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STATISTICAL EVALUATION OF THE EFFECTIVENESS OF FEDERAL MOTOR VEHICLE SAFETY STANDARD 214: SIDE DOOR STRENGTH

Report No. 5 of 7

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Prepared for the National Highway Traffic Safety Administration in support of a program to review existing regulations, as required by Executive Order 12044 and Department of Transportation Order 2100.5. Agency staff will perform and publish an official evaluation of Federal Motor Vehicle Safety Standard 214 based on the findings of this report as well as other information sources. The values of effectiveness and benefits found in this report may be different from those that will appear in the official Agency evaluation.

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16. Abstract

This is the Final Report of the statistical evaluation of the effectiveness of Federal Motor Vehicle Safety Standard (FMVSS) 214: Side Door Strength. It is one of seven statistical evaluations to be conducted under this contract. The seven Standards are:

1. FMVSS 108: Side Marker Lamps (only)
2. FMVSS 202: Head Restraints
3. FMVSS 207: Seat Back Locks (only)
4. FMVSS 213: Child Restraints
5. FMVSS 214: Side Door Beams
6. FMVSS 222: School Bus Seating and Crash Protection
7. FMVSS 301: Fuel System Integrity

FMVSS 214 is an injury reduction Standard which imposes minimum requirements on side door strength for all passenger cars (effective 1 January 1973). The objective of this analysis is to evaluate the effectiveness of FMVSS 214 with respect to reduction in depth of intrusion, reduction in injury severity, and to the extent possible, to establish a causal relation between the former and the latter.

The data used in the analysis are the National Crash Severity Study (NCSS) data files. The 1978 North Carolina accident data file is used primarily for the purpose of obtaining some estimates needed to extrapolate to the national level the estimated annual number of injuries prevented due to the presence of side door beams.

The analysis of intrusion reduction showed that the Standard is effective only in the most severe accident stratum of NCSS. In this stratum, the mean depth of side door intrusion, after adjusting for covariates, showed a reduction of 1.83 inches for the Post-Standard cars, which is statistically significant ($\alpha = 0.05$).

Linear models were fitted to the contingency tables generated by both the weighted and the unweighted samples from the Occupant Oriented File for all five injury characterizations via the GENCAT generalized least squares computer program. Preliminary results indicate a 15 percent reduction in overall injuries (OAIS ≥ 1) for near-side occupants of Post-Standard passenger cars involved in side door impact towaway accidents. This result is statistically significant at $\alpha = 0.05$ level after adjusting for the NCSS sampling scheme. The results also indicate a 11.8 percent reduction in moderate injuries (OAIS ≥ 2), a 20.9 percent reduction in serious injuries (OAIS ≥ 3), and a 7.6 percent reduction in overall injuries due to contact with side structures. However, of the latter, only the 20.9 percent reduction in serious injuries is significant at $\alpha = 0.05$ level. The above results together suggest that FMVSS 214 is effective in reducing serious injuries and fatalities.

Based on some population estimates derived from the 1978 North Carolina accident data, the projections to the national level on the annual number of injuries and fatalities prevented if all passenger cars were to have side door beams are as follows: 51,057 injury cases, 11,830 cases of serious to fatal injuries, and 10,585 cases where the injuries could have resulted from contact with side structures.

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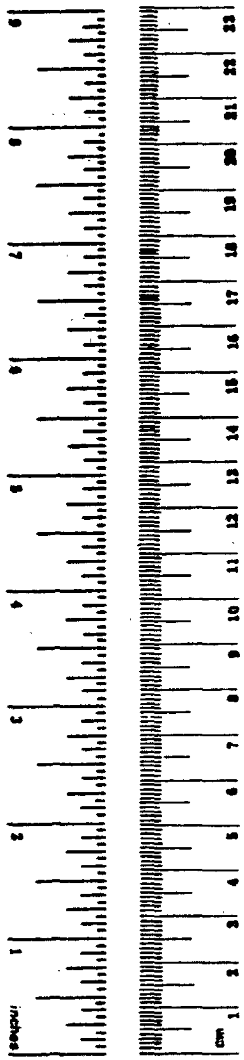
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

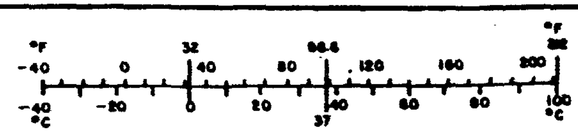
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



Executive Summary

This is the Final Report of the statistical evaluation of the effectiveness of Federal Motor Vehicle Safety Standard (FMVSS) 214: Side-Door Strength.

FMVSS 214 is an injury-reduction standard which imposes minimum requirements on side-door strength for all passenger cars (effective 1 January 1973).

The objective of this analysis is to evaluate the effectiveness of FMVSS 214 with respect to reduction in depth of intrusion and reduction in injury severity, and to the extent possible, establish a causal relation between the former and the latter.

The purpose of the evaluation is to develop a better understanding of the characteristics of depth of intrusion and levels of injury severity in pre-standard passenger cars involved in side-door impact accidents, and to infer the reductions in depth of intrusion and levels of injury severity that might occur in similar types of accidents involving post-standard passenger cars.

The data used in the analysis are the National Crash Severity Study (NCSS) data files. The 1978 North Carolina accident data file is used primarily for the purpose of obtaining some estimates needed to extrapolate to the national level the estimated annual number of injuries prevented due to the presence of side-door beams.

An NCSS Vehicle Oriented File was created specifically for evaluating FMVSS 214 based on the post-April, 1978 data on the NCSS files. Only post-April, 1978 data were used because detailed intrusion information are available only for these accidents. Covariance analyses were conducted based on the Vehicle Oriented File. Initial analysis showed that the Standard is effective only in the most severe accident stratum of NCSS. This is partly attributable to the fact the variable, Depth of Intrusion, was coded 'blank' instead of '0' whenever the depth of intrusion was less than 1 inch. Detailed analysis was carried out only for the most severe accident stratum. The results showed that the variables Total Length of External Crush, Principal Direction of Force, and Standard 214 compliance had significant correlation with intrusion. The mean depth of side-door intrusion adjusted for the covariate, Total Length of External Crush, showed a reduction of 1.83 inches for the Post-Standard passenger cars, which is statistically significant at the $\alpha = 0.05$ level.

An NCSS Occupant Oriented File was also created for evaluating FMVSS 214 based on the complete NCSS files. A two-stage scheme was used to reclassify missing and unknown overall AIS (OAIS) injury information for the purpose of increasing the effective sample size. Based on this reclassification scheme, four injury characterizations were used for occupant injury reduction analysis: OAIS$\geq$1 (any injury), OAIS$\geq$2, (moderate injury), OAIS$\geq$3 (severe to fatal injury) and injury that was identified as due to contact with side-structure. A comprehensive search for significant factors was carried out for all four injury characterizations.

Linear models were fitted to the contingency tables generated by both the weighted and the unweighted samples from the Occupant Oriented File for all four injury characterizations via the GENCAT generalized least squares computer program. The models indicate a 15 percent reduction in overall injuries (OAIS$\geq$1) for nearside occupants of post-standard passenger cars involved in side-door impact towaway accidents could be attributed to Standard 214. This result is statistically significant at α = 0.05 level. The results also indicate a 11.8 percent reduction in moderate injuries (OAIS$\geq$2), a 20.9 percent reduction in severe-to-fatal injuries (OAIS$\geq$3), and a 7.6 reduction in injuries specifically identified as due to contact with side-structures. Of the latter, however, only the 20.9 percent reduction in serious injuries is significant at α = 0.05 level. Because the injury characterizations were not defined in terms of occupant contact with side-door panels (the data do not allow such precise definition), one cannot attribute unequivocally the reduction in occupant injuries to a corresponding reduction in the depth of side-door intrusion (in the more severe accidents). However, by appropriately selecting and controlling for (as many as the data allow) various potential confounding factors, the GENCAT model produced results that do seem to suggest that the standard FMVSS 214 is effective in reducing serious injuries.

Based on some population estimates derived from the 1978 North Carolina accident data, the projections to the national level of the annual number of injuries prevented if all passenger cars were to have side-door beams are as follows: 51,057 injuries, 11,830 cases of severe to fatal injuries, and 10,585 cases where the injuries were shown to have resulted from contact with side-structures.

ACKNOWLEDGEMENTS

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ABBREVIATIONS USED

AIS	Abbreviated Injury Scale
CDC	Collision Deformation Classification
CEM	The Center for the Environment and Man, Inc.
DF	Degrees of Freedom
FMVSS	Federal Motor Vehicle Safety Standard
GENCAT	A Computer Program for Generalized Chi-Square Analysis of Categorical Data
GM	General Motors
GSK	Grizzle-Starmer-Koch Weighted Least Squares Categorical Data Analysis Procedure
HSRC	Highway Safety Research Center
NCA	North CArolina Accident Data
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
OAIS	Overall AIS
SOAIS	Overall AIS Specific to Contact with Side Structure Components
TAD	Traffic Accident Data

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1.0 INTRODUCTION

1.1 Background

This is the fifth in a series of reports of the statistical evaluation of the effectiveness of seven Federal Motor Vehicle Safety Standards (FMVSS). Safety Standards (FMVSS). This work is being conducted under Contract DOT-HS-8-02014, by The Center for the Environment and Man, Inc., (CEM) and its subcontractor, the Highway Safety Research Center (HSRC) of the University of North Carolina. The seven Standards to be statistically evaluated are:

- FMVSS 108: Side Marker Lamps (only)
- FMVSS 202: Head Restraints
- FMVSS 207: Seat Back Locks (only)
- FMVSS 213: Child Restraints
- FMVSS 214: Side Door Strength
- FMVSS 222: School Bus Seating and Crash Protection
- FMVSS 301: Fuel System Integrity

The Final Report for FMVSS 214 (Side Door Strength) is presented herein.

The proposed rule making for FMVSS 214 was announced on October 14, 1967, and introduced on April 23, 1970 (35 F.R.6512). The current revised version was issued on October 30, 1970 (35 F.R.16801). The revision included: (i) restricting the application of the Standard to passenger cars; (ii) lowering of minimum low-level crush forces; (iii) modification of minimum crush resistance forces at intermediate levels of crush; and (iv) setting a ceiling on minimum peak crush forces, eliminating a requirement for forces that increased indefinitely as vehicle weight increased. The Standard, FMVSS 214, became effective on January 1, 1973.

1.1.1 Criteria for Compliance with FMVSS 214

Any passenger car side doors that can be used for occupant egress must meet the following three static crush resistance tests using a specified test device:

- 2250 lb. average over 6 in. of crush (initial crush resistance).
- 3500 lb. average over 12 in. of crush (intermediate crush resistance).
- 7000 lb. or 2 times vehicle curb weight, whichever is less, as the largest force recorded over the entire 18 in. of crush (peak crush resistance).

The initial and intermediate crush resistances are meant to ensure adequate stiffness in the door structure. The maximum force requirement tests the overall strength and resistance to separation of the side structure. In the compliance test, the vehicle frame is anchored to a rigid foundation, and a test device applies a force to the door being tested. The test device is a rigid steel cylinder or semicylinder, 12 in. in diameter. It is applied in a vertical position to effectively contact the door from a point 5 in. above the bottom of the door to the bottom edge of the window in the center of the door. The impact is measured as the midpoint of the horizontal line 5 in. above the bottom of the door. The device is applied at a rate not to exceed 0.5 in./s for 18 in. within 120 s; it is guided to prevent rotation or displacement from the direction of travel, which is perpendicular to the centerline of the vehicle. The forces are measured by plotting a curve of load versus displacement and by obtaining the integral in inch-pounds, then dividing by the specified crush distances to represent the average forces in pounds over distances of 6 and 12 in. The vehicle must meet or exceed the three specified crush resistance values to pass the standard.

1.1.2 Manufacturers' Response

Prior to model year 1969, no domestic passenger cars contained side-door beams. After the October 1967 announcement, General Motors (GM) began developing and testing of improved door structures. The first beam-type door structures appeared in the 1969 model year vehicles. During the transition period from 1969 through 1972, side-door beams were selectively introduced into different make/models [1]. Since the official requirements of FMVSS 214 were not announced until April 1970, it is not clear whether those passenger cars of model years 1969 and 1970 with side door beams actually were in compliance with Standard 214. During the first few years of the transition period, there was a tendency to introduce side-door beams into higher priced, heavier cars. Table 1-1 contains a listing of domestic make/models during this transition period that had side-door beams. From model year 1973 on, all passenger cars contained side door beams.

With respect to foreign make/models manufactured during this transition period, information concerning side-door beams is being solicited through the Automobile Importers of America. With the available information, it appears that foreign automobile manufacturers did not introduce side-door beams prior to the 1973 model, and that the side-door beams of all Mercedes-Benz passenger cars

TABLE 1-1

INTRODUCTION DATES OF SIDE-DOOR REINFORCEMENT BEAMS

Make	Line	Series	Model Year
AMC	Javelin	SST	1971
		Basic	1971
		AMX	1971
GM			
Buick	Buick	Electra	1969
		La Sabre	1969
		Riviera	1971
	Special/Skylark	Skylark	1970
		GS	1970
Cadillac	Cadillac	Calais	1969
		De Ville	1969
		El Dorado	1971
		Fleetwood El Dorado	1971
		Fleetwood Brougham	1969
		Fleetwood Seventy-five	1969
		Fleetwood Sixty Special	1969
Chevrolet	Chevelle	Concours	1970
		Malibu	1970
		Nomad	1970
		Greenbriar	1970
	Chevrolet	Bel Air	1969
		Biscayne	1969
		Caprice	1969
		Kingswood	1969
	Monte Carlo	Monte Carlo	1970
	Vega	Vega	1971
Oldsmobile	F-85/Cutlass	F-85	1970
	Oldsmobile	Delta 88	1969
		98	1969
	Toronado	Toronado	1971
Pontiac	Firebird	Firebird	1970
		Esprit	1970
		Formula	1970
		Trans-Am	1970
	Pontiac	Bonneville	1969
		Catalina	1969
		Executive	1969
		Grand Prix	1969
	Tempest/LeMans	LeMans	1970
CHRYSLER			
Dodge	Challenger	Challenger	1970
		Challenger RT	1971
FORD			
Ford	Fairlane/Torino	Grand Torino	1972
	Ford	Custom	1971
		Galaxie	1971
		LTD Brougham	1971
	Mustang	Mustang	1971
		Grande	1971
	Pinto	Pinto	1971
	Thunderbird	Thunderbird	1972
Lincoln	Lincoln	Continental	1971
		Continental Mark III & IV	1971
Mercury	Cougar	Cougar	1971
		Cougar XR7	1971
	Mercury	Marquis	1971
		Marquis Brougham	1971
		Monterey	1971
	Montego	Montego	1972
		Montego MX, Brougham & GT	1972

TABLE 1-2

INTRODUCTION DATES OF SIDE-DOOR REINFORCEMENT BEAMS IN FOREIGN MAKE/MODELS

Make	Line	Series	Model Year (Introduction Date)
MERCEDES-BENZ			
	Mercedes	450SE	December 1, 1972
		450SEL	December 1, 1972
		6.9	December 1, 1972
		450SL	July 1, 1972
		450SLC	July 1, 1972
		200	July 1, 1972
		200D	July 1, 1972
		230	July 1, 1972
		240	July 1, 1972
		280	July 1, 1972
		250/280C	September 1, 1972
VOLVO			
	Volvo	242 2 door Sedan	September 1, 1972
		244 4 door Sedan	September 1, 1972
		245 Wagon	September 1, 1972
		264 4 door Sedan	September 1, 1972
		265 Wagon	September 1, 1972
VOLKSWAGEN			
	VW	Type 1 Beetle	January, 1973
		Type 3 (1600)	January, 1973
		Type 4 (412)	January, 1973
	Karman Ghia		July, 1972
	Audi	Fox	February, 1972
		100	August, 1972
	VW	Porsche 914	December, 1972
RENAULT			
	Renault	12	June, 1972
		17	June, 1972
	Renault	5 (Le Car)	June, 1973
ROVER			
	Jaguar	XJ4.2	November, 1972
		XJ12	November, 1972
		XKE Series 3 open	November, 1972
		XKE Series 3 FH3	November, 1972
	MG	Midget	August, 1972
		MGB	August, 1972
	Triumph	Spitfire	October, 1972
		TR6	October, 1972
		GT6	October, 1972
		Stag	November, 1972

*This author acknowledges the assistance of Mr. Donald M. Schwentker of the Auto Importers of America and the foreign manufacturers of the above makes in making these data available.

were so designed after the 1973 model to meet FMVSS 214 without side beam reinforcement. Table 2 provides a partial listing of these foreign manufactured make/models. It should be pointed out that information is missing on all of the Japanese manufactured vehicles. As further information becomes available, it will be incorporated into the study. However, for the present, all foreign manufactured passenger cars prior to the 1973 model year will be considered to be pre-standard cars.

1.1.3 Methods of Compliance

A review of present vehicle door construction shows that the method of compliance is primarily the use of formed or channel-shaped metal beams or stampings positioned near or against the inner side of the outer door sheet metal surface, thereby providing the greatest resistance to intrusion for the prescribed force application of FMVSS 214. Attachment of the reinforcing beams consists of spot or seam welds to the vertical door frame members on the hinge and latch sides of the doors. This method of reinforcing the doors is probably universal in the thin structured doors of small cars. Some of the larger vehicles, having a large door thickness between inner and outer panels, appear to comply with the strength requirement by incorporating heavy metal frames within the door which are functional in supporting the window regulators and latch mechanisms, thereby reducing the cost of additional structure for the sole purpose of increasing door strength.

The Standard requires loading for 18 inches of crush. After about 6 inches of deformation, the reinforcement side beam has lost its ability to resist additional load as a beam. Its resistance to side crush becomes a function of the tensile strength of the beam concentrated at the end attachments. Thus, the strength of the door frame and hinge attachments become the critical design features for intrusion of more than about six inches.

1.2 Objective and Purpose

The primary objective of this proposed work is to conduct, during a one-year period, statistical analysis using National Crash Severity Study (NCSS) data to determine:

- the degree to which Standard 214 has reduced passenger compartment intrusion inside impact accidents, and
- the subsequent reduction (if any) in injury severity which is directly attributable to the reduction in the depth of intrusion in a side impact accident.

If the primary objective cannot be realized due to sample size restriction, then one may be constrained to perform simple contingency table analysis.

1.3 Scope

- This analysis of FMVSS 214 will be limited primarily to the analysis of NCSS data.
- Estimates and confidence intervals for the effectiveness of FMVSS 214 for the whole population of NCSS data base, or subpopulations thereof will be derived whenever possible (if sample size permits).
- The report on FMVSS 214 will discuss the initial findings on injury severity and intrusion in Pre-Standard and Post-Standard Passenger cars involved in side impact accidents.

1.4 Approach

1.4.1 Data Sources: National Crash Severity Study

The primary data source is the NCSS acident data. Based on this data detailed analyses are to be carried out to evaluate the effect of side-door beam on occupant injury severity and depth of passenger compartment intrusion.

Of all the candidate data sources for evaluating the effectiveness of this standard, the recently collected NCSS data appeared to offer the most promise. The NCSS was a multi-year effort which began in October 1976, and continued through March 1979. Its goal was to collect accident investigation data on over 10,000 towaway accidents. This accident data was collected by seven NHTSA-sponsored organizations in eight locations: Western New York (CALSPAN), Michigan (HSRI), Miami (University of Miami), San Antonio, Texas (SwRI), thirteen other counties in Texas (SwRI), Kentucky (University of Kentucky), Indiana (University of Indiana), and Los Angeles, California (Dynamic Sciences).

The data base represents a stratified probability sample of police-reported towaway accidents, i.e., at least one automobile was not drivable and hence was towed from the scene where, for each area, the sampling frame represents approximately 10,000 accidents annually. The sampling criteria result basically in the following three strata:

- 100 percent of those accidents involving the transport to a treatment facility <u>and</u> overnight hospitalization <u>or</u> death of at least one towaway-involved automobile occupant;
- 25 percent systematic random sample of accidents which involve transport of at least one towaway-involved automobile occupant to a treatment facility but not overnight hospitalization; and
- 10 percent systematic random sample of all other police-reported towaway accidents (where at least one car is not drivable).

To the extent obtainable, each case contains information on all vehicles and occupants involved in the accident. For the "applicable" or case car(s), which is any towed (i.e., non-drivable) automobile involved in an accident meeting one of the sampling criteria, there is maximum information which includes the following reports (when appropriate): police, environmental, off-road object struck, vehicle, side structure, passenger compartment intrusion, seat performance, fire, rollover, interview, medical and surgical procedures, and an overall summary report. Variables from the seven-page summary report constitute the computerized master file of 10,851 accident cases that is currently available for this analysis.

6683 of these cases were collected prior to April 1, 1978 at which date a revision of the National Crash Severity Study was made and a new format was used. Information in the supplementary reports for these cases were not completely computerized. In particular, the passenger compartment intrusion data, the side structure data, and the occupant contact data are not made available on the master file. However, for the 4168 cases collected after this revision, the interior surface intrusion data, the door intrusion data, and the occupant contact data are all available on the master file. Table 1-3 provides a breakdown of the total number of accident, vehicle, and occupant cases on the master file by the revision date.

Table 1-3

TOTAL NUMBER OF ACCIDENT, VEHICLE, AND OCCUPANT CASES ON THE NCSS MASTER FILE (UNWEIGHTED)

Number of Cases

	Pre-April 1, 1978	Post-April 1, 1978	Total
Accident	6683	4168	10851
Vehicle	12028	7152	19180
Occupant	16513	11204	27717

1.4.2 The Populations Under Study and the Analysis Procedures Used

In this study, only side-impact accidents will be considered. The exact meanings of the underlined descriptives used below to define the two subpopulations will be elaborated in Chapter 3.

a. Depth of Intrusion Analysis

A vehicle oriented file containing only post-April 1, 1978 side-door impacted towaway pre- or post-standard passenger cars is created for the analysis of the depth of door intrusion. The post-April data is used because intrusion related information are available only for these 7152 vehicle cases.

A covariance analysis procedure is used to analyze the reduction (if any) in the depth of door intrusion attributable to the standard FMVSS 214.

b. Occupant Injury Reduction Analysis

The post-April NCSS data contain detailed internal surface intrusion and occupant contact information, and permit a direct link between occupant injury (severity) and the intruded internal surface contacted. However, out of the 11204 occupant cases, only in the neighborhood of 1000 weighted occupant cases are relevant and available for analysis. In view of the sample size requirement, the following occupant oriented file containing all nearside occupants in a side-door impacted towaway pre- or post-standard passenger car is created from the NCSS master file for the analysis of occupant injury reduction attributable to FMVSS 214.

The GSK [4] approach of general Chi-square analysis of categorical data using weighted least squares is used to estimate the reduction (if any) in occupant injury attributable to the standard FMVSS 214. This procedure is analogous to the general linear model approach for continuous variable.

1.5 Limitations of the Study

There are basically three problems that one must address in evaluating FMVSS 214:

(i) Is the Standard effective in reducing depth of intrusion in passenger cars involved in side-door impacted accidents?

(ii) Is the Standard effective in reducing injury severity for nearside occupants in passenger cars involved in side-door impacted accidents?

(iii) If the answers to (i) and (ii) are positive, then is the reduction in injury severity attributable to the reduction in depth of intrusion?

In order to be able to answer these questions, fairly precise measurement on the depth of intrusion and accurate assessment of the injury severity and the internal surface contacted must be available. Injury severity is available for the full NCSS file, but information on depth of intrusion and injury resulting from occupant contact with internal surfaces is available only for the post-April, 1978 data.

