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FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMVSS 208: OCCUPANT CRASH PROTECTION

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16. Abstract This report covers the final design and implementation plan for evaluating the effectiveness of FMVSS 208 (Occupant Crash Protection). The plan for the evaluation study considers measurability criteria, alternative statistical techniques, data availability/collectability, resource requirements, work schedule, and other factors. The Standard presents manufacturers with three options for compliance: (1) a totally passive system which works in several specified crash conditions; (2) a passive system which provides front seat occupant protection in frontal crashes; or (3) an integral lap/shoulder belt system. The ultimate objective the Standard is to reduce the numbers and severity of injuries in automobile accidents. Most manufacturers presently satisfy the Standard with lap/shoulder belts, although a program is underway which will result in about 440,000 air bags and 60,000 passive belts being installed in 1978-1981 model year cars. Presently, there are in use only about 11,000 air bags and 65,000 passive belts. This seriously constrains the amount of accident data available for evaluation of these options of the Standard. The evaluation plan has three distinct features: (1) evaluation of lap/shoulder belts using RSEP and NCSS data that will be available after May 1978, and will include data on change in velocity (ΔV); (2) evaluation of passive systems, first using the limited accident data that will be available, and later incorporating accident data from the half million systems to be installed; (3) a seat belt usage survey, emphasing quality of data collected and collection of data in rural areas, where serious and fatal accidents are disproportionately high, and little is known about seat belt usage.

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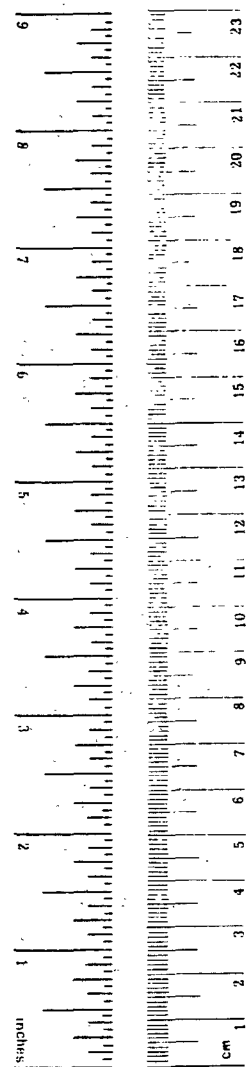
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

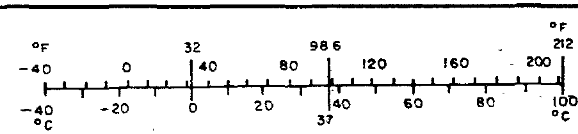
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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). [illegible] NBS Misc. Publ. [illegible] Units of Weights and Measures, Pr[illegible]



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



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ABBREVIATIONS USED

ACRS	Air Cushion Restraint System
AIS	Abbreviated Injury Scale
ANACOVA	Analysis of Covariance
ANOVA	Analysis of Variance
BLS	Bureau of Labor Statistics
CDC	Collision Deformation Classification
CRASH	Calspan Reconstruction of Accident Speeds on the Highway
CTM	Contract Monitor
DOT	Department of Transportation
FMVSS	Federal Motor Vehicle Safety Standard
GAO	General Accounting Office
GM	General Motors
GVW	Gross Vehicle Weight
HSRI	Highway Safety Research Institute
MY	Model Year
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
OIC	Occupant Injury Classification
RSEP	Restraint Systems Evaluation Program
SWRI	Southwest Research Institute
USC	University of Southern California
VIN	Vehicle Identification Number
VW	Volkswagen

1.0 INTRODUCTION

This report is the last in a series of four reports which contain the final design and implementation plan for evaluating the effectiveness of each of four selected Federal Motor Vehicle Safety Standards (FMVSS). The four selected FMVSS which have been examined are:

- FMVSS 214 - Side Door Strength
- FMVSS 215 - Exterior Protection
- FMVSS 301 - Fuel System Integrity
- FMVSS 208 - Occupant Crash Protection

This report contains the final design and implementation plan for evaluating the effectiveness of FMVSS 208 - Occupant Crash Protection.

1.1 Background

Originally introduced in 1968, the Occupant Crash Protection Standard has been modified several times. Its major change has been to allow vehicle manufacturers three options for satisfying the Standard. Options #1 and #2 have less specific equipment criteria and more detailed injury criteria. Option #3 has specific equipment requirements for the seat belt assemblies but few or no injury criteria, depending on the type of assembly installed. The objective of this Standard is to decrease occupant injury through increased usage of restraint systems--active systems such as the current lap/shoulder belt combination, or passive systems typified by the passive belt or air cushion restraint system.* In many of the earlier versions of the Standard, the active methods of occupant crash protection were scheduled for elimination. There has been considerable controversy concerning the relative effectiveness and costs of the alternative active and passive systems. The current version of the Standard does not give any date for the elimination of active systems. Since the Standard became effective on 1 January 1968, automobiles have been equipped with a variety of occupant restraint systems, such as lap belt only, separate lap belt and shoulder belt, and integral lap belt and shoulder belt. At present, the overwhelming majority of vehicles have the integral lap belt and shoulder belt system. Table 1-1 gives the important changes in the Standard by model year.

*The effectiveness of the Standard depends completely on the usage of the protection systems. The passive system is favored because it would always be in use, without an explicit action ("buckling up") on the part of the occupant.

TABLE 1-1

APPLICABILITY OF THE STANDARD BY MODEL YEAR

Model Year	Occupant Crash Protection Standard Requirements
Pre-1968	• No requirements, but lap belts were standard equipment on most cars.
1968*	• Type 1 (lap) or Type 2 (lap and shoulder) seat belt assemblies required at each seat position. (FMVSS 209 specifically described the assembly and FMVSS 210 described requirements for the anchorage.)
1972**	• Manufacturers were given three options for meeting the Standard. The first option required a totally passive system for crash protection. The second option required a lap belt and some other passive features to meet the frontal crash requirements. The third option specified an integral lap/shoulder belt system with warning device and had no injury criteria. (After August 15, 1973, the third option was to be eliminated; however, that date was continually postponed.
1974	• The third option was modified to require an ignition interlock device.
	• If only a lap belt is used, the vehicle had to meet the frontal barrier crash requirements and injury criteria.
	• The second option was upgraded to a complete passive protection system in head-on test crashes although some type of seat belt was still required.
(1975)	(• The ignition interlock requirement was revoked early in the 1975 model year--29 October 1974. However, many models were produced with the interlock system.)

*FMVSS 208 became effective 1 January 1968, which was after the beginning of the 1968 model year.

**This change came after the start of the 1972 model year (1 January 1972); however, this change did not affect how the manufacturers were complying.

Purpose of FMVSS 208

- The specific purpose is to establish performance requirements for the protection of vehicle occupants in crash situations.
- The general purpose is to reduce the number of deaths and the overall severity of injuries in motor vehicle accidents.

General Requirements of FMVSS 208

The current Standard allows the manufacturer to comply under three different options, each with different performance criteria. In general, the requirements are:

- Option #1 requires a completely passive protection system which meets all the injury criteria in the frontal barrier crash at 30 mph and the lateral moving barrier crash at 20 mph. In the rollover test at 30 mph the only injury criterion is that the test dummy should be contained within the passenger compartment throughout the test. Other injury criteria limit the forces on the head, chest and upper leg during crash tests.

- Option #2 requires a head-on passive protection system for front seating positions which meets all the injury criteria in a 30 mph perpendicular, frontal barrier crash. The option also requires installation of at least a lap belt with warning system.

- Option #3 requires only a lap and shoulder belt protection system with a belt warning system. If only a lap belt is provided, then the vehicle must be capable of meeting the perpendicular frontal barrier crash requirements including injury criteria.

Measures of Effectiveness

Since the Standard's stated purpose is to reduce the occurrence and severity of injury, injury-related measures are the most obvious means of assessing the Standard's effectiveness. The injury criteria employed for testing under the Standard are:

- The test dummies used in each crash test are to be contained within the passenger compartment throughout the test.

- The acceleration of the head of the test dummies cannot exceed an index level of 1,000. The index is an integrated expression of the acceleration forces on the head in any period during the crash. Prior to 31 August 1976, the acceleration was measured during any period when the head is in contact with any part of the vehicle other than the belt system.

- The acceleration forces on the chest are measured at the center of gravity of the upper thorax. These forces must not exceed 60g for longer than 3 milliseconds total. Prior to 31 August 1976, this acceleration was measured with a severity index which could not exceed 1,000.

- The axial forces on the upper leg cannot exceed 1,700 pounds.

The above explicit injury criteria, however, are applicable only under the first two options for passive protection systems.* The vast majority of automobiles in recent model years (1973-1977) are equipped with seat belt assemblies which comply with the third option and thus the net effectiveness of this restraint system depends on their usage by vehicle occupants. For this reason, the estimating of the effectiveness of the Standard must cover both the effectiveness and usage of the system. Because the Standard's stated purpose is the reduction of the number and severity of injury, the Abbreviated Injury Scale (AIS) is the most obvious measure of effectiveness of the Standard.

*With the exception that under Option #3, if only a lap belt is provided, then the vehicle must be capable of meeting the perpendicular frontal barrier crash requirements, including injury criteria.

Means of Complying with the Standard

Since 1 January 1972, manufacturers have had three options under which they could comply with FMVSS 208. The first option was to provide a totally passive system: no manufacturer has complied under this option. The second option encourages the manufacturer to provide some passive protection systems, but does not require complete reliance on the passive systems as the first option does. Option #2 requires, when using the passive system alone, that injury criteria must be met for front seat passengers in frontal collision into a barrier at 30 mph. However, these vehicles are also required to have seat belt assemblies with warning systems, with some exceptions in the case of passive belts. Some manufacturers have provided systems which have met this option on some of their cars. General Motors provided an Air-Cushion Restraint System (ACRS) as an option on a few of their larger vehicles for several model years. Volvo is currently field testing an air bag type system on some of their cars. Since 1975, Volkswagen has offered a passive belt system as an option in its VW Rabbit.

The vast majority of cars sold in the U.S. today comply with FMVSS 208 under the third option--combination lap/shoulder belt assemblies with warning devices. If a manufacturer chooses to provide just a lap belt, then he has to show that the vehicle meets the perpendicular frontal crash test requirements, which include injury criteria. By providing the lap/shoulder belt combination, the manufacturer has only to meet hardware requirements, not crash performance criteria. The seat belt assemblies must fit a wide range of persons. The lap belt portion must fit everyone from a 50th-percentile 6-year old to a 95th-percentile male (i.e., 47 to 215 lbs, respectively). The shoulder portion must fit everyone from a 5th-percentile female to the 95th-percentile male with the seat in any position. The lap belt portion must have an emergency-locking or automatic-locking retractor, while the shoulder portion must be adjustable manually or with an emergency-locking retractor.

The seat belt warning system has many detailed specifications about when and how it should operate. During the 1974 model year and part of 1975, the seat belt warning/ignition interlock system stirred considerable controversy. The interlock requirement was revoked by Congress in 1974. Presently, both a visible and an audible warning are given for at least four and not more than eight seconds when a seat is occupied and the belt is not buckled.

Since the introduction of the Standard, there have been several variations of the seat belt restraint system in cars sold in the U.S. Table 1-2 below describes by model year the method used in most models.

TABLE 1-2
PRIMARY CRASH PROTECTION COMPLIANCE METHODS

Model Year(s)	Common Type of Seat Belt Assembly
1968 - 1971	• Domestic manufacturers supplied cars equipped with lap belt systems. Some provided additional shoulder belts. [Foreign manufacturers often supplied a Type 2 (3-point) belt.]
1972	• Late model year cars came equipped with a persistent belt warning system. More domestic manufacturers supplied separate lap belts (Type 1) and shoulder belts (Type 2a)-- a 4-point system.
1973	• The Standard required a Type 2 belt with a detachable shoulder portion.
1974 - 1975	• Ignition interlock was introduced to be used with Type 2 belts (non-detachable shoulder belts). The persistent warning system was changed to a simple (4-8 second) warning system in early 1975 model year cars.
1976-Present	• Although the ignition interlock requirement was revoked early in the 1975 model year, the interlock system was not removed from most cars until the following model year.

Real World Performance of the Standard

The real world performance of FMVSS 208 is dependent on a number of key factors which can be grouped under the following headings: (1) Usage; (2) Characteristics of Occupants; (3) Actions of Occupants; (4) Characteristics of Car Interior; and (5) Type of Accident.

Usage. The overwhelming majority of cars complies with FMVSS 208 through the inclusion of active restraint systems which require action on the part of the driver and other occupants. A significant majority of drivers and passengers does not use the system and, hence, completely negates any potential benefits in terms of injury reduction or elimination which could accrue from the Standard. Urban usage surveys suggest that usage is 20 to 30 percent.

Characteristics of Occupants. Requirements for the seat belt assembly are that (1) the lap portion must fit persons from a 50th-percentile 6-year old to a 95th-percentile male (47 lb to 215 lb) and (2) the upper torso restraint must fit all persons between a 5th-percentile female and a 95th-percentile male with the seat in any adjusted position. Persons outside these ranges may find it difficult to make use of the restraints system and/or could experience seat belt-related injuries, if used. Even with properly adjusted belts, the flexing of the flesh and the type of clothing worn affect belt restraint effectiveness.

The potential for occupant injury is, of course, affected by other occupant characteristics. Occupant health, age and sex may have a significant effect. The very old and the very young can experience more severe injuries than a healthy adult in his or her middle years, for example. Tall people have an increased potential for head injury, especially in small cars.

Actions of Occupants. A number of actions taken prior to and during an accident can affect injury risk with the use of lap and/or shoulder belts. Loosely worn and impropertly adjusted belts negate the load-limiting effects of belts and may cause additional injuries due to the belt. The retractable 3-point lap/shoulder belt system reduces the likelihood of an improperly worn belt in the front outboard seating positions.

Proper seating position will affect the potential for the restraint system to protect an occupant from injury. Obviously, when an occupant is leaning forward or sitting sideways, the lap/shoulder belt system may be ineffective or less effective in preventing injury. Further, during an actual crash situation, an occupant may be able to assume a protective defensive position.

Characteristics of Car Interior. The effectiveness of belt restraint in minimizing injuries will be affected by the quality of instrument panel padding and bending and/or fracture strength. An instrument panel that is well padded and has "give" is obviously preferred to a stiff, poorly-padded panel. The adjusted front seat position regulating the distance from the driver/passenger to the steering wheel/front dashboard is another factor affecting possible injuries. Other factors such as an open glove compartment or ash tray or loose objects can contribute to injuries.

Type of Accident. The action and potential effectiveness of restraint systems in reducing or preventing injury are related both to type of impact and collision speed. At very low speeds, there is usually no injury, while at extremely high speeds all occupants are usually killed or injured, often because of destruction or major deformation of the passenger compartment, occupant ejection, or fire. Seat belts are expected to have their greatest effectiveness at moderate speeds.

The type of impact is also important. Rear collisions cause rearward neck strain which is not addressed in the Standard. In this case, the back of the seat and head restraint comprise the restraint system. The effectiveness of belt restraint in frontal and side impacts may be quite different, due to significant differences in the lateral and longitudinal loading forces.

