hat{R}_{i'}) - 2\frac{R_{i'}}{R_i^3} \mathrm{Cov}(\hat{R}_i,\hat{R}_{i'}) \tag{E.17}$$

The only problem remaining is to estimate $\mathrm{Cov}(\hat{R}_i,\hat{R}_{i'})$. This can be done by expressing $\hat{R}_i,\hat{R}_{i'}$ as bilinear forms and then combining into a quadratic form (see Searle, 1971, p. 66) as follows:

$$Cov(\hat{R}_i,\hat{R}_{i'}) = Cov(\underset{\sim}{w}'\underset{\sim}{I}_d\underset{\sim}{p}_i,\underset{\sim}{w}'\underset{\sim}{I}_d\underset{\sim}{p}_{i'})$$

$$= tr(\underset{\sim}{B}_{wi}\underset{\sim}{B}_{wi'} + \underset{\sim}{B}_{ii'}\underset{\sim}{V}) + \underset{\sim}{\mu}'\underset{\sim}{B}_{wi}\underset{\sim}{\pi}_{i'} + \underset{\sim}{\mu}'\underset{\sim}{B}_{ii'}\underset{\sim}{\mu} + \underset{\sim}{\pi}_i'\underset{\sim}{V}\underset{\sim}{\pi}_{i'} + \underset{\sim}{\pi}_i'\underset{\sim}{B}_{wi'}\underset{\sim}{\mu} \qquad (E.18)$$

where $\underset{\sim}{B}_{ii'} = Cov(\underset{\sim}{p}_i,\underset{\sim}{p}_{i'}) = E\left[(\underset{\sim}{p}_i - \underset{\sim}{\pi}_i)(\underset{\sim}{p}_{i'} - \underset{\sim}{\pi}_{i'})\right]$

with diagonal elements $b_{ii'}^{(h)}$ and off-diagonal elements zero because of the independence of the strata.

Again, several cases are of interest.

a) w_h constant

$$Cov(\hat{R}_i,\hat{R}_{i'}) = \underset{\sim}{\mu}'\underset{\sim}{B}_{ii'}\underset{\sim}{\mu} = \sum_h w_h^2 b_{ii'}^{(h)} \qquad (E.19)$$

b) w_h and p_{hi1} independent random variables (i=1,2,3)

$$Cov(\hat{R}_i,\hat{R}_{i'}) = tr(\underset{\sim}{B}_{ii'}\underset{\sim}{V}) + \underset{\sim}{\mu}'\underset{\sim}{B}_{ii'}\underset{\sim}{\mu} + \underset{\sim}{\pi}_i'\underset{\sim}{V}\underset{\sim}{\pi}_{i'}$$

$$= \frac{i}{n_{\cdots}} \sum_h w_h(1-w_h)\left[b_{ii'}^{(h)} + p_{hi1}p_{hi'1}\right] + \sum_h w_h^2 b_{ii'}^{(h)} \qquad (E.20)$$

c) w_h and p_{hi1} correlated random variables

$$Cov(\hat{R}_i,\hat{R}_{i'}) = \sum_h b_{wi}^{(h)}b_{wi'}^{(h)} + \frac{1}{n_{\cdots}} \sum_h w_h(1-w_h)b_{ii'}^{(h)} + \sum_h w_h b_{wi}^{(h)} p_{hi'1}$$

$$+ \sum_h w_h^2 b_{ii'}^{(h)} + \frac{1}{n_{\cdots}} \sum_h w_h(1-w_h)p_{hi1}p_{hi'1} + \sum_h w_h b_{wi'}^{(h)} p_{hi1} \qquad (E.21)$$

which reduces to (E.20) under the previously examined assumption that the $b_{wi}^{(h)}$ are negligible (and hence assumed to be zero). The $b_{ii'}^{(h)}$ can be estimated from

$$V\left[F(\underset{\sim}{p}_h)\right] = V\left[\exp(\underset{\sim}{A}_2 \ln\left[\underset{\sim}{A}_1 \underset{\sim}{p}_h\right])\right]$$

where

$$\underset{\sim}{p}_h = \left[\frac{n_{h11}}{n_{h..}}, \frac{n_{h12}}{n_{h..}}, \ldots, \frac{n_{h32}}{n_{h..}}\right]$$

$$A_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

using GENCAT. The off-diagonal elements of $\hat{V}\left[F(\underset{\sim}{p}_h)\right]$ will yield estimates of $b_{ii'}^{(h)}$ for (E.20). However, again experience with the Level 2 file suggests that these covariances are negligible.