For the depth of intrusion reduction analysis, only post-April data is used. The post-April data does not provide enough cases with/without injuries resulting from contact with internal surface or side-door panel or with other internal surfaces, or with injuries resulting from no apparent contact. Consequently, for the injury reduction analysis in this study, four of the five injury characterizations are defined in terms of overall AIS injury scores (OAIS) without reference to internal surface contacted. The fifth one is in terms of OAIS and the general occupant contact information which is available on the full NCSS file but which does not specify that the overall injury (OAIS) is a consequence of occupant contact with certain internal surface. By restricting oneself to the nearside occupant involved in a side-impact accident, the implicit association between occupant overall injury and occupant contact with side-structures is at least credible. However, one can not specifically say that the overall injury is associated with occupant contact with side-door panel.

Because of sample size constraint due to missing/unkwown information on various items of interest affirmative answer to (i) can be expected for certain subpopulations, and affirmative answer to (ii) can be expected for certain injury characterizations. If in the analysis one controls for all extraneous factors that are confounded with the standard, such as presence of B-pillar, bench or bucket seats, and direction of force, then the inference in (iii) is at least credible in light of the affirmative answers to (i) and (ii) for these subpopulations and injury characterizations.

Thus if the answers to questions (i) and (ii) are indeed positive for certain subpopulations, after controlling for significant confounding factors, then one may attribute with more credibility the reduction in occupant injury to a corresponding reduction in the depth of side-door intrusion at least for these subpopulations.

1.6 Outline of the Report

Section 2 of this report summarizes the analyses performed for FMVSS 214. It includes a discussion of the measure of effectiveness; the estimated effectiveness of the Standard; confidence limits on estimated effectiveness; overall success of the evaluation; credibility of the analysis; comparison of results; and findings, conclusions, and recommendations.

In Section 3, detailed analyses of NCSS data are described for all five injury characterizations. Predicted injury rates and effectiveness estimates are obtained for FMVSS 214. Evaluation of the effectiveness of FMVSS 214 in terms of reduction in the depth of side-door intrusion is also discussed via the results obtained through a covariance analysis.

The appendices include a derivation of the variance adjustment factor needed to account for the NCSS sampling scheme, a discussion of the HSR Body Style Codes, a variable selection procedure, and the codes for some selected NCSS variables.

1.7 References for Section 1

1. Braun, R.L., et al. *Evaluation Methodology for Federal Motor Vehicle Safety Standards. Volume I: Executive Summary.* Menlo Park, California, Stanford Research Institute, May 1977. (DOT-HS-802340)

2. Braun, R.L., et al. *Evaluation Methodology for Federal Motor Vehicle Safety Standards. Volume II: Technical Findings.* Menlo Park, California, Stanford Research Institute, May 1977. (DOT-HS-802341)

3. Clark, V.J., *Single Variable Tabulations for 1973-1976 North Carolina Accidents,* June 1977. Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina 27514.

4. Grizzle, J.E., C.F. Starmer, and G.G. Koch. *Analysis of Categorical Data by Linear Models,* 1969, Biometrics 25, 489-504.

5. Hedeen, C.E. and D.D. Campbell (*Fisher Body Division, General Motors Corporation)* Side Impact Structures. Society of Automotive Engineers, 1969.

6. Northrop, G.M. *Evaluation Methodologies for Four Federal Motor Vehicles Safety Standards: FMVSS 214: Side Door Strength; FMVSS 215: Exterior Protection; FMVSS 301: Fuel System Integrity; FMVSS 208: Occupant Crash Protection;* Hartford, Connecticut, The Center for the Environment and Man, Inc., May 1977. (DOT-HS-802346; CEM 4207-568)

7. Reidy, J.C., Jr., and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 214: Side Door Strength,* Hartford, Connecticut, The Center for the Environment and Man, Inc., May 1977. (DOT-HS-802345; CEM 4207-564)

2.0 SUMMARY OF ANALYSES PERFORMED ON FMVSS 214

2.1 Introduction

The primary objective of this study is to evaluate the effectiveness of the Federal Motor Vehicle Safety Standard 214 (FMVSS 214) which sets the standard for side-door strength. Prior to the introduction of this standard, a number of studies had been made on side-impact accidents suggesting a strong (negative) correlation between the strength of side-door and the depth of side-door intrusion and associated injury. Among these are the works of Friedberg, Garrett, and Kihlberg (1969), and Anderson (1974). More recently, O'Day and Kaplan (1979) conducted a study based on the Fatal Accident Reporting System (FARS) files, on the relative frequency of various kinds of collisions. Among their main findings is that approximately 60 percent of passenger-car-occupant fatalities resulting from side-impact crashes in the U.S. occur as a result of the car's striking or being struck by a truck or a fixed object and that most of the other 40 percent of side-impact fatalities resulted from impact by another passenger car. Since the introduction of FMVSS 214, the only study that has been reported on the effectiveness of this standard is the work of Kahane (1979) based on a preliminary sample of the National Crash Severity Study (NCSS) files. Among his main findings are that Standard 214 is effective in reducing injuries in the non-lateral, side-impact crashes, and is most effective in preventing fatalities and injuries in single-vehicle crashes. The present study represents an evaluation of Standard 214 based on the complete NCSS files and is partly based upon the recommendations contained in the report by Reidy and Northrop (1977) on the design and implementation plan for evaluating this standard.

2.2 Data Sources

The primary accident data used for the evaluation of FMVSS 214 is the National Crash Severity Study (NCSS) data. This was a multi-year effort which began in October 1976, and continued through March 1979. A total of 10,851 towaway accident cases were collected by seven NHTSA-sponsored organizations in eight geographically distributed locations: western New York (CALSPAN), Michigan (HSRI), Miami (University of Miami), San Antonio, and thirteen other counties in Texas (SWRI), Kentucky (University of Kentucky), Indiana (University of Indiana), and Los Angeles, California (Dynamic Sciences).

The data base represents essentially a multi-stage stratified clustered sample of police reported towaway accidents. The sampling criteria result basically in the following three strata:

- 100 percent of those accidents involving the transport to a treatment facility and overnight hospitalization or death of at least one towaway-involved automobile occupant;
- 25 percent systematic sample of accidents which involved transport of at least one towaway-involved automobile occupant to a treatment facility but not overnight hospitalization; and
- 10 percent systematic random sample of all other police-reported towaway accidents (where at least one car is not drivable).

Of the 10,851 accident cases, 6683 cases were collected prior to April 1, 1978 at which date a revision of the NCSS was made and a new format was used. Information in the supplementary reports for these cases were not computerized and are not available. In particular, the passenger compartment intrusion data, the side-structure data, and the occupant contact data are not available for these cases. However, for the 4168 cases collected after the above date, the interior surface intrusion data, the side-door intrusion data, and the occupant contact data are all available on the file. The table below provides a breakdown of the total number of accident, vehicle, and occupant cases on the master file by the revision date.

Total Number of Accident, Vehicle, and Occupant
Cases on the NCSS Master File (Unweighted)

	Number of Cases	
	Pre-April 1, 1978	Post-April 1, 1978
Accident	6683	4168
Vehicle	12028	7152
Occupant	16513	11204

2.3 Methods of Evaluating the Effectiveness of FMVSS 214

The effectiveness of FMVSS 214 is being evaluated in two parts. The first part measures the effectiveness of FMVSS 214 in terms of reduction in the mean depth of side-door intrusion. The second part measures the effectiveness of FMVSS 214 in terms of occupant injury reduction.

2.3.1 Reduction in Depth of Side-Door Intrusion

Since information on the intrusion data supplements are available only for the post-April data, this analysis is based only on the post-April data. A vehicle oriented file containing only post-April 1, 1978 side-door impacted towaway pre- or post-standard passenger cars is created.

A covariance analysis procedure (SAS GLM procedure) is used to analyze the reduction (if any) in the adjusted mean depth of side-door intrusion attributable to the standard FMVSS 214.

2.3.2 Reduction in Occupant Injury

Evaluating FMVSS 214 in terms of injury reduction requires a meaningful definition of injury. More specifically, the injury characterization should be defined in terms of injury resulting from occupant contact with the interior surface of the side-door panel. This type of injury characterization is necessary if one were prepared to attribute unequivocally any reduction in injury to a corresponding reduction (if any) in the depth of side-door intrusion. However, such injury characterization would require detailed information which relate occupant injuries to the specific interior object (surface) contacted. This kind of data is available only in the post-April data. Both because of insufficient sample size due to missing and/or unknown information on many important variables and because the post-April data was made available at a relatively late stage, this injury characterization is not used.

Three of the four injury characterizations used in this study are listed below in terms of overall AIS injury scores (OAIS) without reference to the internal object (surface) contacted, and the four injury characterization is defined in terms of OAIS and a general occupant contact variable which is available on the full NCSS file but which does not specify that the overall injury (OAIS) was a consequence of occupant contact with certain internal object (surface). However, by restricting the analysis to an occupant oriented file which includes only the nearside occupant involved in side-impact accident, the implicit association between occupant overall injury and occupant contact with side-structure is strengthened. Further post-stratification by potential standard confounding factors such as presence of B-pillar, bench or bucket seat, direction of force, etc. which were selected by a relatively objective variable screening procedure, the implicit association between overall injury and occupant contact of side-door panel is more credible.

Injury Characterization	Definition
OAIS* $\geq$ 1	Injured if overall AIS $\geq$ 1
OAIS $\geq$ 2	Injured if overall AIS $\geq$ 2
OAIS $\geq$ 3	Injured if overall AIS $\geq$ 3
SOAIS $\geq$ 1	Injured if overall AIS $\geq$ 1 and if the injuries resulted from contact with side structure components

*In the definitions, the variable, Overall AIS, has been reclassified by the two-stage scheme discussed in Section 3 of this report.

For each injury characterization, the measure of effectiveness is essentially defined as:

$$E = \frac{\text{(Overall Injury Rate/Pre-Standard) - (Overall Injury Rate/Post-Standard)}}{\text{(Overall Injury Rate/Pre-Standard)}}$$

where the overall injury rates will be (stratum) weighted average of predicted stratum injury rates based on a specific model fitted.

2.4 The Effectiveness of FMVSS 214

2.4.1 Estimated Reduction in Side-Door Intrusion

The following variables were considered in the initial multiple regression analysis on the depth of side-door intrusion: SVEHWT (striking vehicle weight), VEHWT (struck vehicle weight), DIML (total length of external crush), MAXC (maximum depth of external crush), INCREASE (whether or not door intrusion was increased by components damaged), BPILLAR (presence or absence of B-pillar), DFORCE (principal direction of force), AREAD (location of primary impact, left or right side), STRATA (sampling strata), and STANDARD (pre- or post-standard car). Non-significant effects and interactions were dropped and the results showed that STANDARD has a significant effect only in the 100% sampling stratum (corresponding to the most severe accidents). Thus subsequent multiple regression analysis was carried out only for the 100% sampling stratum. The results indicated that the factors DIML, MAXC, DFORCE, STANDARD and the interaction term MAXCxDFORCE were significant. Furthermore, the interactions DIMLxSTANDARD, MAXCxSTANDARD, and MAXCxDFORCExSTANDARD were not significant and hence justify the subsequent covariance analysis. The following model was used for the covariance analysis:

MODEL I: $\text{Depth of Side-door Intrusion} = \beta_0 + \beta_1(\text{STANDARD}) + \beta_2(\text{DFORCE}) + \beta_3(\text{MAXC}) + \beta_4(\text{DIML}) + \beta_5((\text{DFORCExMAXC}) + \text{Error}$,

where DIML, MAXC and DFORCExMAXC are the covariates. The estimated reduction in the adjusted mean depth of side-door intrusion is 1.97 inches. The inclusion of the variable MAXC in the above model may cast some doubt on the result because of the fact that MAXC is confounded with STANDARD. Such confounding, however, has a non-significant effect on the resulting estimate because the interaction MAXCxSTANDARD was not significant. In fact, further analysis by deleting the factors MAXC and DFORCE x MAXC from the above model showed that the following reduced model

MODEL II: Depth of Side-door Intrusion = $\beta_0 + \beta_1$(STANDARD) + β_2(DFORCE) + β_3(DIML) + Error

still explain the variation very well and the estimated reduction in the adjusted mean depth of side-door intrusion is 1.83 inches which is still significantly different from 0 with a p-value of 0.038.

The summary statistics in the following table show that the adjusted means are lower than the observed means for both pre- and post-standard cars and that the estimated reductions are greater than the observed reduction for both models. Furthermore, a difference of 0.14 inches between the estimated reduction based on model I and the estimated reduction based on model II is attributable to the confounding effect of MAXC with STANDARD. This difference is small enough that it does not affect the significance of the estimated reduction.

One concludes that the post-standard cars have significantly lower mean depth of side-door intrusion than the pre-standard cars in the severe accidents. No significant reduction in the mean depth of side-door intrusion was detected in the case of less severe accidents. This is perhaps attributable to the fact the cars with depth of intrusion less than an inch have the variable depth of intrusion coded 'blank' instead of '0.' If they had been coded '0', then an overall effectiveness of FMVSS 214 in terms of reduction in the depth of side-door intrusion might have been observed also for the less severe accidents.

Table 2.1

EFFECTIVENESS ESTIMATES FOR FMVSS 214 IN TERMS OF REDUCTION IN ADJUSTED MEAN DEPTH OF SIDE DOOR INTRUSION IN 100% SAMPLING STRATUM

MEAN DEPTH OF INTRUSION

	MODEL I	MODEL II	OBSERVED
PRE-STANDARD	10.09	10.27	11.58
POST-STANDARD	8.12	8.44	9.86
REDUCTION IN MEAN DEPTH OF INTRUSION	1.97	1.83	1.72

2.4.2 Estimated Reduction in Occupant Injury

Many factors pertaining to the crash, the vehicle, and the occupant may be associated with both the presence or absence of side-door beams, and with the degree of injury to the occupant. Thus, in order to obtain unbiased estimates of side-door beams effectiveness it is necessary to first identify these factors. Models using these factors could then be developed to estimate side-door beam effectiveness.

As an initial step in this factor identification or variable selection, the marginal association between each potential variable and standard type, and between each variable and injury was examined from a series of two-way contingency tables. The variables that showed significant interactions with both injury and the standard were retained for use in models for side-door beams effectiveness.

When a larger number of variables were significantly associated with both injury and standard type, the stepwise variable selection procedure of Clarke and Koch (1976) was used to select those variables most strongly associated with injury from the subset of those that were significantly associated with standard type. With this procedure, partial associations are tested using Chi-square and Mantel-Haenszel tests.

After the appropriate set of variables was selected, side-door beams effectiveness estimates were obtained by fitting linear models to the injury rate data for the standard types partitioned by the control variables. The weighted least squares procedure (GENCAT) was used for the modeling. The effectiveness estimates produced by these models are shown in Table 2-2.

Table 2.2

EFFECTIVENESS ESTIMATES FOR FMVSS 214
IN TERMS OF INJURY REDUCTION

Injury Characterization	Effectiveness Estimate	95% Confidence Interval
OAIS $\geq$ 1	15.0%	(5.0%, 25.0%)
OAIS $\geq$ 2	11.8%	(-5.3%, 28.9%)
OAIS $\geq$ 3	20.9%	(4.0%, 37.8%)
SOAIS $\geq$ 1	7.6%	(-4.2%, 19.4%)

Table 2-2 shows that all of the effectiveness estimates are postive. However, for OAIS $\geq$ 2 and SOAIS $\geq$ 1 the estimates are not statistically significant at $\alpha = 0.05$ level. Higher effectiveness estimates should be expected for the more severe injury characterizations in view of the significant reduction in the depth of side-door intrusion for post-standard cars involved in more severe accidents.

2.3.3 National Estimate of Injuries Avoided Due to the Presence of Side-Door Beams

Since significant effectiveness was found for post-standard cars relative to pre-standard cars for three of the five injury characterizations, estimates are given below based on the 1978 figures of the number of injuries, nationwide, that were avoided in 1978 if side-door beams were to be present in all passenger cars. The estimates are derived from the following formula:

$$\text{Injuries avoided} = (\hat{r}_{Pre} - \hat{r}_{Post}) \times N_O \qquad (2.1)$$

where $\hat{r}_{Pre}$ = the predicted injury rate for nearside occupant in a side-impacted towaway passenger car/station wagon, and $\hat{r}_{Post}$ = the predicted injury rate for nearside occupants in a side-impacted towaway passenger car/station wagon. N_O = the 1978 nationwide total number of nearside occupants in a side-door impacted towaway passenger car/station wagon. N_O is estimated as follows:

The 1978 national total (number) of vehicles involved in multi-vehicle (2,671,380), other collisions (980,000), and non-collision (2,400,000) accidents (excluding Pedestrian accidents) (1978 Accident Facts), is equal to

$$N = (2,671,380 \times 2) + 980,000 + 2,400,000 = 32,980,000 \text{ (vehicle cases).}$$

Let P_s = 0.025 = Proportion of towaway and side-impacted cars/ station wagon (estimated from North Carolina data).

Now let

$$N(L,S) = N \times p_s \times p(L|S) = \text{Total number of towaway left side-impacted passenger cars/station wagon}$$

$$N(R,S) = N \times p_s \times p(R|S) = \text{Total number of towaway right side-impacted passenger cars/station wagon} \qquad (2.2)$$

where

$p(L|S)$ = 0.537 = proportion of a left side-impact among all side-impact towaways. (Estimated from North Carolina Data)

$p(R|S) = 0.463$ = proportion of a right side-impact among all side-impact towaways. (Estimated from North Carolina Data)

Then

$$
\begin{aligned}
N_o = N(L,S) &+ N(L,S) \times p(4|L,S) \times p(LR|4,L,S) + \\
&+ N(R,S) \times p(RF|R,S) + \\
&+ N(R,S) \times p(4|R,S) \times p(RR|4,R,S))
\end{aligned} \qquad (2.3)
$$

where

$p(4|L,S) = 0.423$ = Proportion of 4-door cars among all the towaway left side-impacted cars. (Estimated from North Carolina Data)

$p(4|R,S) = 0.444$ = Proportion of 4-door cars among all the towaway right side-impacted cars. (Estimated from North Carolina Data)

$p(LR|4,L,S) = 0.095$ = The probability of an occupant present in the left rear position of a 4-door left side-impacted car. (Estimated from North Carolina Data)

$p(RF|R,S) = 0.386$ = The probabilty of an occupant present in the right front position of a side-impacted car. (Estimated from North Carolina Data)

$p(RR|4,R,S) = 0.087$ = The probability of an occupant present in the right rear position of a 4-door right side-impacted car. (Estimated from North Carolina Data)

By substituting the appropriate values in equations (2.2) and (2.3), one obtains an estimate of the total 1978 nationwide number of nearside occupants in a towaway side-impacted accidents as

$$N_o = 622648$$

Based on this figure and the predicted injury rates for pre- and post-standard cars, one can estimate the 1978 nationwide total number injuries avoided if all passenger cars/station wagon were to have met the standard FMVSS 214 in 1978. These figures are given in Table 2.3.

Table 2.3

NATIONAL ESTIMATE OF THE TOTAL NUMBER OF INJURIES AVOIDED FOR NEARSIDE OCCUPANTS IN A TOWAWAY SIDE-IMPACTED PASSENGER CAR/STATION WAGON BASED ON THE 1978 ACCIDENT DATA

Injury Characterization	$\hat{r}_{Pre} - \hat{r}_{Post}$	1978 National Total of Injuries Avoided
OAIS $\geq$ 1	8.2%	51057
OAIS $\geq$ 2	1.9%	11830
OAIS $\geq$ 3	1.9%	11830
SOAIS $\geq$ 1	1.7%	10585

2.5 Evaluation of Effectiveness Analysis

All of the analyses were done using a weighted data file. That is, for example, an observation from the 10 percent sample was treated as 10 identical observations. To compensate for this inflation of the actual data, all variances were similarly inflated by the ratio of weighted to unweighted cases. This variance inflation factor varied from situation to situation, depending upon the injury characterization used. The derivation of these variance adjustment factors is discussed in detail in Appendix A. The confidence intervals in Table 2.2 have all been adjusted to account for the NCSS sampling scheme. Even though, the positive effectiveness estimates for OAIS $\geq$ 2 and SOAIS $\geq$ 1 are not statistically significant, the overall effectiveness of the standard FMVSS 214 is apparent.

The fact that the effectiveness of the standard in terms of adjusted mean depths of side-door intrusion is statistically significant at $\alpha = 0.05$ level only for the 100% sampling stratum should be expected, because cars with maximum extent of intrusion less than one inch are coded 'blank'. Consequently, there is no way one can be sure whether a car has 0 inch in intrusion or actually has missing intrusion information. Since these cases are not included in the analysis, the above result might be expected. On the other hand, the 100% sampling stratum corresponds to the seriously injured cases (more severe accidents). This result may also partially account for the large and significant effectiveness estimate (52.7%) for the injury characterization OAIS $\geq$K.

For purpose of comparisons, Table 2-4 presents the effectiveness estimates for the subpopulations defined by the factors controlled in the models based on OAIS $\geq$ 1 and OAIS $\geq$ 2.

Table 2-4

EFFECTIVENESS ESTIMATES FOR SOME SUBPOPULATIONS BASED ON THE INJURY CHARACTERIZATIONS OAIS $\geq$ 1 AND OAIS $\geq$ 2

Injury Characterization	Variable	Subpopulations	Effectiveness Estimate
OAIS $\geq$ 1	Sex	Male	15.4%
		Female	15.1%
	B-pillar	Absent	8.5%
		Present	18.2%
	Type of seat	Bench	0.8%
		Bucket	28.1%
	Direction of force	Lateral	9.7%
		Non-lateral	26.1%
OAIS $\geq$ 2	Number of vehicles	Single	25.1%
		Multi	7.6%
	Vertical location of impact	A	28.1%
		E+L	5.8%

The results in Table 2-4 show that the standard is especially effective in the presence of B-pillar, in cars with bucket seats, in non-lateral impact crashes, in single vehicle accidents, and when the vertical location of impact is A. This suggests that the standard FMVSS 214 is particularly effective in reducing injuries when the accidents are expected to be severe, such as single vehicle accidents, impacted cars are small (Type of Seat = Bucket), or vertical impact location = A. These results seem to support the earlier findings of Kahane (1979) concerning the effectiveness of Standard 214 in single-vehicle accidents. However, the above results show that the standard is effective in both lateral and non-lateral impact crashes, but with the standard being more effective in the non-lateral cases. The results here may be the consequences of a larger sample size than that available in Kahane's study. Nevertheless, this study seems to support the general findings of Kahane (1979).

2.6 References for Section 2

1. Anderson, T. (1974). *Passenger Compartment Intrusion in Automobile Accidents - Final Report.* Pub. No. DOT-HS-801238, National Technical Information Service, Springfield, Virginia.

2. Cesari, D., Ramet, M. and Cavallero, C. (1977). *Influence of Intrusion in Side Impact. Report on the Sixth International Technical Conference on Experimental Safety Vehicles.* Pub. No. DOT-HS-802501, U.S. Department of Transportation National Highway Traffic Safety Administration, Washington, pp. 703-714.

3. Friedberg, M., Garrett, J., and Kihlberg, J. (1969). *Automobile Side Impacts and Related Injuries.* Calspan, Buffalo.

4. Higgins, J. E. and Koch, G. G. (1977). *Variable Selection and Generalized Chi-square Analysis of Categorical Data Applied to a Large Cross-Sectional Occupational Health Survey.* International Statistical Review 45, 51-62.

5. Kahane, C. J. (1979). *An Evaluation of Standard 214.* Pub. No. DOT-HS-804858, U.S. Department of Transportation National Highway Traffic Safety Administration, Washington.

6. O'Day, J., and Kaplan, R. J. (1979). *The FARS Data and Side-Impact Collisions.* HSRI, University of Michigan, Ann Arbor, Michigan, UM-HSRI-79-36.