1.2 Summary of Evaluation, Cost Sampling, and Work Plan

The plan to evaluate the effectiveness of FMVSS 208 will be concerned with three analyses. These are:

- Seat Belt Effectiveness Analysis.
- Passive System Effectiveness Analysis: Air Bags and Passive Belts.
- Comprehensive Restraint System Usage Survey.

The first analysis makes use of existing RSEP and NCSS data. The latter two analyses require major data collection or acquisition efforts.

1.2.1 Seat Belt Effectiveness Analysis

An analysis of the effectiveness of FMVSS 208 requires an evaluation of active seat belt restraint systems, since most cars on the road today comply with the Standard under Option 3 of FMVSS 208. The two samples of data to be used in this analysis are the Restraint Systems Evaluation Program (RSEP) data and the National Crash Severity Study (NCSS) data. The original RSEP analysis of 1973-1975 model year cars did not include ΔV,which is currently being added.* The addition of NCSS data will approximately double the sample size.** The data preparation effort will include deriving required variables from existing information and standardizing the variables such that analyses can be performed using RSEP and NCSS data individually and with the two data bases combined. Restraint system usage will be classified according to (1) no restraint used, (2) lap belt only used, and (3) lap/shoulder belt used. Single and two-car accidents will be distinguished,as will direct rear-end impacts. The analysis may be limited to the driver and front right passenger because of sample size requirements. The basic analysis approach will consist of a contingency table analysis of injury occurrence and severity,with the probability of various levels of injury estimated by regression analysis with independent variables. (See Appendix A for discussion of statistical methods.)

1.2.2 Passive Systems Effectiveness Analysis: Air Bags and Passive Belts

The analysis of the effectiveness of the air bag-lap belt system and the VW passive shoulder belt system can be accomplished with historical data,

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*ΔV = Change in velocity.

**RSEP and NCSS combined will total about 20,000 accidents.

once a sufficient period of exposure for cars so equipped has elapsed. Presently there are only about 11,000 air bag-equipped cars on the road. Only a very preliminary analysis of air bag effectiveness will be possible until a significant portion of the more than 240,000 air bag-equipped cars planned for model years 1980 and 1981 are in the car population. The larger number of VW Rabbit cars equipped with passive shoulder belt systems (65,000 in model years 1973-1977) should permit a more definitive analysis of this system at an earlier date. The statistical techniques employed will be very similar to those used in the active seat belt effectiveness study. In both the air bag and the VW passive belt analysis, comparison must be made with a control group. The air bag effectiveness analysis must consider air bag deployment, lap belt use and lap/shoulder belt use in the control group. The passive belt effectiveness analysis must consider the occurrence of passive system disconnection and use of the lap/shoulder belt in the control VW group. Other factors to be considered in the analyses include ΔV, angle of impact, seating position and vehicle weight.

1.2.3 Comprehensive Restraint System Usage Survey

Estimates of restraint system usage are necessary if an estimate of the reduction in fatalities and injuries due to the Standard is to be made. The tabulations of usage of most interest are (1) age, (2) sex, (3) rural/urban, (4) restraint system and (5) vehicle class. The analysis results will be compared with results from earlier studies and particular emphasis will be given to determining whether substantial usage difference exist between categories which had not previously been investigated. Examples of these include rural/urban usage and trip type. Over 30,000 observations will be required. The new data collection will be obtained by both observation and interview followups.

1.2.4 Cost Sampling Plan

A cost sampling plan has been developed to estimate costs as a function of the following cost categories: (1) direct manufacturing; (2) indirect manufacturing; (3) capital investment (including testing); (4) manufacturers' markup;* (5) dealers' markup;* and (6) taxes.* "Out-of-pocket" costs are

* CEM considers that for these items, reliable information for specific models is not available.

only loosely related to the items listed above and lifetime operating and maintenance costs are explicitly excluded. A frequency sampling plan has been proposed which considers vehicle manufacturer, seating configuration, and inertia reel. In consideration of data gathering costs, it is desirable to limit the number of models sampled. This necessitates making assumptions about the variance of cost data and the representativeness of the stratifications used. An experimental design has been formulated in gather data in two replications for three seating configuration (4-, 5-, and 6-seats) and electrically and mechanically activated inertia reels.

1.2.5 Work Plan

The work plan for the evaluation study and cost analysis comprises four tasks. The work on all four tasks could be conducted simultaneously, since the tasks are basically independent of each other. The total personnel resources required for all four tasks are 10.5 person-years, 8.5 of which are consumed in Task 2 and Task 3. Task 2 begins in the tenth month after the study has begun and continues (with breaks in effort) for a 39-month period due to the need to obtain a sufficient volume of air bag-equipped car accident data.

Task 1 is concerned with the acquisition and analysis of RSEP and NCSS data to evaluate seat belt effectiveness under Option 3 of FMVSS 208. The 9-month effort will require resources of 1.0 person-year, $2000 for computer processing and $1000 for data acquisition costs.

Task 2 deals with the evaluation of the effectiveness of air bag-lap belt systems and the VW passive shoulder belt system, both systems complying under Option 2 of FMVSS 208. Data acquisition includes both the air bag and VW passive belt accident data and data for appropriate control groups. The acquisition of the data and subsequent analysis will be performed in three iterative cycles. The 39-month study will require resources of 4.0 person-years, $5000 for computer processing and $50,000 for data acquisition.

Task 3 is directed toward collecting and analyzing restraint system usage data. The data is collected both by observation and follow-up interview. Resources of 4.5 person-years, $2000 for computer processing and $15,000 for the training of personnel and collection of data are required.

Task 4 is concerned with the determination of direct costs to implement FMVSS 208. Resources of 1.0 person-year and $1000 for computer processing are needed for the seven-month effort.

2.0 OVERVIEW OF THE EVALUATION

The purpose of FMVSS 208 is to reduce the number of deaths and overall severity of injuries in motor vehicle accidents by establishing performance requirements for the protection of vehicle occupants in crash situations.

The principal difficulties in evaluating this Standard are:

(1) The effectiveness of the existing implementation of the Standard depends on the actual usage of the restraint system. Measures of such usage in actual accident situations are often based on estimates.

(2) In meeting the Standard, an assortment of methods have been used; these must apply to a wide range of individuals and crash situations.

(3) Manufacturers can comply with the Standard under any of three options, and are continually encouraged to upgrade the effectiveness of their systems.

Other problems in evaluating the Standard are:

(4) The 1974 and some 1975 models had ignition interlocks which substantially changed the degree of belt usage in those model year cars.

(5) There are relatively few vehicles presently on the road meeting the more rigorous Option 2 criteria. However, recent agreements between DOT and the manufacturers promise to increase that number, but not before the 1980 model year.

To obtain information on the effectiveness of this Standard, three approaches have been proposed:

(1) Analysis of a combined NCSS/RSEP* data base.

(2) Analysis of accidents of existing air bag and passive belt vehicles, with plans to incorporate new data.

(3) Collection of a nationally representative sample of restraint system usage.

The first two approaches concentrate on the effectiveness of the Standard, given the usage of the occupant protection system. The purpose of the third task is to provide the background necessary to determine the overall effect of the Standard in the entire driving population.

Combining the RSEP and NCSS data bases will provide not only more data but also a broader range of model years and new information on impact speed.**

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*RSEP - Restraint System Effectiveness Program; NCSS - National Crash Severity Study.

**ΔV is being added to the RSEP data base; it was not available in the original study.

The differences between the proposed analysis and the RSEP study lie in this newly available data. Tests can now be made for effects of speed, impact angle and possibly restraint system locking systems. The statistical analysis would also differ to a certain extent because continuous variables will be used, such as speed.

In the case of passive systems, a limited number of air bag and passive belt-equipped vehicles are presently on the road--approximately 11,000 and 65,000 respectively. Because of the limited numbers of vehicles made available with these options, the present population may be highly biased. However, the present agreement between DOT and the manufacturers promises to make these vehicles more broadly available--but for air bags not before the 1980 model year. Therefore, the analysis recommended in this case focuses on developing analysis programs and some initial estimates of effectiveness, and then processing additional data as it becomes available. The recommended statistical anlaysis is very similar to that for the NCSS/RSEP data, to provide comparability of results.

The restraint system usage survey is presented in response to a request expressed by the Contract Technical Monitor. The usage information obtained from existing accident studies is biased towards the accident population. Also, these studies rely largely on claimed system usage, although RSEP and other serious studies are very careful about this. In order to assess the overall effect of the Standard, one must have some measure of usage in the general driving population. The basic purpose of this study is to provide background for the overall evaluation of the Standard, rather than to estimate direct effect of the restraint systems when used.

In conclusion, the first analysis will address the additional questions about the effects of speed and angle of impact which could not be addressed in the RSEP study. The second analysis will concentrate on the passive systems and will prepare for the large number which will come into the vehicle population with the 1980 and 1981 model year cars. The third analysis is necessary to place the effectiveness of the Standard in an overall context. However, some may judge that existing restraint system usage studies already supply adequate information.

3.0 EVALUATION PLAN

3.1 Seat Belt Effectiveness Analysis

FMVSS 208 specifies three options by which automobile manufacturers may comply with the Standard. Since most cars are equipped with seat belt assemblies which comply under Option 3 (non-passive with warning system), the following analysis of seat belt effectiveness is recommended. A previous study, which was part of NHTSA's Restraint Systems Evaluation Program (RSEP), conducted an extensive data collection effort and detailed analysis of 1973-1975 model year cars in towaway accidents.* The data base used in that analysis did not yet have available an estimate of ΔV or sufficient information to determine the weight of the striking vehicle in two-vehicle accidents. The effect of ΔV on injury severity is well established and it is particularly important when analyzing towaway accidents because of the likely bias toward higher ΔV's. The RSEP data base is currently being appended with reconstructed estimates of ΔV and when this task is complete, a re-analysis of RSEP data would be valuable. In addition, data collected in the National Crash Severity Study (NCSS) will contain all the necessary information (including ΔV) for a new analysis. The addition of NCSS data will approximately double the sample size available from RSEP data and will provide cases of other than just 1973-1975 model year vehicles. The portion of "lap belt only" cases should increase from the 17 percent present in the RSEP data as a result of including pre-1973 vehicles. The larger sample size might allow further stratifications such as analyzing the effectiveness of different types of lap/shoulder belt systems (3-point *vs.* 4-point, mechanical *vs.* electronic inertial reel, etc.) rather than the single category used in the prior study. The additional data should increase confidence levels and might delineate effects which were too small to find previously.

3.1.1 Data Requirements

The RSEP file contains data on 15,818 (weighted) occupants who were involved in towaway accidents of 1973-1975 model year vehicles in the calendar year 1974 or 1975. Data were collected by five NHTSA-sponsored teams located in Western New York (CALSPAN), Michigan (HSRI), Miami (U. of Miami), San Antonio, Texas (SWRI), and Los Angeles, California (USC). The general sampling criteria were 100 percent of all such accidents where at least one front seat occupant was treated by a hospital and 50 percent of all such accidents where no hospital treatment was involved. The latter data were chosen according to the odd-even

*Reinfurt, Silva, and Seila. *A Statistical Analysis of Seat Belt Effectiveness in 1973-1975 Model Cars Involved in Towaway Crashes* [1].

status of the last license plate digit. There were variations to this scheme in specific sampling areas for specific time periods, but it was the primary scheme used.

An accurate determination of the type of restraint system used by the occupant is important for this evaluation and is available in RSEP data. The variables listed in Table 3-1 are also necessary for the proposed analysis. The Sideswipe, Impact Point Angle, and Force Angle variables are not directly available on the RSEP data base, but they can be determined by decoding the Collision Deformation Classification (CDC) and ΔV.

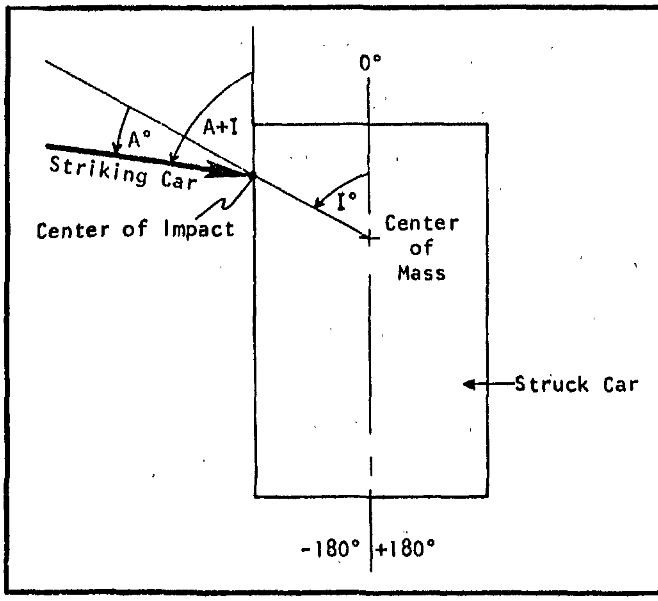
TABLE 3-1

INFORMATION NEEDED FOR ANALYZING SEAT BELT EFFECTIVENESS

Variable Names	
Vehicle Make, Model, Model Year	Occupant Seating Position
ΔV	Type of Collision
Force Angle	Overall AIS
Angle of Impact	Restraint System Available
Vehicle Weight	Restraint System Usage
Vehicle Age	Belt Caused Injury
Age of Occupant	Sideswipe
Sex of Occupant	Height of Occupant

The NCSS data base differs from the RSEP data in sampling criteria, areas of data collection, period of data collection, and extent of information on other accident vehicles. The NCSS is an 18-month effort which began in October 1976 and will continue through March 1978. The goal is to collect data on 10,000 accidents by 1978. Data are being collected by seven NHTSA-sponsored organizations in eight locations: Western New York (CALSPAN), Michigan (HSRI), Miami (U. of Miami), San Antonio, Texas (SWRI), thirteen other counties in Texas (SWRI), Kentucky (U. of Kentucky), Indiana (Indiana U.) and Los Angeles, California (Ultrasystems). The sampling criteria are based on towaway accidents which are divided into three strata. Stratum 1 is sampled at 100 percent and consists of accidents where an occupant's injury requires at least an overnight stay in a hospital (includes fatalities). Stratum 2 is sampled at 25 percent and consists of accidents where an occupant requires hospital attention but does not stay overnight. Stratum 3 is sampled at 10 percent and covers all remaining towaways.

The definitions of "Force Angle," "Angle of Impact," and "Impact Point Angle" are given in Figure 3-1,as well as a diagram of how to measure them.



I = Impact point angle. It is the angle made by the longitudinal line through the center of mass of the car and the line passing through the point of impact and the center of mass.

A = Force angle. It is the angle formed at the point of impact by the line passing through the center of mass of the struck vehicle and the point of impact, and the velocity vector of the striking car.

A + I = Angle of impact.

Figure 3-1. Diagram for measuring "Impact Point" and "Force" angles.

The "Angle of Impact" comes directly from the "Principal Direction of Force" variable of the Collision Deformation Classification (CDC). The other two angles can be derived from information supplied in the "CRASH" program [2,3] which is used to reconstruct ΔV. Variables such as occupant sex and occupant height have been included in Table 3-1,but their effect on occupant injury is only speculative.