APPENDIX F

Sensitivity Analyses

(based on data from the Interim Report)

Table F.1. Sensitivity analysis of injury rates estimates using GENCAT: Overall and selected subpopulations.

Variables in the Model

Variables Population			WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
Overall		U	.11969 (.0041)	.11990 (.0041)	.12338 (.0042)	.12146 (.0041)	.11960 (.0041)	.12063 (.0042)	.12086 (.0041)	.11757 (.0040)	.12398 (.0043)	.12324 (.0042)	.12143 (.0041)	.12370 (.0042)	.12032 (.0041)	.12354 (.0042)	.12089 (.0041)	.12314 (.0042)
		L	.09346 (.0067)	.08998 (.0068)	.08609 (.0066)	.08908 (.0068)	.08997 (.0068)	.09031 (.0070)	.08830 (.0067)	.09353 (.0071)	.08505 (.0066)	.08559 (.0080)	.08848 (.0068)	.08475 (.0066)	.08955 (.0070)	.08588 (.0066)	.08757 (.0067)	.08485 (.0065)
		L/S	.05096 (.0041)	.05285 (.0043)	.04913 (.0041)	.04931 (.0040)	.05092 (.0041)	.05068 (.0042)	.04970 (.0040)	.05477 (.0044)	.04900 (.0041)	.05059 (.0041)	.05096 (.0041)	.05017 (.0041)	.05203 (.0043)	.04812 (.0040)	.05045 (.0040)	.04991 (.0041)
Car Weight	COMP	U	.12234 (.0057)		.12655 (.0060)	.12452 (.0058)	.12219 (.0057)	.12387 (.0058)	.12405 (.0058)		.12694 (.0060)					.12674 (.0059)		.12644 (.0059)
		L	.11092 (.0098)		.09951 (.0097)	.10279 (.0099)	.10458 (.0100)	.10383 (.0104)	.10209 (.0098)		.09801 (.0096)					.09847 (.0096)		.09834 (.0096)
		L/S	.05887 (.0056)		.05622 (.0055)	.05604 (.0054)	.05878 (.0056)	.05711 (.0056)	.05613 (.0054)		.05502 (.0054)					.05513 (.0054)		.05531 (.0054)
	FULL	U	.11647 (.0058)		.11952 (.0060)	.11774 (.0059)	.11644 (.0058)	.11668 (.0059)	.11697 (.0058)		.12037 (.0060)					.11964 (.0060)		.11962 (.0060)
		L	.07221 (.0090)		.06976 (.0087)	.07240 (.0091)	.07219 (.0090)	.07384 (.0091)	.07151 (.0090)		.06928 (.0087)					.07056 (.0089)		.06949 (.0087)
		L/S	.04133 (.0061)		.04049 (.0060)	.04116 (.0060)	.04135 (.0061)	.04285 (.0064)	.04188 (.0061)		.04167 (.0062)					.03959 (.0059)		.04085 (.0060)
Damage Severity	MOD	U	.09047 (.0040)	.09037 (.0040)		.09114 (.0041)	.09040 (.0040)		.09084 (.0040)	.08832 (.0040)			.09105 (.0041)				.09049 (.0040)	.09071 (.0040)
		L	.07268 (.0066)	.07209 (.0065)		.07156 (.0065)	.07261 (.0066)		.07125 (.0065)	.07576 (.0069)			.07068 (.0065)				.07062 (.0064)	.07094 (.0064)
		L/S	.03430 (.0037)	.03494 (.0037)		.03395 (.0036)	.03433 (.0037)		.03436 (.0037)	.03537 (.0038)			.03467 (.0037)				.03498 (.0037)	.03472 (.0037)
	SEV	U	.28622 (.0144)	.12248 (.0067)		.29425 (.0146)	.28599 (.0144)		.29191 (.0146)	.28142 (.0141)			.29456 (.0146)				.29411 (.0146)	.29201 (.0146)
		L	.21188 (.0248)	.07838 (.0100)		.18895 (.0265)	.18891 (.0259)		.18548 (.0260)	.19480 (.0271)			.18993 (.0269)				.18417 (.0260)	.18468 (.0260)
		L/S	.14588 (.0177)	.05775 (.0069)		.13680 (.0170)	.14545 (.0176)		.13711 (.0170)	.16531 (.0193)			.14383 (.0176)				.13863 (.0167)	.14216 (.0173)