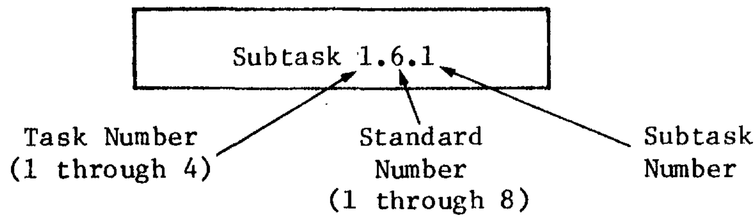
7. Preston, F., and Shortridge, R. (1973). *An Evaluation of the Effectiveness of Side Door Beams Based on Accident Exposure.* HSRI, University of Michigan, Ann Arbor, Michigan, UM-HSRI-SA-73-8.

8. Reidy, J. C., Jr., and Northrop, G. M. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 214: Side Door Strength.* Hartford, Connecticut, The Center for the Environment and Man, Inc., May, 1977. (DOT-HS-802345; CEM 4207-564).

3.0 ANALYSIS OF THE NCSS DATA

3.1 Introduction

The analysis of FMVSS 214 (Side Door Strength) is based on the detailed accident reports available through the NCSS data base. Figure 3-1 is a flow diagram indicating the suggested steps in the three tasks originally proposed for the analysis of FMVSS 214.



This numbering sequence was chosen for the following reasons:

- Task Number. All eight Standards will involve four (3) Tasks:

  Task 1: Review Methodology and Develop Work Plans

  Task 2: Analysis of Data

  Task 3: Final Analysis and Final Report on the Standard

- Standard Number. For convenience throughout the entire study, we will use the following "Standard Numbers."

  1 = FMVSS 108: Side Marker Lamps
  2 = FMVSS 202: Head Restraints
  3 = FMVSS 207: Seat Back Locks
  4 = FMVSS 213: Child Seating Systems
  5 = FMVSS 214: Side Door Strength
  6 = FMVSS 222: School Bus Seats and Crash Protection
  7 = FMVSS 301: Fuel System Integrity

  All CEM report numbers will have last digits in the sequence noted above.)

- Subtask Number. Sequential numbers, beginning with "1".

3.2 The NCSS Data

The NCSS data were acquired by HSRC from the Department of Transportation. Beginning April 1, 1978, a new format was used in recording the accident data reflecting a NCSS revision. The post-April data contain detailed intrusion and occupant contact data. However, of the 10851 accident cases on the NCSS master file, only 4168 cases belong to this category. Consequently the evaluation of FMVSS 214 in terms of potential reduction in the depth of intrusion, can be based only on the post-April data.

Figure 3-1

STEPS IN THE ANALYSIS OF FMVSS 214

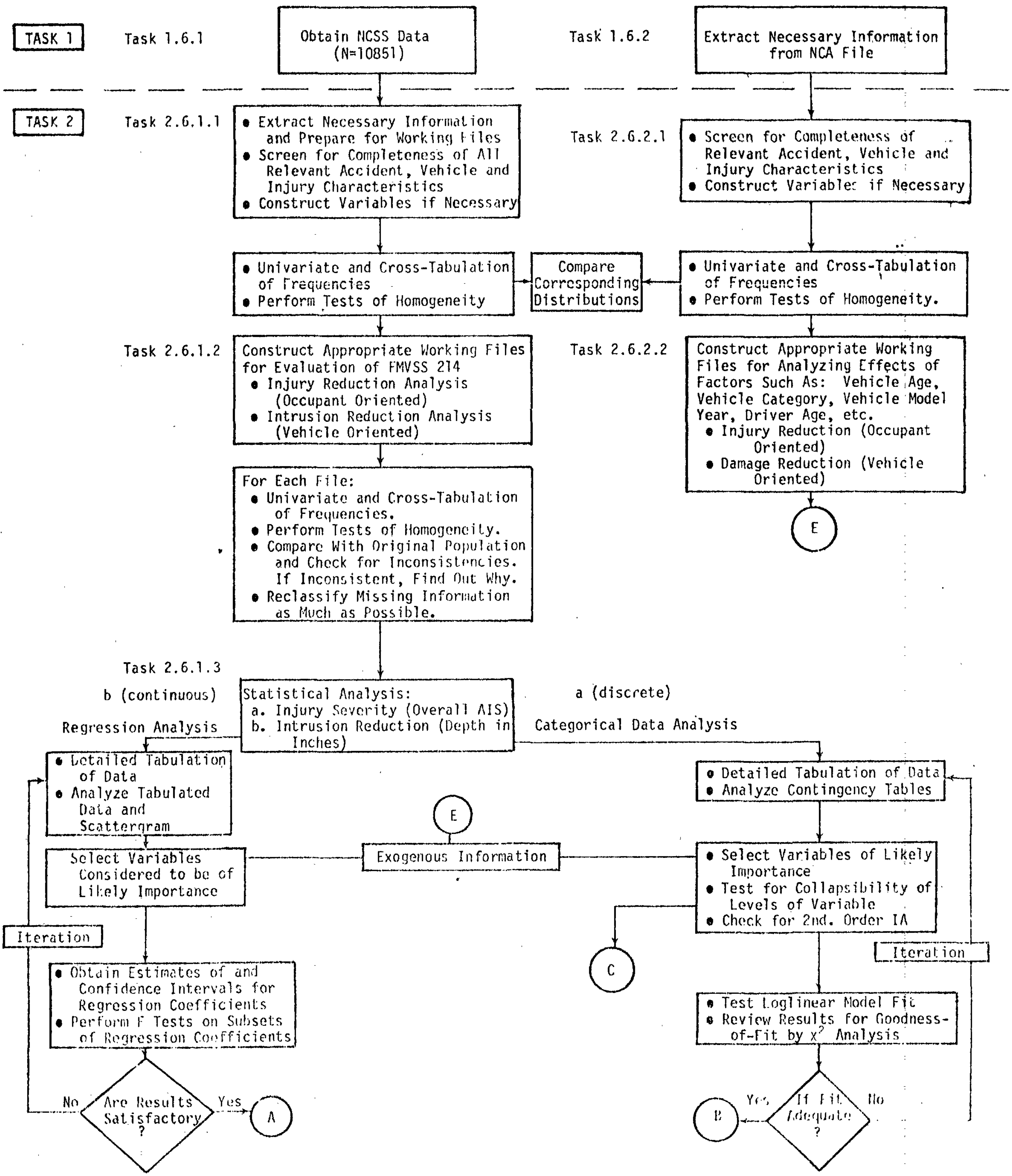
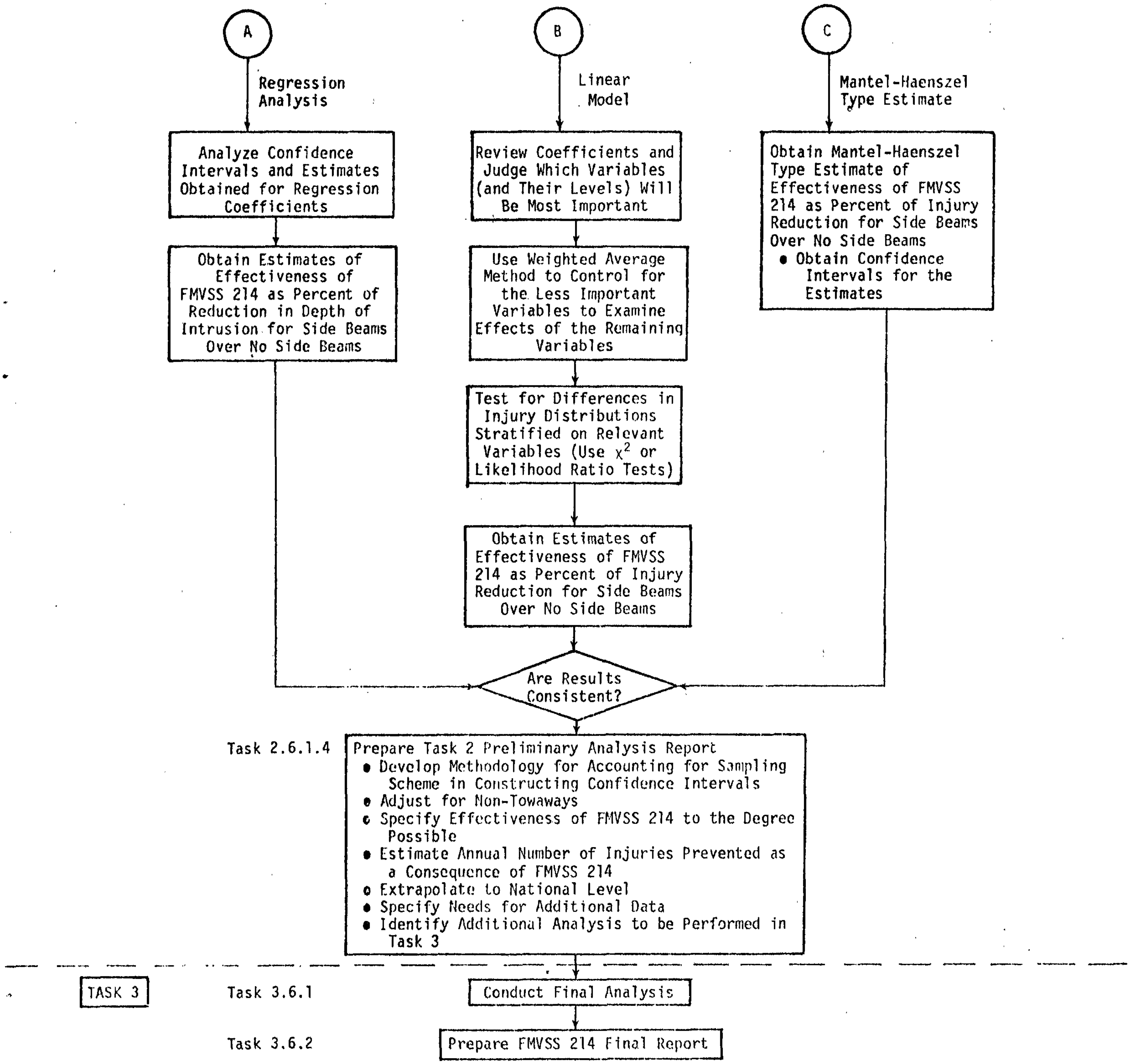


Figure 3-1 (continued)



3.3 Working Files Created for Evaluation of FMVSS 214

Relevant information have been extracted from the NCSS master file for the purpose of examining the completeness of all relevant accident, vehicle, and occupant injury characteristics. The following additional variables have been created:

1. STANDARD: This variable indicates whether a passenger car is Pre- or Post- standard (based on Table 1.1 and Table 1.2).

2. DOOR: This variable indicates whether a passenger car is two- or four-door (based on the transformation given in Table B-1 of Appendix B).

3. B-PILLAR: This variable indicates whether a passenger car has B-pillars or not (based on the transformation given in Table B-1 of Appendix B).

4. DFORCE: This variable indicates whether the passenger car sustained a lateral impact (principal direction of force is between 2 and 4 o'clock, or 8 and 10 o'clock), or a non-lateral impact.

5. SVEHWT: Weight of the striking vehicle in a multi-vehicle accident.

After some preliminary analyses, two working files were specifically created for evaluating FMVSS 214. They are:

(i) The Vehicle Oriented File: This file is created for conducting depth of door intrusion reduction analysis. It consists of all side-door impacted towaway Pre- or Post-standard passenger cars from the post-April NCSS data. An additional variable, MAXC, is created which gives the maximum depth in inches of the external crush.

(ii) The Occupant Oriented File: This file is created for the purpose of conducting occupant injury reduction analysis. It consists of all nearside front seat occupants in a side-door impacted tow-away Pre-or Post-Standard passenger car.

The following are definitions of those descriptives used in defining the above two working files. Some relevant discussions are given after each definition.

1. Depth of Intrusion: This is a measure of the maximum extent (depth) of intrusion (from the original interior position). Coupled with

the information on intruded area, one can obtain the depth of door intrusion (in inches) which will be the primary dependent variable used in a multivariate covariance analysis to assess the effectiveness of FMVSS 214.

2. Passenger Car: This is defined as either a 2 or 4 door passenger car, station wagon, convertible, or a passenger car with pickup body. (NCSS code: Body style = 01, 02, 03, or 04. See Appendix D for NCSS codes).

3. Pre-Standard Car: Any U.S. or foreign manufactured passenger car prior to the 1973 model year with the exception of those listed in Table 1-1 is defined as a Pre-Standard car.

   This definition has the effect of putting all foreign manufactured passenger cars prior to 1973 model year in the Pre-Standard category. This is not an unreasonable assumption, since based on the latest information, Mercedes-Benz, Volvo, and Renault did not modify their side door structure to meet the standard until the 1973 models (see Table 1-2).

4. Post-Standard Car: Any U.S. or foreign car manufactured starting with the 1973 model year or any one of those listed in Table 1-1 is defined as a Post-Standard car.

   Table 3-1 provides a frequency count of the number of Pre- and Post-Standard passenger cars in the Vehicle Oriented File.

Table 3-1

PROPORTION OF PRE- AND POST-STANDARD PASSENGER CARS IN THE VEHICLE ORIENTED FILE

	Frequency
Pre-Standard	253 (27.1)
Post-Standard	680 (72.9)
Total	933*

*Weighted

5. Left Side-door Impacted: A car is left side-door impacted if its primary impact site (NCSS Code: Area of Deformation) = L (left) and if its primary Horizontal Location of Impact (NCSS Code: Horizontal Location) = D, P, Y, or Z [side (or end) distributed, side center, side (or end) front and center, side (or end) rear and center].

6. Right Side-door Impacted: A car is right side-door impacted if its impact site (NCSS CODE: Area of Deformation) = R (right) and if its primary Horizontal Location of Impact (NCSS Code: Horizontal Location of Impact) = D, P, Y or Z.

7. Side-door Impacted: A car is side-door impacted if it is either left or right side-door impacted.

8. Towaway: A passenger car is a towaway if the towing indicator (NCSS Code: Vehicle Towed) = 1.

9. Nearside Occupant: A nearside front seat occupant is one occupying the front seat on the side of the impact. A nearside rear seat occupant is one occupying the rear seat on the side of the impact in a 4-door car. Thus, by definition, the center front or center rear (in a 4-door car) occupants are excluded from the study.

10. Injury Characterizations: The primary injury severity measure to be used is the overall AIS (OAIS) score. The OAIS scores are defined as follows:

Table 3-2

OAIS SCORES

0 = None	5 = Critical
1 = Minor	6 = Maximum (fatal)
2 = Moderate	8 = Injured, unknown severity
3 = Serious	9 = Unknown, if injured

The following five injury characterizations are proposed for the subsequent analyses.

Injury Characterization	Definition of Injured
OAIS $\geq$ 1	OAIS = 1-6
OAIS $\geq$ 2	OAIS = 2-6
OAIS $\geq$ 3	OAIS = 3-6
OAIS $\geq$ K	OAIS = 6
SOAIS $\geq$ 1	SOAIS*= 1-6

*The SOAIS injury scores are injury severity scores resulted from contact with side-structure components (NCSS Code: Occupant Contact = 15-24) and are defined in Table 3-4 on the following page. Table 3-3 provides an indication of how the primary occupant injury severity scores are distributed with respect to the generalized (primary) interior object contacted. Cases collected during January-May, 1977 have no object contact information and hence are not included for this injury characterization.

Table 3-3

GENERALIZED INTERIOR OBJECT CAUSING MOST SEVERE INJURY BY INJURY SEVERITY FOR THE OCCUPANT ORIENTED FILE

Generalized Primary Interior Object Contacted	NCSS Primary Interior Object Contact Code	AIS 1: 1	2	3	4	5	6	8	Total
Front	01-14	93† 49.2* 19.7**	54 28.6 30.5	23 12.2 16.2	12 6.3 40.0	3 1.6 14.3	1 0.5 5.9	3 1.6 9.7	189
Side	15-24	264 50.6 55.9	88 16.9 49.7	108 20.7 76.1	15 2.9 50.0	15 2.9 71.4	4 0.8 23.5	28 5.4 90.3	522
Others ††	25-89	40 48.2 8.5	29 34.9 16.4	4 4.8 2.8	3 3.6 10.0	2 2.4 9.5	5 6.0 29.4	0 0.0 0.0	83
Impact Force	90	75 78.1 15.9	6 6.3 3.4	7 7.3 4.9	0 0.0 0.0	1 1.0 4.8	7 7.3 41.2	0 0.0 0.0	96
	Total	472	177	142	30	21	17	31	890

*Row percent
**Column percent
†Weighted
††including ejections and external objects

Note: There were 1,397 cases with object contact coded unknown and there were 2,379 cases with both AIS1 and object contacted information missing (mostly due to no injury sustained)

Table 3-4

DEFINITION OF SIDE-STRUCTURE INJURY SEVERITY (SOAIS) SUSTAINED BY AN OCCUPANT RESULTING FROM CONTACT WITH SIDE-STRUCTURE COMPONENTS

Generalized Primary Interior Object Contacted	Primary Injury Severity	Generalized Secondary Interior Object Contacted	Secondary Injury Severity	Side Structure Injury Severity Scores SOAIS
Side	AIS1	Side	AIS2	OAIS
Side	AIS1	≠ Side	AIS2	AIS1
≠ Side	AIS1	≠ Side	AIS2	0
Missing		Missing		9

TABLE 3-5

INJURY SEVERITY BY STANDARD TYPE
(BASED ON THE WEIGHTED OCCUPANT ORIENTED FILE)

	OAIS										Total
	.	0†	1	2	3	4	5	6	8	9	
Pre-Standard	11	545 41.4*	207 15.7	62 4.7	54 4.1	13 1.0	11 0.8	11 0.8	205 15.6	209 15.9	1317 28.5**
Post-Standard	28	1327 40.1	556 16.8	163 4.9	151 4.6	27 0.8	25 0.8	21 0.6	457 13.8	583 17.6	3310 71.5
Total	39	1872 40.5*	763 16.5	225 4.9	205 4.4	40 0.9	36 0.8	32 0.7	662 14.3	792 17.1	4627

*Row percent
**Column percent
†For the meaning of these OAIS scores, consult Table 3-2

The above table shows that of the total 4666 cases in the weighted Occupant Oriented File, 17.8% (831 cases) have unknown OAIS (OAIS = · or 9) and 14.2% have unknown injury severity scores (OAIS = 8). Together they constitute 32% of the total. Since injury will be the primary dependent variable considered in the subsequent analyses, these cases with unknown OAIS are reclassified for the first four injury characterizations (hence also for SOAIS) according to the following two-stage schemes:

TWO STAGE SCHEME FOR RECLASSIFICATION OF MISSING AND/OR UNKNOWN OAIS

STAGE I

OAIS	Number of Cases	AIS1*	AIS2*	AIS3*	Injury Characterizations OAIS $\geq$ 1	OAIS $\geq$ 2	OAIS $\geq$ 3	OAIS $\geq$ K
.	36	.	.	.	Stage II	Stage II	Stage II	Stage II
9	792	.	.	.	Stage II	Stage II	Stage II	Stage II
9	2	.	4,5	≤AIS2	Yes	Yes	Yes	No
9	1	3	0	.	Yes	Yes	Yes	No
8	575	.	.	.	Yes	Stage II	Stage II	Stage II
8	12	.	0	.	Yes	Stage II	Stage II	Stage II
8	4	.	1	.	Yes	Stage II	Stage II	Stage II
8	1	.	5	1	Yes	Yes	Yes	No
8	4	1	1	.	Yes	Stage II	No	No
8	1	3	3	8	Yes	Yes	Yes	Stage II
8	6	8	0	.	Yes	Stage II	Stage II	Stage II
8	41	8	1	<AIS2	Yes	Stage II	Stage II	Stage II
8	3	8	2	≤AIS2	Yes	Yes	Stage II	Stage II
8	6	8	3,4	≤AIS2	Yes	Yes	Yes	Stage II
8	3	8	8	0 or 1	Yes	Stage II	Stage II	Stage II
8	1	8	8	2	Yes	Yes	Stage II	Stage II
8	1	8	8	3	Yes	Yes	Yes	Stage II
8	4	8	8	8	Yes	Stage II	Stage II	Stage II

*AIS1 = Most Severe Injury Score, AIS2 = Second Most Severe Injury Score, AIS3 = Third Most Severe Injury Score

STAGE II

	Injury Characterizations OAIS $\geq$ 1	OAIS $\geq$ 2	OAIS $\geq$ 3	OAIS $\geq$ K
Fatal	Yes	Yes	Yes	Yes
Non-Fatal Hospitalized	Yes	Yes	Yes	No
Non-Fatal Not Hospitalized	Yes	No	No	No
Other Treatment	Yes	No	No	No
Not Transported Treatment Unknown	No	No	No	No
Not Transported No Treatment	No	No	No	No

Based on Table 3-6 which cross-classifies OAIS by NCSS injury classification for the 3173 cases with known OAIS in the Weighted Occupant Oriented File, one can calculate the percentage of potentially misclassified cases for each of the four injury characterizations, and these figures are given below:

Injury Characterizations	Percent of Potentially Misclassified Cases
OAIS $\geq$ 1	0.6%
OAIS $\geq$ 2	6.8%
OAIS $\geq$ 3	6.5%
OAIS $\geq$ K	1.6%

Table 3-6

OAIS BY NCSS INJURY CLASSIFICATION
(BASED ON THE WEIGHTED OCCUPANT ORIENTED FILE)

NCSS Injury Classification	OAIS 0	1	2	3	4	5	6	Total
Killed				1 1.7*	4 6.9	21 36.2	32 55.2	58 1.8**
Non-Fatal Hospitalized		44 12.5	107 30.4	154 43.8	32 9.1	15 4.3		352 11.1
Non-Fatal Not Hospitalized	18 2.2	647 79.2	108 13.2	40 4.9	4 0.5			817 25.7
Other Treatment		72 18.3	10 10.9	10 10.9				92 2.9
No Treatment	1854 100.0							1854 58.4
	1872 59.0*	763 24.0	225 7.1	205 6.5	40 1.3	36 1.1	32 1.0	3173

*Row percent
**Column percent

3.4 Variable Selection (Occupant Injury Reduction Analysis)

This section contains a summary description of the variable selection procedure used. Table 3-7 provides a list of variables that are considered to be potentially confounding factors that are relevant to the evaluation of FMVSS 214.

Table 3-7

A LIST OF POTENTIAL CONFOUNDING FACTORS AS
CANDIDATE VARIABLES TO BE SELECTED FOR CONTROL

Characteristics	Variable	NCSS Variable	Number of Categories	Description of the Categories
Occupant	SEX	Sex	2	Male, Female
	BELT	Belt Usage	2	Unbelted, Belted
	SEAT	Seat Area	2	Front, Rear
	AGE	Age	3	0-21, 22-35, 36+
Vehicle	WEIGHT	Vehicle Wt.	3	0-3000, 3000-4000 4000+
	BPILLAR		2	B-pillar absent B-pillar present
	DOOR		2	2-door, 4-door
	SWEIGHT	Striking Vehicle Wt.	3	0-3000, 3000-4000 4000+
	TYPESEAT	Type of Seat	2	Bench, Bucket
Primary Impact	AREAD	Area of Deformation	2	Left Side, Right Side
	HORIZ	Horizontal Location	3	D (Side Distributed) P (Side Center) Y+Z (Side Center Front & Side Center Rear)
	VERT	Vertical Location	3	A*, E+L, M+H+G
	DIST	Type of Damage Distribution	4	N*, W, S, O
	DFORCE	Direction of Impact	2	Lateral, Non-Lateral
Accident	NBVEH	Number of Vehicles Involved	2	Single Vehicle Multi-Vehicle
	LOC	Location of Accident	2	Rural, Urban
Extent of Veh. Damage	LATCH	Latch/Hinge Damage	2	None, Yes
	INTRUS	Presence of Intrusion	2	None, Yes
	EXT	Primary Extent of Damage	2	0-1, 2+
	VLDT	Lateral V (Damage & Trajectory)	3	<-5, 1-5 to +5, >+5

*See NCSS codes in Appendix D.