3.1.2 Data Acquisition and Preparation

Both the NCSS and RSEP studies are NHTSA-sponsored work and it is assumed that both data bases are available at NHTSA in the form of magnetic tapes with associated coding manuals. The names of variables needed for extraction from NCSS and RSEP are listed in Table 3-2. The information which was originally missing on the RSEP data base (ΔV) and which is currently being added, is assumed to be available in the same format as it exists in the NCSS data base.

Some data pre-processing is necessary to translate NCSS data into the format required to perform the suggested analyses. Part of this effort will consist of recording existing variables onto different scales, particularly in the

TABLE 3-2

VARIABLES FOR EXTRACTION FROM RESP AND NCSS DATA BASES

RSEP	NCSS
1. Type of Accident 2. Type of Impact	Type of Impact
3. Occupant Ejected	Ejection/Entrapment
4. Vehicle Make/Model Code	Make/Model
5. Model Year	Model Year
6. Evidence of Restraint System 7. Active Restraint System Usage	Restraint System
8. Objects Contacted and CDC *	Vehicle Damage
9. Occupant Role 10. Seat Position 11. Sex 12. Age 13. Height	Vehicle Occupants
14. OIC†	Injury Description
15. Belt Caused Injury	Injury Source
16. ΔV Total	ΔV Total
17. ΔV Lateral	ΔV Lateral
18. ΔV Longitudinal	ΔV Longitudinal
19. (must be decoded from 4.)	Vehicle Weight

*Collision Deformation Classification.

†Occupant Injury Classification.

case of categorical variables. For example, the analysis might limit vehicle weight to five categories, whereas on the NCSS file, vehicle weight is in terms of hundreds of pounds. The other major portion of the preprocessing activity will be the reconstruction of variables needed for the analysis but which are not directly available in the data bases. "Vehicle Weight" is not directly available on the RSEP file and can be reconstructed from Vehicle Make, Model, and Model Year. Overall AIS is defined differently on RSEP and NCSS files. The code on the NCSS is based on a clinical judgment of the occupants' overall severity of injury, whereas the RSEP uses the maximum severity of the occupants' first three individual injuries. The RSEP's definition is less subjective but it does not consider three AIS = 2 injuries as more severe than a single AIS = 2 injury. Since the NCSS definition of overall AIS is not available in the RSEP data base, to perform equivalent analyses of NCSS and RSEP data, it will be necessary to reconstruct a NCSS Overall AIS using the RSEP definition.

The preparation of both data bases will include the following steps:

- Decode the variables on the file.
- Extract and construct variables needed for the analysis.
- Re-encode variables into standardized formats.
- Extract relevant accident types.
- Merge condensed information onto one (if possible) data tape for analysis denoting from which data base the case originates.

At this point the data will be ready for the analysis outlined in the next section.

3.1.3 Data Analysis

There are several statistical techniques which might be used to analyze detailed accident data. Three general categories of such techniques are: regression analysis, contingency table analysis, and "index" methods. They differ in their distributional assumptions about the population to be sampled and they treat variables on different scales (continuous *vs.* categorical). A more detailed discussion of these techniques and how they apply to the recommended analysis is given in Appendix A. The models proposed in this section encompass aspects of each of these analytical approaches.

To remove selection effects, the sample will include only towaway accidents, since such accidents will usually be reported by vehicle damage rather than occupant injury. Some towaways will occur because the driver is incapacitated, rather than due to vehicle damage. But according to information obtained from various police sources, the number of these cases should be small.

Single and two-car accidents should be analyzed separately because the parameters may be different. If analyses show that there is no significant difference, then they can be combined. All trucks with GVW greater than 10,000 lb should be excluded because of differences in collision dynamics. Smaller trucks (pickup) can possibly be included but they might have to be analyzed separately or require an additional model variable (i.e., truck *vs.* non-truck). The following discussion will be in terms of two-car accidents.

Direct rear end impacts should be examined separately, since the effects of seat belts is minimal in those collisions. The construction and usage of head restraints will have a significant effect on occupant injury in such cases. The recommended analysis will be limited to the driver and front left passenger for purely empirical reasons. The frequency of rear occupancy is small and the usage of seat belts in the rear is infrequent. The number of cases expected in that category would be insufficient for the proposed analysis,but simple tabulations could be made. The data should be stratified by driver and right front passenger, since the steering wheel on the driver's side creates a non-symmetrical situation.

Restraint system usage will define at least three additional stratifications of the data:

- No Restraint Used.
- Lap Belt Only.
- Lap/Shoulder Belt.

If the data bases are combined and sufficient data are available, additional stratification of the Lap/Shoulder Belt category may be possible. It may be valuable to distinguish between belt-sensitive and inertia locking reels,or detachable versus non-detachable shoulder belts.

The analysis will depend significantly on the nature of the injuries reported and the AIS scale used to differentiate them. The AIS scale, like almost any other injury scale, is not an interval scale but rather an ordinal one. That is, while 6 and 3 are more severe than 5 and 2, respectively, there is no reason to believe that the difference between 5 and 6 is the same as that between 1 and 2. For example, graphs such as those in Figure 3-2 can be constructed from exactly the same ordinal data. Therefore, regression analysis is not recommended.

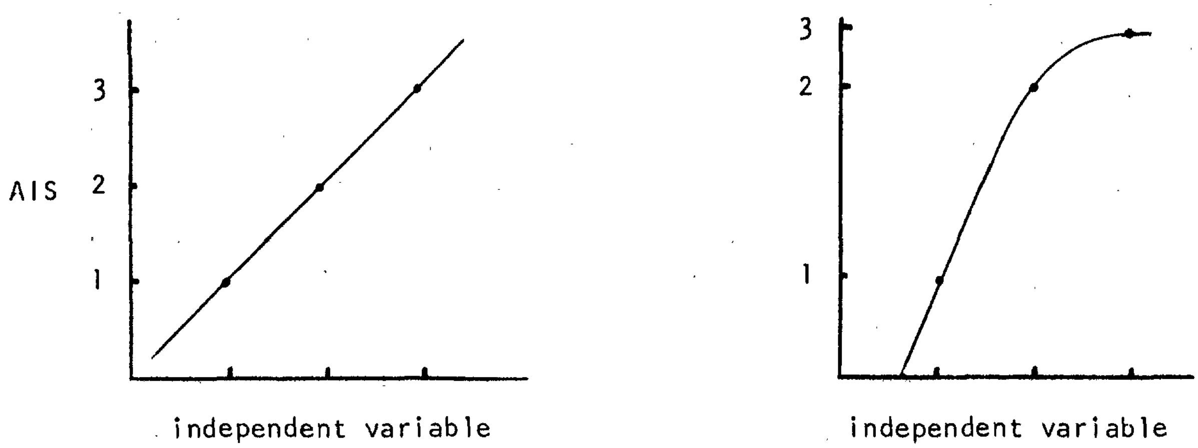


Figure 3-2. Illustration of the inapplicability of regression analysis of AIS-scale data, using a nonlinear ordinal scale.

What is recommended is a contingency table analysis with a regression structure on the probabilities. The probabilities of the various levels of injury (e.g., AIS $\geq$ 2, AIS $\geq$ 4) should be estimated as functions of the independent variables for each of the seat belt systems (e.g., none, lap, shoulder). Thus, P_N^2 = fnc(speed, direction,...) can denote the probability of an injury $\geq$ 2 on the AIS scale for no seat belt used,as a function of the independent variables.

A functional form is proposed for the estimated probabilities because an overall measure of effectiveness can mask important results. As an example, consider the effect of speed. Seat belts are expected to have their greatest effectiveness at moderate speeds,with effectiveness decreasing as speed becomes very low or very high. That is, at very low speeds no one gets hurt, while at extremely high speeds all occupants are usually killed, or injured. An overall measure would include the high and low speed situations and thus tend to negate observed effectiveness at moderate speeds. Similar remarks can be made for other independent variables such as the point where the struck car is hit. Using a functional relationship will allow one to determine effectiveness in various important situations.

The Basic Model

One recommended analytic method involves fitting a multinomial response model with both continuous and discrete explanatory variables. The notation "p" will be used generically to represent any individual cell probability or any cumulated cell probability. The model is expressed in functional structure to yield log p. A list of primary model variables and their description are shown in Table 3-3 below.

TABLE 3-3

DESCRIPTION OF INDEPENDENT VARIABLES

Variable	Type	Definition
ΔV = Change in Velocity	Quadratic	NCSS file definition
I = Impact Point Angle	Angular	See Figure 3-1
A = Force Angle	Angular	See Figure 3-1
W = Weight of Case Vehicle	Nominal	Weight categories < 2000 lb,2000-3000,etc.
M = Model Year Group	Dichotomous	Model Year categories: before 1969,after 1969
G = Age of Occupant	Nominal	Age groups 16-25, 26-35, etc.
S = Sideswipe Variable	Dichotomous	No Sideswipe = 0, Sideswipe = 1

Some of the nominal variables are in fact continuous but since their influence is likely to be relatively small, they might be treated as categorical with only a few categories. On the other hand, both the main factor velocity change and angle of impact could be treated as categorical variables with sufficiently many levels. The Model Year Group variable (M) has been included to control for the effect of other safety Standards implemented at various times, e.g.,steering wheel Standards which would affect injury severity in certain crash configurations. The Case Vehicle Weight variable (W) has been included to account for the added structural strength of heavier vehicles (the effect of larger mass is implicit in ΔV). The effect of age on injury severity in an accident is well-documented and thus the Occupant Age variable (G) is another independent variable. Sideswipes are physically special cases,and since the Impact Point Angle (I) and Force Angle (A) are not defined for sideswipes, the Sideswipe variable (S) is introduced as a zero-one variable.

The variables defined in Table 3-3 are primary, i.e., those which are known or hypothetically important and have principal effects. Some secondary variables whose effects are purely speculative are: occupant sex, occupant height, vehicle age, and type of seat (bench *vs.* bucket). Secondary variables could be investigated by including them individually in the model at a later stage of the analysis.

The most likely interactions are:

$(\Delta V \times I)$, $(\Delta V \times A)$, and $(\Delta V \times (A+I))$

Each of the injury probabilities is a function of the various independent variables. The logarithm of the probability is given a functional structure that depends on these variables:

$$\begin{aligned}
\log p = \mu \\
&+ a_1 \Delta V + a_2 \Delta V^2 + && \text{(continuous)} \\
&+ W_i + M_j + G_k + S_\ell && \text{(categorical)} \\
&+ b_1 \Delta V \cos I + b_2 \Delta V \cos 2I + b_3 \Delta V \cos 3I \\
&+ c_1 \Delta V \sin I + c_2 \Delta V \sin 2I + d_1 \Delta V \cos A && \text{(continuous interactions)} \\
&+ d_2 \Delta V \cos 2A + e_1 \Delta V \sin A + f_1 \Delta V \cos (A+I),
\end{aligned}$$

where p is the probability of equaling or exceeding a particular AIS level for a particular belt system usage, and

$\mu, a_1, a_2, b_1, b_2, \ldots, f_1$

are coefficients to be estimated from the data.

The subscript for each of the categorical mean effects runs over the possible categories for this variable. Typical constraints force the sum of these effects weighted by cell size over the indexing subscript to be zero. The interactions of Change in Velocity with Angle enter simply as other continuous variables in the model. The concepts of Impact Point Angle and Force Angle and their manner of inclusion in the model need more discussion. Their definitions and an illustrative diagram are given in Figure 3-1. These angles have periodicity; that is, going 360° around the car, returns one to the start point. This suggests that these angles should appear in the model as trigonometric functions. The symmetry of right and left introduces the cosine functions. The asymmetry implied by the driver's being to the left of center requires the sine functions. Cosine (A+I) is included, since A+I is the standard "angle of impact" and has been considered in other work.

The physics of the problem suggests that these angles may be more informative than the usual nominal impact point and direction variables.

Frontal Impacts

The Standard addresses frontal impacts; therefore, it is necessary to consider carefully frontal and near-frontal impacts. Perhaps one can determine how well a full frontal crash predicts the effects of less than direct frontal collisions. Impacts farther back than side door impact carry no information for this analysis, and in fact are expected to introduce "noise."

A model similar to that described above can be used, but since only the frontal sector of the car is of interest, the trigonometric functions may not be as appropriate as before. Changes at small angles (of no more than 15° to 30°) are of interest, and while a high frequency term (e.g., sine 30A) would work, too many terms would have to be fitted. Instead, one may replace the cosines with even power terms: i.e., $b_1(\Delta V)\ I^2 + b_2\ (\Delta V)\ I^4 + b_3\ (\Delta V)\ I^6$. The sine terms could be replaced also, but the contributions of these terms may be small enough for them to be omitted.

Discussion of the Model

The model encompasses fifteen independent variables. It is probably too cumbersome to consider all variables at once. It is recommended that more and more variables be included in a sequential manner beginning with those deemed likely to be most significant (*via* other considerations) until a sufficient degree of explanation of variance is attained. The two proposed analyses can be applied to any submodel of this overall model.

The first approach arises "naturally" from the model as formulated. As the model stands, one must estimate μ, the a's, b's, and c's and also the W_i, M_j, G_k, etc. Since the model involves a quantitative or regression component and a qualitative or analysis of variance component, the most plausible approach seems to be to consider the setup as an analysis of covariance problem. In using such an approach, the regression portion of the model (i.e., the continuous variables) is fitted by estimating μ and the a's, b's, and c's. Then the analysis of variance portion of the model (i.e., the discrete variables) is considered in the presence of these covariates. Package programs are available to handle an ANACOVA* of the size we are discussing, so that "in principle" the analysis may be performed. Included in these packages are provisions to run significance tests and to obtain confidence intervals for the regression coefficients and also to run significance tests and multiple comparisons for the main and interaction effects.

However, there are several intrinsic problems with this analysis for injury severity as the dependent variable. At the heart of the problem is the fact that an analysis of covariance assumes the dependent variables to be continuous and normally distributed. Even if it is assumed that five or more ordered categories (e.g., the AIS scale), somewhat approximate a continuous variable, the data reveal that observations will be concentrated in the small values of these categories and hence do not exhibit even remotely normal symmetry. A further problem which is of consequence in interpreting the results of an ANACOVA is that the covariates are not independent of the ANOVA* portion of the model, which is a basic assumption in the ANACOVA model. By virtue of phrasing interactions involving a covariate with various main effects, a dependence between the two portions exists. Thus, although we may innocently run a package ANACOVA program, the prior knowledge that we fail to satisfy basic distributional assumptions certainly must temper our confidence in the accuracy of the resultant significance tests and confidence intervals.