Table F.1. Continued

Crash Configuration	Variable / Population	WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
A	U/L	.14353 (.0078)	.11942 (.0054)	.12242 (.0056)		.11923 (.0054)	.11925 (.0054)		.11699 (.0053)		.12212 (.0055)			.11871 (.0054)			.12180 (.0055)
	U/LS	.11497 (.0129)	.10189 (.0098)	.09941 (.0097)		.10253 (.0098)	.10213 (.0099)		.10281 (.0098)		.09591 (.0094)			.10056 (.0097)			.09855 (.0096)
	L/LS	.06351 (.009)	.05352 (.0059)	.04942 (.0057)		.05197 (.0058)	.05254 (.0061)		.05650 (.0062)		.05061 (.0058)			.05419 (.0061)			.05082 (.0058)
B	U/L	.10926 (.0058)	.10966 (.0069)	.11270 (.0072)		.10961 (.0070)	.11052 (.0070)		.10712 (.0068)		.11246 (.0071)			.11029 (.0070)			.11253 (.0071)
	U/LS	.08614 (.0099)	.06591 (.0098)	.06092 (.0091)		.06483 (.0097)	.06127 (.0091)		.06784 (.0101)		.06308 (.0094)			.06148 (.0092)			.06096 (.0091)
	L/LS	.04754 (.0056)	.04704 (.0063)	.04635 (.0063)		.04661 (.0063)	.04642 (.0063)		.04757 (.0063)		.04820 (.0065)			.04672 (.0063)			.04641 (.0062)
C	U/L	.11130 (.0085)	.16043 (.0150)	.16830 (.0157)		.15855 (.0148)	.16586 (.0155)		.15949 (.0149)		.16950 (.0157)			.16658 (.0155)			.15724 (.0155)
	U/LS	.08167 (.0129)	.11001 (.0246)	.10217 (.0234)		.11025 (.0240)	.12922 (.0324)		.13472 (.0315)		.10914 (.0536)			.12958 (.0317)			.10494 (.0241)
	L/LS	.04237 (.0072)	.07040 (.0190)	.05768 (.0137)		.06077 (.01383)	.05562 (.0131)		.07136 (.0160)		.05924 (.0141)			.05920 (.0139)			.05923 (.0139)

Table F-1. Continued.

Variables Population			WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
Age	Y	U		.11380 (.0042	.11760 (.0044)	.11545 (.0042)					.11868 (.0044)	.11783 (.0044)	.11575 (.0043)	.11839 (.0044)				.11782 (.0043)
		L		.09292 (.0073)	.08879 (.0071)	.09153 (.0073)					.08726 (.0070)	.08701 (.0070)	.09076 (.0073)	.08655 (.0070)				.08696 (.0070)
		L/S		.05055 (.0044)	.04634 (.0041)	.04686 (.0041)					.04647 (.0042)	.04817 (.0043)	.04874 (.0043)	.04792 (.0042)				.04755 (.0042)
	O	U		.17700 (.0159)	.17745 (.0164)	.17771 (.0160)					.17361 (.0160)	.17394 (.0161)	.17456 (.0157)	.17340 (.0160)				.17563 (.0161)
		L		.06241 (.0175)	.06083 (.0169)	.06619 (.0185)					.06439 (.0179)	.07237 (.0512)	.06714 (.0193)	.06784 (.0192)				.06593 (.0184)
		L/S		.07432 (.0185)	.07523 (.0162)	.07221 (.0153)					.07266 (.0156)	.07316 (.0155)	.07181 (.0150)	.07130 (.0150)				.07047 (.0148)
Seat Position	D	U									.12575 (.0050)	.12502 (.0050)	.12294 (.0049)	.12559 (.0050)				.12546 (.0050)
		L									.08678 (.0074)	.08726 (.0074)	.08972 (.0076)	.08595 (.0074)				.08579 (.0073)
		L/S									.04548 (.0043)	.04830 (.0045)	.04799 (.0044)	.04734 (.0044)				.04739 (.0044)
	P	U									.11855 (.0079)	.11779 (.0078)	.11679 (.0077)	.11789 (.0078)				.11720 (.0078)
		L									.07973 (.0142)	.08048 (.0234)	.08467 (.0150)	.0810[illegible] (.0144)				.08100 (.0144)
		L/S									.05983 (.0100)	.05760 (.0096)	.06011 (.0097)	.05888 (.0097)				.05993 (.0098)

Table F.2. Sensitivity analysis of effectiveness estimates using GENCAT: Overall and selected subpopulations.