3.4.1 The Variable Screening Procedure

a. Calculation of Relevant Statistics

At each stage of the selection procedure, for each candidate variable V, or V joint with variables already selected from preceding stages, the following statistics are calculated using the PARCAT computer program [1].

1. $T_1 = \chi^2$ (V x STANDARD): The Pearson Chi-squared statistic for measuring the association between V and STANDARD.

2. $T_2 = \chi^2$ (V x INJURY): The Pearson Chi-squared statistic for measuring the association between V and INJURY.

If both T_1/d.f. and T_2/d.f. are significant, then the following additional statistics are calculated:

3. $T_{3,Pre} = \chi^2$ ([V x INJURY| PRE-STANDARD]) and $T_{3,Post} = \chi^2$ ([V x INJURY| POST-STANDARD]): The statistics for measuring the partial association of V and INJURY for PRE- and POST-STANDARD (see Figure 3-2).

4. $T_4 = \chi^2$ ([V x INJURY|STANDARD]): The generalized Cochran-Mantel-Haenszel statistic for measuring the association of V and INJURY across STANDARD (see Figure 3-2).

Figure 3-2

THE THREE-WAY (WEIGHTED) CONTINGENCY TABLE
STANDARD x V x INJURY

		Injury		
Standard	V	No	Yes	Partial Association
Pre	v_1 v_2	n_{111} n_{121}	n_{112} n_{122}	χ^2([V x INJURY| PRE-STANDARD])
Post	v_1 v_2	n_{211} n_{221}	n_{212} n_{222}	χ^2([V x INJURY|POST-STANDARD])

The Generalized Cochran-Mantel Haenszel Statistic — χ^2([V x INJURY|STANDARD])

b. Screening Criteria

Consider the criteria:

Criterion A: Both statistics T_1 and T_2 must be significant

If the association between V and STANDARD, as measured by T_1, is not significant, then its exclusion will not affect the effectiveness estimate regardless of the significance of the association between V and INJURY (i.e., T_2). If the association between V and INJURY is not significant, then the inclusion of V as a control will not contribute significantly to the reduction of variation in the injury experiences.

Criterion B: The significant relationship between V and INJURY should be consistent for both PRE- and POST-STANDARD populations.

The relationship between V and INJURY is consistent for both PRE- and POST-STANDARD if $T_4 \geq \max \{T_{3,PRE}, T_{3,POST}\}$ The relationship is not consistent if $0 \leq T_4 \leq \max \{T_{3,PRE}, T_{3,POST}\}$

By controlling for all such variables, one can presumably attribute the remaining variation in the injury experience to STANDARD.

c. The Selection Criterion

Among the variables that met both screening criteria, select one preferably with the largest T_1/d.f. and T_2/d.f. statistics. If there are several variables with about the same magnitude for the statistics, T_1/d.f. and T_2/d.f., then the index $I = T_4/(T_{3,PRE}+T_{3,POST})$ may be used to measure the presence of interaction. If I = 1.0 then it implies that interaction is not present, i.e., the association between V and INJURY is unaffected by controlling for STANDARD. Such factors should provide the cleanest control. Thus, there is a certain element of subjectivity involved in the selection process. The procedure repeats itself after each selection and will be terminated if one of the following situations occurs.

(i) No more relevant variables are available for consideration, or

(ii) The statistics T_1/d.f. and/or T_2/d.f. are not significant (after adjustment to account for sampling scheme) for the remaining variables.

3.4.2 Variables Selected for the Various Injury Characterizations

Repeated applications of the preceding procedure for the five injury characterizations result in the following selections:

Injury Characterization	Variables Selected
OAIS $\geq$ 1	SEX, BPILLAR, TYPESEAT, DFORCE
SOAIS $\geq$ 1	SEX, LOC, AREA
OAIS $\geq$ 2	NBVEH, VERT
OAIS $\geq$ 3	NBVEH, VERT
OAIS $\geq$ K	NBVEH, VERT

A discussion of their selections follows.

a. <u>For OAIS $\geq$1:</u>

Table 3-8 summarizes the statistics generated for some of the significant variables in the selection process for OAIS $\geq$ 1. For a more detailed results for OAIS $\geq$ 1, please refer to Table C-1 in Appendix C.

In stage I, the variable SEX has the largest T_2/d.f. statistic (128.8) and a relatively large T_1/d.f. statistic (39.0). In stage II after controlling for SEX, the variable BPILLAR is selected becasue it has the second largest T_2/d.f. (43.3) and the largest T_1/d.f. (45.0), and an index value of 0.99. In the final stage, after controlling for SEX and BPILLAR, the variables SWEIGHT, TYPESEAT, DFORCE, AND NBVEH all have approximately equal magnitude for the statistics T_1/d.f. and T_2/d.f. The variable TYPESEAT was selected because it has an index of 0.88, the highest among the four indices. At this stage, the variable DFORCE was selected without further screening because it has significant T_1/d.f. and T_2/d.f. statistics and an index of 0.80

b. <u>For SOAIS $\geq$1:</u>

A summary of the statistics generated for some of the variables in the selection process for SOAIS $\geq$ 1 is given in Table 3-9. Detailed results are available in Table C-2 of Appendix C.

In the first stage, the variable SEX was clearly the choice. In stage II, after controlling for SEX, the variable LOC was selected because both T_1/d.f. (28.9) and T_2/d.f. (28.0) are significant (at 0.01 level) after adjustment, and also it has an index of 0.97. After controlling for SEX and LOC, none of the remaining variables is really significant after adjustment except for AREA, which also has an index of 0.92.

c. <u>For OAIS $\geq$2:</u>

Table 3-10 contains the statistics generated for some of the variables in the selection process for OAIS $\geq$2. Detailed results are given in Table C-3 of Appendix C.

Table 3-8

Statistics† Generated for Some Variables in the Variable Selection Process for Injury Characterization OAIS $\geq$ 1

Selection Stage	Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
1	SEX*	2	39.0 (1) 39.0	128.8 (1) 128.8	32.8 (1) 98.1 (1) 130.9 (2)	130.9 (1) 1.00
	AGE	3	32.7 (2) 16.4	22.8 (2) 11.4	5.2 (2) 19.3 (3) 24.5 (4)	23.1 (2) 0.94
	WEIGHT	3	139.1 (2) 69.5	52.3 (2) 26.2	38.4 (2) 26.1 (2) 64.5 (4)	52.9 (2) 0.82
	SWEIGHT	3	32.1 (2) 16.1	110.6 (2) 55.3	21.2 (2) 99.4 (2) 120.6 (4)	117.8 (2) 0.98
	NBVEH	2	17.4 (1) 17.4	22.7 (1) 22.7	33.7 (1) 2.9 (1) 36.6 (2)	22.5 (1) 0.61
2	WEIGHT	3	213.8 (5) 42.7	181.4 (5) 36.3	63.5 (5) 133.1 (5) 196.4 (10)	182.7 (5) 0.93
	BPILLAR*	2	136.0 (3) 45.0	129.9 (3) 43.3	34.1 (3) 99.1 (3) 133.2 (6)	132.3 (3) 0.99
	TYPESEAT	2	93.9 (3) 31.3	159.9 (3) 53.3	62.9 (3) 115.9 (3) 195.9 (6)	166.8 (3) 0.93
	NBVEH	2	49.9 (3) 16.6	176.9 (3) 58.9	78.1 (3) 117.8 (3) 195.9 (6)	178.2 (3) 0.91
3	SWEIGHT	3	263.7 (11) 24.0	251.9 (11) 22.9	108.9 (11) 123.9 (11) 232.8 (22)	111.2 (11) 0.48
	TYPESEAT*	2	191.3 (7) 27.3	165.1 (7) 23.6	138.0 (7) 183.9 (7) 321.9 (14)	282.1 (7) 0.88
	DFORCE	2	170.9 (7) 24.4	154.5 (7) 22.1	61.2 (7) 136.4 (7) 197.6 (14)	158.9 (7) 0.80
	NBVEH	2	151.2 (7) 21.6	180.9 (7) 25.8	71.9 (7) 126.9 (7) 198.8 (14)	88.4 (7) 0.44

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling scheme. To obtain the adjusted χ^2, divide the χ^2 values in the table by 3.7 (see Appendix A for derivation of the adjustment factors)

††The index I = $T_4/T_{3,Pre} + T_{3,Post})$

Table 3-9

Statistics† Generated for Some of the Significant Variables in the Variable Selection Process for Injury Characterization SOAIS $\geq$ 1

Selection Stage	Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	T_3,Pre (d.f.) T_3,Post (d.f.) T_3,Pre + T_3,Post (d.f.)	T_4 (d.f.) I††
1	SEX*	2	45.8 (1) 45.8	56.3 (1) 56.3	28.1 (1) 31.4 (1) 59.6 (2)	56.0 (1) 0.94
	WEIGHT	3	86.9 (2) 43.5	24.8 (2) 12.4	20.0 (2) 10.0 (2) 30.0 (4)	25.6 (2) 0.85
2	BELT	2	55.6 (3) 18.5	77.8 (3) 25.9	48.3 (3) 40.7 (3) 89.1 (6)	72.4 (3) 0.81
	WEIGHT	3	181.0 (5) 36.2	81.9 (5) 16.4	57.3 (5) 45.9 (5) 103.1 (10)	81.8 (5) 0.79
	BPILLAR	2	124.9 (3) 41.6	63.0 (3) 21.0	33.1 (3) 35.1 (3) 68.2 (6)	62.7 (3) 0.92
	TYPESEAT	2	73.4 (3) 24.5	62.8 (3) 20.9	56.4 (3) 32.0 (3) 88.4 (6)	64.9 (3) 0.73
	NBVEH	2	51.4 (3) 17.1	104.2 (3) 34.7	37.3 (3) 75.2 (3) 112.5 (6)	103.8 (3) 0.92
	LOC*	2	86.7 (3) 28.9	84.1 (3) 28.0	37.6 (3) 48.7 (3) 86.2 (6)	83.9 (3) 0.97
3	BELT	2	105.7 (7) 15.1	102.9 (7) 14.7	55.8 (7) 56.6 (7) 112.4 (14)	102.5 (7) 0.91
	VERT	3	138.6 (11) 12.6	243.1 (11) 22.1	70.3 (11) 191.9 (11) 62.2 (22)	236.3 (11) 0.90
	BPILLAR	2	182.7 (7) 26.1	99.4 (7) 14.2	57.6 (7) 61.7 (7) 119.3 (7)	99.4 (7) 0.83
	AREA*	3	105.0 (7) 15.0	123.9 17.7	45.5 (7) 88.5 (7) 134.0 (14)	123.7 (7) 0.92
	WEIGHT	2	236.5 (11) 21.5	129.8 (11) 11.8	108.0 (11) 69.5 (11) 177.5 (22)	129.5 (11) 0.73

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling scheme. To obtain the adjusted χ^2, divide the χ^2 values in the table by 2.3 (see Appendix A for derivation of the adjustment factors)

††The index I = $T_4/(T_{3,Pre} + T_{3,Post})$

Table 3-10

Statistics† Generated for Some of the Significant Variables in the Variable Selection Process for Injury Characterization OAIS $\geq$ 2

Selection Stage	Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
1	BELT	2	19.0 (1) 19.0	12.0 (1) 12.0	1.7 (1) 10.2 (1) 11.8 (2)	11.7 (1) 0.99
	AGE	3	32.7 (2) 16.3	35.4 (2) 17.7	19.9 (2) 22.2 (2) 42.1 (4)	36.1 (2) 0.86
	SWEIGHT	3	32.1 (2) 16.1	59.1 (2) 29.5	8.8 (2) 56.1 (2) 64.9 (4)	63.1 (2) 0.097
	NBVEH*	2	17.4 (1) 17.4	41.4 (1) 41.4	32.2 (1) 14.2 (1) 46.4 (2)	40.8 (1) 0.88
2	SEX	2	67.0 (3) 22.3	39.4 (3) 13.1	56.8 (3) 17.9 (3) 74.7 (6)	63.2 (3) 0.85
	BELT	2	56.4 (3) 18.8	47.4 (3) 15.8	46.2 (3) 14.0 (3) 60.2 (6)	50.6 (3) 0.84
	WEIGHT	3	122.2 (5) 24.4	88.4 (5) 17.7	28.4 (5) 46.6 (5) 74.9 (10)	30.2 (5) 0.40
	BPILLAR	2	44.2 (3) 14.7	39.9 (3) 13.3	57.6 (3) 14.9 (3) 72.5 (6)	50.2 (3) 0.69
	VERT*	3	60.9 (5) 12.2	213.0 (5) 42.6	158.4 (5) 41.4 (5) 199.8 (10)	181.1 (5) 0.91

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling scheme. To obtain the adjusted χ^2, divide the χ^2 values in the table by 1.8 (see Appendix A for derivation of the adjusted factors)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$

Table 3-11

Statistics† Generated for Some of the Significant Variables in the Variable Selection Process for Injury Characterization OAIS $\geq$ 3

Selection Stage	Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	T_3,Pre (d.f.) T_3,Post (d.f.) T_3,Pre + T_3, Post(d.f.)	T_4 (d.f.) I††
1	BELT	2	19.0 (1) 19.0	12.3 (1) 12.3	2.9 (1) 9.0 (1) 11.9 (2)	11.9 (1) 1.00
	AGE	3	32.7 (2) 16.3	33.3 (2) 16.6	1.6 (2) 39.8 (2) 41.4 (4)	34.3 (2) 0.83
	SWEIGHT	3	32.1 (2) 16.1	38.2 (2) 19.1	2.0 (2) 44.3 (2) 46.3 (4)	42.6 (2) 0.92
	NBVEH*	2	17.4 (1) 17.4	26.2 (1) 26.2	33.1 (1) 3.2 (1) 36.3 (2)	25.4 (1) 0.70
2	BELT	2	56.4 (3) 18.8	42.3 (3) 14.1	45.1 (3) 13.0 (3) 58.1 (6)	45.6 (3) 0.78
	VERT*	3	60.9 (5) 12.2	246.1 (5) 49.2	170.8 (5) 26.7 (5) 197.5 (10)	172.9 (5) 0.88

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling scheme. To obtain the adjusted X^2, divide the X^2 values in the table by 1.4 (see Appendix A for derivation of the adjusted factors)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$

Table 3-12

Statistics† Generated for Some of the Significant Variables in the Variable Selection Process for Injury Characterization OAIS $\geq$ K

Selection Stage	Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$ (d.f.)	T_4 (d.f.) I††
1	NBVEH*	2	17.4 (1) 17.4	40.5 (1) 40.5	30.7 (1) 11.6 (1) 42.3 (2)	38.4 (1) 0.91
	SEX	2	67.0 (3) 22.3	41.6 (3) 13.9	46.5 (3) 12.1 (3) 58.6 (6)	48.7 (3) 0.83
	BELT	2	56.4 (3) 18.8	52.1 (3) 17.4	48.5 (3) 11.5 (3) 60.1 (6)	46.1 (3) 0.77
2	WEIGHT	3	122.2 (5) 24.4	60.4 (5) 12.1	9.3 (5) 44.4 (5) 53.7 (10)	21.4 (5) 0.40
	BPILLAR	2	44.2 (3) 14.7	44.3 (3) 14.8	48.4 (3) 12.2 (3) 60.7 (6)	43.5 (3) 0.72
	DOOR	2	116.4 (3) 38.8	38.7 (3) 12.9	12.1 (3) 32.8 (3) 44.9 (6)	4.0 (3) 0.09
	VERT*	3	60.9 (5) 12.2	253.1 (5) 50.6	127.4 (5) 6.0 (5) 133.5 (10)	107.7 (5) 0.85

*Variable selected at the given stage

† These statistics have not been adjusted to account for the sampling scheme. To obtain the adjusted χ^2, divide the χ^2 values in the table by 1.4 (see Appendix A for derivation of the adjusted factors)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$

The variable NBVEH was selected first because it has the largest T_2/d.f. (41.4) and its T_1/d.f. (17.4) is significant (after adjustment) at $p = 0.05$ level. In the second stage, after controlling for NBVEH, the variable VERT was selected because it has the largest T_2/d.f. (42.6) and an index of 0.91 even though its value for T_1/d.f. (12.2) is barely significant (after adjustment) at $p = 0.05$ level.

Table 3-11 and Table 3-12 contain similar statistics for some of the variables considered in the selection process for OAIS $\geq$ 3 and OAIS $\geq$ K respectively. For the same reasons as in OAIS $\geq$ 2, the variables NBVEH and VERT were selected. It is of interest to observe that the statistic T_2/d.f. for the variable VERT increases as the injury becomes more severe.

3.5. Estimation of Effectiveness of FMVSS 214 (Injury Reduction)

Based on the appropriate set of control variables selected in the preceding analysis, a series of modules were fitted to the injury data for the pre- and post-standard comparison relative to each one of the five injury characterizations. The effectiveness estimate for FMVSS 214 was then computed using the smoothed injury rates resulting from the last model fitted.

A discussion of the model fitting process and the subsequent derivation of the effectiveness estimate is given below in detail for OAIS $\geq$ 1 and in abbreviated fashion for the other injury characterizations.

3.5.1. Effectiveness Estimates for OAIS > 1

Relative to the injury characterization OAIS $\geq$ 1, the weighted injury data for both pre- and post-standard cars are given for each combination of levels of the factors: occupant sex (SEX), presence of B-pillar (BPILLAR), type of seat (TYPESEAT), and direction of force (DFORCE) as shown in Table 3-13.

Linear models of the form, $\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$, were then fitted to the data of Table 3-13 via the Grizzle-Starmer-Koch method of weighted least squares procedure [3], where $\underset{\sim}{P}$ is the vector of observed injury proportions in the various subpopulations defined by SEX, BPILLAR, TYPESEAT, DFORCE, and STANDARD, $\underset{\sim}{X}$ is a design matrix, and $\underset{\sim}{\beta}$ is a vector of model coefficients.

The first step involved the analysis of a saturated model where the design matrix X contains all main effects and interactions. A second model was then fitted where the design matrix X was obtained by deleting all columns (from the design matrix of the saturated model) that correspond to the non-significant main effects and interaction terms. The results indicated significant interactions of all orders between occupant sex and the other factors. Furthermore, from Table 3-13 female occupants seemed to have generally higher injury rates than male occupants. Therefore in order to better explain these higher order interactions, occupant sex was used to define a saturated 2-module model. Figure 3-3 shows the vector of injured proportions, the design matrix corresponding to this saturated 2-module model, and the estimated model coefficients resulting from fitting the design matrix to the data.

The design matrix X is in block diagonal form. The partition is defined by the variable occupant sex. The submatrix $\underset{\sim}{X}_1$ is the design matrix for the module corresponding to male occupants and $\underset{\sim}{X}_2$ is the design matrix for the

Table 3-13

Data for Pre- and Post-Standard Comparison

Relative to OAIS $\geq$ 1 Injury Characterization

Occupant Sex	Presence of B-PILLAR	Type of Seat	Direction of Force	Standard	OAIS $\geq$ 1 Injury No	OAIS $\geq$ 1 Injury Yes	Proportion Injured	Stratum Weight
MALE	NO	BENCH	LATERAL	PRE	103	57	0.356	0.078
				POST	62	93	0.600	
			NON-LATERAL	PRE	34	30	0.469	0.044
				POST	85	27	0.241	
		BUCKET	LATERAL	PRE	50	50	0.500	0.066
				POST	100	66	0.397	
			NON-LATERAL	PRE	45	25	0.357	0.040
				POST	69	23	0.250	
	YES	BENCH	LATERAL	PRE	21	66	0.759	0.095
				POST	164	134	0.450	
			NON-LATERAL	PRE	75	29	0.279	0.069
				POST	125	48	0.277	
		BUCKET	LATERAL	PRE	29	35	0.547	0.103
				POST	224	127	0.362	
			NON-LATERAL	PRE	42	17	0.288	0.060
				POST	112	72	0.391	
FEMALE	NO	BENCH	LATERAL	PRE	36	37	0.507	0.061
				POST	84	88	0.512	
			NON-LATERAL	PRE	20	23	0.535	0.029
				POST	56	17	0.233	
		BUCKET	LATERAL	PRE	8	17	0.680	0.042
				POST	47	96	0.671	
			NON-LATERAL	PRE	0	9	0.989	0.014
				POST	20	29	0.592	
	YES	BENCH	LATERAL	PRE	41	76	0.650	0.106
				POST	118	194	0.622	
			NON-LATERAL	PRE	60	25	0.294	0.070
				POST	115	82	0.416	
		BUCKET	LATERAL	PRE	10	54	0.844	0.083
				POST	90	181	0.668	
			NON-LATERAL	PRE	0	14	0.993	0.040
				POST	67	80	0.544	

module corresponding to female occupants. The vectors of injured proportions, $\underset{\sim}{P}$, and model coefficients, $\underset{\sim}{\beta}$, are similarly partitioned. After successively deleting columns of the design matrix $\underset{\sim}{X}$ corresponding to non-significant model coefficients in Figure 3-3, a final design matrix $\underset{\sim}{X}_f$ was fitted to the data. Figure 3-4 shows this final design matrix, the corresponding model coefficient estimates resulting from fitting this design matrix to the data, the predicted injury rates based on the linear model $\underset{\sim}{P} = \underset{\sim}{X}_f\underset{\sim}{\beta}$, the goodness of fit statistic for this model, and the overall effectiveness estimate for FMVSS 214 derived from the predicted (smoothed) injury rates and the stratum weights.

For male occupants, the two main effects, TYPESEAT (T) and STANDARD (G) and the interaction TYPESEAT x DFORCE (TxF) are statistically significant at α = 0.05 level. The 3rd order interaction, TYPESEAT x DFORCE x STANDARD (TxFxG) is statistically significant at χ = 0.05 level only in the absence of B-pillar.

For female occupants, the two main effects, DFORCE (F) and STANDARD (G), and the interactions, BPILLAR x TYPESEAT (BxT), TYPESEAT x STANDARD (TXG), DFORCE x STANDARD (FxG), and TYPESEAT x DFORCE x STANDARD (TxFxG) are all statistically significant at the $\alpha = 0.05$ level.

The main effect standard is significant at $\alpha = 0.05$ for both the male occupants ($\beta_3 = 0.110$, $\chi^2(\beta_3) = 5.98$, $p < 0.05$) and the female occupants ($\beta_8 = 0.531$, $\chi_2(\beta_8) = 86.8$, $p < .001$). The fact that β_3 and β_8 are both positive implies that the occupants of post-standard passenger cars have lower injury rate than the occupants of pre-standard passenger cars. Furthermore, the test statistic $\beta_3 - \beta_8 = -0.421$ ($\chi^2(\beta_3 - \beta_8) = 33.26$, $p < .001$) shows that the standard has significantly different effects on the female occupants as opposed to the male occupants.

There is also a significant difference in the overall injury rates between the male occupants and the female occupants as evidenced by the statistic $\beta_1 - \beta_6 = -0.113$ with $\chi^2(\beta_1 - \beta_6) = 4.38$ and $p < .005$.