We propose a second and likely preferable alternative approach for injury severity which retains the multinomial character of the dependent variables at a relatively minor sacrifice. If categorization is imposed on ΔV and I, then a log-linear model may be fitted to the data. The log-linear model presumes essentially a higher order contingency table type categorization with respect to the observed independent variables and a dichotomous response for the

*ANACOVA = Analysis of Covariance.
ANOVA = Analysis of Variance.

dependent variable. The logarithm of the probability of one of these responses is given a linear representation in terms of the levels (categories) of the independent variables. The model then only requires that at a given set of levels for these variables, observed responses follow a binomial model with the corresponding model-specified probability of occurrence. The model previously given needs only be amended with respect to the continuous portion; i.e., replace:

$$\underbrace{a_1\Delta V + a_2\Delta V^2}_{} + \underbrace{b_1\Delta V \cos I + \ldots + c_2\Delta V \sin 2I}_{}$$

by

$$\Delta V_g + (I \times \Delta V)_{gh}$$

where the index $g = 1, 2\ldots, n$ denotes the n categories in to which ΔV is divided and $h = 1, 2, \ldots, m$ denotes the m categories into which I is divided. $(I \times \Delta V)_{gh}$ becomes an $m \times n$ table corresponding to the intersection of ΔV_g and I_h. The more comfortable application of this model to the type of experimental results anticipated seems to outweigh the disagreeable necessity for categorizing I and ΔV. The same substitution applies to the Force Angle (A) and ΔV.

There is one further point. Since the response cells are multinomial, the following procedural artifice is needed to formally achieve the binomial response mandated by the log-linear model. The cumulative cells AIS $\leq$ 0, AIS $\leq$ 1, AIS $\leq$ 2, AIS $\leq$ 3 would be fitted in sequence, i.e., in log p, p = P(AIS $\leq$ i) for each of i = 0, 1, 2, 3. Tabulations of RSEP data* show that the frequency of AIS $\geq$ 4 is low (i.e., 0.8% overall and 0.6% in frontal impacts); therefore, all AIS $\geq$ 4 are grouped and P(AIS $\geq$ 4) is estimated by 1 - P(AIS $\leq$ 3). The estimates of the multinomial cell probabilities are obtained by subtraction i.e., P(AIS = 1) = P(AIS $\leq$ 1) - P(AIS $\leq$ 0), etc. Fitting the most populated cells cumulatively and leaving the least populated to the remainder is recommended.

The size of the described model should be manageable with existing log-linear model programs. How does one make comparisons and test hypotheses within a log-linear model framework? The first consideration is how the effect of some variables may be "controlled" in order to see the effects of others. We illustrate the idea briefly *via* an abbreviated example in which two variables are controlled to examine the effect of a third.

*Reference [4] Table 113, page 107.

For example, assume the fit:

$$\log p_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha \times \beta)_{ij}$$

and "control" the effects of variables j and k to see the effect of variable i. Compute an average:

$$\log \hat{p}_i = \frac{\sum_{j,k} n_{ijk} \log \hat{p}_{ijk}}{\sum_{j,k} n_{ijk}} .$$

Hence, the corresponding $\hat{p}_i$ may be obtained and then $\hat{p}_i$ may be studied as i changes to assess the effect of various levels of i. Comparisons of multinomial cell proportions are typically done via contingency table tests of homogeneity (possible goodness of fit test) or simple one and two sample binomial tests when applicable.

A Comparison Index

To compare the protection afforded by the three belt systems, we recommend the following measure or index. Let P_N^3 denote the probability of injury at least as severe as AIS = 3 (i.e., AIS $\geq$ 3) when the driver is not using seat belts. Let P_L^3 and P_S^3 be the corresponding probabilities with lap belts and shoulder-lap belts, respectively. We propose the index

$$I^3(L,N) = \log_2 \frac{P_N^3}{P_L^3}$$

as a measure of the improved protection of lap belts over no belts for AIS $\geq$ 3.* For other injury levels the definition is similar. This index has several desirable properties. If the probability of injury is the same, $P_N^3 = P_L^3$, then $I^3(L,N) = 0$. Should lap belts decrease the probability by 1/2, then $P_L^3 = 1/2\ P_N^3$ and

$$I^3(L,N) = \log_2 2 = 1.$$

*The choice of the base for the logarithm is arbitrary. Base 2 was chosen because it is conceptually desirable for differences on the order of 0.5, e.g., between lap belts and no belts. Log_e would be conceptually more desirable for small differences because it would correspond to percentage differences. Preference in choice of base for the logarithm can be investigated further when performing the analysis.

Conversely, if no use of belts decreases the probability by 1/2, then $P^3_N = 1/2\ P^3_L$, and

$$I^3(L,N) = \log_2 1/2 = -1.$$

Furthermore, the index is additive in the following sense. If $I^3(L,N) = 1.8$ and $I^3(S,L) = 0.5$, then

$$I^3(S,N) = 2.3.$$

Also, note that order is important: $I^3(L,N) = -I^3(N,L)$.

Since the estimates of the injury probabilities are functions of the independent variables, the indices are also functions of these variables. This is desirable because any improvement due to seat belts would not be expected to be uniform across all situations.

A flow chart of the proposed analysis scheme follows in Figure 3-3.

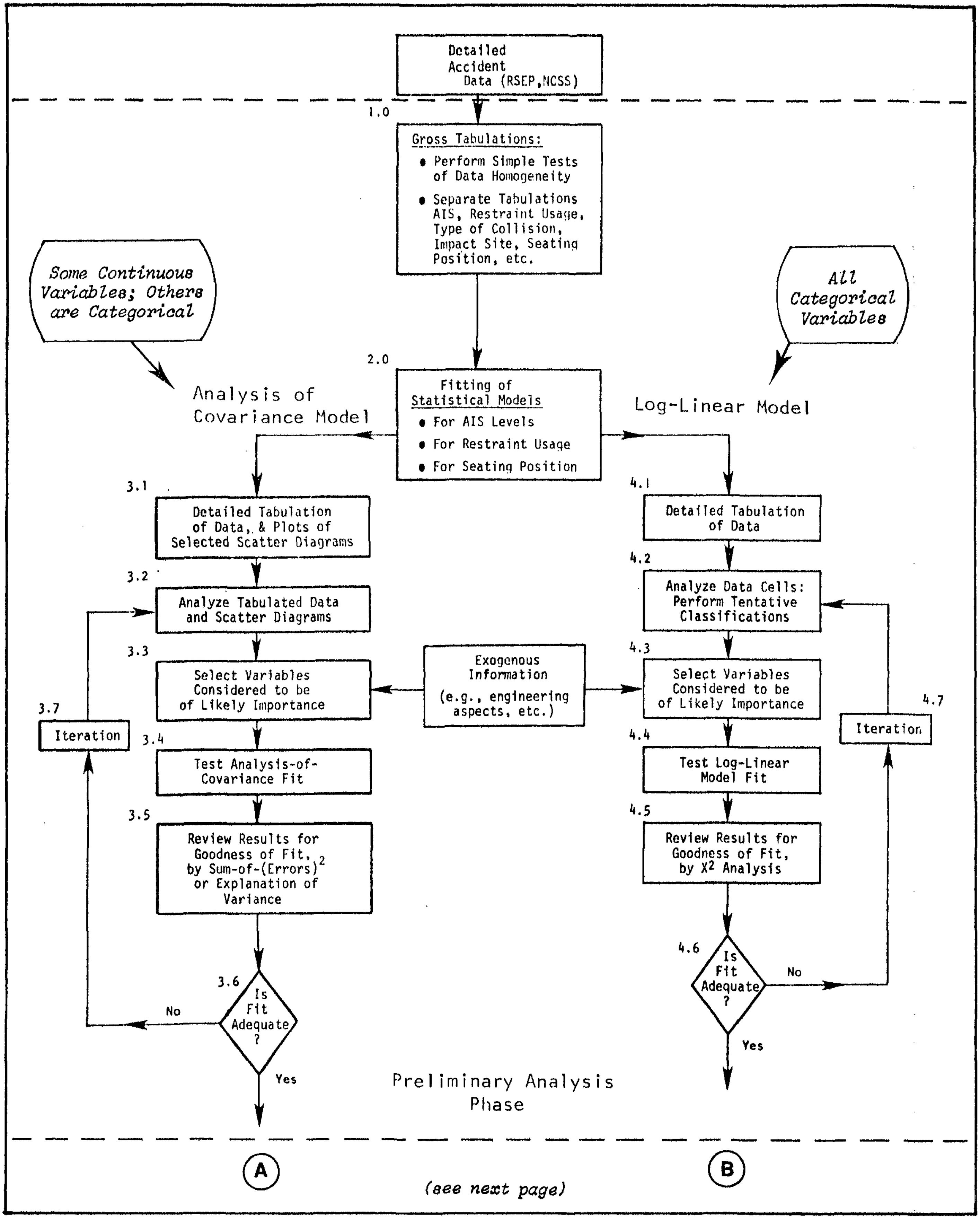


Figure 3-3. Proposed Statistical Analysis Scheme for evaluating Seat Belt Effectiveness.

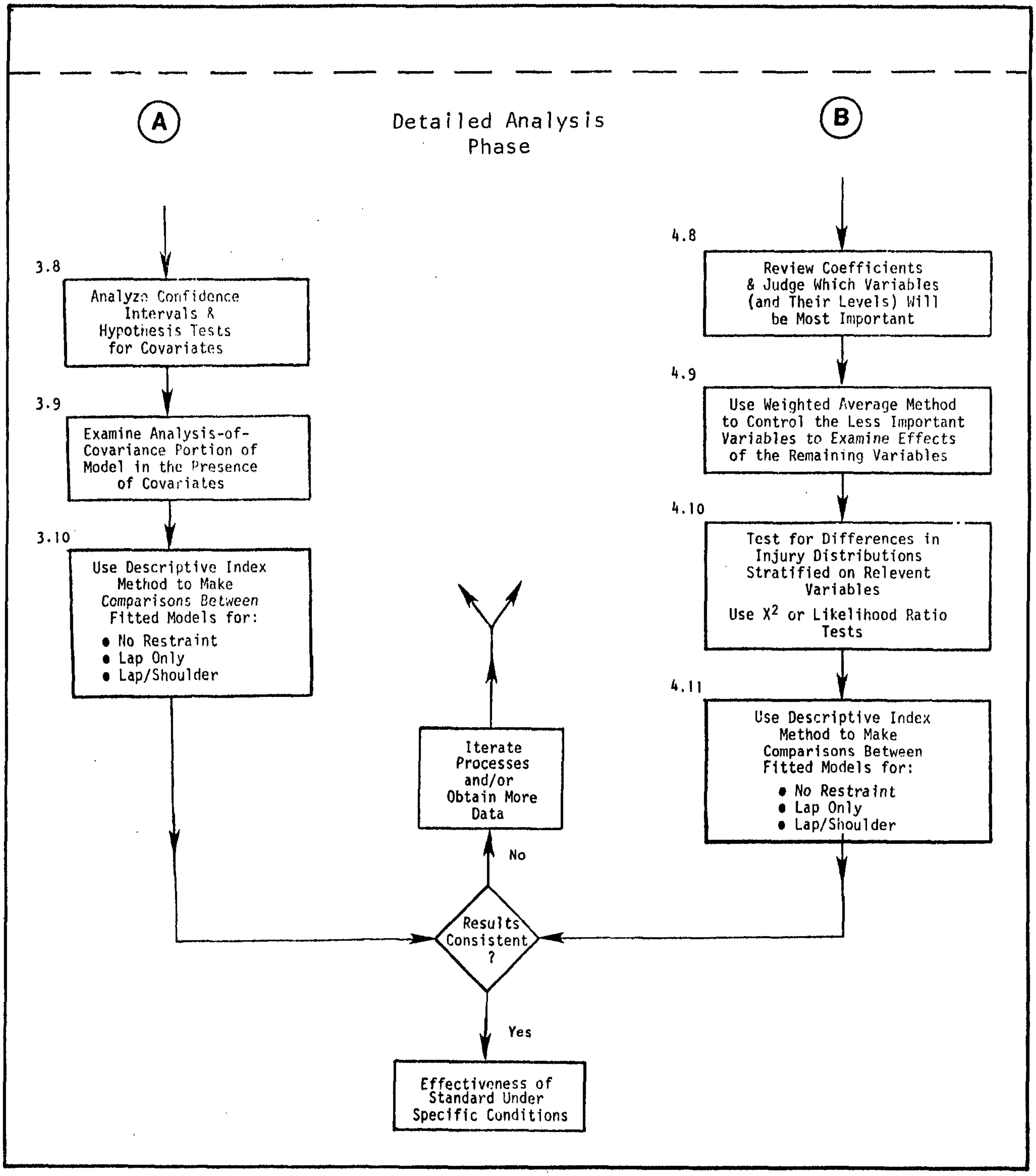


Figure 3-3. (Continued)

3.2 Passive Systems Effectiveness Analysis: Air Bags and Passive Belts

3.2.1 Data Requirements

The analysis of the effectiveness of the air bag passive restraint system for fatality and injury reduction can be accomplished with historical data, once a sufficient period of exposure for cars equipped with air bags has been realized. The accident data required has many similarities to that noted in the requirements for the seat belt effectiveness analyses and includes the following variables:

- Air bag deployment
- Lap belt usage
- AIS injury (head and torso)
- Vehicle make/model
- Vehicle model year
- ΔV
- Force angle
- Angle of impact
- Vehicle weight (both vehicles)
- Calendar year (vehicle age)
- Vehicle deformation
- Age of driver
- Occupants and seating positions
- Sideswipe occurrence
- Type of collision.

The first three variables in the left-hand column above are specifically characteristic of the air bag effectiveness analysis. Obviously, data on air bag deployment and lap belt usage are essential for an analysis of the effectiveness of the system. If the volume of data permits, it may be helpful to stratify injury occurrence according to the head and the torso. In the collection of data on the VW Rabbit passive shoulder belt system, the first two variables are replaced by a variable indicating whether or not the system was disconnected.

3.2.2 Data Acquisition and Preparation

Air Bag-Equipped Cars

There are very few air bag-equipped cars on the road today; in fact the estimate is only about 11,000. The number of air bag-equipped cars manufactured through model year 1976 is given in Table 3-4 from [5]. Very few 1977 model year cars were air bag-equipped.

TABLE 3-4

AIR BAG-EQUIPPED CARS THROUGH MODEL YEAR 1976

Model Year	Car Model	Number Manufactured
1972	Mercury Monterey	831
1973	Chevrolet Impala	1,000
1974	Buick, Cadillac, Olds	5,518
1975	Buick, Cadillac, Olds and Volvo (only seventy-five)	4,081
1976	Buick, Cadillac, Olds (through April 30, 1976)	427
	Total	11,857

It is clear that the sample of air bag-equipped cars does *not* represent a random cross-section of all automobiles. The large, more expensive Buicks, Cadillacs and Oldsmobiles from model years 1974 and 1975 dominate the present sample. The owners/drivers of these cars are also likely to be unrepresentative of the driving population in that they may be, on the average, older, more conservative in driving habits, and possibly more safety-conscious than the general population.

The status of plans for the future manufacture of air bag-equipped cars was revealed in a January 18, 1977 press release. The plans are summarized in Table 3-5 [6]. It is recognized that the current agreements between DOT and the

TABLE 3-5

PLANNED MANUFACTURE OF AIR BAG-EQUIPPED CARS

Model Year	Description	Number to be Manufactured
1980	GM Intermediate	150,000*
	Ford Compact (driver side only)	70,000*
	Mercedes-Benz Sedan	750
	Total 1980 MY	220,750
1981	GM Intermediate	150,000*
	Ford Compact (driver side only)	70,000*
	Mercedes-Benz	1,500
	Total 1981 MY	221,500
	Grand Total	442,250

*For GM and Ford cars it is assumed that an equal number of air bag-equipped cars are manufactured in each model year.

manufacturers are subject to review and renegotiation, but for the purpose of discussion and analysis plans given in this section, the numbers in Table 3-5 are assumed.