Variable Population			Variables in the Model															
			WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
Overall		U/L	.21917 (.0618)	.24954 (.0623)	.30219 (.0588)	.26656 (.0611)	.24773 (.0622)	.25137 (.0637)	.26940 (.0609)	.20453 (.0662)	.31400 (.0581)	.30549 (.0693)	.27135 (.0612)	.31489 (.0582)	.25573 (.0633)	.30480 (.0587)	.27563 (.0603)	.31098 (.0591)
		U/LS	.57425 (.0371)	.55924 (.0388)	.60183 (.0356)	.59406 (.0356)	.57426 (.0372)	.57991 (.0377)	.58878 (.0361)	.53418 (.0399)	.60478 (.0355)	.58955 (.0364)	.58030 (.0365)	.59440 (.0359)	.56754 (.0384)	.61048 (.0348)	.58267 (.0360)	.59467 (.0357)
		L/LS	.45476 (.0586)	.41268 (.0654)	.42940 (.0643)	.44652 (.0616)	.43406 (.0624)	.43885 (.0639)	.43714 (.0627)	.41441 (.0642)	.42387 (.0654)	.40901 (.0736)	.42401 (.0641)	.40798 (.0667)	.41895 (.0656)	.43970 (.0632)	.42387 (.0636)	.41174 (.0659)
Car Weight	COMP	U/L	.09338 (.0837)		.21365 (.0850)		.14417 (.0903)	.16174 (.0927)	.17701 (.0876)		.22794 (.0839)					.22301 (.0840)		.22219 (.0841)
		U/LS	.51885 (.0505)		.55575 (.0481)		.51895 (.0505)	.53899 (.0499)	.54755 (.0479)		.56658 (.0470)					.56505 (.0469)		.56255 (.0472)
		L/LS	.46928 (.0681)		.43505 (.0778)		.43792 (.0751)	.45004 (.0769)	.45023 (.0743)		.43862 (.0777)					.44021 (.0770)		.43759 (.0774)
	FULL	U/L	.38002 (.0828)		.41631 (.0787)		.38000 (.0829)	.36719 (.0841)	.38866 (.0823)		.42448 (.0782)					.41026 (.0801)		.41903 (.0786)
		U/LS	.64512 (.0551)		.66122 (.0533)		.64490 (.0551)	.63278 (.0579)	.64200 (.0553)		.65381 (.0543)					.66907 (.0520)		.65846 (.0532)
		L/LS	.42760 (.1103)		.41959 (.1130)		.42726 (.1104)	.41970 (.1124)	.41439 (.1129)		.39848 (.1173)					.43884 (.1095)		.41211 (.1139)
Damage Severity	MOD	U/L	.19667 (.0809)	.20229 (.0805)		.21484 (.0792)	.19681 (.0810)		.21571 (.0792)	.14711 (.0864)			.22375 (.0790)				.21964 (.0786)	.21802 (.0790)
		U/LS	.62086 (.0442)	.61333 (.0446)		.62747 (.0432)	.62025 (.0443)		.62174 (.0439)	.60178 (.0462)			.61925 (.0439)				.61348 (.0443)	.61726 (.0440)
		L/LS	.52805 (.0664)	.51528 (.0677)		.52554 (.0666)	.52720 (.0666)		.51770 (.0677)	.53309 (.0657)			.50950 (.0689)				.50469 (.0698)	.51055 (.0682)
	SEV	U/L	.25972 (.0940)	.36004 (.0880)		.35785 (.0957)	.33944 (.0960)		.36461 (.0946)	.30781 (.1021)			.35519 (.0968)				.37388 (.0936)	.36754 (.0946)
		U/LS	.49032 (.0665)	.52852 (.0614)		.53508 (.0621)	.49141 (.0664)		.53032 (.0628)	.41259 (.0742)			.51169 (.0645)				.52864 (.0612)	.51318 (.0640)
		L/LS	.31150 (.1149)	.26326 (.1280)		.27600 (.1355)	.23006 (.1399)		.26079 (.1383)	.15137 (.1535)			.24271 (.1416)				.24727 (.1397)	.23027 (.1433)

Table F.2. Continued.