The effectiveness estimate $\hat{E}$ for FMVSS 214 is derived from the predicted injury rates $\hat{\underset{\sim}{P}}$ as follows. There are 16 strata or factor level combinations corresponding to the four factors: SEX (2 levels), BPILLAR (2 levels), TYPESEAT (2 levels), and DFORCE (2 levels). For the ith stratum, a weight w_i which corresponds to the proportion of occupants in the ith stratum is calculated and appears in the last column of Table 3-13. Within the ith stratum, the predicted injury rate $\hat{P}_{i,Pre}$ for occupants of Pre-standard passenger cars, and the difference in the predicted injury rates, $P_{i,Pre} - P_{i,Post}$, between the

Figure 3-3

Observed Injury Proportion ($\tilde{P}$), Saturated 2-Module Design Matrix ($\tilde{X}$), and Model Coefficient Estimates ($\tilde{\beta}$) Partitioned with Respect to Occupant Sex

$$\underset{32\times1}{\tilde{P}} = \begin{bmatrix} \underset{16\times1}{\tilde{P}_1} \\ \hline \underset{16\times1}{\tilde{P}_2} \end{bmatrix} \qquad \underset{32\times32}{\tilde{X}} = \left[\begin{array}{c|c} \underset{16\times16}{\tilde{X}_1} & \underset{16\times16}{\tilde{0}} \\ \hline \underset{16\times16}{\tilde{0}} & \underset{16\times16}{\tilde{X}_2} \end{array}\right] \qquad \underset{32\times1}{\tilde{\beta}} = \begin{bmatrix} \underset{16\times1}{\tilde{\beta}_1} \\ \hline \underset{16\times1}{\tilde{\beta}_2} \end{bmatrix}$$

where

$$\underset{16\times1}{\tilde{P}_1} = \begin{bmatrix} 0.356 \\ 0.600 \\ 0.469 \\ 0.241 \\ 0.500 \\ 0.397 \\ 0.357 \\ 0.250 \\ 0.759 \\ 0.450 \\ 0.279 \\ 0.277 \\ 0.547 \\ 0.362 \\ 0.288 \\ 0.391 \end{bmatrix}, \quad \underset{16\times1}{\tilde{P}_2} = \begin{bmatrix} 0.507 \\ 0.512 \\ 0.535 \\ 0.989 \\ 0.680 \\ 0.671 \\ 0.989 \\ 0.592 \\ 0.650 \\ 0.622 \\ 0.294 \\ 0.416 \\ 0.844 \\ 0.668 \\ 0.993 \\ 0.544 \end{bmatrix} \quad \underset{16\times16}{\tilde{X}_1} = \underset{16\times16}{\tilde{X}_2} = \begin{bmatrix} 1&1&1&1&1&1&1&1&1&1&1&1&1&1&1&1 \\ 1&1&1&1&0&1&1&0&1&0&0&1&0&0&0&0 \\ 1&1&1&0&1&1&0&1&0&1&0&0&1&0&0&0 \\ 1&1&1&0&0&1&0&0&0&0&0&0&0&0&0&0 \\ 1&1&0&1&1&0&1&1&0&0&1&0&0&1&0&0 \\ 1&1&0&1&0&0&1&0&0&0&0&0&0&0&0&0 \\ 1&1&0&0&1&0&0&1&0&0&0&0&0&0&0&0 \\ 1&1&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 1&0&1&1&1&0&0&0&1&1&1&0&0&0&1&0 \\ 1&0&1&1&0&0&0&0&1&0&0&0&0&0&0&0 \\ 1&0&1&0&1&0&0&0&0&1&0&0&0&0&0&0 \\ 1&0&1&0&0&0&0&0&0&0&0&0&0&0&0&0 \\ 1&0&0&1&1&0&0&0&0&0&1&0&0&0&0&0 \\ 1&0&0&1&0&0&0&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&1&0&0&0&0&0&0&0&0&0&0&0 \\ 1&0&0&0&0&0&0&0&0&0&0&0&0&0&0&0 \end{bmatrix}$$

(Model Coefficient Estimates and Standard Errors)

Interpretation of Model Coefficient	MALE Model Coefficient	MALE Coefficient Estimates	MALE S.D.	FEMALE Model Coefficient	FEMALE Coefficient Estimates	FEMALE S.D.
Overall Injury Rate	β_1	0.391	0.069	β_{17}	0.544	0.079
Main Effects						
B-PILLAR (B)	β_2	-0.141	0.111	β_{18}	0.189	0.192
TYPESEAT (T)	β_3	-0.114	0.095	β_{19}	-0.128	0.104
DFORCE (F)	β_4	-0.029	0.085	β_{20}	0.124	0.096
STANDARD (G)	β_5	-0.103	0.133	β_{21}	0.449	0.090
2nd Order Interactions						
BxT	β_6	0.105	0.150	β_{22}	-0.231	0.195
BxF	β_7	0.177	0.142	β_{23}	-0.044	0.182
BxG	β_8	0.210	0.193	β_{24}	-0.052	0.175
TxF	β_9	0.202	0.121	β_{25}	0.082	0.129
TxG	β_{10}	0.105	0.170	β_{26}	-0.571	0.147
FxG	β_{11}	0.288	0.185	β_{27}	-0.273	0.137
3rd Order Interactions						
BxTxF	β_{12}	0.010	0.198	β_{28}	0.117	0.234
BxTxG	β_{13}	0.016	0.263	β_{29}	0.476	0.273
BxFxG	β_{14}	-0.293	0.262	β_{30}	-0.116	0.281
TxFxG	β_{15}	0.019	0.238	β_{31}	0.423	0.205
4th Order Interactions						
BxTxFxG	β_{16}	-0.486	0.349	β_{32}	-0.341	0.388

Figure 3-4

Final Model for Pre- and Post-Standard Comparison Based on OAIS ≥ 1 Injury Characterization

$$\underset{32\times1}{\underset{\sim}{P}} = \begin{bmatrix} \underset{16\times1}{\underset{\sim}{P}_1} \\ \hline \underset{16\times1}{\underset{\sim}{P}_2} \end{bmatrix} \qquad \underset{32\times12}{\underset{\sim}{X}} = \left[\begin{array}{c|c} \underset{16\times5}{\underset{\sim}{X}_1} & \underset{16\times7}{\underset{\sim}{0}} \\ \hline \underset{16\times5}{\underset{\sim}{0}} & \underset{16\times7}{\underset{\sim}{X}_2} \end{array}\right] \qquad \underset{12\times1}{\underset{\sim}{\beta}} = \begin{bmatrix} \underset{5\times1}{\underset{\sim}{\beta}_1} \\ \hline \underset{7\times1}{\underset{\sim}{\beta}_2} \end{bmatrix}$$

where $\underset{\sim}{P}_1$, $\underset{\sim}{P}_2$, $\underset{\sim}{X}_1$, $\underset{\sim}{X}_2$ and $\underset{\sim}{\beta}_1$, $\underset{\sim}{\beta}_2$ are given in the table below.

Observed and Predicted Injury Rates, the Final 2-Module Design Matrix, and the Model Coefficients

Sex S	B-Pillar B	Type of Seat	Dir. of Force	STD G	Observed Injury Rates $\underset{\sim}{P}$	Predicted Injury Rates $\hat{\underset{\sim}{P}} = \underset{\sim}{X}_f\underset{\sim}{\beta}$	Final Design Matrix $\underset{\sim}{X}_f$		Model Coefficients $\underset{\sim}{\beta}$
M	No	BENCH	L	PRE	0.356	0.356	1 1 1 1 1		β_1
				POST	0.600	0.532	1 1 0 1 0		
			NL	PRE	0.469	0.362	1 1 1 0 0		β_2
				POST	0.241	0.252	1 1 0 0 0		
		BUCKET	L	PRE	0.500	0.458	1 0 1 0 0		β_3
				POST	0.397	0.348	1 0 0 0 0		
			NL	PRE	0.357	0.458	1 0 1 0 0	0	β_4
				POST	0.250	0.348	1 0 0 0 0	16x7	
	Yes	BENCH	L	PRE	0.759	0.642	1 1 1 1 0		β_5
				POST	0.450	0.532	1 1 0 1 0		
			NL	PRE	0.279	0.362	1 1 1 0 0		β_6
				POST	0.277	0.252	1 1 0 0 0		
		BUCKET	L	PRE	0.547	0.458	1 0 1 0 0		β_7
				POST	0.362	0.348	1 0 0 0 0		
			NL	PRE	0.288	0.458	1 0 1 0 0		β_8
				POST	0.391	0.348	1 0 0 0 0		
							X_1 16x5	X_2 16x7	β_9
F	No	BENCH	L	PRE	0.507	0.514		1 1 1 1 1 1 1	β_{10}
				POST	0.512	0.517		1 1 0 1 0 0 0	
			NL	PRE	0.535	0.273		1 0 1 1 1 0 0	β_{11}
				POST	0.233	0.330		1 0 0 1 0 0 0	
		BUCKET	L	PRE	0.680	0.812		1 1 1 0 0 1 0	β_{12}
				POST	0.671	0.648		1 1 0 0 0 0 0	
			NL	PRE	0.989	0.992		1 0 1 0 0 0 0	
				POST	0.592	0.461	0	1 0 0 0 0 0 0	
	Yes	BENCH	L	PRE	0.650	0.645	16x5	1 1 1 0 1 1 1	
				POST	0.622	0.648		1 1 0 0 0 0 0	
			NL	PRE	0.294	0.405		1 0 1 0 1 0 0	
				POST	0.416	0.461		1 0 0 0 0 0 0	
		BUCKET	L	PRE	0.844	0.812		1 1 1 0 0 1 0	
				POST	0.668	0.648		1 1 0 0 0 0 0	
			NL	PRE	0.993	0.992		1 0 1 0 0 0 0	
				POST	0.544	0.461		1 0 0 0 0 0 0	

Figure 3-4 (continued)

Interpretation of Model Coefficient	Male Model Coefficients	Male Coefficient Estimates	Male S.D.	Female Model Coefficients	Female Coefficient Estimates	Female S.D.
Overall Injury Rate						
Male Occupant	β_1	0.348	0.030			
Female Occupant				β_6	0.461	0.044
Main Effects						
BPILLAR (B)						
TYPESEAT (T)	β_2	-0.096	0.049			
DFORCE (F)				β_7	0.187	0.053
STANDARD (G)	β_3	0.110	0.045	β_8	0.531	0.057
Interactions						
BxT				β_9	-0.131	0.055
TxF	β_4	0.281	0.057			
TxG				β_{10}	-0.587	0.089
FxG				β_{11}	-0.367	0.101
TxFxG				β_{12}	0.420	0.135
BxTxFxG	β_5	-0.286	0.090			

Test Statistics

Difference in Injury Rates Between Male and Female Occupants	$\beta_1 - \beta_6$	-0.113	0.054	
	$\chi^2 (\beta_1 - \beta_6)$ = 4.38 with 1 degree of freedom			$p < .005$
Difference in the Effects of Standard upon Male and Female Occupants	$\beta_3 - \beta_8$	-0.421	0.073	
	$\chi^2 (\beta_3 - \beta_8)$ = 33.26 with 1 degree of freedom			$p < 0.001$

Goodness of Fit Statistic

χ^2 due to Error = 21.95 with 20 degrees of freedom $p = 0.40$

Effectiveness Estimate for FMVSS 214
E = 15.0%
STANDARD ERROR = 5.1%
$\chi^2 = 8.65$, $p = 0.005$

occupants of Pre-standard cars and the occupants of post-standard cars can be given in terms of the estimated model coefficients $\hat{\beta}$ via the (linear model) equation $\underset{\sim}{P} = \underset{\sim}{X}_f\underset{\sim}{\beta}$. An overall predicted injury rate for the occupants of pre-standard cars can be given by a weighted average of $P_{i,Pre}$ as $\hat{P}_{Pre} = \sum_i w_i P_{i,Pre}$ and similarly an overall difference in the predicted injury rates between the occupants of pre-standard and post-standard cars can be given by $\hat{P}_{Pre} - \hat{P}_{Post} = \sum_i w_i(\hat{P}_{i,Pre} - \hat{P}_{i,Post})$.

More specifically, in terms of the model coefficients, one has

$$P_{Pre} = (\sum_{i=1}^{8} w_i)[\beta_1+\beta_3] - w_3\beta_3 + (w_1+w_5)[\beta_2+\beta_4] + (w_2+w_6)\ \beta_2+w_1\beta_5 + (\sum_{i=9}^{16} w_i)[\beta_6+\beta_8] + (w_9+w_{11}+w_{13}+w_{15})\beta_7 + (w_9+w_{10})[\beta_9+\beta_{10}] + (w_{13}+w_{14})\beta_{10} + (w_9+w_{13})[\beta_{11}+\beta_{12}] + w_{15}\beta_{12}$$

and

$$\hat{P}_{Pre}-\hat{P}_{Post} = (\sum_{i=1}^{8} w_i)\beta_3 + w_1\beta_5 + (\sum_{i=9}^{16} w_i)\beta_8 + (w_9+w_{10}+w_{13}+w_{14})\beta_{10} + (w_9+w_{11}+w_{13}+w_{15})\beta_{11} + (w_9+w_{13})\beta_{12}$$

The vector $\underset{\sim}{Q} = \begin{bmatrix} P_{Pre} \\ P_{Pre}-P_{Post} \end{bmatrix}$ along with its covariance matrix can be estimated via the GENCAT program [3] by a series of matrix operations. These estimates in turn can be further analyzed to provide an estimate of effectiveness of FMVSS 214 as

$$E = 100\ \frac{\hat{P}_{Pre}-\hat{P}_{Post}}{\hat{P}_{Pre}} = 100.\ \mathrm{Exp}[\underset{\sim}{A}\ \log \underset{\sim}{Q}]$$

where $\underset{\sim}{A}$ is the matrix [-1,1]. The program also provides an estimate of the variance of E. The estimate of E and the associated standard deviation are given at the bottom of Figure 3-4.

3.5.2 Effectiveness Estimate Relative to OAIS $\geq$ 2

Based on the injury characterization OAIS $\geq$ 2, the weighted injury data for occupants of both pre- and post-standard cars are given in Table 3-14 for each combination of the levels of the selected factors: NBVEH (number of vehicles involved) and VERT (primary vertical location of impact).

Initially, a saturated linear model $\underset{\sim}{P} = \underset{\sim}{X}\beta$ was fitted to the data of Table 3-14 via the GSK method where $\underset{\sim}{P}$ is the (12x1) column vector of observed injury proportion, X is a saturated design matrix, and $\underset{\sim}{\beta}$ is the saturated model coefficients. Non-significant terms were deleted and new models were successively fitted. The final model arrived at is shown in Figure 3-5.

Table 3-14
Data for Pre- and Post-Standard Comparison
Relative to OAIS $\geq$ 2 Injury Characterization

NBVEH	VERT	Standard	OAIS $\geq$ 2 Injury No	Yes	Proportion Injured	Stratum Weight
1	A	PRE	86	48	0.358	0.083
		POST	190	65	0.255	
	E+L	PRE	82	20	0.196	0.068
		POST	184	29	0.136	
	M+H+G	PRE	20	0	0.048*	0.007
		POST	10	1	0.091	
2+	A	PRE	11	16	0.593	0.050
		POST	122	82	0.402	
	E+L	PRE	888	116	0.116	0.769
		POST	2292	292	0.113	
	M+H+G	PRE	40	1	0.024	0.024
		POST	64	7	0.099	

*The '0' injury frequency was replaced by '1.'

Figure 3-5
Final Model for Pre- and Post-Standard Comparison
Based on OAIS $\geq$ 2 Injury Characterization

NBVEH	VERT	Standard	Observed Injury Rate	Predicted Injury Rates	Final Design Matrix	Model Coefficients Estimates
1	A	PRE	0.358	0.370	1 1 1 1 1 0	β_1
		POST	0.255	0.250	1 1 0 1 0 0	β_2
	E+L	PRE	0.196	0.121	1 0 1 0 0 1	β_3
		POST	0.136	0.114	1 0 0 0 0 0	β_4
	M+H+G	PRE	0.048	0.024	1 0 1 0 0 0	β_5
		POST	0.091	0.114	1 0 0 0 0 0	β_6
2+	A	PRE	0.593	0.531	1 1 1 0 1 0	
		POST	0.402	0.410	1 1 0 0 0 0	
	E+L	PRE	0.116	0.121	1 0 1 0 0 1	
		POST	0.113	0.114	1 0 0 0 0 0	
	M+H+G	PRE	0.024	0.024	1 0 1 0 0 0	
		POST	0.099	0.114	1 0 0 0 0 0	

Model Coefficient Estimates and Standard Deviations

Interpretation of Model Coefficient	Model Coefficients	Coefficient Estimates	S.D.
Overall Mean Injury Rate	β_1	0.114	0.008
Main Effects			
VERT = A (V_1)	β_2	0.296	0.044
VERT = E+L (V_2)			
NBVEH			
STANDARD (G)	β_3	-0.090	0.027
Interactions			
V_1x NBVEH	β_4	-0.160	0.054
V_1x G	β_5	0.210	0.065
V_2x G	β_6	0.096	0.029

Test Statistics

Effect of STANDARD When Primary Vertical Location of Impact = A	$\beta_3 + \beta_5$	0.120	0.059
	$X^2\ (\beta_3+\beta_5) = 4.16$ with 1 degree of freedom $p < 0.05$		
Effect of STANDARD When Primary Vertical Location of Impact = E+L	$\beta_3 + \beta_6$	0.007	0.015
	$X^2\ (\beta_3+\beta_6) = 0.19$ with 1 degree of freedom $p > 0.70$		
Effect of STANDARD When Primary Vertical Location of Impact = M+G+H	β_3	-0.090	0.027
	$X^2\ (\beta_3) = 11.0$ with 1 degree of freedom $p < 0.001$		
Overall Net Effect of STANDARD	$\beta_3+0.13\beta_5+0.84\beta_6$	0.019	0.015
	$X^2(\beta_3+0.13\beta_5+0.84\beta_6) = 1.57$ with 1 degree of freedom $p < 0.25$		

Goodness of Fit Statistic
X^2 due to Error = 3.21 with 6 degrees of freedom and $p > 0.75$
Effectiveness Estimate for FMVSS 214
E = 11.8%
STANDARD ERROR = 7.8%
$X^2 = 1.84$, $p = 0.18$

The interpretation of the model coefficients as shown in Figure 3-5 can be easily asessed from the following equivalent representation of the final linear model $\underset{\sim}{P}=\underset{\sim}{X}_f\underset{\sim}{\beta}$ obtained by equating both sides of this equation.

Figure 3-6

An Equivalent Representation of the Linear Model

$\underset{\sim}{P}=\underset{\sim}{X}_f\underset{\sim}{\beta}$ for OAIS $\geq$ 2

Injury Rates			Primary Vertical Location of Impact A	E+L	M+G+H
Number of Vehicles Involved	1	Pre-Standard	$P_1=\beta_1+\beta_2+\beta_3+\beta_4+\beta_5$	$P_3=\beta_1+\beta_3+\beta_6$	$P_5=\beta_1+\beta_3$
		Post-Standard	$P_2=\beta_1+\beta_2+\beta_4$	$P_4=\beta_1$	$P_6=\beta_1$
	2+	Pre-Standard	$P_7=\beta_1+\beta_2+\beta_3+\beta_5$	$P_9=\beta_1+\beta_3+\beta_6$	$P_{11}=\beta_1+\beta_3$
		Post-Standard	$P_8=\beta_1+\beta_2$	$P_{10}=\beta_1$	$P_{12}=\beta_1$

In particular, from the above table, one can easily observe that β_3 represents the effect of the STANDARD on injury rates when the primary vertical location of impact is M+G+H. The fact that $\beta_3=-0.090$ is negative implies that in this type of vertical impact, the occupants of post-standard cars have slightly higher injury rates in both single and multi-vehicle accidents. Similarly, $\beta_3+\beta_5$ and $\beta_3+\beta_6$ represent the net effects of the standard when the primary vertical locations of impact are A and E+L respectively. The fact that $\beta_3+\beta_5 = 0.025$ and $\beta_3+\beta_6 = 0.007$ implies that the occupants of post-standard cars have lower injury rates in these types of vertical impacts in both single and multi-vehicle accidents. The overall net effect of the standard is given by the statistic $\underset{\sim}{C}\underset{\sim}{\beta}$ where $\underset{\sim}{C}$ is the contrast matrix

$$\underset{\sim}{C} = [0 \quad 0 \quad 1 \quad 0 \quad 0.133 \quad 0.837]$$

Equivalently, C is the sum of the effects of the STANDARD in each stratum weighted by the stratum weight W_i. It is of interest to point out that even though the overall net effect of the STANDARD is not significant at $\alpha = 0.05$, the effect of the standard is significant in the situations where the vertical location of impact is A.

The effectiveness estimate $\hat{E}$ for FMVSS 214 is 11.8%. However, this is not significant.

3.5.3 Effectiveness Estimate Relative to OAIS > 3

Relative to the injury characterization OAIS $\geq$ 3, the weighted injury data for occupants of both pre- and post-standard cars are given in Table 3-15 for each combination of the levels of the selected factors: NBVEH (number of vehicles involved) and VERT (primary vertical location of impact).

Initially, a saturated model $\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$ was fitted to the data of Table 3-15 via the GSK method where $\underset{\sim}{P}$ is the (12x1) column vector of observed injury proportions, $\underset{\sim}{X}$ is a saturated design matrix, and $\underset{\sim}{\beta}$ is the saturated model coefficients. Non-significant terms were deleted and new models were successively fitted. The final model arrived at is shown in Figure 3-7.

Table 3-15
Data for Pre- and Post-Standard Comparison
Relative to OAIS $\geq$ 3 Injury Characterization

NBVEH	VERT	Standard	OAIS $\geq$ 3 Injury No	OAIS $\geq$ 3 Injury Yes	Proportion Injured	Stratum Weight
1	A	PRE	95	39	0.291	0.083
		POST	212	43	0.169	
	E+L	PRE	90	12	0.118	0.068
		POST	205	8	0.038	
	M+H+G	PRE	20	0	0.048*	0.007
		POST	10	1	0.091	
2+	A	PRE	12	15	0.556	0.050
		POST	141	63	0.309	
	E+L	PRE	940	64	0.064	0.769
		POST	2409	175	0.068	
	M+H+G	PRE	40	1	0.024	0.024
		POST	70	1	0.014	

*The '0' injury frequency was replaced by '1'.

Figure 3-7
Final Model for Pre- and Post-Standard Comparison
Based on OAIS $\geq$ 3 Injury Characterization

NBVEH	VERT	Standard	Observed Injury Rate	Predicted Injury Rates	Final Design Matrix						Model Coefficient Estimates
1	A	PRE	0.291	0.307	1	1	0	1	1	1	β_1
		POST	0.169	0.163	1	1	0	0	1	0	β_2
	E+L	PRE	0.118	0.065	1	0	1	1	0	0	β_3
		POST	0.038	0.065	1	0	1	0	0	0	β_4
	M+G+H	PRE	0.024	0.019	1	0	0	1	0	0	β_5
		POST	0.091	0.019	1	0	0	0	0	0	β_6
2+	A	PRE	0.556	0.463	1	1	0	1	0	1	
		POST	0.309	0.319	1	1	0	0	0	0	
	E+L	PRE	0.064	0.065	1	0	1	1	0	0	
		POST	0.068	0.065	1	0	1	0	0	0	
	M+H+G	PRE	0.024	0.019	1	0	0	1	0	0	
		POST	0.014	0.019	1	0	0	0	0	0	

Model Coefficient Estimates and Standard Deviations

Interpretation of Model Coefficient	Model Coefficients	Coefficient Estimates	S.D.
Overall Mean Injury Rate	β_1	0.018	0.014
Main Effects			
VERT = A (V_1)	β_2	0.302	0.039
VERT = E+L (V_2)	β_3	0.046	0.014
NBVEH			
STANDARD (G)	β_4	0.003	0.010
Interactions			
V_1 x NBVEH	β_5	-0.156	0.044
V_1 x STANDARD	β_6	0.140	0.050

Goodness of Fit Statistic

X^2 due to Error = 6.75 with 6 degrees of freedom and $p > 0.45$
Effectiveness Estimate for FMVSS 214

E = 20.9%
STANDARD ERROR = 8.6%
$X^2 = 5.9$, $p < 0.020$

The interpretation of the model coefficients as shown in Figure 3-7 can be assessed from the following equivalent representation of the final linear model $\underset{\sim}{P} = \underset{\sim}{X}_f\underset{\sim}{\beta}$ obtained by equating both sides of this equation.