The number of *reportable* accidents which involve air bag-equipped cars that can be estimated to become available for analysis is given in Table 3-6. The minimum criteria for reportable accidents differ greatly among states but based on accidents accumulated in the national accident reporting system, one can assume that approximately one in ten cars will become involved in a reportable accident annually. At least an equal fraction of cars will be involved in an unreported accident where damage was below the minimum required for reporting and injuries were absent or very minor.

Assuming the rough estimate of about one in ten cars becoming involved in a reportable accident and the estimated air bag-equipped car populations in the previous two tables, an estimate of the cumulative number of reportable accidents involving these cars at the end of each calendar year is given in Table 3-6. In making the rough estimates, calendar years were not distinguished from model years. It must also be recognized that a period of time is required after the given calendar year, before information on all accidents in that calendar year are available for analysis.

TABLE 3-6

ESTIMATE OF CUMULATIVE OCCURRENCE OF REPORTABLE ACCIDENTS INVOLVING AIR BAG-EQUIPPED CARS

Year	Estimated Cumulative Number of Accidents
1974	600
1975	1,500
1976	2,600
1977	3,800
1978	5,000
1979	6,100
1980	18,000
1981	53,000
1982	110,000

For example, if the air bag effectiveness study is begun in early 1978, it is estimated that between 2600 and 3800 reportable accidents might be available.

The initial problem in the acquisition of data is the lack of sufficient numbers of air bag crashes. This creates the need for a reliable procedure to track air bag-equipped vehicles so that data are collected on all accidents which do occur. There are currently several sources which document air bag accidents. The NHTSA maintains a National Response Center which provides a 24-hour phone service for reporting air bag vehicle accidents. General Motors Corporation provides the National Response Center phone number on the sun visor of all its air bag-equipped cars. Once an air bag deployment is identified, NHTSA performs a Level 2 or Level 3 accident investigation to record the relevant crash characteristics. Automobile insurance carriers are another source of information. Allstate Insurance offers premium discounts for air bag-equipped vehicles and believes it insures a high proportion of the existing air bag vehicle population. In addition, Allstate operates its own fleet of approximately 475 air bag vehicles. Allstate also maintains its own 24-hour phone service for reporting air bag accidents, and drivers in their fleet are instructed to report all accidents. Insurance claims on policies covering air bag-equipped cars are monitored, and the Chicago police cooperate by reporting any air bag deployments they encounter. Identified Allstate fleet accidents are investigated by Allstate, and all air bag crashes are reported to the NHTSA. Car manufacturers and other insurance companies also cooperate with Allstate in air bag vehicle accident reporting.

The above procedures probably detect almost all air bag deployment accidents. However, a significant percentage of non-deployment air bag accidents may not be reported. The NHTSA could try to obtain information on the unreported accidents by surveying current owners of air bag-equipped vehicles. Assuming the manufacturers have recorded the Vehicle Identification Numbers of these vehicles, postcards could be sent to owners asking if the air bag-equipped vehicle had been in an accident, and other relevant data. The responses could then be cross-indexed with reported accidents to add cases and evaluate the current reporting procedures.

The number of accident-related air bag deployments per year is given in Table 3-7, based on data in [5]. The deployment data indicate that perhaps 50

TABLE 3-7

NUMBER OF AIR BAG DEPLOYMENT ACCIDENTS PER YEAR

Year	Number of Accidents with Deployments
1972	1
1973	15
1974	26
1975	39
1976	30 (As of Aug. 1976)

cars out of 11,000 cars are involved in a deployment accident in a year (only 0.5 percent). If we assume that 10 percent of all air bag-equipped cars are involved in a reportable accident then only 5 percent of the reportable accidents involve a deployment. This may be a reasonable figure when it is realized that non-deployment accidents involve (1) all rear-end impacts; (2) most side impacts (especially considering that the air bag cars are large) and (3) all frontal collisions where the speed is less than 12 mph. Thus, while the existing population of about 11,000 air bag-equipped cars permits a reasonably rapid accumulation of non-deployment accidents, this is not the case for deployment accidents. The accumulation of a sufficient number of cases of the latter may have to await the large number of air bag-equipped cars which will be introduced in the 1980 and 1981 model years.

A second facet of the data acquisition requirements for the air bag effectiveness analysis involves the need for a control sample of cars with active restraint systems. Approximately 5 percent of the present NCSS and RSEP data bases is believed to involve comparable 1974 to 1976 model year Buicks, Cadillacs and Oldsmobiles. It may be acceptable to include in the control sample other full-sized General Motors cars as well as full-sized cars manufactured by Ford, Chrysler and AMC. If it is necessary to supplement this control group, it is suggested that towaway accidents with similar cars be considered. It must be recalled that all accidents in the control group generally must have comparable information to that given in Section 3.2.1. This is especially true regarding seat belt usage, speed and impact angle.

Passive Belt

There is currently only one passive belt implementation in actual production. This is the Volkswagen Rabbit passive shoulder belt system which has been an option since the 1975 model year. Volkswagen instructs its dealers to report Rabbit accidents to the main office when the damage cost is above a threshold quantity (approximately $700) and then sends out investigators to collect data on the accident. Volkswagen will then notify the Accident Investigation Division of NHTSA about the accident. Even if this procedure is faithfully followed, the data would be heavily biased toward serious accidents. To obtain data on unreported passive belt accidents, the NHTSA might use the same type of postcard survey of Rabbit owners as that used to obtain data on air bag non-deployment accidents.

It is estimated that by the completion of model year 1980, 125,000 passive seat belts in VW cars will have been manufactured [7]. This includes an agreed-upon 60,000 cars (at least) so equipped in model years 1978, 1979 and 1980 [6] and an estimated 65,000 VW Rabbits with the passive shoulder belt system in model years 1975, 1976 and 1977. Table 3-8 shows the cumulative estimate of the number of reportable accidents involving VW's with passive systems that are assumed to be manufactured in each model year. The estimated cumulative accident involvement is certainly very approximate and is based on the rough assumption that each year one in ten of the VW cars with the passive belt system will be involved in a reportable accident. If the estimates are reasonable, it is obvious that sufficient accident experience with VW Rabbits equipped with a passive belt system will have been achieved by 1978 to permit an initial analysis. However, the acquisition of accident data involving these cars requires the implementation of a comprehensive tracking scheme similar to that which is currently used with air bag-equipped vehicles. As is the case in the air bag vehicle data collection, it will be necessary to obtain data for a control group. This group will consist of VW Rabbits with active belt systems.

TABLE 3-8

ESTIMATE OF CUMULATIVE OCCURRENCE OF REPORTABLE ACCIDENTS INVOLVING PASSIVE BELT-EQUIPPED CARS

Year	Assumed Number of VW Models Sold	Estimated Cumulative Number of Accidents
1975	30,000	1,500
1976	20,000	5,000
1977	15,000	11,000
1978	20,000	19,000
1979	20,000	28,000
1980	20,000	40,000

3.2.3 Data Analysis

Air Bag Effectiveness Analysis

The statistical techniques used and analyses undertaken are similar to those described in detail in Section 3.1. However, a number of special considerations must be given to the air bag analysis. The air bag will deploy only in those accidents where the frontal impact exceeds 12 mph. In the large majority of accidents the air bag will not deploy. These include all impacts in the rear, most side impacts and all front impacts under 12 mph. In addition to the consideration of air bag deployment, the question of lap belt use must be addressed. This is important in both deployment and non-deployment accidents. When the air bag does not deploy, the lap belt is the only restraint system protection. In the case of deployment, it is still desirable to know if the lap belt was being used. Thus, accidents will be classified according to four categories as follows:

- Group A : Air bag deployment with lap belt use.
- Group B : Air bag deployment without lap belt use.
- Group C : Air bag non-deployment with lap belt use.
- Group D : Air bag non-deployment without lap belt use.

Two types of analyses must be carried out. The first type of analysis involves comparisons of injuries and fatalities within the air bag-equipped cars accident sample. The second type of analysis involves comparisons between the air bag population and the control group.

In the first type of analysis the primary analysis consists of a comparison of injuries and fatalities for Group A *vs.* Group B and Group C *vs.* Group D, the groups being defined above. This analysis is directed toward determining the effects of lap belt use in both deployment and non-deployment accidents. The comparison of Group A *vs.* Group B and other analyses discussed in this section obviously requires a sufficiently large sample of deployment cases. At the present rate of accumulation of reported deployment accidents, it is our judgment that only very preliminary analyses involving air bag deployment accidents will be possible until the significant volume of model year 1980 and 1981 air bag-equipped cars are part of the vehicle propulation.

A number of other factors can be evaluated in the analysis of the air bag accident sample. These include:

- Injury occurrence with and without air bag deployment.
- Frequency of air bag deployment and relationship to ΔV, force angle and angle of impact.
- Variation of injury occurrence by seating position as a function of air bag deployment and type of collision.
- Effects of vehicle weight on air bag deployment and injury occurrence in side impacts.

It is clear that the investigation of some of the above factors must await the advent of 1980/1981 model year air bag-equipped cars. Prior to that time, the air bag analysis could be limited to considering only those variables found significant in the seat belt analyses, plus a few selected variables deemed relevant to air bag analysis.

The second type of analysis mentioned above concerns the comparison of air bag-equipped car accidents with the accidents of a control group. This analysis is far from straightforward and simple. A rigorous evaluation of and complete answers to the questions discussed below will not be possible until the early 1980's, given the present size of the air bag-equipped car populations and plans for additional air bag-equipped cars.

The sample populations which must be considered in the evaluation are:

- Air bag-equipped car with lap belt use.
- Air bag-equipped car without lap belt use.
- Non-equipped car with lap/shoulder belt use.
- Non-equipped car without lap/shoulder belt use.

The latter two categories, of course, come from the control sample. The above categories of restraints systems must be compared in the light of (1) the occurrence of deployment and non-deployment accidents and their frequency and (2) the frequency of use of lap belts in air bag-equipped cars and the frequency of use of lap/shoulder belts in non-equipped cars. The primary comparisons would be (1) air bag deployment with lap belt use (Group A) *vs.* non-equipped car with lap/shoulder belt use in accidents with speed greater than 12 mph and (2) air bag deployment without lap belt use (Group B) *vs.* non-equipped car without lap/shoulder belt use in accidents with speed greater than 12 mph. The above comparison permits an evaluation of the effectiveness of the air bag-lap belt system relative to the lap/shoulder belt system for deployment-type accidents, given lap and lap/shoulder belt use. A complete evaluation of the air bag/lap belt system, however, requires the consideration of non-deployment type accidents also. Thus, the secondary comparisons involve (1) air bag non-deployment with lap belt use (Group C) *vs.* non-equipped car with lap/shoulder belt use in accidents at less than 12 mph and (2) air bag non-deployment without lap belt use (Group D) *vs.* non-equipped car without lap/shoulder belt use in accidents at less than 12 mph.

Given the real-world low rate of seat belt usage, in perhaps 80 percent of accidents there is no difference in the non-deployment type crash (neither lap belts nor lap/shoulder belts are in use) and in deployment type crashes the difference is strictly a function of the protective restraint of the air bag, as again neither a lap belt or lap/shoulder belt is in use. However, one must still consider the possible effects of seat belt use. Specifically, in non-deployment accidents the use of a lap belt only (in constast to a lap/shoulder belt) may result in an increase in injury occurrence or severity.

Passive Belt

Some of the consideration and factors involved in the analysis of the effectiveness of the air bag-lap belt systems are appropriate to the analysis of the effectiveness of the Volkswagen Rabbit passive belt system. Basically there are three classes of restraint system protection to consider:

(1) No restraint system protection--the passive system has been disconnected or the active lap/shoulder belt system is not used.

(2) Passive shoulder harness system is operative.

(3) Lap/shoulder belt system is used.

The analysis of the effectiveness of the Volkswagen Rabbit passive belt system includes the following:

- Comparison of injuries and fatalities when the passive system is operable and the active lap/shoulder belt system is used. This comparison will be on an overall basis and will be stratified according to collision type (frontal, side, etc.) and impact speed.

- Comparison of the frequency that the passive belt system is rendered inoperable *vs.* the times that the active lap/shoulder belt system is not used.

Clearly, as in the air bag analysis, the analysis of the VW passive belt system requires data from a control group of VW's in which the active belt system is the available restraint system.

3.3 Comprehensive Restraint System Usage Survey

Estimates of restraint system usage are necessary if one wishes to project the total number of deaths and injuries avoided due to the Standard. Estimates of usage from accident studies have usually been based on personal claims.* This section was included in response to a request by the Contract Technical Monitor.

3.3.1 Data Requirements

The data items required would be:

- License Number
- Seating Position
  - Driver
  - Front seat passenger
  - Rear seat passenger
- Restraint System Use (for driver and any other passenger)
  - Lap belt
  - Lap/shoulder belt
- Age (driver and any other passenger)
  - Young
  - Mature
  - Old
- Sex (driver and any other passenger)
  - Male
  - Female
- Vehicle Make
  - Domestic
  - Foreign
- Model Year
- Vehicle Size
  - Subcompact
  - Compact
  - Intermediate
  - Full Size
- Restraint System Available
  - Lap belt only
  - Seat belt interlock
  - 3-point belt
  - 4-point belt

(Model Year, Vehicle Size and Restraint System Available: From Registration and VIN Decoding)

- Highway Type
  - Urban/suburban streets
  - Limited access highways
  - Main rural roads
  - Secondary rural roads

*However, the RSEP study was very careful in classifying the reliability of information on restraint system usage.

- Time of Day/Day of Week
  - Commuter hours
  - Mid-day
  - Evening
  - Late Night
- Area Population Density.

Other information--length and types of trip and consistency of usage--would only be available through an interview followup situation following direct observation.* Such followup could also be valuable as an estimate of the accuracy of the data collection procedure.

Currently,Kirschner Associates, Inc.(and, previously, Opinion Research) is conducting safety belt usage surveys for NHTSA's Office of Driver and Pedestrian Research. The Opinion Research surveys only focused on recent model years, and while the current effort looks at all model years, it only collects data on the driver. Also, the observations are largely restricted to urban intersections and suburban primary road intersections (or highway exits). Data quality is questionable [8].

3.3.2 Data Acquisition and Preparation

The method of data collection would differ from the existing efforts in the following ways:

- Two-person teams to observe and record the information.
- Broader range of highway types, including on-the-highway observation and accompanying police on random roadside vehicle inspection.
- Collection of data in the same geographic areas as RSEP data: Western New York, Michigan, Miami, San Antonio, rural Texas, and Los Angeles.
- Interview followups on a sample of observations to gain additional information on trip type and length and consistency of belt usage and also to check overall data collection accuracy.

The number of observations required in each cell** depends on the desired accuracy of the estimate and the frequency of occurrence of the desired event. For the purposes of determining sample size, we assume that the distribution of restraint system usage is binomial. Assuming that the desired accuracy is $\pm$ 10%, the sample size for a 40 percent usage rate would be 576; a 5

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*The CTM also requested other items of information be considered--usage in non-towaway accidents and by AIS level. However, this information would only be available in an accident-based survey.