Crash Configuration	Variable Population	WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
A	U/L	.19900 (.0986)	.14673 (.0901)	.18799 (.0871)	.17452 (.0877)	.14003 (.0906)	.14358 (.0912)		.12119 (.0921)		.21462 (.0850)			.15287 (.0904)			.19090 (.0969)
	U/LS	.55750 (.0676)	.55135 (.0528)	.59635 (.0500)	.54999 (.0476)	.56417 (.0521)	.55941 (.0547)		.51708 (.0565)		.58557 (.0509)			.54353 (.0556)			.58272 (.0509)
	L/LS	.44756 (.1000)	.47478 (.0764)	.50290 (.0749)	.45485 (.0737)	.49320 (.0743)	.48554 (.0775)		.45049 (.0792)		.47232 (.0794)			.46116 (.0802)			.48127 (.0770)
B	U/L	.21164 (.0995)	.39891 (.0971)	.45944 (.0878)	.38505 (.0830)	.40857 (.0955)	.44564 (.0896)		.36672 (.1021)		.43909 (.0913)			.44620 (.0905)			.45827 (.0830)
	U/LS	.56495 (.0559)	.57104 (.0628)	.58870 (.0613)	.65079 (.0540)	.57477 (.0633)	.58003 (.0627)		.55594 (.0652)		.57141 (.0636)			.57640 (.0630)			.58756 (.0612)
	L/LS	.44816 (.0903)	.28636 (.1424)	.23912 (.1533)	.43213 (.1098)	.28102 (.1443)	.24241 (.1522)		.29879 (.1397)		.23590 (.1536)			.24003 (.1528)			.23366 (.1529)
C	U/L	.26618 (.1282)	.31428 (.1656)	.39291 (.1503)		.30465 (.1639)	.22086 (.2084)		.15530 (.2119)		.35611 (.3216)			.22213 (.2035)			.37253 (.1553)
	U/LS	.61934 (.0705)	.56119 (.1246)	.65725 (.0875)		.61671 (.0935)	.66462 (.0850)		.55250 (.1075)		.65051 (.0893)			.64462 (.0899)			.64582 (.0895)
	L/LS	.48127 (.1195)	.36008 (.2233)	.43543 (.1063)		.44878 (.1231)	.56956 (.1481)		.47032 (.1708)		.45722 (.2961)			.54313 (.1551)			.43554 (.1855)

Table F.2. Continued.

Variable	Population	WCSP	CSP	WCP	WSP	WCS	WC	WS	CS	WP	CP	SP	P	C	W	S	Unadjusted Injury Rate
Age Y	U/L		.18345 (.0708)	.24490 (.0665)	.20723 (.0691)					.26478 (.0652)	.26159 (.0654)	.21595 (.0680)	.26093 (.0649)				.26194 (.0651)
Age Y	U/LS		.55577 (.0414)	.60598 (.0381)	.59412 (.0386)					.60042 (.0381)	.59116 (.0393)	.57895 (.0397)	.59520 (.0388)				.59645 (.0385)
Age Y	L/LS		.45597 (.0634)	.47813 (.0626)	.48802 (.0606)					.46740 (.0643)	.44632 (.0663)	.46299 (.0634)	.44639 (.0663)				.45323 (.0651)
Age O	U/L		.64740 (.1033)	.65720 (.1003)	.62752 (.1094)					.62912 (.1080)	.58396 (.2963)	.61537 (.1157)	.60077 (.1161)				.62458 (.1102)
Age O	U/LS		.53909 (.1107)	.57607 (.0992)	.59369 (.0929)					.50148 (.0975)	.57938 (.0971)	.50866 (.0932)	.50081 (.0942)				.59875 (.0921)
Age O	L/LS		-.19090 (.4456)	-.23667 (.4331)	-.09082 (.3820)					-.12844 (.3959)	-.01101 (.7466)	-.69427 (.3000)	-.05102 (.3697)				-.06879 (.3735)
Position D	U/L									.30987 (.0651)	.30203 (.0657)	.27021 (.0682)	.31561 (.0646)				.31617 (.0646)
Position D	U/LS									.63034 (.0371)	.61362 (.0393)	.60966 (.0391)	.62307 (.0383)				.62226 (.0384)
Position D	L/LS									.47596 (.0667)	.44643 (.0700)	.46513 (.0670)	.44925 (.0690)				.44761 (.0700)
Position P	U/L									.32750 (.1276)	.31676 (.2037)	.27503 (.1362)	.31256 (.1306)				.30981 (.1314)
Position P	U/LS									.49536 (.0906)	.51104 (.0874)	.40532 (.0892)	.50053 (.0884)				.48950 (.0903)
Position P	L/LS									.24961 (.1830)	.20435 (.2396)	.29007 (.1694)	.27344 (.1760)				.26142 (.1787)

APPENDIX G

Empirical Bayes Estimation

For a given age/sex/treatment/injury class category, let the number of injury subclasses be $k > 3$. Let $\bar{X}_i$ be the sample mean of the quantity of interest (hospital cost, professional cost or hospital days) for the i^{th} subsample, and assume that X_i has a normal distribution with mean θ_i and variance D_i. We wish to estimate θ_i, $i = 1,2,\ldots,$ using $\bar{X}_1, \bar{X}_2,\ldots, \bar{X}_k$. The maximum likelihood estimator (MLE) of θ_i is X_i.