Figure 3-8
An Equivalent Representation of the Linear Model
$\underset{\sim}{P} = \underset{\sim}{X}_f\underset{\sim}{\beta}$ for OAIS $\geq$ 3

		Injury Rates	Primary Vertical Location of Impact: A	E+L	M+G+H
Number of Vehicles Involved	1	Pre-Standard	$P_1=\beta_1+\beta_2+\beta_4+\beta_5+\beta_6$	$P_3=\beta_1+\beta_3+\beta_4$	$P_5=\beta_1+\beta_4$
		Post-Standard	$P_2=\beta_1+\beta_2+\beta_5$	$P_4=\beta_1+\beta_3$	$P_6=\beta_1$
	2+	Pre-Standard	$P_7=\beta_1+\beta_2+\beta_4+\beta_6$	$P_9=\beta_1+\beta_3+\beta_4$	$P_{11}=\beta_1+\beta_4$
		Post-Standard	$P_8=\beta_1+\beta_2$	$P_{10}=\beta_1+\beta_3$	$P_{12}=\beta_1$

From the above table, one can observe that the overall mean injury rate β_1 is also equal to the injury rates for occupants of post-standard cars involved in either single- or multi-vehicle accidents where the primary vertical location of impact is M+G+H, β_2 is the effect of primary vertical location of impact being equal to A. β_3 is the effect of a change in vertical location of impact from E+L to M+G+H. β_4 is the overall effect of the standard and β_5 is the effect of a change from single-vehicle accident to multi-vehicle accident when the vertical location of impact is A, and β_6, which is significant at $\alpha = 0.05$ is the effect of STANDARD when the primary vertical location of impact is A. Note that even though the overall effect of STANDARD β_4 is not significant the effect of the standard when VERT=A (β_6) is significant. Consequently, the effectiveness of FMVSS 214 for this injury characterization is primarily realized in accidents where the primary vertical location of impact is A. The effectiveness estimate for FMVSS 214 based on OAIS $\geq$ 3 is 20.9% with a standard error of 8.6%.

3.5.4 Effectiveness Estimate Relative to OAIS $\geq$ K

Relative to the injury characterization OAIS $\geq$ K, the weighted injury data for occupants of both pre- and post-standard cars are given in Table 3-16 for each combination of the levels of the selected factors: NBVEH (number of vehicles involved) and VERT (primary vertical location of impact).

Initially, a saturated model $\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$ was fitted to the Table 3-16 via the GSK method, where the P is the observed injury proportions, $\underset{\sim}{X}$ is the saturated design matrix defined by the factors NBVEH and VERT, and $\underset{\sim}{\beta}$ is the model coefficient vector corresponding to this saturated model. Non-significant terms were deleted and new models were successively fitted. The final model arrived at is shown in Figure 3-9.

Table 3-16
Data for Pre- and Post-Standard Comparison
Relative to OAIS $\geq$ K Injury Characterization

NBVEH	VERT	Standard	OAIS $\geq$ K Injury No	Yes	Proportion Injured	Stratum Weight
1	A	PRE	120	14	0.105	0.083
		POST	242	13	0.051	
	E+L	PRE	98	4	0.039	0.068
		POST	210	3	0.014	
	M+H+G	PRE	20	0	0.048*	0.007
		POST	11	0	0.083*	
2+	A	PRE	18	9	0.333	0.050
		POST	184	20	0.098	
	E+L	PRE	1000	4	0.004	0.769
		POST	2568	16	0.006	
	M+H+G	PRE	41	0	0.024*	0.024
		POST	71	0	0.014*	

*The '0' injury frequencies have been replaced by '1'.

Figure 3-9
Final Model for Pre- and Post-Standard Comparison
Based on OAIS $\geq$ K Injury Characterization

NBVEH	VERT	Standard	Observed Injury Rate	Predicted Injury Rates	Final Design Matrix	Model Coefficients
1	A	PRE	0.105	0.118	1 1 1 1 1 1	β_1
		POST	0.051	0.047	1 1 1 0 1 0	β_2
	E+L	PRE	0.039	0.018	1 1 0 1 0 0	β_3
		POST	0.014	0.019	1 1 0 0 0 0	β_4
	M+G+H	PRE	0.048	0.018	1 1 0 1 0 0	β_5
		POST	0.083	0.019	1 1 0 0 0 0	β_6
2+	A	PRE	0.333	0.177	1 0 1 1 0 1	
		POST	0.098	0.106	1 0 1 0 0 0	
	E+L	PRE	0.004	0.004	1 0 0 1 0 0	
		POST	0.006	0.006	1 0 0 0 0 0	
	M+H+G	PRE	0.024	0.004	1 0 0 1 0 0	
		POST	0.014	0.006	1 0 0 0 0 0	

Model Coefficient Estimates and Standard Deviations

Interpretation of Model Coefficient	Model Coefficients	Coefficient Estimates	S.D.
Overall Mean Injury Rate	β_1	0.006	0.002
Main Effects			
NBVEH	β_2	0.013	0.008
VERT = A	β_3	0.100	0.024
STANDARD (G)	β_4	-0.002	0.003
Interaction			
NBVEH x A	β_5	-0.072	0.030
A x G	β_6	0.072	0.033

Goodness of Fit Statistic

X^2 due to Error = 5.25 with 6 degrees of freedom and p = 0.52

Effectiveness Estimate for FMVSS 214

E = 33.6%

STANDARD ERROR = 16.2%

X^2 = 4.3, p = 0.04

Figure 3-10
An Equivalent Representation of the Linear Model
$\underset{\sim}{P} = X_f \underset{\sim}{\beta}$ for OAIS $\geq$ K

		Injury Rates	Primary Vertical Location of Impact: A	E+L	M+G+H
Number of Vehicles Involved	1	Pre-Standard	$P_1=\beta_1+\beta_2+\beta_3+\beta_4+\beta_5+\beta_6$	$P_3=\beta_1+\beta_2+\beta_4$	$P_5=\beta_1+\beta_2+\beta_4$
		Post-Standard	$P_2=\beta_1+\beta_2+\beta_3+\beta_5$	$P_5=\beta_1+\beta_2$	$P_6=\beta_1+\beta_2$
	2+	Pre-Standard	$P_7=\beta_1+\beta_3+\beta_4+\beta_6$	$P_9=\beta_1+\beta_4$	$P_{11}=\beta_1+\beta_4$
		Post-Standard	$P_8=\beta_1+\beta_3$	$P_{10}=\beta_1$	$P_{12}=\beta_1$

From the equivalent representation of the linear model $\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$ as shown in Figure 3-10, one can easily note that β_4, which is not significant at $\alpha = 0.05$, is the effect of STANDARD. However, $\beta_4 + \beta_6 = 0.070$ (s.e. 0.033) which represents the effect of the Standard in those accident cases where the vertical location of impact, VERT = A, is statistically significant at $\alpha = 0.05$, futhermore, since $\beta_4 + \beta_6$ is positive, this implies that the occupants of post-standard cars have lower fatality rates than the occupants of pre-standards cars, in these types of accidents.

Nevertheless the relatively high reduction in fatalities should be scaled down somewhat in view of the potential for spurious significant result obtained as a consequence of modeling contingency tables with small frequencies.

The resulting effectiveness estimate E = 33.6% for FMVSS 214 is statistically significant at p = 0.04 with a standard error of 16.2%.

3.5.5 Effectiveness Estimate Relative to SOAIS $\geq$ 1

Relative to the side structure injury characterization SOAIS $\geq$ 1, the weighted injury data for occupants of both pre- and post-standard cars are given in Table 3-17 for each combination of the levels of the selected factors: SEX (of occupants), LOC (rural or urban), and AREAD (primary area of impact = left or right side).

Initially a saturated 2-module model $\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$ is fitted to the data of Table 3-17 via the GSK method where P is the observed injury proportions, $\underset{\sim}{X}$ is the saturated 2-module design matrix partitioned by the varaible SEX, and $\underset{\sim}{\beta}$ is the corresponding model coefficients. Non-significant terms were deleted and new 2-module models were successively fitted. The final 2-module model is shown in Figure 3-11.

Table 3-17

Sex	Location	Area	Standard	SOAIS $\geq$ 1 No	SOAIS $\geq$ 1 Yes	Observed Injury Rates	Predicted Injury Rates	Stratum Weight
M	Rural	Left	PRE	76	16	0.174	0.167	0.125
			POST	268	53	0.165	0.167	
		R	PRE	10	7	0.412	0.351	0.027
			POST	47	24	0.300	0.351	
	Urban	L	PRE	318	59	0.159	0.169	0.333
			POST	592	126	0.175	0.169	
		R	PRE	114	13	0.102	0.107	0.108
			POST	203	25	0.110	0.107	
F	Rural	L	PRE	35	22	0.386	0.437	0.046
			POST	57	38	0.400	0.369	
		R	PRE	9	9	0.500	0.324	0.031
			POST	56	29	0.341	0.324	
	Urban	L	PRE	99	38	0.277	0.260	0.204
			POST	435	101	0.188	0.192	
		R	PRE	49	17	0.258	0.324	0.125
			POST	233	113	0.327	0.324	

Figure 3-11
Final 2-Module Model for Pre- and Post-Standard Comparison
Based on SOAIS $\geq$ 1 Site Structure Injury Characterization

Occ. Sex	Location	AREAD	Standard	Observed Injury Rates	Predicted Injury Rates	Final 2-Module Design Matrix		Model Coefficient
M	Rural	Left	PRE	0.174	0.167	1 1 1 1		β_1
			POST	0.165	0.167	1 1 1 1		β_2
		Right	PRE	0.412	0.351	1 1 0 0		β_3
			POST	0.300	0.351	1 1 0 0	0	β_4
	Urban	Left	PRE	0.159	0.169	1 0 1 0	8x4	β_5
			POST	0.175	0.169	1 0 1 0		β_6
		Right	PRE	0.102	0.107	1 0 0 0		β_7
			POST	0.110	0.107	1 0 0 0		β_8
F	Rural	Left	PRE	0.386	0.437		1 1 1 1	
			POST	0.400	0.369		1 1 1 0	
		Right	PRE	0.500	0.324		1 0 0 0	
			POST	0.341	0.324	0	1 0 0 0	
	Urban	Left	PRE	0.277	0.260	8x4	1 1 0 1	
			POST	0.188	0.192		1 1 0 0	
		Right	PRE	0.258	0.324		1 0 0 0	
			POST	0.327	0.324		1 0 0 0	

Model Coefficient Estimates and Standard Deviations

Interpretation of Model Coefficients	Model Coefficients	Coefficient Estimates	S.D.
Male Occupants			
Overall Mean Injury Rate	β_1	0.017	0.0250
Main Effects			
Location (L)	β_2	0.244	0.081
AREAD (A)	β_3	0.062	0.030
Interaction			
LxA	β_4	-0.246	0.088
Female Occupants			
Overall Mean Injury Rate	β_5	0.324	0.031
AREAD (A)	β_6	-0.132	0.040
STANDARD (G)			
Interactions			
LxA	β_7	0.177	0.066
AxG	β_8	0.068	0.057

Test Statistics

Difference in Overall Mean Injury Rates Between Male and Female Occupants — $\beta_1 - \beta_5$ -0.217   0.040

$\chi^2(\beta_1-\beta_5)$ = 29.43 with 1 degree of freedom $p < .001$

Effects of Standard on Female Injury Rate in Left Side Impact — β_8 -0.068   0.057

$\chi^2(\beta_8)$ = 1.42 with 1 degree of freedom $p = 0.24$

Goodness of Fit Statistic
due to Error = 2.69 with 8 degrees of freedom $p = 0.95$
Effectiveness Estimate for FMVSS 214
E = 7.62%
STANDARD ERROR = 6.01%
χ^2 = 1.61, $p = 0.20$

Figure 3-12
An Equivalent Representation of the Linear Model
$\underset{\sim}{P} = \underset{\sim}{X}\underset{\sim}{\beta}$ for SOAIS $\geq$ 1

	Location	Injury Rates	Left Side	Right Side
Male	Rural	Pre-Standard	$P_1 = \beta_1+\beta_2+\beta_3+\beta_4$	$P_3 = \beta_1+\beta_2$
		Post-Standard	$P_2 = \beta_1+\beta_2+\beta_3+\beta_4$	$P_4 = \beta_1+\beta_2$
	Urban	Pre-Standard	$P_5 = \beta_1+\beta_3$	$P_7 = \beta_1$
		Post-Standard	$P_6 = \beta_1+\beta_3$	$P_8 = \beta_1$
Female	Rural	Pre-Standard	$P_9 = \beta_5+\beta_6+\beta_7+\beta_8$	$P_{11} = \beta_5$
		Post-Standard	$P_{10} = \beta_5+\beta_6+\beta_7$	$P_{12} = \beta_5$
	Urban	Pre-Standard	$P_{13} = \beta_5+\beta_6+\beta_8$	$P_{15} = \beta_5$
		Post-Standard	$P_{14} = \beta_5+\beta_6$	$P_{16}\ \beta_5$

From Figure 3-11, it is seen that the primary effect of STANDARD is not significant and does not appear in the final model. The only STANDARD effect of relative significance appears as the interaction term AREAD x STANDARD (AxG) which corresponds to the model coefficient β_8 = 0.068 (X^2=1.42, p=0.24). These facts are reflected in Figure 3-21 by the observation that with the exception of female occupants involved in left side impacted accidents, all other predicted injury rates are identical for occupants of pre- and post-standard cars. For female occupants involved in left side impacted accidents, the positive value of 0.068 for β_8 indicates the positive effect of STANDARD, although it is not significant with a p-value of 0.24. The effectiveness estimate for FMVSS 214 is 7.62% with a standard error of 6.0% and a p-value of 0.20.

3.6. Evaluation of Effectiveness of FMVSS 214 (Intrusion Reduction)

This section discusses the depth of intrusion analysis for FMVSS 214. The purpose is to evaluate the effectiveness of FMVSS 214 by comparing the expected depth of intrusion for pre-standard cars to the expected depth of intrusion for post-standard cars. A multiple regression analysis was first made on the dependent variable, Depth of Intrusion, to test whether the two straight lines fitted for pre- and post-standard cars are indeed parallel. Subsequently, an analysis of covariance was conducted to test for significant difference in the adjusted group mean depths of intrusion.

3.6.1. The Data File for Intrusion Reduction Analysis

For each struck vehicle in the Vehicle Oriented File (see §3.3) one determines the specific door of the car that was damaged in the primary impact. To do this, one must first determine whether it is a 2-door or a 4-door car. In case it is a 2-door car and the primary area of impact equals left (right) side, then the left (right) door is the door impacted. In case it is a 4-door car, and the primary area of impact equals left (right) side, and the principal direction of force is $9 \leq \text{CDC} \leq 12$ ($12 \leq \text{cdc} \leq 3$), then the left (right front door is the door impacted; however, if the principal direction of force is $6 \leq \text{CDC} < 9$ ($3 < \text{CDC} \leq 6$), then the left (right) rear door is the door impacted.

Once the specific door damaged in the primary impact has been determined, one can obtain the depth of intrusion information from the INTRUSION OF THE INTERNAL SURFACES OF THE PASSENGER COMPARTMENT FORMS as follows: among the list of Intrusion Numbers, select the one whose Occupant Space Number matches the specific door damaged (e.g. Occupant Space Number = 11 corresponds to left front door, etc.), whose Associated Impact Number equals 1 (indicating that it is associated with the primary impact), and whose Intruded Area Number equals 7 (indicating that the intruded internal surface area is the side or door panel). Record the Maximum Extent of INTRUSION (in inches) information associated with this selected Intrusion Number. This Maximum Extent of Intrusion variable is the dependent variable, Depth of Door Intrusion.

Some additional variables were created for this data file. These are listed below:

SVEHWT	:	Weight of striking vehicle
DIML	:	Total length of external crush
MAXC	:	Maximum depth of external crush
INCREASE	=	0, if door intrusion were not increased by components damaged 1, Otherwise
B-pillar	=	0, if B-pillar were absent 1, if B-pillar were present
Door	=	2, if vehicle is 2-door 4, if vehicle is 4-door

3.6.2 Covariance Analysis on Depth of Side-Door Intrusion

The following variables were considered in the initial multiple regression analysis: SVEHWT (striking vehicle weight), VEHWT (struck vehicle weight), DIML (total length of external crash), MAXC (maximum depth of external crush), INCREASE (whether or not door intrusion was increased by components damaged, BPILLAR (presence or absence of B-pillar), DFORCE (principal direction of force), AREAD (location of primary impact, left or right side), STRATA (sampling strata), and STANDARD (pre- or post-standard car). Appropriate dummy variables were defined prior to calling the SAS GLM procedure (SAS USER's GUIDE) for the multiple regression analysis. Non-significant effects and interactions were dropped and the results showed that STANDARD has a significant effect only in the 100% sampling stratum (corresponding to the most severe accidents). Thus, subsequent multiple regression analysis was carried out for the 100% sampling stratum only. The results indicated that the factors, DIML, MAXC, DFORCE, STANDARD and the interaction MAXC x DFORCE are significant. Furthermore, the interactions DIML x STANDARD, MAXC x STANDARD, and MAXC x DFORCE x STANDARD were not significant. Consequently, a covariance analysis was carried out using the model:

$$\text{DEPTH OF DOOR INTRUSION} = \beta_0 + \beta_1 \text{ (MAXC)} + \beta_2 \text{ (DIML)} + \beta_3 \text{ (STANDARD)} + \beta_4 \text{ (DFORCE)} + \beta_5 \text{(MAXC x DFORCE)} + \text{Error}$$

where DIML, MAXC and MAXC x DFORCE were the covariates. Results of the covariance analysis are given in Figure 3-13.

The Type I SS for STANDARD gives the between standards sum-of-squares that would have been obtained for the ANOVA model Y = STANDARD. The Type IV SS is the STANDARD sum of squares adjusted for the covariates.

The F values and the PR > F values for Type IV SS tests are equivalent to the results of a t-test for testing the hypothesis that the regression parameter equals zero.

The intercept and the model coefficient estimates are given together with the Student t values for testing the null hypothesis that the parameter equals zero and the corresponding p-values.

Figure 3-13
Analysis of Covariance for Depth of Door Intrusion

Dependent variable: Y = Depth of Door Intrusion in Inches

Model $Y = \beta_0 + \beta_1 (STANDARD) + \beta_2 (DFORCE) + \beta_3 (MAXC) + \beta_4 (DIML) + \beta_5 (DFORCE \times MAXC) + ERROR$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	Pr > F	R-Square	C.V.
Model	5	3694.1	738.8	33.6	0.0001	0.45	45.7
Error	204	4531.8	22.2				
Corrected Total	209	8226.0			Y Mean 10.3	STD DEV 4.7	

Source of Variation	Degrees of Freedom	Type I SS	F-Value	PR > F	Type IV SS	F-Value	PR > F
STANDARD	1	153.4	6.9	0.0093	177.0	8.0	0.0052
DFORCE	1	563.0	25.3	0.0001	300.8	13.5	0.0003
MAXC	1	1949.3	87.8	0.0001	703.4	31.7	0.0001
DIML	1	153.9	6.9	0.0091	174.3	7.9	0.0056
DFORCE x MAXC	1	874.5	39.4	0.0001	874.5	39.4	0.0001

					Number of Cases		
Parameter	Estimate	T For Ho: =0	PR > ITI	STANDARD Error of Estimate	PRE-STD	POST-STD	Total
Intercept (β_0)	5.42	4.0	0.0001	1.36	73	146	219
STANDARD (β_1)	-1.97	-2.8	0.0052	0.70			
DFORCE (β_2)	5.95	3.7	0.0003	1.62			
MAXC (β_3)	0.52	11.1	0.0001	0.05			
DIML (β_4)	-0.03	-2.8	0.0056	0.01			
DFORCE x MAXC (β_5)	-0.55	-6.3	0.0001	0.09			

Least Squares Means Adjusted for Covariates

STANDARD	Observed Mean for Y	LSMEAN for Y	STD ERROR for LSMEAN	PR > ITI Ho: LSMEAN=0	PR > ITI: Ho: PRE-STANDARD LSMEAN = POST-STANDARD LSMEAN
PRE-STANDARD	11.58	10.09	0.67	0.0001	0.0052
POST-STANDARD	9.86	8.12	0.55	0.0001	
REDUCTION	1.72	1.97			

From the results in Figure 3-13, it is clear that all parameter estimates are significant. Note that no variance adjustments are necessary because this subpopulation came from the 100% sampling stratum.

The interactions of STANDARD with the covariates MAXC, DIML, and DFORCE x MAXC are not significant and hence this justifies the use of covariance analysis to adjust the mean depth of door intrusion for these covariates. Both the observed mean depths of door intrusion and the adjusted (for covariates) mean depths of door intrusion are given at the bottom of Figure 3-13 for pre-standard and post-standard cars. The adjusted means are lower than the observed means for both pre- and post-standard cars. Both adjusted mean depths of intrusion are significantly different from 0, and moreover the mean depth of intrusion for post-standard cars is significantly lower than the mean depth of intrusion for pre-standard car with a p-value of 0.0052. The two regression lines for mean depth of intrusion are parallel and their equations are given by

$$Y_{\text{PRE-STANDARD}} = 5.42 + 0.52\,(\text{MAXC}) - 0.03\,(\text{DIML}) + 5.95\,(\text{DFORCE}) - 0.55\,(\text{DFORCE} \times \text{MAXC})$$

$$Y_{\text{POST-STANDARD}} = 3.45 + 0.52\,(\text{MAXC}) - 0.03\,(\text{DIML}) + 5.95\,(\text{DFORCE}) - 0.55\,(\text{DFORCE} \times \text{MAXC})$$

Note that the difference in the adjusted mean depths of intrusion for pre-standard and post-standard cars, $Y_{Post-std}$ (adjusted)-$Y_{Pre-std}$ (adjusted)=-1.97 which is precisely the model coefficient estimate for β_3. It is also of interest to observe that the negative coefficients for DIML and DFORCE x MAXC show that the two variables Total Length of External Crush and Maximum Depth of External Crush in Non-lateral Impact are negatively correlated with Depth of Door Intrusion.

The inclusion of the variable MAXC in the above model may cast some doubt on the result because of the fact that MAXC is confounded with STANDARD. Such confounding, however, has a non-significant effect on the resulting estimate because the interaction MAXC x STANDARD was not significant. In fact, further analysis by deleting the factors MAXC and DFORCE x MAXC from the above model showed that the reduced model still explain the variation very well and the estimated reduction in the adjusted mean depth of side-door intrusion is 1.83 inches which is still significantly different from 0 with a p-value of 0.038. The summary statistics based on this reduced model are given in Table 3-14.