**A data cell can be considered as gross as male safety belt usage, which is a simple male/female categorization; or as fine as young, female driver driving domestic subcompact,which includes 144 categories.

percent usage rate would require 7,300 observations. Therefore, higher levels of accuracy might need to be sacrificed if usage rate is low. If a sample size of 500 in each cell for a variable is used, then the spread of the 95% confidence interval increases. At 20 percent usage, the 95% confidence interval is approximately 23.4 to 16.6 percent. At 10 percent usage, the range is 12.5 to 7.5 percent; while at 5 percent usage, the range is 7 to 3 percent. For example, 32,000 ovservations would be needed for a three-way tabulation of vehicle size, time of day, and highway type, assuming an even distribution of 500 observations in each cell, and each variable is categorized at four levels (500 x 4 x 4 x 4 = 32,000).

Data checking and automation are not inconsiderable problems. The use of two-person teams and of interview followups will improve the accuracy and give some estimate of error for the estimates. After the data are in hand, they should be keypunched and verified before creating computer files.

3.3.3 Tabulation and Analysis

The analysis of the restraint system usage data would be rudimentary, primarily examining various patterns of usage through different tabulations.*
The tabulations of most interest will be seat belt usage vs.

- Age
- Sex
- Rural/urban
- Restraint system
- Vehicle class

and possibly combinations of these with other variables. Simple tests of independence should be made to determine whether estimates are significantly different from one another.

The main questions addressed will be whether this study (1) finds any difference from earlier studies and (2) finds substantial differences between categories which had not been established before, such as rural/urban usage, or by trip type.

*The Standard Errors of the estimates should be presented as an Appendix.

3.4 References for Section 3.0

1. Reinfurt, Silva, and Seila. *A Statistical Analysis of Seat Belt Effectiveness in 1973-1975 Model Cars Involved in Towaway Crashes*, Final Report, Vol. I. DOT-HS-802-035, Highway Safety Research Center, University of North Carolina, Sept. 1976.

2. McHenry, R.R. *A Comparison of Results Obtained with Different Analytical Techniques for Reconstruction of Highway Accidents*, SAE No. 750893 SAE Meeting, October 13-17, 1975, Detroit, Michigan.

3. _____. *Computer Aids for Accident Investigation*, 1976 SAE Automobile Engineering and Manufacturing Meeting, October 18-22, 1976.

4. Hall, R.G. *Fact Book: A Summary of Information About Towaway Accidents Involving 1973-1975 Model Cars*, Final Report, Vol. II, DOT-HS-802-036, September 1976.

5. National Highway Traffic Safety Administration. *Summary of Field Experience Involving Air-Bag Equipped Cars*, 74-14-GR-45, Office of Statistics and Analysis, September 1976.

6. Department of Transportation. "Secretary Coleman Announces Results of Negotiations Regarding Passive Restraint Demonstration Program, DOT-16-77, Press Release from the Office of the Secretary, January 18, 1977.

7. "Pacts to Offer Air Bags Signed by Three Car Makers," *Wall Street Journal*, January 19, 1977.

8. Private communication from Mr. Peter Zeigler, National Highway Traffic Safety Administration, 3 March 1977.

4.0 COST DATA AND SAMPLING PLAN

4.1 Background

The current version of FMVSS 208 provides three options for compliance with the Standard. Option #1 specifies a completely passive protection system where only occupant injury criteria have to be met. To date, no method for compliance under this option has been implemented.

Option #2 requires a lap belt protection system with audible and visual belt disconnect warnings. Injury criteria must be met only for the frontal barrier crash. Two passive systems have been developed and implemented to satisfy FMVSS 208 under Option #2. One system is the Air Cushion Restraint System (ACRS) with a lap belt and warning device which was offered by Ford on some 1972 models and by General Motors on some 1973 and later models. Also, Volvo offered an air bag system on 1975 and later models. Under this option, a lap belt or detachable lap/shounder belt must be included for each designated seating position. The second system is a passive belt system offered by Volkswagen on 1975 and later model Rabbits.

Option #3 very explicitly specifies a Type 2 non-detachable lap/shoulder belt assembly for the two outboard front seating positions. Some variations in the method of compliance occur in the seat belt warning system, in the belt system in non-outboard front seating positions, and in the emergency locking retractor and latch mechanism. The compliance approach under this option requires the active participation of occupants for system protection.

Estimates of the average cost per car incurred in complying with various Standards have been made by GAO for Model Years 1966-1974 [1]. The average combined cost of compliance with FMVSS 208, FMVSS 209 (seat belt assemblies for passenger cars, multi-purpose passenger vehicles, truck and buses), and FMVSS 210 (seat belt assembly anchorages) was estimated to be $94 per car for the 1974 model year. This cost refers to the typical Type 2 active combined lap/shoulder seat belt for the two front outboard seat positions and lap belts for other seat positions as specified by Option 3 of FMVSS 208.

A detailed analysis of the cost to the consumer of three restraint systems has been performed [2]. In this analysis the cost of driver-only, 2-front seats, and 3-front seats was estimated for (1) the current active lap/shoulder belt system; (2) the VW Rabbit passive belt and knee panel system (2-front seats only); and (3) the air cushion and lap belt system. The results of the analysis are summarized in Table 4-1. The VW Rabbit estimates are based on a production volume of approximately 30 percent of total U.S. Rabbit sales. The estimates for the air cushion lap belt system assumes a 100 percent inclusion of the system in production.

TABLE 4-1

COMPARISON OF THE COSTS OF ACTIVE AND PASSIVE SYSTEMS
(Summary of analysis from Reference 4)

Restraint System	Driver Only (dollars)	Two Front Seats (dollars)	Three Front Seats (dollars)
Active Lap/Shoulder Belt			
Initial Price Increase	23.00	45.00	51.00
Total Cost	28.60	56.10	62.50
VW Rabbit Passive Belt & Knee Panel			
Initial Price Increase	41.50	73.00	
Total Cost	49.80	89.20	
Air Cushion and Lap Belt			
Lap Belt System	11.94	24.53	31.13
Air Cushion System	24.00	58.00	67.00
Vehicle Manufacturer	10.80	18.70	21.00
Air Cushion System Markup	14.20	30.80	35.20
Total Costs	72.00	161.50	191.00

The analysis in Reference 2 includes the initial cost of all components of each system. For example, included as major components of the current active lap/shoulder belt system are: automatic locking retractor, emergency locking retractor, lap and shoulder belt, mounting bolts, anchor plates, and reminder (warning) system. In addition to this, the cost analysis adds increased fuel cost due to the added weight of the restraint system. The air cushion-lap belt system costs include such items as knee padding, changes in structure to the steering column and instrument panel, the warranty, etc. The total costs for this system include one deployed air bag based on accident frequencies. In summary, the initial costs per car for the respective systems for two front seat positions are:

- Active lap/shoulder belt system $ 45
- VW Rabbit passive belt and knee restraint $ 73
- Air Cushion-lap belt $132

The total costs per car for the three systems for two front seat positions are:

- Active lap/shoulder belt system $ 56
- VW Rabbit passive belt and knee restraint $ 89
- Air Cushion-lap belt $162

In a different study, the total costs for a 6-seat passenger car were compared for three systems [3]. The total costs were:

- Active lap/shoulder belt system $102
- Air Cushion alone $171
- Air Cushion/lap belt $240

Thus, two studies indicate that the air bag-lap belt system will cost about two and one-half times more than the current active lap/shoulder belt system. Obviously, this increase is higher when only front seat positions are considered, since the cost for lap belts in rear seating positions should not differ greatly between the two systems.

4.2 Relevant Cost Items

The major components of the active and passive belt systems and the passive air cushion system are summarized in Table 4-2 below. Costs relating to these items should be included.

TABLE 4-2

MAJOR COMPONENTS OF COMPLIANCE APPROACHES TO FMVSS 208

Passive Air Cushion Approach [6,7]
Driver air cushion and inflator assembly Passenger air cushion Air tank and inflator assembly Driver and passenger knee restraints Dashboard indicator warning light Dashboard sensor Front bumper detector Lap belts at all designated seat positions Lap belt anchors
Passive Upper Torso Belt Approach [2]
Knee restrainer panel Single upper torso belt in front outboard positions Automatic belt retractor Floor anchors for belt retractor Seat belt warning system Reinforced anchorage on side doors for upper torso belts Lap belts for designated rear seat positions Rear seat belt anchors
Active Type 2 Lap/Shoulder Belt Approach [8,9]
Seat belt warning system Two 3-point lap/shoulder belts for front outboard positions Lap belts for other designated seating positions Shoulder harness retractors Lap belt retractors Floor anchors for retractors and belts

In determining the costs of meeting the Standard, NHTSA has stated that to measure the consumer's out-of-pocket expenses, the cost categories should be:

- Direct manufacturing
- Indirect manufacturing
- Capital investment (including testing)
- Manufacturers' markup
- Dealers' markup
- Taxes [4]

However, the latter three cost categories cannot be estimated reliably for specific car models or market classes. Also we have found that the cost of complying with the FMVSSs, as estimated by the General Accounting Office, and the retail price increases of cars are loosely related [5]. (See Appendix B for a detailed discussion of problems associated with evaluating the latter 3 cost categories.)

4.3 Frequency Sampling Plan

The purpose of this activity is to acquire reliable estimates of the increased costs incurred by manufacturers in complying with FMVSS 208. As mentioned in Section 4.2, NHTSA, GAO, and BLS use different methods for assigning costs to individual safety standards. GAO and BLS use direct information from automobile manufacturers as the principal source of cost data. Manufacturers appear to have the most reliable cost figures, but controls are needed for accounting variations among the companies. We, therefore, recommend that cost estimates be obtained from manufacturers and NHTSA for FMVSS 208.

FMVSS 208 has changed through the years and manufacturers' methods of compliance have changed in response. For cost data acquisition for active systems, we are only concerned with implementations that are currently in production which eliminates from consideration all but the three-point combination lap/shoulder belt for outboard front seat occupants. Within each manufacturer there are three safety belt configurations depending on the size of the vehicle:

- Four seater - 2 lap/shoulder belts in front
  2 lap belts in rear
- Five seater - 2 lap/shoulder belts in front
  3 lap belts in rear
- Six seater - 2 lap/shoulder belts (outboard) and 1 lap-belt (center) in front
  3 lap belts in rear.

All the current lap/shoulder belts in production use one or both of the following inertia activated systems:

- Mechanical locking activated by electronic vehicle deceleration sensor,
- Totally mechanical locking activated by sudden pulling action on belt.

We will assume for cost purposes that all manufacturers use basically the same locking retractor system for lap belts. The experimental design shown in Table 4-3 is a balanced incomplete block design which is also balanced for the effect of inertia reel system.

Manufacturers I to IV are the four major U.S. companies: GM, Ford, Chrysler, and AMC. Manufacturers V and VI are foreign companies chosen on the basis of volume or possibly a unique restraint system. The assignment of manufacturers to specific columns is arbitrary and may be rearranged according to appropriate car production configurations. For those manufacturers which use only one type of inertia reel, both cost entries may be taken from the corresponding configuration type. For example, if Manufacturer I only uses inertia

TABLE 4-3

BALANCED INCOMPLETE BLOCK DESIGN FOR SAFETY BELT COST DATA ACQUISITION

Configuration	Manufacturer					
	I	II	III	IV	V	VI
4 Seats	A			B	A	B
5 Seats	B	A	B	A		
6 Seats		B	A		B	A

- A = Electrically activated inertia reel.
- B = Mechanically activated inertia reel.

system "A," both 4 seat and 5 seat costs may be entered using "A" system costs. If a manufacturer produces more than one model with identical seating configurations and the restraint system costs differ, the model with the largest sales volume may be chosen.*

The cost data acquisition plan in Table 4-3 is only intended for implementations that fall into FMVSS 208 - Option 3. There are only two current implementations which fall into Option 2. The Volkswagen Rabbit passive belt and the General Motors ACRS air bag/lap belt system. Both are unique enough to justify separate cost data acquisition and analysis.

*A statistical justification for this method may be found in Appendix C.

4.4 References for Section 4.0

1. General Accounting Office, *Effectiveness, Benefits, and Costs of Federal Safety Standards for Protection of Passenger Car Occupants,* Report to the Committee on Commerce, U.S. Senate, CED-16-121, July 1976.

2. Cooke, C., *Consumer Cost of Occupant Crash Protection Systems,* Motor Vehicle Programs, National Highway Traffic Safety Administration, July 1976.

3. DeLorean, J.A., *Automotive Occupant Protective Safety Air Cushion Expenditure/Benefit Study,* Allstate Insurance Company, August 1975.

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5. Joksch, H., J. Reidy and G. Haas, CEM Report 4194-576: *Program Priority and Limitation Analysis,* December 1976, Contract No. DOT-HS-01225.

6. Anonymous, *1973 Report on Progress in Areas of Public Concern,* General Motors Technical Center, February 1973.

7. Anonymous, *Automotive Air Bags, Questions and Answers,* Allstate Insurance Company, July 1976.

8. Anonymous, *Toyota Seat Belt System Repair Manual for 1974 Models,* Toyota Motor Sales Co., LTD., August 1973.

9. Anonymous, *Ford 1974 Shop Manual, Volume 4 - Body,* Ford Marketing Corporation, February 1974.

5.0 WORK PLAN

The work plan for the evaluation study of FMVSS 208 is divided into a total of four tasks. The fourth task is an analysis of costs to the consumer for implementation of FMVSS 208. The work to be conducted under each of the first three evaluation tasks is basically self-contained and independent of efforts undertaken in the other tasks. For this reason, the work in each task could be carried out concurrently and the work plan is formulated such that Tasks 1, 3 and 4 begin at the initiation of the study. Task 2, however, is not initiated until 9 months after the start of the study, because of the limited volume of available air bag accident data. Following the development of data collection and analysis procedures and the analysis of available existing data, the task is suspended until increased volumes of air bag deployment accident data occur with the 1980 model year cars. For the purpose of developing this work plan, the entire study is assumed to start on January 1, 1978.

The logical sequence of subtasks within each task is given in Figure 5-1. The time sequencing within each task and the estimated resources required (personnel, data processing, and other significant expenses) are given in Figure 5-2.

5.1 Task 1 - Seat Belt Effectiveness Analysis

Task 1 is concerned with the acquisition of Restraint Systems Evaluation Program (RSEP) and National Crash Severity Study (NCSS) data for a new analysis of seat belt effectiveness. The original RSEP study did not contain ΔV (which is currently being added) and the addition of NCSS data will enlarge the data base. Much of the initial data acquistion and preparation effort will be devoted to deriving or reconstructing needed variables and standardizing the variables used in the study so that the NCSS and RSEP data base can be analyzed both separately and jointly. A total of 0.6 person-year is required for this portion of the effort. The entire 9-month study is estimated to require resources of 1.0 person-year to accomplish the data collection, preparation and analysis. Additional resources required are estimated to be $2,000 for computer processing and $1,000 for data acquisition.