This estimator may be unsuitable if the sample size in subclass i is so small that the variance is extremely large. Stein (1955) has shown that in fact the MLE can always be improved upon if the measure of estimation efficiency is squared error loss. The James-Stein estimator (Efron and Morris, 1975) is an estimator which always has smaller mean-squared error than the MLE. A modification of the James-Stein estimator which was used by Carter and Rolph (1974) to estimate fire alarm probabilities was implemented to estimate costs and hospital days. In the paper by Carter and Rolph, this is referred to as the proportional prior estimator.

For the i^{th} subsample, let

$$\bar{D} = \frac{1}{k} \sum_{i=1}^{k} D_i$$

$$\alpha_i = \frac{\bar{D}}{D_i}$$

$$\gamma_i = \frac{\alpha_i}{\sum_{i=1}^{k} \alpha_i}$$

$$\bar{X} = \sum_{i=1}^{k} \gamma_i \bar{X}_i$$

$$S = \sum_{i=1}^{k} \alpha_i (\bar{X}_i - \bar{X})^2$$

Then the proportional prior empirical Bayes estimator is

$$\hat{\theta}_i = (1-B)\ \bar{X}_i + B\bar{X}\ ,$$

where

$$B = \min\left[\frac{(k-3)\ \bar{D}}{S}\ ,\ 1\right]$$

Since, in the present application, the subclass variances $D_1, D_2, \ldots, D_k$ are not known, the sample values were used in their place.

The proportional prior empirical Bayes estimator has the property that, if the subclass means $\theta_1, \theta_2, \ldots, \theta_k$ are assumed to be independently normally distributed with common mean ν and variance AD_i, then $\hat{\theta}_i$ is the Bayes estimate of θ_i, with sample values substituted for population values of ν and A (which are unknown but which would be assumed known in the Bayesian contex). Another useful property of the empirical Bayes estimator is that, as the number of observations in subclass i gets infinitely large, $\hat{\theta}_i$ converges to θ_i and B_i converges to 1. Finally, as stated before, the empirical Bayes estimator has uniformly smaller mean-square error than the MLE.

APPENDIX H

Estimation Procedure for Examining Seat Belt Effectiveness Using Direct Injury Costs

Let

$c_{hi.k}$ = cost for the k-th individual in the h-th stratum and in the i-th restraint system irrespective of injury condition ($h = 1,\ldots,d$; $i = 1,2,3$; $k = 1,\ldots,n_{hi.}$)

$$\bar{c}_{hi.} = \frac{1}{n_{hi.}} \sum_{k=1}^{n_{hi.}} c_{hi.k}$$ = average cost for individuals in the h-th stratum using the i-th restraint system.

$$s_{hi.} = \left[\frac{1}{n_{hi.}(n_{hi.}-1)} \sum_{k=1}^{n_{hi.}} (c_{hi.k} - \bar{c}_{hi.})^2\right]^{\frac{1}{2}}$$ = standard error of $\bar{c}_{hi.}$

$$w_h = \frac{n_{h..}}{n_{...}} = \frac{\sum_i n_{hi.}}{\sum_{h,i} n_{hi.}}$$ = sample weight for the h-th stratum

$$\hat{C}_{i.} = \sum_h w_h \bar{c}_{hi.}$$ = estimated average direct injury cost for the i-th restraint system, $i = 1,2,3$

$$\hat{E}_{ii'} = \frac{\hat{C}_i - \hat{C}_{i'}}{\hat{C}_i}$$ = cost-reducing effect of i'-th restraint system with respect to the i-th restraint system ("effectiveness")

Define

$\underset{\sim}{w} = [w_1,\ldots,w_h \ldots w_d]'$ = vector of sample strata weights

$\underset{\sim}{\mu}$ = vector of population strata weights

$\bar{\underset{\sim}{c}}_{i.} = [\bar{c}_{1i.} \ldots \bar{c}_{hi.} \ldots \bar{c}_{di.}]'$ = vector of average costs per stratum for the i-th restraint system

Assume $\bar{\underset{\sim}{c}}_{i.} \sim N(\underset{\sim}{Y}_{i.}, \underset{\sim}{V}_{i.})$, $i = 1,2,3$ with $\hat{\underset{\sim}{Y}}_{i.} = [\bar{c}_{1i.} \ldots \bar{c}_{hi.} \ldots \bar{c}_{di.}]'$ and $\hat{\underset{\sim}{V}}_{i.} = \text{Diag}(s^2_{1i.} \ldots s^2_{hi.} \ldots s^2_{di.})$ (can assume independence of average costs between strata).