Figure 3-14
Analysis of Covariance for Depth of Door Intrusion

Dependent variable: Y = Depth of Door Intrusion in Inches
Model $Y = \beta_0 + \beta_1 (STANDARD) + \beta_2 (DFORCE) + \beta_3 (DIML) + Error$

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Value	Pr > F	R-Square
Model	3	935.7	311.9	8.81	0.0001	0.11
Error	206	7290.3	35.4			
Corrected Total	209	8226.0			Y Mean	STD DEV
					10.3	5.9

Source of Variation	Degrees of Freedom	Type I SS	F-Value	PR > F	Type IV SS	F-Value	PR > F
STANDARD	1	153.4	4.33	0.0386	154.0	4.35	0.038
DFORCE	1	563.0	15.91	0.0001	319.2	9.02	0.003
DIML	1	219.3	6.20	0.0136	219.3	6.20	0.013

Parameter	Estimate	T For Ho: =0	PR > ITI	STANDARD Error of Estimate	Number of Cases PRE-STD	Number of Cases POST-STD	Number of Cases Total
Intercept (β_0)	14.95	11.34	0.0001	1.32	73	146	219
STANDARD (β_1)	-1.83	-2.09	0.0382	0.88			
DFORCE (β_2)	-3.66	-3.00	0.0030	1.22			
DIML (β_3)	-0.03	-2.49	0.0136	0.14			

Least Squares Means Adjusted for Covariates

STANDARD	Observed Mean for Y	LSMEAN for Y	STD ERROR for LSMEAN	PR > ITI Ho: LSMEAN=0	PR > ITI: Ho: PRE-STANDARD LSMEAN = POST-STANDARD LSMEAN
PRE-STANDARD	11.58	10.27	0.84	0.0001	0.0382
POST-STANDARD	9.86	8.44	0.66	0.0001	
REDUCTION	1.72	1.83			

As Table 3-15 shows, the difference between the reductions in the adjusted mean depth of intrusion based on the first model and the reduced model (excluding MAXC and DFORCE x MAXC) is 0.14 inches. This difference is attributable to the confounding effect of MAXC and the result indicates that the confounding of MAXC with the standard has no significant impact on the estimated reduction in the adjusted mean depth of intrusion.

Table 3-15

EFFECTIVENESS ESTIMATES FOR FMVSS 214 IN TERMS OF REDUCTION IN ADJUSTED MEAN DEPTH (IN INCHES) OF SIDE-DOOR INTRUSION IN 100% SAMPLING STRATUM

	Initial Model	Reduced Model	Observed
Pre-standard	10.09	10.27	11.58
Post-standard	8.12	8.44	9.86
Reduction in Adjusted Mean Depth	1.97	1.83	1.72

In conclusion, the post-standard cars have significantly lower mean depth of door intrusion than the pre-standard cars only in severe accidents. No significant reduction in mean depth of intrusion was detected in the case of less severe accidents. This is perhaps attributable to the fact that cars with depth of intrusion less than one inch have the variable MAXIMUM EXTENT OF INTRUSION coded 'blank' instead of '0'. If they had been coded '0', then the effectiveness of the standard FMVSS 214 might also have been found to be significant in the less severe accident cases.

3.7 References for Section 3

1. Higgins, J. E. and Koch, G. G. (1977). *Variable Selection and Generalized Chi-square Analysis of Categorical Data Applied to a Large Cross-Sectional Occupational Health Survey.* International Statistical Review 45, 51-62.

2. Kleinbaum, D. G. and Kupper, L. L. *Applied Regression Analysis and Other Multivariable Methods.* Duxbury Press, North Scituate, Massachusetts, 1978.

3. Landis, J. R., Stanish, W. M., Freeman, J. L., and Koch, G. G. (1976). *A Computer Program for the Generalized Chi-square Analysis of Categorical Data Using Weighted Least Squares.* University of North Carolina at Chapel Hill, Biostatistics Technical Report No. 8.

4. Landis, J. R., Cooper, M. M., Kennedy, T. and Koch, G. G. (1979). *A Computer Program for Testing Average Partial Association in Three-Way Contingency Tables (PARCAT).* Computer Programs in Biomedicine 9, 223-246.

5. McDole, T. and Hoffman, E. (1978). *Users Manual for Measurement of Intrusion in Motor Vehicle Accidents.* HSRI, Ann Arbor, Michigan, UM-HSRI-78-17-2.

6. Reynolds, H. T. *The Analysis of Cross-Classifications.* The Free Press, MacMillan Publishing Co., Inc., New York, 1977.

7. Scott, R. (1978). *Coding Manual for Measurement of Intrusion in Motor Vehicle Accidents.* HSRI, Ann Arbor, Michigan, UM-HSRI-78-17-3.

8. *SAS User's Guide 1979 Edition.* SAS Institute.

APPENDIX A

Variance Adjustment to Account for NCSS Sampling Scheme

The linear model estimates of the model coefficients, the injury rates and the effectiveness measures are all based on the weighted sample from the NCSS data file. The weighting was based on the NCSS sampling scheme. Consequently, the sample size has been artificially inflated which makes the estimated variances look better than they really are. Similarly, the Pearson Chi-squared statistics being an increasing function of the sample size tends to suggest stronger association or more significance if the weighted sample is used. Therefore, adjustments to these estimated variances (or confidence intervals) and the Pearson Chi-squared statistics are necessary. The following analysis shows that the adjustments can be made by fitting a linear model to the unweighted sample. The estimated injury rates and effectiveness measures based on this unweighted sample should be theoretically identical to that obtained based on the weighted sample. The adjustment factor can then be obtained by simply taking the ratio of their estimated variances.

For a given injury definition, consider the following Table A-1 cross-classifying Sampling Stratum x Standard Type x Injury based on the unweighted sample. For simplicity, only three sampling strata are considered, even though there is an additional 20% sampling stratum.

Now, if $k_1 = 1$, $k_2 = 4$, and $k_3 = 10$ represent the sampling weights for the 100%, 25%, and 10% sampling strata respectively, then the overall injury rate for occupants of pre-standard vehicles is given by

$$R_1 = \left(\sum_{i=1}^{3} k_i n_{i12}\right) \Big/ \left(\sum_{i=1}^{3} k_i n_{i1*}\right)$$

and that for the occupants of post-standard vehicles is given by

$$R_2 = \left(\sum_{i=1}^{3} k_i n_{i22}\right) \Big/ \left(\sum_{i=1}^{3} k_i n_{i2*}\right)$$

and the estimate of the effectiveness measure based on the weighted sample is given by

$$\hat{E}_W = \frac{R_1 - R_2}{R_1} \qquad (3.1)$$

Table A-1

SAMPLING FRACTION BY STANDARD BY INJURY BASED ON UNWEIGHTED OCCUPANT ORIENTED FILE

Sampling Fraction	Standard Type	Not Injured	Injured	Total
100%	Pre-std	n_{111}	n_{112} r_{112}*	n_{11*}
	Post-std	n_{121}	n_{122} r_{122}	n_{12*}
25%	Pre-std	n_{211}	n_{212} r_{212}	n_{21*}
	Post-std	n_{221}	n_{222} r_{222}	n_{22*}
10%	Pre-std	n_{311}	n_{312} r_{312}	n_{31*}
	Post-std	n_{321}	n_{322} r_{322}	n_{32*}

*r_{ij2}, $= n_{ij2}/n_{ij*}$

with an estimate of its variance given approximately by

$$\hat{V}(\hat{E}_w) \simeq \frac{1}{R_1^2} \left[\frac{R_2}{R_1}^2 \quad \hat{V}(R_1) + \hat{V}(R_2) \right]$$

where

$$\hat{V}(R_k) = \frac{R_k(1-R_k)}{\sum_{i=1}^{3} k_i n_{ik*}} \quad , \; k = 1,2$$

On the other hand,

$$\frac{R_1 - R_2}{R_1} = \frac{\sum_{i=1}^{3} r_{i12}\, w_{i1} - \sum_{i=1}^{3} r_{i22}\, w_{i2}}{\sum_{i=1}^{3} r_{i12}\, w_{i1}} \qquad (3.2)$$

where,

$$w_{i1} = \frac{k_i n_{i1*}}{\sum_{i=1}^{3} k_i n_{i1*}} \quad , \ i=1,2,3$$

$$w_{i2} = \frac{k_i n_{i2*}}{\sum_{i=1}^{3} k_i n_{i2*}} \quad , \ i=1,2,3$$

Hence,Equation (3.2) demonstrates that the estimate of the effectiveness measure based on the weighted sample given by Equation (3.1) is equivalent to the estimate of the effectiveness measure derived from the weighted average of the injury rate estimates based on the unweighted sample. With the weights (w_{i1}, w_{i2}) being determined by the proportion of each sampling stratum relative to the total weighted sample for pre- and post-standard respectively.

Thus, if a linear model is fitted to the unweighted Table A-1, then one obtains the predicted injury rates $\hat{r}_{i12}$, $\hat{r}_{i22}$ together with their variance estimates $V(r_{i12})$ and $V(r_{i22})$ for i=1,2,3. Equation (3.2) then will given an estimate E_{uw} for the effectiveness measure which is equivalent to E_w with an estimated variance given approximately by

$$\hat{V}(\hat{E}_{uw}) \simeq \frac{1}{\left(\sum_{i=1}^{2} \hat{r}_{i12} w_{i1}\right)^2} \left[\left(\frac{\sum_{i=1}^{3} \hat{R}_{i22} w_{i2}}{\sum_{i=1}^{3} \hat{R}_{i12} w_{i1}} \right)^2 \sum_{i=1}^{3} \hat{V}(\hat{r}_{i12}) w_{i1}^2 + \sum_{i=1}^{3} \hat{V}(\hat{r}_{i22}) w_{i2}^2 \right]$$

The ratio, $f = \frac{\hat{V}(\hat{E}_{uw})}{\hat{V}(\hat{E}_w)}$ provides the necessary adjustment factor for the variance.

The confidence intervals for any other parameter estimates can now be adjusted by the square root of this factor. It should be pointed out that the adjustment factor will vary with the injury characterization used. The following Table A-2 summarizes the adjustment factors calculated for each of the five injury characterizations used in this study. It should be noted that the factors are closer to one (i.e., less need for adjustment) as the injury becomes more severe. This is intuitively obvious because the more severe injuries tend to occur in the 25% and 100% sampling strata which is implicit in the NCSS Sampling scheme.

Table A-2

Variance Adjustment Factors for All Five Injury Characterizations

Injury Characterization	Adjustment Factor f	$\sqrt{f}$
OAIS $\geq$ 1	3.72	1.93
OAIS $\geq$ 2	1.78	1.33
OAIS $\geq$ 3	1.43	1.20
OAIS $\geq$ K	1.38	1.17
SOAIS $\geq$ 1	2.30	1.52

In the analysis of FMVSS 214, it is necessary to determine whether a passenger car is two-door or four-door. Using the vehicle VIN (NCSS Code V9), Vehicle Make (NCSS Code V10), and Model Year (NCSS Code V12) information, one can determine, using the Vehicle Identification Number Analysis System (VINA)*, the HSR Body Style Code for a particular vehicle. A complete list of these codes are given on the next page. A (conservative) correspondence between these Body Style Codes and Door Types and presence or absence of B-pillars are given in Table B-1. The frequency distributions of these variables based on the NCSS Vehicle Oriented File is also given in Table B-1.

*The Vehicle Identification Number Analysis System (VINA) was developed by R. L. Polk & Co. For a more detailed discussion of the capability of this system, please refer to the Users' Manual: Vehicle Identification Number Verification and Analysis System, published by R. L. Polk & Co., January 1978, 400 Pike Street, Cincinnati, Ohio 45202, and the report: H.S.R. Vehicle Classification Codes Through 1979 Model Year, by C. Williams and E. Hamilton, Highway Safety Research Center, University of North Carolina, Chapel Hill, N.C. 27514.

HSR BODY STYLE CODES

01 Pillard Hardtop 2 door (Sedan)
02 Hardtop 2 door
03 Convertible 2 door
04 Stationwagon 2 door
05 Pillard Hardtop 4 door (Sedan)
06 Hardtop 4 door
07 Convertible 4 door
08 Stationwagon 4 door (2 seat)
09 Stationwagon 4 door (3-4 seat)
10 Sports Van
11 Sedan*
12 Hardtop*
13 Convertible*
14 Stationwagon
15 Coupe
16 Notchback
17 Hatchback
18 Runabout 3 door
19 Formal Hardtop 2 door
20 Roadster
21 Limousine
22 Ambulance
23 Hearse
24 Utility**
25 Utility (Blazer, Jimmy, Scout, etc.)
26 Convertible (Jeep)
27 Roadster (Jeep)
28 Stationwagon truck
29 Travelall (Suburban & Carryall)
30 Van
31 Step Van & Vannette (including Metro and Handy Van)
32 Panel Truck
33 Parcel delivery
34 Van camper
35 Pick-up
36 Pick-up with camper mounted on the bed
37 Motorized Home, Motor Home Cutaway
38 Bus
39 Forward Control
40 Conventional cab
41 Truck body - long hood
42 Truck body - short hood
43 Truck body - cab-over-engine
44 Tilt cab
45 Tilt Tandem
46 Tandem
47 Tractor Truck (Diesel)
48 Tractor Truck (Gasoline)
49 Cargo Cutaway
50 Chassis and Cab
51 Flat-bed or Platform
52 Gliders
53 Stake or Rack
54 Armored Truck
55 Auto carrier
56 Concrete or Transit Mixer
57 Crane
58 Dump Truck
59 Fire Truck
60 Garbage or Refuse
61 Grain
62 Hopper
63 Tank
64 Tow Truck Wrecker
65 Liftback
66 Chassis & Cab (Chevy Luv)**
67 Cutaway
00,99 Unknown

*Used only when number of doors is unknown
**To code trucks commonly registered as passenger cars

Table B-1

Distributions of HSR Body Style Codes, Presence/Absence of B-Pillar, and Number of Doors Based on the Unweighted Overall NCSS Vehicle Oriented File

HSR Body Style Code	Presence/Absence of B-Pillar	Number of Doors	Frequency
.	Unknown	Unknown	2815 (14.6)*
0	Unknown	Unknown	2609 (15.9)
1	Yes	2	1251 (7.6)
2	No	2	4027 (24.6)
5	Yes	4	2304 (14.1)
6	No	4	906 (5.5)
11	Yes	Unknown	169 (1.0)
13	No	Unknown	171 (1.0)
14	Yes	4	1107 (6.8)
15	Yes	2	1609 (9.8)
16	Yes	2	46 (0.3)
17	Yes	2	442 (2.7)
18	Yes	2	200 (1.2)
19	No	2	215 (1.3)
20	Unknown	Unknown	18 (0.1)
30	Unknown	Unknown	168 (1.0)
35	Unknown	Unknown	746 (4.6)
Others	Unknown	Unknown	331 (1.7)
99	Unknown	Unknown	46 (0.3)
Total			19180

*Percentages based on weighted file are nearly the same.

The statistics generated in the selection process for each variable in Table 3-7 for the injury characterizations OAIS $\geq$ 1, SOAIS $\geq$ 1, OAIS $\geq$ 2, OAIS $\geq$ 3, and OAIS $\geq$ K are summarized in Table C-1 through Table C-5 respectively.

The procedure basically calls for the calculation of the following statistics for each variable V or each variable V joint with all previously selected variables:

(i) $T_1(V) = \chi^2$ (VxSTANDARD)

The Pearson chi-squared statistic for measuring the association between V and STANDARD

(ii) $T_2(V) = \chi^2$ (VxINJURY)

The Pearson chi-squared statistic for measuring the association between V and INJURY.

(iii) $T_{3,Pre}(V) = \chi^2$ (Vx INJURY/PRE-STANDARD) and
$T_{3,Post}(V) = \chi^2$ (VxINJURY/POST-STANDARD)

The Pearson chi-squared statistics for measuring partial associations of V and INJURY by STANDARD.

(iv) $T_4(V) = \chi^2$ (VxINJURY/STANDARD)

The generalized Cochran-Mantel-Haenszel statistic for average partial association between V and INJURY across STANDARD.

(v) $I(V) = T_4(V)/(T_{3,Pre}(V) + T_{3,Post}(V))$

Note that $I(V) \leq 1.0$. This index provides an indication of whether the association between V and INJURY is independent of STANDARD.

At each stage, a variable V will be considered if both $T_1(V)$ and $T_2(V)$ are significant, and if the relationship between V and INJURY is consistent across STANDARD (i.e., if $T_4(V) \geq$ Max. $T_{3,pre}(V)$, $T_{3,Post}(V)$. Generally, the variable with the most significant $T_2(V)$/d.f. is to be selected. However, if there are several variables that are potential candidates, then the one with a larger index and/or a more significant $T_1(V)$/d.f. is to be preferred. Certain element of subjectivity is to be expected.

The procedure will repeat itself after each stage of selection and will terminate if one of the following situations occurs.

(a) No more relevant variables are to be considered.

(b) The statistics T_1 and T_2 are not significant (after adjustment to account for sampling scheme) for the remaining variables.

Table C-1

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS $\geq$ 1

STAGE I

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
SEX*	2	39.0 (1) 39.0	128.8 (1) 128.8	32.8 (1) 98.1 (1) 130.9 (2)	130.9 (1) 1.00
BELT	2	19.0 (1) 19.0	0.9 (1) 0.9		
SEAT	2	1.7 (1) 1.7	10.2 (1) 10.2		
AGE	3	32.7 (2) 16.4	22.8 (2) 11.4	5.2 (2) 19.3 (2) 24.5 (4)	23.1 (2) 0.94
WEIGHT	3	139.1 (2) 69.5	52.3 (2) 26.2	38.4 (2) 26.1 (2) 64.5 (4)	52.9 (2) 0.82
BPILLAR	2	70.2 (1) 70.2	4.0 (1) 4.0		
DOOR	2	0.3 (1) 0.3	9.5 (1) 9.5		
SWEIGHT	3	32.1 (2) 16.1	110.6 (2) 55.3	21.2 (2) 99.4 (2) 120.6 (4)	117.8 (2) 0.98
TYPESEAT	2	54.7 (1) 54.7	4.6 (1) 4.6		
AREA	2	5.1 (1) 5.1	20.3 (1) 20.3		
HORIZ	3	6.5 (2) 3.3	10.1 (2) 5.1		
VERT	3	16.1 (2) 8.1	215.4 (2) 107.7		
DIST	4	13.8 (3) 4.6	79.2 (3) 26.4		
DFORCE	2	3.9 (1) 3.9	51.7 (1) 51.7		
NBVEH	2	17.4 (1) 17.4	22.7 (1) 22.7	33.7 2.9 (1) 36.6 (2)	22.5 (1) 0.61
LOC	2	2.1 (1) 2.1	0.9 (1) 0.9		
LATCH	2	11.6 (1) 11.6	151.0 (1) 151.0		
INTRUS	2	8.6 (1) 8.6	508.2 (1) 508.2		
EXT	2	3.7 (1) 3.7	867.2 (1) 867.2		
VLDT	3	6.0 (2) 3.0	131.5 (2) 65.8		

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling schemes. To obtain the adjusted χ^2, divide the χ^2 values in the table by 3.7. (See Appendix A).

††The index I = $T_4/(T_{3,Pre} + T_{3,Post})$

Table C-1 (con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS ≥ 1

STAGE II

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
SEX	2				
BELT	2	60.3 (3) 20.1	132.9 (3) 44.3	49.6 (3) 99.8 (3) 149.4 (6)	134.7 (3) 0.90 149.4 (6)
SEAT	2	54.4 (3) 18.1	145.8 (3) 48.6		
AGE	3	84.9 (5) 17.0	159.8 (5) 31.9		
WEIGHT	3	213.8 (5) 42.7	181.4 (5) 36.3	63.3 (5) 133.1 (5) 196.4 (10)	182.7 (5) 0.93
BPILLAR*	2	136.0 (3) 45.0	129.9 (3) 43.3	34.1 (3) 99.1 (3) 133.2 (6)	132.3 (3) 0.99
DOOR	2	45.7 (3) 15.2	139.7 (3) 46.6		
SWEIGHT	3	57.6 (5) 11.5	182.6 (5) 36.5		
TYPESEAT	2	93.9 (3) 31.3	159.9 (3) 53.3	62.9 (3) 115.9 (3) 178.8 (6)	166.8 (3) 0.93
AREA	2	44.9 (3) 14.9	135.8 (3) 45.2		
HORIZ	3	65.1 (5) 13.0	140.1 (5) 18.0		
VERT	3	60.7 (5) 12.1	360.9 (5) 72.2		
DIST	4	64.2 (7) 9.1	244.9 (7) 35.0		
DFORCE	2	25.7 (3) 8.6	144.2 (3) 48.1		
NBVEH	2	49.9 (3) 16.6	176.9 (3) 58.9	78.1 (3) 117.8 (3) 195.9 (6)	178.2 (3) 0.91
LOC	2	58.9 (3) 19.6	144.2 (3) 48.0	44.5 (3) 104.8 (3) 149.3 (6)	145.9 (3) 0.98
LATCH	2	34.3 (3) 11.4	264.9 (3) 88.3		
INTRUS	2	32.7 (3) 10.9	952.3 (5) 190.5		
EXT	2	46.1 (3) 15.3	1023.6 (3) 341.2		
VLDT	3	90.7 (5) 18.1	190.1 (5) 38.0		

Table C-1 (con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS ≥ 1

STAGE III

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre}$ + $T_{3,Post}$	T_4 (d.f.) f††
SEX	2				
BELT	2	188.1 (7) 26.9	144.5 (7) 20.6	85.7 (7) 103.5 (7) 189.2 (14)	42.6 (7) 0.23
SEAT	2	188.7 (11) 17.2	173.8 (11) 15.8		
AGE	3				
WEIGHT	3	369.1 (11) 33.6	225.3 (11) 20.5	101.3 (11) 60.9 162.2	49.3 (11) 0.30
BPILLAR	2				
DOOR	2				
SWEIGHT	3	263.7 (11) 24.0	251.9 (11) 22.9	108.9 (11) 123.9 (11) 232.8 (22)	111.2 (11) 0.48
TYPESEAT*	2	191.3 (7) 27.3	165.1 (7) 23.6	138.0 (7) 183.9 (7) 321.9 (14)	282.1 (7) 0.88
AREA	2				
HORIZ	3				
VERT	3	161.6 (11) 14.7	410.5 (11) 37.3		
DIST	4	168.3 (15) 11.2	268.0 (15) 17.9		
DFORCE	2	170.9 (7) 24.4	154.5 (7) 22.1	61.2 (7) 136.4 (7) 197.6 (14)	158.9 (7) 0.80
NBVEH	2	151.2 (7) 21.6	180.9 (7) 25.8	71.9 (7) 126.9 (7) 198.8 (14)	88.4 (7) 0.44
LOC	2	185.8 (7) 26.5	147.9 (7) 21.1		
LATCH	2	122.8 (7) 17.5	282.3 (7) 40.3		
INTRUS	2				
EXT	2				
VLDT	3				

Table C-2

Statistics† Generated in the Variable Selection Process for Injury Characterization SOAIS $\geq$ 1

STAGE I

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
SEX*	2	45.8 (1) 45.8	56.3 (1) 56.3	28.1 (1) 31.4 (1) 59.6 (2)	56.0 (1) 0.94
BELT	2	5.9 (1) 5.9	14.5 (1) 14.5		
SEAT	2	0.0 (1) 0.0	3.2 (1) 3.2		
AGE	3	28.9 (2) 14.5	5.1 (2) 2.5		
WEIGHT	3	86.9 (2) 43.5	24.8 (2) 12.4	20.0 (2) 10.0 (2) 30.0 (4)	25.6 (2) 0.85
BPILLAR	2	45.4 (1) 45.4	6.3 (1) 6.3		
DOOR	2	1.6 (1) 1.6	10.3 (1) 10.3		
SWEIGHT	3	7.9 (2) 3.9	84.9 (2) 42.5		
TYPESEAT	2	30.7 (1) 30.7	2.0 (1) 2.0		
AREA	2	7.3 (1) 7.3	11.6 (1) 11.6		
HORIZ	3	14.0 (2) 7.0	18.7 (2) 9.3		
VERT	3	1.6 (2) 0.8	132.9 (2) 66.4		
DIST	4	20.9 (3) 6.9	35.1 (3) 11.7		
DFORCE	2	2.8 (1) 2.8	31.9 (1) 31.9		
NBVEH	2	9.3 (1) 9.3	26.8 (1) 26.8	5.5 (1) 22.2 (1) 27.7 (2)	27.2 (1) 0.98
LOC	2	3.7 (1) 3.7	16.2 (1) 16.2		
LATCH	2	6.5 (1) 6.5	52.6 (1) 52.6		
INTRUS	2	10.5 (1) 10.5	256.6 (1) 256.6		
EXT	2	2.2 (1) 2.2	439.8 (1) 439.8		
VLDT	3	1.4 (2) 0.7	80.0 (2) 40.0		

*Variable selected at the given stage

† These statistics have not been adjusted to account for the sampling schemes. To obtain the adjusted χ^2, divide the χ^2 values in the table by 2.3.