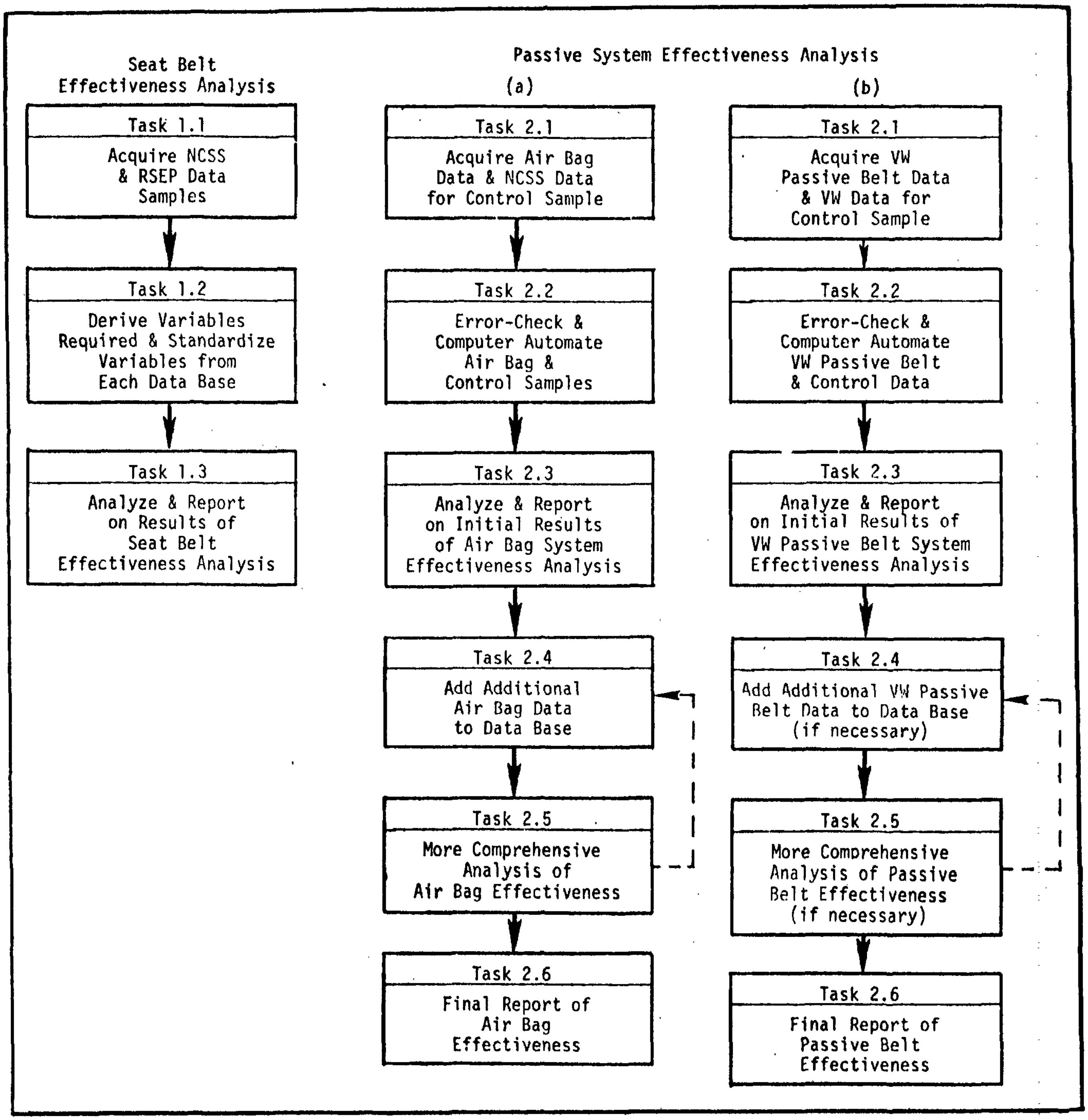

Figure 5-1. Flow chart for study to evaluate FMVSS 208.

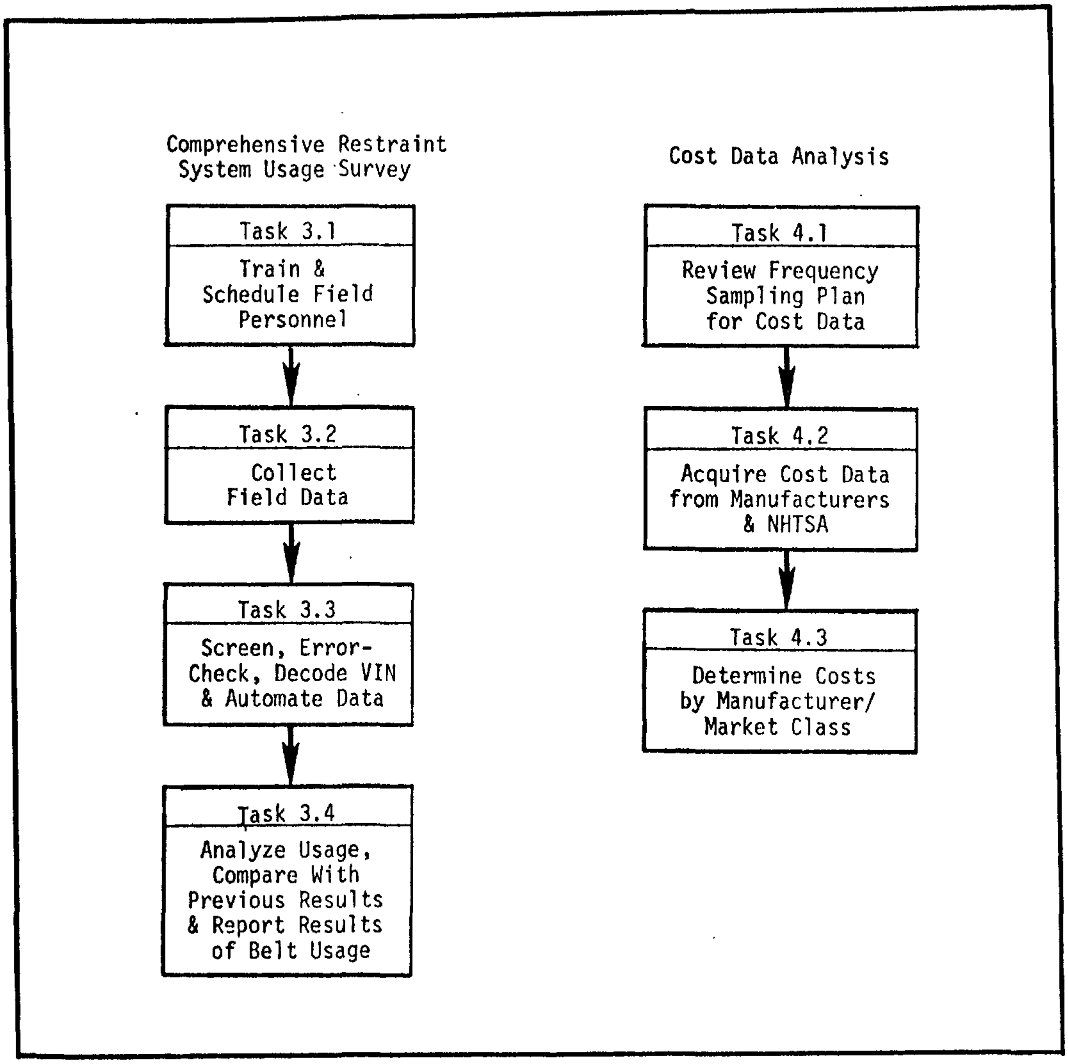

Figure 5-1 (continued).

Task	Description	Months (3 6 9 12 15 18 21 24 27 30 33 36 39 42 45 48)	Resources Required: Person-Years	Resources Required: Data Processing ($ K)	Resources Required: Other Costs ($ K)
	Seat Belt Effectiveness Analysis				
1.1	Acquire RSEP/NCSS Data		0.2		$ 1.0
1.2	Derive Valuables & Standardize Data		0.4	$ 1.0	
1.3	Analyze & Report Results		0.4	$ 1.0	
			1.0	$ 2.0	$ 1.0
	Passive System Effectiveness Analysis				
2.1	Acquire Air Bag, Passive Belt & Control Data		1.0		$50.0
2.2	Error-Check & Computer Automate Data		1.0	$ 1.0	
2.3	Analyze & Report Initial Results		0.6	$ 1.0	
2.4	Acquire Additional Data		0.4		*
2.5	Conduct More Comprehensive Analysis		0.7	$ 3.0	
2.6	Final Report of Air Bag/Passive Belt Effectiveness		0.3		
			4.0	$ 5.0	$50.0
	Comprehensive Restraint Systems Usage Survey				
3.1	Train & Schedule Field Personnel		0.5		$ 5.0
3.2	Collect Field Data		3.0		$10.0
3.3	Error-Check & Automate Data		0.5	$ 1.0	
3.4	Analyze, Synthesize & Report Results		0.5	$ 1.0	
			4.5	$ 2.0	$15.0
	Cost Data Analysis				
4.1	Review Frequency Sampling Plan		0.1		
4.2	Acquire & Preprocess Data		0.3	$ 0.4	
4.3	Analyze Costs & Report Results		0.6	$ 0.6	
			1.0	$ 1.0	
	TOTAL RESOURCES REQUIRED		10.5	$10.00	$ 66.00

*The cost of additional data acquisition will depend on the type of tracking system used for air bag-equipped cars and whether subsequent collection of VW accident data are necessary.

Figure 5-2. Schedule of tasks and required resources for evaluating FMVSS 208.

5.2 *Task 2 - Passive Systems Effectiveness Analysis*

Task 2 deals with the analysis of the effectiveness of the air bag-lap belt system and the VW passive shoulder belt system. It is planned that this task will be carried out over a protracted period of time, 39 months, due to the unlikelihood that definitive results can be obtained prior to the appearance of air bag-equipped cars in large numbers in model years 1980 and 1981. Thus, the study is planned to start October 1, 1978 and conclude December 31, 1981. During part of that 39 month time period, the task will be inactive.

The first three subtasks are directed to collecting and analyzing air bag-equipped vehicle accident data from the current population of 11,000 cars and also collecting and analyzing data required for a control sample. In parallel, accident data on VW Rabbits with passive belts and the conventional active lap-shoulder belt (control group) will be collected and analyzed. The initial analysis of the passive belt system is likely to be more definitive than the air bag analysis because a larger volume of data is available. The first three subtasks will establish data collection procedures, data processing procedures, computer programs and analysis approaches which can be used in additional analyses later in the task, when more data are available. The estimated resources required for the initial analysis of air bag and passive belt effectiveness are 2.6 person-years, $2,000 for computer processing, and $50,000 for data acquisition expenses.

The last three subtasks involve the acquisition and analysis of additional data. These subtasks are absolutely essential for any meaningful analysis of air bag effectiveness and may be required for a comprehensive analysis of the effectiveness of passive seat belts. The acquisition of additional data and the analysis will be performed twice. The first iteration will include 1980 model year data and the second iteration will include both 1980 and 1981 model year data. Naturally, data from earlier model years will be included also. The estimated resources required for the latter three subtasks are 1.4 person-years and $3,000 for computer processing. Data acquisition costs will depend significantly on the type of tracking system used with the large volume of air bag-equipped cars in MY 1980 and 1981, and also whether additional acquisition of VW accident data will be required. Because of the high degree of uncertainty at this time, a dollar value is not given. The entire task is estimated to require 4.0 person-years, $5,000 for computer processing and $50,000 for data acquisition (task 2.1 only).

5.3 Task 3 - Comprehensive Restraint System Usage Survey

Task 3 deals with the collection and analysis of data on restraint system usage. Two-person teams will be trained to observe and record information at a broad range of road type locations in the same geographical area which RSEP data were collected. The training and data collection effort will involve 11 months and require resources of 3.5 person-years and $15,000 for training, materials, travel and other expenses. It is estimated that over 30,000 observations are required. The error checking,automation of data, analysis, synthesis and reporting of results will require resources of 1.0 person-year and $2,000 for computer processing. The total resources required for the 15-month task are 4.5 person-years, $2,000 for computer processing and $15,000 for data collection and personnel training.

5.4 Task 4 - Cost Data Analysis

Task 4 is directed toward the determination of direct costs to implement FMVSS 208. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes.* A frequency sampling plan for FMVSS 208 Option 3 implementation specifies the cost data will be sampled for selected manufacturers using three seat configurations (4-, 5-, and 6-seats) and electrically and mechanically activated inertia reels. Two replications of the sampling procedure will be carried out. With an adequate sampling plan, the direct cost to the consumer of the Standard implementation can be obtained for most models through a statistical analysis. FMVSS 208 Option 2 implementations require separate cost data acquisition and analysis. Task 4 will be completed seven months after the start of the study. It is estimated that 1.0 person-year will be required for Task 4 work, together with up to $1,000 for computer processing.

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*These are the cost categories specified by NHTSA. One should realize that manufacturers' and dealers' markups are not easily obtainable for specific models (if at all). The overall "markup" is the difference between the actual price set at the time of sale, largely according to market conditions, and the total manufacturing costs, which are to some extent determined years in advance, when the car is designed, and to some extent by the volume actually produced, which results from the market conditions.

Taxes play a different role: some are a factor which can enter the cost calculation (e.g., property taxes). Income taxes, however, are levied on profit, which is a residual and not predictable (if a manufacturer operates at a loss, no income taxes are due).

APPENDIX A

DISCUSSION OF STATISTICAL METHODS

A.1 INTRODUCTION

A number of statistical techniques can be considered as analytical tools to evaluate the effects of implementing FMVSS 208. Four of these techniques are discussed in this appendix.

- Regression Analysis
- Contingency Table Analysis
- Log Linear Analysis
- Index Method Analysis.

A.2 REGRESSION ANALYSIS

Statistics uses the term regression in two senses, one a broad sense and the other a restriction of the broad sense to a more "specific" one. Before we discuss these two (or more) concepts a word should be said about the term "regression" since it has various connotations that are not appropriate to most work. In the previous century, the British scientist, Galton, studied the "intelligence" of fathers and first born sons and found that if the father was more "intelligent" than average, the son usually was also, but he tended to be more average than the father. Galton referred to this phenomenon as "regression of mediocrity." The first part of the term has stuck as the name of the whole technique of which Galton's work is merely an early example. By the way, the above does not imply that the next generation is less intelligent than the previous, since, for example, for sons more "intelligent" than average, the fathers tend to be more average than the sons.

In the current broad-sense usage, regression is the study of the functional relationship between a dependent variable and one or more independent variables. The choice of terms does not imply a cause-and-effect relationship. In fact, taking the extreme case, the dependent variable could be the cause and the independent variable the effect, e.g., if one tried to regress the size of a bomb on the amount of damage caused.

It would be somewhat more precise to say that regression is the study of the mean or average structure of the dependent variable by means of the independent variates. One is usually not trying (in a primary sense) to find the variability of distribution of the dependent variable from the other variates. It is true that the research does look at the variability, but only in the second sense of wanting to see the stability or precision of the functional relationship of the average values of the dependent and independent variables.

Some examples of general regression would be:

(1) Finding the relationship between a student's college record (quantity point ratio) and his/her high school record, college boards and other records.

(2) The position of a stellar object as a function of time and previous positions.

(3) The probability of rain as a function of air pressure, previous weather, temperature, etc.

(4) The probability of a person's having blond hair as a function of whether or not he is Swedish, whether he is under 10 years, between 10 and 20, and over 20, etc.