Then, if w_h's are <u>non-random</u> or fixed (i.e. $w_h = \mu_h$, h=1,...d)

$$E[\hat{C}_{i.}] = E[\sum_h w_h \bar{c}_{hi.}] = \underset{\sim}{\mu}'\underset{\sim}{\boldsymbol{\gamma}}_{i.} = C_{i.} \tag{H.1}$$

(i.e., the true direct injury cost for the i-th restraint system),

$$\text{and } V_{i.} = V[\hat{C}_{i.}] = \underset{\sim}{\mu}'\underset{\sim}{V}_{i.}\underset{\sim}{\mu} = \sum_h w_h^2 s_{hi.}^2 \tag{H.2}$$

If, also one can assume that the $\hat{C}_{i.}$'s are uncorrelated, the variance of $\hat{E}_{ii'}$ can be estimated as in Appendix E by

$$\hat{V}[\hat{E}_{ii'}] = \frac{\hat{C}_{i'.}^2}{\hat{C}_{i.}^4} V_{i.} + \frac{1}{\hat{C}_{i.}^2} V_{i'.} \tag{H.3}$$

Suppose, as is more likely the case, that the stratum weights are not fixed but are <u>random</u>. Specifically, assume $\underset{\sim}{w} \sim N(\underset{\sim}{\mu},\underset{\sim}{V})$ with

$$\underset{\sim}{\mu} = \left[\frac{n_{1..}}{n_{...}} \quad \cdots \quad \frac{n_{h..}}{n_{...}} \quad \cdots \quad \frac{n_{d..}}{n_{...}}\right]' \tag{H.4}$$

and

$$\hat{\underset{\sim}{V}} = \frac{1}{n_{...}}[\underset{\sim}{\text{Diag}}\ (\underset{\sim}{w}) - \underset{\sim}{w}\underset{\sim}{w}'] \tag{H.5}$$

Then, proceeding as in Appendix E (see Searle, 1971, p. 65)

$$E[\underset{\sim}{w}'\underset{\sim}{\bar{c}}_{i.}] = tr(\underset{\sim}{C}_{wi}) + \underset{\sim}{\mu}'\underset{\sim}{\boldsymbol{\gamma}}_{i.} \tag{H.6}$$

$$V[\underset{\sim}{w}'\underset{\sim}{\bar{c}}_{i.}] = tr(\underset{\sim}{C}_{wi})^2 + tr(\underset{\sim}{V}_{i.}\underset{\sim}{V}) + \underset{\sim}{\mu}'\underset{\sim}{V}_{i.}\underset{\sim}{\mu} + \underset{\sim}{\boldsymbol{\gamma}}_{i.}'\underset{\sim}{V}\underset{\sim}{\boldsymbol{\gamma}}_{i.} + 2\underset{\sim}{\mu}'\underset{\sim}{C}_{wi}\underset{\sim}{\boldsymbol{\gamma}}_{i.} \tag{H.7}$$

where

$$\underset{\sim}{C}_{wi} = E[(\underset{\sim}{w} - \underset{\sim}{\mu})\ (\underset{\sim}{C}_i - \underset{\sim}{\boldsymbol{\gamma}}_i)']$$

$$= \underset{\sim}{\text{Diag}}(E[(w_h - \mu_h)\ (\bar{c}_{hi.} - \boldsymbol{\gamma}_{hi.})])$$

and

$$tr(\underset{\sim}{C}_{wi}) = \text{trace}(\underset{\sim}{C}_{wi})$$

Two cases are of interest:

a) Assume w_h and $\bar{c}_{hi.}$ are <u>independent</u> random variables. Then $\underset{\sim}{C}_{wi} = \underset{\sim}{0}$, $E[\underset{\sim}{w}'\underset{\sim}{\bar{c}}_{i.}] = \underset{\sim}{\mu}'\underset{\sim}{\boldsymbol{\gamma}}_{i.}$ and $V[\underset{\sim}{w}'\underset{\sim}{\bar{c}}_{i.}] = tr(\underset{\sim}{V}_{i.}\underset{\sim}{V}) + \underset{\sim}{\mu}'\underset{\sim}{V}_{i.}\underset{\sim}{\mu} + \underset{\sim}{\boldsymbol{\gamma}}_{i.}'\underset{\sim}{V}\underset{\sim}{\boldsymbol{\gamma}}_{i.}$.