†† The index $I = T_4/(T_{3,Pre} + T_{3,Post})$.

Table C-2 (con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization SOAIS $\geq$ 1

STAGE II

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre} + T_{3,Post}$	T_4 (d.f.) I††
SEX	2				
BELT	2	55.6 (3) 18.5	77.8 (3) 25.9	48.3 (3) 40.7 (3) 89.1 (6)	72.4 (3) 0.81
SEAT	2	58.5 (3) 19.5	60.6 (3) 20.2		
AGE	3	73.4 (5) 14.7	61.3 (5) 12.2	40.5 (5) 39.2 (5) 79.8 (10)	61.0 (5) 0.76
WEIGHT	3	181.0 (5) 90.5	81.9 (5) 16.4	57.3 (5) 45.9 (5) 103.1 (10)	81.8 (5) 0.79
BPILLAR	2	124.9 (3) 41.3	63.0 (3) 21.0	33.1 (3) 35.1 (3) 68.2 (6)	62.7 (3) 0.92
DOOR	2	60.0 (3) 20.0	67.5 (3) 22.5		
SWEIGHT	3	61.9 (5) 12.4	146.6 (5) 29.3	76.2 (5) 92.9 (5) 169.0 (10)	157.5 (5) 0.93
TYPESEAT	2	73.4 (3) 24.5	62.8 (3) 20.9	56.4 (3) 32.0 (3) 88.3 (6)	64.9 (3) 0.73
AREA	2	54.5 (3) 18.2	70.4 (3) 23.4		
HORIZ	3	63.4 (5) 12.7	78.6 (5) 15.7		
VERT	3	53.5 (5) 10.7	200.7 (5) 40.1	64.1 (5) 145.6 (5) 209.7 (10)	200.4 (5) 0.96
DIST	4	82.2 (7) 11.7	102.7 (7) 14.7	108.2 (7) 53.8 (7) 162.0 (14)	102.7 (7) 0.63
DFORCE	2	27.9 (3) 9.3	64.7 (3) 21.4	12.4 (3) 62.7 (3) 75.1 (6)	64.4 (3) 0.86
NBVEH	2	51.4 (3) 17.1	104.2 (3) 34.7	37.3 (3) 75.2 (3) 112.5 (6)	103.8 (3) 0.92
LOC*	2	86.7 (3) 28.9	84.1 (3) 28.0	37.6 (3) 48.7 (3) 86.2 (6)	83.9 (3) 0.97
LATCH	2	21.8 (3) 7.2	99.3 (3) 33.1	55.9 (3) 65.7 (3) 121.5 (6)	99.5 (3) 0.82
INTRUS	2	40.5 (3) 13.5	325.5 (3) 108.5		
EXT	2	47.6 (3) 15.8	526.1 (3) 175.3		
VLDT	3	72.5 (5) 14.5	136.1 (5) 27.2		

Table C-2 (con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization SOAIS ≥ 1

STAGE III

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,Post}$ (d.f.) $T_{3,Pre}+T_{3,Post}$	T_4 (d.f.) I††
SEX	2				
BELT	2	105.6 (7) 15.1	102.8 (7) 14.7	55.8 (7) 56.6 (7) 112.4 (14)	102.5 (7) 0.91
SEAT	2				
AGE	3	132.2 (11) 12.0	109.4 (11) 9.9	57.1 (11)	
WEIGHT	3	236.6 (11) 21.5	129.4 (11) 11.8	108.0 (11) 69.5 (11) 177.5 (22)	129.5 (11) 0.73
BPILLAR	2	182.8 (7) 26.1	99.6 (7) 14.2	57.6 (7) 61.7 (7) 119.3 (14)	99.4 (7) 0.83
DOOR	2				
SWEIGHT	3	76.7 (11) 7.0	216.9 (11) 19.7	101.7 (11)	
TYPESEAT	2	134.5 (7) 19.2	76.1 (7) 10.9	69.7 (7) 41.4 (7) 111.1 (14)	77.7 (7) 0.70
AREA*	2	105.2 (7) 15.0	123.9 (7) 17.7	45.5 (7) 88.5 (7) 134.0 (14)	123.7 (7) 0.92
HORIZ	3	133.3 (11) 12.1	107.4 (11) 9.8		
VERT	3	138.6 (11) 12.6	243.1 (11) 22.1	70.3 (10) 191.9 (11) 262.5 (21)	236.3 (11) 0.90
DIST	4	162.4 (15) 10.8	168.1 (15) 11.2		
DFORCE	2	73.5 (7) 10.5	112.0 (7) 16.0	29.4 (7)	
NBVEH	2	27.2 (7) 3.9	32.7 (7) 4.7	55.3 (7)	
LOC	2	182.8 (7) 26.1	99.6 (7) 14.2	57.6 (7)	
LATCH	2	86.9 (7) 12.4	108.8 (7) 15.5	69.0 (7) 73.1 (7) 142.1 (14)	108.9 0.77
INTRUS	2				
EXT	2				
VLDT	3				

Table C-3

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS ≥ 2

STAGE I

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$ (d.f.) $T_{3,post}$ (d.f.) $T_{3,Pre}+T_{3,Post}$	T_4 (d.f) I††
SEX	2	39.0 (1) 39.0	11.6 (1) 11.6		
BELT	2	19.0 (1) 19.0	12.0 (1) 12.0	1.7 (1) 10.2 (1) 11.8 (2)	11.7 (1) 0.99
SEAT	2	1.7 (1) 1.7	1.3 (1) 1.3		
AGE	3	32.7 (2) 16.3	35.4 (2) 17.7	19.9 (2) 22.2 (2) 42.1 (4)	36.1 (2) 0.85
WEIGHT	3	13.9 (2) 6.9	10.4 (2) 5.2		
BPILLAR	2	70.2 (1) 70.2	4.1 (1) 4.1		
DOOR	2	0.2 (1) 0.2	0.5 (1) 0.5		
SWEIGHT	3	32.1 (2) 16.1	59.1 (2) 29.5	8.8 (2) 56.1 (2) 64.9 (4)	63.1 (2) 0.97
TYPESEAT	2	54.7 (1) 54.7	0.0 (1) 0.0		
AREA	2	5.1 (1) 5.1	21.7 (1) 21.7		
HORIZ	3	6.5 (2) 3.2	4.9 (2) 2.5		
VERT	3	16.1 (2) 8.1	223.0 (2) 111.5		
DIST	4	13.8 (3) 4.6	56.3 (3) 18.8		
DFORCE	2	3.9 (1) 3.9	43.6 (1) 43.6		
NBVEH*	2	17.4 (1) 17.4	41.4 (1) 41.4	32.2 (1) 14.2 (1) 46.4 (2)	40.8 (1) 0.88
LOC	2	2.1 (1) 2.1	66.8 (1) 66.8		
LATCH	2	11.6 (1) 11.6	107.4 (1) 107.4	22.4 (1) 85.4 (1) 107.8 (2)	107.2 (1) 0.99
INTRUS	2	5.6 (1) 5.6	209.0 (1) 209.0		
EXT	2	3.7 (1) 3.7	533.2 (1) 533.2		
VLDT	3	6.0 (2) 3.0	71.3 (2) 35.6		

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling schemes. To obtain the adjusted X^2, divide the X^2 values in the table by 1.8. (See Appendix A)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$.

Table C-3 (Con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS $\geq$ 2

STAGE II

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$(d.f.) $T_{3,Post}$(d.f.) $T_{3,Pre}+T_{3,post}$	T_4 (d.f.) I††
SEX	2	67.0 (3) 22.3	39.4 (3) 13.1	56.8 (3) 17.9 (3) 74.7 (6)	63.2 (3) 0.85
BELT	2	56.4 (3) 18.8	47.4 (3) 15.8	46.2 (3) 14.0 (3) 60.2 (6)	50.6 (3) 0.84
SEAT	2				
AGE	3	59.5 (5) 11.9	169.4 (5) 33.9	51.2 (5) 56.4 (5) 107.7 (10)	43.2 (5) 0.40
WEIGHT	3	112.2 (5) 24.4	88.4 (5) 17.7	28.4 (5) 46.6 (5) 74.9 (10)	30.2 (5) 0.40
BPILLAR	2	44.2 (3) 14.7	39.9 (3) 13.3	57.6 (3) 14.9 (3) 72.5 (6)	50.2 (3) 0.69
DOOR	2	116.4 (3) 38.8	52.3 (3) 17.4	65.8 (3) 53.9 (3) 119.6 (6)	36.2 (3) 0.30
SWEIGHT	3	37.5 (5) 7.5	99.3 (5) 19.8		
TYPESEAT	2	86.3 (3) 28.8	15.8 (3) 5.3		
AREA	2	28.7 (3) 9.6	86.1 (3) 28.7		
HORIZ	3	31.8 (5) 6.4	88.1 (5) 17.6		
VERT*	3	60.9 (5) 12.2	213.0 (5) 42.6	158.4 (5) 41.4 (5) 199.8 (10)	181.1 (5) 0.91
DIST	4	51.0 (7) 7.3	146.5 (7) 20.9		
DFORCE	2	16.9 (3) 5.6	126.8 (3) 42.3		
NBVEH	2				
LOC	2	29.6 (3) 9.9	90.3 (3) 30.1		
LATCH	2				
INTRUS	2				
EXT	2				
VLDT	3				

Table C-4

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS ≥ 3

STAGE I

Variable	Number of Categories	T_1 (d.f.) / T_1/d.f.	T_2 (d.f.) / T_2/d.f.	$T_{3,Pre}$(d.f.) / $T_{3,Post}$(d.f.) / $T_{3,Pre}+T_{3,Post}$	T_4 (d.f.) / I††
SEX	2	39.0 (1) 39.0	10.8 (1) 10.8		
BELT	2	19.0 (1) 19.0	12.3 (1) 12.3	2.9 (1) 9.0 (1) 11.9 (2)	11.9 (1) 1.0
SEAT	2	1.7 (1) 1.7	0.4 (1) 0.4		
AGE	3	32.7 (2) 16.3	33.3 (2) 16.6	1.6 (2) 39.8 (2) 41.4 (4)	34.3 (2) 0.83
WEIGHT	3	13.9 (2) 6.9	0.8 (2) 0.4		
BPILLAR	2	70.2 (1) 70.2	1.6 (1) 1.6		
DOOR	2	0.2 (1) 0.2	2.5 (1) 2.5		
SWEIGHT	3	32.1 (2) 16.1	38.2 (2) 19.1	2.0 (2) 44.3 (2) 46.3 (4)	42.6 (2) 0.92
TYPESEAT	2	54.7 (1) 54.7	3.4 (1) 3.4		
AREA	2	5.1 (1) 5.1	18.9 (1) 18.9		
HORIZ	3	6.5 (2) 3.2	1.5 (1) 1.5		
VERT	3	16.1 (2) 8.1	247.7 (2) 123.8		
DIST	4	13.8 (3) 4.6	56.6 (3) 18.9		
DFORCE	2	3.9 (1) 3.9	43.6 (1) 43.6		
NBVEH*	2	17.4 (1) 17.4	26.2 (1) 26.2	33.1 (1) 3.2 (1) 36.3 (2)	25.4 (1) 0.70
LOC	2	2.1 (1) 2.1	38.3 (1) 38.3		
LATCH	2	11.6 (1) 11.6	96.1 (1) 96.1		
INTRUS	2	5.6 (1) 5.6	144.5 (1) 144.5		
EXT	2	3.7 (1) 3.7	389.4 (1) 389.4		
VLDT	3	6.0 (2) 3.0	52.1 (2) 26.1		

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling schemes. To obtain the adjusted χ^2, divide the χ^2 values in the table by 1.4. (See Appendix A)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$

Table C-4 (Con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS $\geq$ 3

STAGE II

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$(d.f.) $T_{3,Post}$(d.f.) $T_{3,Pre}+T_{3,Post}$	T_4(d.f.) I††
SEX	2	67.0 (3) 22.3	29.3 (3) 9.8		
BELT	2	56.4 (3) 18.8	42.3 (3) 14.1	45.1 (3) 13.0 (3) 58.1 (6)	45.6 (3) 0.78
SEAT	2				
AGE	3	59.5 (5) 11.9	164.3 (5) 32.8	50.9 (5) 73.2 (5) 124.1 (10)	61.9 (5) 0.50
WEIGHT	3	122.2 (5) 24.4	51.7 (5) 10.3		
BPILLAR	2	44.2 (3) 14.7	34.8 (3) 11.6		
DOOR	2	116.4 (3) 38.8	28.1 (3) 9.4		
SWEIGHT	3	37.5 (5) 7.5	65.5 (5) 13.1		
TYPESEAT	2	86.3 (3) 28.8	12.9 (3) 4.3		
AREA	2	28.7 (3) 9.6			
HORIZ	3	31.8 (5) 6.4			
VERT*	3	60.9 (5) 12.2	246.1 (5) 49.2	170.8 (5) 26.7 (5) 197.5 (10)	172.9 (5) 0.88
DIST	4	51.0 (7) 7.3	94.5 (7) 13.5		
DFORCE	2	16.9 (3) 5.6	29.5 (3) 29.8		
NBVEH	2				
LOC	2	29.6 (3) 9.9	54.7 (3) 18.2		
LATCH	2				
INTRUS	2				
EXT	2				
VLDT	3				

Table C-5

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS ≥ K

STAGE I

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$(d.f.) $T_{3,Post}$(d.f.) $T_{3,Pre}+T_{3,Post}$	T_4(d.f.) I††
SEX	2	39.0 (1) 39.0	4.2 (1) 4.2		
BELT	2	19.0 (1) 19.0	5.0 (1) 5.0		
SEAT	2	1.7 (1) 1.7	0.0 (1) 0.0		
AGE	3	32.7 (2) 16.3	0.8 (2) 0.4		
WEIGHT	3	13.9 (2) 6.9	1.8 (2) 0.9		
BPILLAR	2	70.2 (1) 70.2	1.4 (1) 1.4		
DOOR	2	0.2 (1) 0.2	0.6 (1) 0.6		
SWEIGHT	3	32.1 (2) 16.1	16.8 (12) 8.4		
TYPESEAT	2	54.7 (1) 54.7	0.2 (1) 0.2		
AREA	2	5.1 (1) 5.1	5.2 (1) 5.2		
HORIZ	3	6.5 (2) 3.2	5.8 (1) 5.8		
VERT	3	16.1 (2) 8.1	215.7 (2) 107.9		
DIST	4	13.8 (3) 4.6	16.1 (3) 5.3		
DFORCE	2	3.9 (1) 3.9	3.8 (1) 3.8		
NBVEH*	2	17.4 (1) 17.4	40.5 (1) 40.5	30.7 (1) 11.6 (1) 42.3 (2)	38.4 (1) 0.91
LOC	2	2.1 (1) 2.1	56.9 (1) 56.9		
LATCH	2	11.6 (1) 11.6	20.1 (1) 20.1		
INTRUS	2	5.6 (1) 5.6	18.0 (1) 18.0		
EXT	2	3.7 (1) 3.7	87.1 (1) 87.1		
VLDT	3	6.0 (2) 3.0	4.4 (2) 2.2		

*Variable selected at the given stage

†These statistics have not been adjusted to account for the sampling schemes. To obtain the adjusted X^2, divide the X^2 values in the table by 1.4. (See Appendix A)

††The index $I = T_4/(T_{3,Pre} + T_{3,Post})$

Table C-5 (Con't)

Statistics† Generated in the Variable Selection Process for Injury Characterization OAIS $\geq$ K

STAGE II

Variable	Number of Categories	T_1 (d.f.) T_1/d.f.	T_2 (d.f.) T_2/d.f.	$T_{3,Pre}$(d.f.) $T_{3,Post}$(d.f.) $T_{3,Pre}+T_{3,Post}$	T_4(d.f.) I††
SEX	2	67.0 (3) 22.3	41.6 (3) 13.9	46.5 (3) 12.1 (3) 58.6 (6)	48.7 (3) 0.83
BELT	2	56.4 (3) 18.8	52.1 (3) 17.4	48.5 (3) 11.5 (3) 60.1 (6)	46.1 (3) 0.77
SEAT	2				
AGE	3	59.5 (5) 11.9	92.1 (5) 18.4		
WEIGHT	3	122.2 (5) 24.4	60.4 (5) 12.1	9.3 (5) 44.4 (5) 53.7 (10)	21.4 (5) 0.40
BPILLAR	2	44.2 (3) 14.7	44.3 (3) 14.8	48.4 (3) 12.3 (6) 60.7 (6)	43.5 (3) 0.72
DOOR	2	116.4 (3) 38.8	38.7 (3) 12.9	12.1 (3) 32.8 (3) 44.9 (6)	4.0 (3) 0.09
SWEIGHT	3	37.5 (5) 7.5	65.3 (3) 21.8		
TYPESEAT	2	86.3 (3) 28.8	19.6 (3) 6.5		
AREA	2	28.7 (3) 9.6	20.5 (3) 6.8		
HORIZ	3	31.8 (5) 6.4	75.0 (5) 15.0		
VERT*	3	60.9 (5) 12.2	253.1 (5) 50.6	127.4 (5) 6.0 (5) 133.5 (10)	107.7 (5) 0.81
DIST	4	51.0 (7) 7.3	78.4 (7) 11.2		
DFORCE	2	16.9 (3) 5.6	51.8 (3) 17.3		
NBVEH	2				
LOC	2	29.6 (3) 9.9	82.3 (3) 27.4		
LATCH	2				
INTRUS	2				
EXT	2				
VLDT	3				

In this appendix, the codes for some selected NCSS variables are given. A complete listing of all NCSS variables is available from the author.

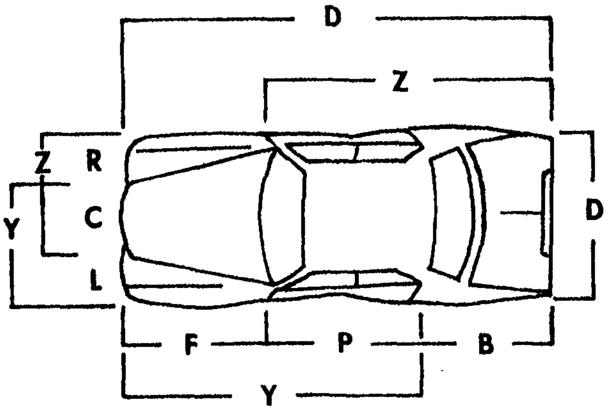
Type of Variable	Variable Symbol	Description	Codes
Accident	NBVEH	Number of Vehicles involved	1-7
	LOC	Location of accident	1=Rural 2=Urban 9=Unknown
	WFAC	Weighting Factor	1=sampled at 100% 4=sampled at 25% 10=sampled at 10% 20=sampled at 5%
Vehicle	STYLE	Body style	01=passenger car 02=station wagon 03=convertible 04=car, pickup body 05=van-passenger 06=van-cargo 07=multi-purpose 08=pick-up 09=straight truck 10=tractor trailer 11=school bus 12=other bus 13=motorcycle 98=other body style 99=unknown
	WEIGHT SWEIGHT	Vehicle weight Striking vehicle weight	001-998 = weighted to the nearest 100 lbs. Example: 3860=039 999 = unknown,
	CDC	Principal direction of force	01-12 = o'clock direction of principal force at impact Example: 12 = frontal force 03 = right side force 00=Not available (mostly rollover) 99=unknown

Type of Variable	Variable Symbol	Description	Codes
	CONTACT	Object Contacted	<u>Interior Objects Contacted Front of Passenger Compartment</u> 01 = Instrument panel 02 = Steering assembly 03 = Windshield 04 = Glove compartment area 05 = Hardware items (ashtrays, instruments, knobs) 06 = Heater or AC ducts 07 = A/C or ventilating ducts 08 = Mirrors 09 = Parking brake 10 = Radio 11 = Sunvisors, fittings and/or top molding (header) 12 = Transmission selector lever 13 = Add-on equipment (CB, tape deck, air conditioners) 14 = Parcel Tray <u>Sides</u> 15 = Surface or side interiors 16 = Hardware 17 = Armrests 18 = A-Pillar 19 = B-Pillar 20 = C-Pillar 21 = D-Pillar 22 = Courtesy lights 23 = Window glass 24 = Window frame

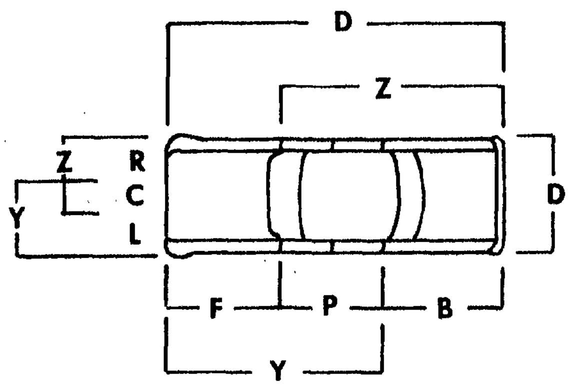
Type of Variable	Variable Symbol	Description	Codes
	CONTACT	Object Contacted	<u>Interior</u> 25 = Back of seats 26 = Restraint system hardware 27 = Restraint system webbing 28 = Head restraints 29 = Air cushion 30 = Other occupants 31 = Interior object loose <u>Roof</u> 32 = Roof side rails 33 = Sunvisors, fittings and/or top molding (header) 34 = Roof or convertible top 35 = Coat hooks <u>Floor</u> 36 = Transmission selector lever 37 = Parking brake handle 38 = Floor 39 = Foot controls 49 = Console <u>Rear</u> 41 = Backlight (rear window) 42 = Backlight header

Type of Variable	Variable Symbol	Description	Codes
	DIST	Type of Primary Damage Distribution	W = Wide Impact Area N = Narrow Impact Area S = Sideswipe U = Rollover X = Overhanging structure E = Corner 0 = NA/unknown
	TOW	Case Vehicle Towed	1 = Yes 2 = No 9 = Unknown
	TYPESEAT*	Front Seat Type	1 = Bench 2 = Split 3 = Bucket 8 = Other/NA 9 = Unknown
Occupant	SEX	Sex of Occupant	1 = Male 2 = Female 3 = Female, pregnant 4 = Female, unknown if pregnant 9 = Unknown
	NCSS	NCSS Injury Classification	1 = Fatal - autopsy obtained 2 = Fatal - medical diagnosis 3 = Fatal - not documented 4 = Non-fatal - overnight hospitalization 5 = Non-fatal - transported and released 6 = Other treatment 7 = Treatment unknown, - not transported 8 = No treatment - not transported 9 = Unknown

Type of Variable	Variable Symbol	Description	Codes
	AREA	Primary Area of Deformation	F = Front R = Right side B = Back (rear) L = Left side T = Top U = Undercarriage X = Unclassified 0 = NA or Unknown



Type of Variable	Variable Symbol	Description	Codes
	HORLOC	Primary Horizontal Location	D = Distributed-side/end L = Left-front/rear C = Center-front/rear R = Right-front/rear F = Side front-left/right P = Side center-left/right B = Side rear-left/right Y = side/end-F+P/L+C Z = side/end-B+P/R+C 0 = NA/unknown



Type of Variable	Variable Symbol	Description	Codes
	VERT	Primary Vertical Area	A = All H = Top of frame to top E = Everything below belt line G = Belt line and above M = Middle-top of frame to belt line or hood L = Low-top of frame, frame, and below X = Undercarriage 0 = NA/unknown