Therefore,

$$V_{i.} = \hat{V}[\underset{\sim}{w}'\bar{\underset{\sim}{c}}_{i.}] = \frac{1}{n_{...}} \sum_h (w_h - w_h^2) s_{hi.}^2 + \sum_h w_h^2 s_{hi.}^2$$

$$+ \frac{1}{n_{...}} [\sum_h w_h \bar{c}_{hi.}^2 - (\sum_h w_h \bar{c}_{hi.})^2] \qquad (H.8)$$

$$= \sum_h w_h^2 s_{hi.}^2 + \frac{1}{n_{...}} [\sum_h w_h s_{hi.}^2 - \sum_h w_h^2 s_{hi.}^2 + \sum_h w_h \bar{c}_{hi.}^2$$

$$- (\sum_h w_h \bar{c}_{hi.})^2] \qquad (H.9)$$

Comparing (H.9) with (H.2) we can note an additional term due to the assumption of the weights w_h being random variables.

b) Assume w_h and $\bar{c}_{hi.}$ are <u>dependent</u> random variables. A reasonable estimator for $\underset{\sim}{C}_{wi}$ is $\hat{\underset{\sim}{C}}_{wi} = s_{wi.} \underset{\sim}{I}_d$ with

$$s_{wi.} = \frac{1}{d-1} \sum_h (w_h - \bar{w}_h)(\bar{c}_{hi.} - \bar{\bar{c}}_{i.}), \qquad \bar{\bar{c}}_{i.} = \frac{1}{d} \sum_h \bar{c}_{hi.}, \; i = 1,2,3.$$

Then, from (H.6) we have $E[\underset{\sim}{w}'\bar{\underset{\sim}{c}}_{i.}] = ds_{wi.} + \underset{\sim}{\mu}'\underset{\sim}{\gamma}_{i.}$ and from (H.7) and (H.9):

$$V_{i.} = \hat{V}[\underset{\sim}{w}'\bar{\underset{\sim}{c}}_{i.}] = ds_{wi.}^2 + \sum_h w_h^2 s_{hi.}^2 + \frac{1}{n_{...}} [\sum_h w_h s_{hi.}^2 - \sum_h w_h^2 s_{hi.}^2$$

$$+ \sum_h w_h \bar{c}_{hi.}^2 - (\sum_h w_h \bar{c}_{hi.})^2] + 2s_{wi.} \sum_h w_h \bar{c}_{hi.} \qquad (H.10)$$

Note that (H.9) and (H.10) differ only by $(ds_{wi.}^2 + 2s_{wi.} \sum_h w_h \bar{c}_{hi.})$, a quadratic function of $s_{wi.}$.

The standard error of $\hat{E}_{ii'}$ (efficiency of the i'-th restraint system relative to the i-th restraint system) can be estimated by using a Taylor series expansion as in Appendix E, i.e.,

$$V[\hat{E}_{ii'}] = \frac{C_{i'.}^2}{C_{i.}^4} V[\hat{C}_{i.}] + \frac{1}{C_{i.}^2} V[\hat{C}_{i'.}] - 2 \frac{C_{i'.}}{C_{i.}} Cov[\hat{C}_{i.}, \hat{C}_{i'.}] \qquad (H.11)$$

To estimate the covariance between two average costs, we can proceed as in Appendix E. Let

$$s_{ii'} = cov(\bar{c}_{hi.}, \bar{c}_{hi'.}) = \frac{1}{d-1} \sum_h (\bar{c}_{hi.} - \bar{\bar{c}})(\bar{c}_{hi'.} - \bar{\bar{c}}); \text{ then:}$$

a) when the w_h's are constant,

$$Cov[\hat{C}_{i.}, \hat{C}_{i'.}] = s_{ii'} \sum_h w_h^2 \tag{H.12}$$

b) when the w_h's are random and uncorrelated with the $\bar{c}_{hi.}$'s,

$$Cov[\hat{C}_{i.}, \hat{C}_{i'.}] = \frac{s_{ii'}}{n_{...}} \sum_h w_h(1 - w_h) + s_{ii'} \sum_h w_h^2 + \frac{1}{n_{...}} \sum_h \bar{c}_{hi.}\bar{c}_{hi'.}w_h(1 - w_h) \tag{H.13}$$

c) when the w_h's are random variables correlated with the $\bar{c}_{hi.}$'s,

$$Cov[\hat{C}_{i.}, \hat{C}_{i'.}] = ds_{wi.}s_{wi'.} + \frac{s_{ii'}}{n_{...}} \sum_h w_h(1 - w_h) + s_{ii'} \sum_h w_h^2 + (\sum_h w_h\bar{c}_{hi'.})s_{wi.}$$
$$+ \frac{1}{n_{...}} \sum_h \bar{c}_{hi.}\bar{c}_{hi'.}\, w_h(1 - w_h) + (\sum_h w_h\bar{c}_{hi.})s_{wi'.} \tag{H.14}$$

In the analysis used on the cost data, it seemed most reasonable to assume that the stratum weights are random and uncorrelated with the random average belt-related costs. Thus, (H.9) is utilized.