This general restricted concept of regression considers dependent variables that have an interval scale, usually independent variables that are interval scaled, and a random error term. The random error term is assumed to be normally distributed. The independent variables are either values that can be adjusted by the researcher (e.g., the speed at which a test vehicle is driven) or normal random variables (e.g., the speeds of the cars in the population of cars considered is assumed to have a normal distribution). Both of these assumptions imply, in the linear case, that the dependent variable is normally distributed.

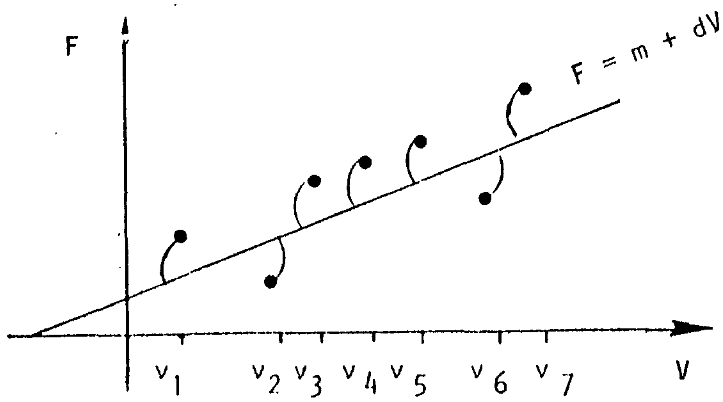
As an example, we might be interested in a model regressing fuel consumption per mile F, on velocity of the vehicle V, the weight W, and the horsepower H. As a first approximation, we would have:

$$F = \mu + \alpha V + \beta W + \delta H + \varepsilon,$$

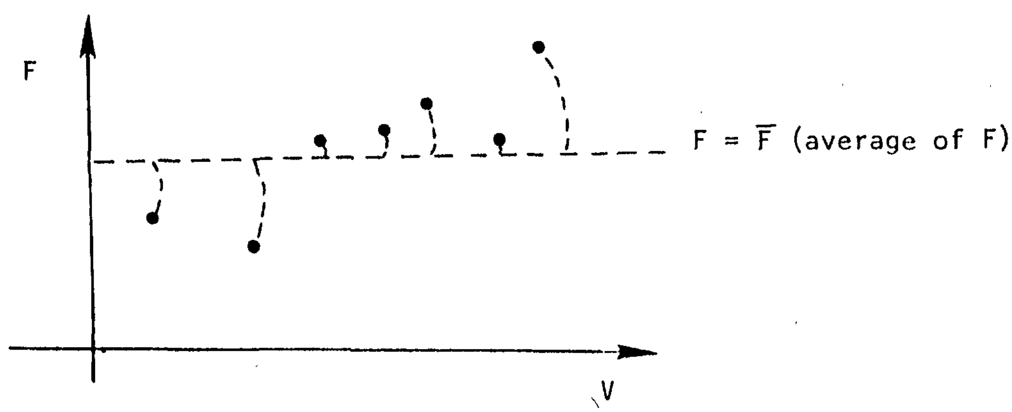
where ε is the random error term. Since each of the independent variables appears as a linear (first degree) term, we call this a linear equation. If we run the experiment under lab conditions and choose the speed, weight and horsepower values, these are considered fixed values and ε is usually assumed to have a normal distribution. On the other hand, if the data are sampled (collected) from a random selection of actual vehicles, then the values of the independent variables are not selected by the researcher and, in fact, have random distributions due to the random selection. However, the estimation of the usually unknown coefficients is, in both cases, carried out by least squares analysis. To accomplish this for all the data, we choose the values of m, a, b, c to minimize the summation

$$\Sigma\ (F_i - m - aV_i - bW_i - cH_i)^2.$$

The objective is to find the precise equation that is closest to the observed data. If we consider the equation, $F = \mu + dV$, then graphically we can obtain the following illustration.



If the dots represent the data points, the line F = m + dV is chosen so that the sum of the squared distances represented by ")" is as small as possible. In order to judge whether or not the line gives a good fit to that data, we compare the original variability of the data from a horizontal line,



with the sum of the squared distances from the sloping line. If the sloping line is a good fit there should be a substantial denumeration of the variability.

In practice there are various difficulties that can only be handled approximately at this stage of statistical development. In general, data are not normally distributed. In many cases the linear equation does not fit the data well enough and higher order terms are needed. However, if V is normally distributed, then V^2, V^3, etc. are not. Nonetheless, the procedure seems to work quite well even when the assumptions of normality are not satisfied. One of its great advantages is its widespread use in many applied fields. Furthermore, the procedures are quite standard and secondary analyses, such as comparing coefficients, can be done with little difficulty. On the other hand if the data, especially the dependent variable, are ordinal or nominal and if the range of the dependent variable is bounded, the results can be less than satisfactory. Also, if the dependent variable is not approximately normally distributed, the procedure is not as efficient as others that use any distributional knowledge. In addition, various statistical tests can be misleading if the distributional model does not reflect the true nature of the data in certain aspects.

A.3 CONTINGENCY TABLE ANALYSIS

A more recent development has been that of contingency table analysis based on log linear models. While the basic contingency table analysis goes back to Karl Pearson and his chi-square test, the log linear means structure is a more recent development.

In the Pearson chi-square v x c table, we usually have two factors or variables, for example, degree of injury and speed. These are made categorical e.g., injury is on the scale of slight or none, moderate or severe, while speed might be slow or fast. The body of the table contains the number of cases in each r and their respective probabilities (the latter) usually unknown in practice category.

INJURY	SPEED: Slow	SPEED: Fast	
Slight or None	100_{P11}	110_{P12}	210_{P1+}
Moderate or Severe	50_{P21}	80_{P22}	130_{P2+}
	150_{P+1}	190_{P+2}	340

$P_{1+} = P_{11}+P_{12}$, $P_{+1} = P_{11}+P_{21}$, etc.
and $P_{11}+P_{12} + P_{21} + P_{22} = 1$.

The usual chi-square analysis would give*

$$\chi^2 = \frac{(100-92.65)^2}{92.65} + \frac{(110-117.35)^2}{117.35} + \frac{(80-72.65)^2}{72.65} + \frac{(50-57.35)^2}{57.35} = 2.44$$

with 1 degree of freedom. The value 2.44 is not significant at $\alpha = 0.10$.

This result indicates that there is no dependence between speed and injury (for these data) and so the apparent discrepancies are due to random fluctuation. However, an interpretation of the effects of speed and injury is not all that clear.

A.4 LOG LINEAR ANALYSIS

A log linear model can be formulated such that

$$\log P_{ij} = \mu + \Lambda_i + M_j + (\Lambda M)_{ij},$$

where

$$\Lambda_1 + \Lambda_2 = 0;\ M_1 + M_2 = 0;\ (\Lambda M)_{1j} + (\Lambda M)_{2j} = 0;\ (\Lambda M)_{i1} + (\Lambda M)_{i2} = 0;$$

and Λ is the effect of injury (deviation of frequency of injury from the average) and M is the speed effect and (ΛM) is the interaction, i.e., how much different speeds affect different levels of injury. This formula also gives the expected number E_{ij} in each cell ij as

$$\log E_{ij} = \log NP_{ij} = \log N + \log P_{ij}$$

$$= \log N + \mu + \Lambda_i + M_j + (\Lambda M)_{ij}$$

$$= \mu' + \Lambda_i + M_j + (\Lambda M)_{ij}$$

where N is the total number of cases.

The above χ^2 test tells us that $(\Lambda M)_{ij} = 0$ for all vehicle speeds, Λ_{ij}. Thus, we can say by appropriate analysis that the estimates of the E_{ij} are $\hat{E}_{11} = 92.65$, $\hat{E}_{12} = 117.35$, $\hat{E}_{21} = 57.35$, and $\hat{E}_{22} = 72.65$ and $\hat{\mu} = 4.41$, $\hat{\Lambda}_1 = -\hat{\Lambda}_2 = 0.237$, $\hat{M}_1 = -\hat{M}_2 = -0.121$. One can check these values of μ, the $\hat{M}$'s and the $\hat{\Lambda}$'s given the appropriate $\hat{E}_{ij}$'s. While this analysis can be done without the log linear model for this simple case, the model can easily be extended to more variables with the interpretation being similar to the usual analysis of variance. By extending the model we could include other factors such as weight of vehicle.

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* In general, $\chi^2 = \Sigma \frac{(\text{Observed}_{ij} - \text{Expected}_{ij})^2}{\text{Expected}_{ij}}$

An important property of the model is that it uses the discrete, multinomial character of the data, something the normal model fails to do. This fact should make the analysis more precise. However, one failing of such an analysis is that the dependent and independent variables are made discrete, which means that we cannot force the model to accept any ordering that we wish, e.g., we cannot force the effect of speed to be monotonic increasing.

Another choice of analysis is to allow the contingency table analysis to have a functional relationship that has continuous and discrete independent variables. One would still have the advantage of the underlying multinomial distribution but this would allow the type of interval variables that are found in the regression concept. Namely, consider models of the form $\log P = \mu + \Lambda_i + aC$ where Λ_i is discrete as before and the C is a continuous variable. Such an analysis should also consider interaction terms, e.g., what is the effect of impact angle with or without a head restraint.

APPENDIX B

DISCUSSION OF PROPOSED STANDARD IMPLEMENTATION COST CATEGORIES

NHTSA has stated that to measure the consumer's out-of-pocket expenses the cost categories should be:

- Direct manufacturing
- Indirect manufacturing
- Capital investment (including testing)
- Manufacturers' markup
- Dealers' markup
- Taxes*

However, we feel that the consumer's initial costs are determined by a complex process, with different types of bargaining at the retail, wholesale, and manufacturing levels. It is well recognized, and also acknowledged by the auto manufacturers, that wholesale prices are set in response to market conditions, and that their relationship to manufacturing cost is loose. In a recent CEM study† this question was examined and no relation was found between annual increases in manufacturers' cost of satisfying FMVSS's as estimated by GAO, and the retail price increases.

Certain cost categories can be well estimated: direct and indirect manufacturing, and capital investment, including testing. These costs represent real resources used. The question of markups is conceptually very difficult, considering the manufacturers' pricing strategies (trying to cover a market spectrum) and the oligopolistic nature of the market. Using average gross profits for the manufacturing markup would be incorrect and misleading. To find the true markup would require a major study examining manufacturers' detailed cost data and pricing practices (internal and external).

The question of dealer markup is somewhat easier to consider conceptually; however, to determine it in practice is complicated by the trade-in of used cars. It appears highly likely that there is no fixed percentage markup on the dealer level, but a more complicated relationship which depends on the value of the new vehicle, the trade-in and other market conditions. Using an average gross profit, or the difference between wholesale and retail prices, would also be inaccurate and misleading.

With regard to the issue of taxes, this cost is not only borne in the form of a sales tax as the fraction of the components cost of the total car, but it is also accumulated at every stage of manufacturing in the form of property, payroll, sales (intermediate) and excise taxes. Income taxes are another cost;

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*Personal communication from Warren G. Halleist, Contract Technical Monitor, 18 January 1977.

†CEM Report 4194-574, *Program Priority and Limitation Analysis*, Dec. 1976, Contract DOT-HS-5-0.225.

however, they are not directly related to the resources used but to the profitability of the manufacturers.

Therefore, based on the above discussion, we consider it beyond the state-of-the-art to estimate the true out-of-pocket cost of new car buyers due to satisfying the FMVSS. Good estimates of the costs of real resources consumed can be made, but these costs apparently are not passed on immediately or directly to the consumer of that model. Other costs (markups and taxes) are conceptually and practically difficult to establish. The most reliable estimate of consumer cost would have to be aggregated over the entire market and a several year period in order to account for changes in market strategy and conditions.

Another point of concern with regard to the collection of data on cost items is the periods of comparison--one model year before the effective data *vs.* the model year that the Standard became effective or the next model year. The first point is that manufacturers have made changes to vehicles prior to the effective date of compliance, especially in the case of totally new models. Secondly, there is the learning curve effect in most manufacturing processes which will reduce the effective cost of manufacturing over time. With regard to this second effect, savings would be difficult to estimate, especially as these new components become more integrated into the basic structure of the vehicle. Therefore, using these time periods for comparison may tend to overestimate the cost of the Standard.

APPENDIX C

A STATISTICAL METHOD FOR COST DATA ACQUISITION:

HOW TO SELECT THE MAKE AND MODEL PRODUCED BY A MANUFACTURER

APPENDIX C: STATISTICAL DISCUSSION ON CHOOSING A PARTICULAR MAKE/MODEL WITHIN MANUFACTURER FOR COST DATA ACQUISITION

Consider any cell in the experimental design corresponding to a particular manufacturer and market class. Suppose within this cell there are K different possible cars to choose with known sales volumes $n_1, n_2, \ldots n_k$ (let $n = \sum_{i=1}^{K} n_i$). Suppose also the respective unknown costs are $c_1, c_2, \ldots c_k$.

We seek an estimate of the overall average cost

$$\bar{c} = \sum_i c_i \frac{n_i}{n} \qquad \text{based on one observation.}$$

Any decision rule may be described by a set $p_1, \ldots p_k$ where p_i is the probability of selecting the i^{th} possible car and then obtaining its cost c_i.

The risk associated with any rule, under squared error loss (obviously appropriate under variance considerations) is

$$\sum_i (c_i - \bar{c})^2 p_i$$

The natural inclination at this point is to attempt to minimize this risk over the p_i. The answer is set $p_i = 1$ at c_i closest to $\bar{c}$. But this is clearly worthless since the c_i are unknown. (If they were known, $\bar{c}$ would also be known and there would be no problem.)

Hence, the choice of the p_i's can only depend on the n_i. The natural approach suggests the unbiased estimator $p_i = \frac{n_i}{n}$ so that the expected value of the estimator is $\bar{c}$. The associated risk is

$$\sum_i (c_i - \bar{c})^2 \frac{n_i}{n}$$

We wish to examine which of these is the smaller. First we solve the problem if k=2 in which case $n_1/n > 1/2$.

Claim: $$(c_1 - \bar{c})^2 < (c_1 - \bar{c})^2 \frac{n_1}{n_1+n_2} + (c_2 - \bar{c})^2 \frac{n_2}{n_1+n_2}$$

Proof: Obvious: plug in $\bar{c} = c_1 \frac{n_1}{n_1+n_2} + c_2 \frac{n_2}{n_1+n_2}$ and verify.

More generally, if we write

$$\bar{c} = c_1 \frac{n_1}{n} + \frac{\sum_{i=2}^{k} n_i c_i}{n}$$

$$= c_1 \frac{n_1}{n} + c' \frac{n-n_1}{n}$$

where $c' = \sum_{i=2}^{k} \frac{n_i c_i}{n-n_i}$

In other words, $\bar{c}$ is the weighted average of c_1 with the weighted average of the remaining c_i's. Then,

$$\sum_{i=1}^{k} (c_i-\bar{c})^2 \frac{n_i}{n} = (c_1 - \bar{c})^2 \frac{n_1}{n} + \sum_{i=2}^{k} (c_i-c' + c'-\bar{c})^2 \frac{n_i}{n}$$

$$= (c_1 - c)^2 \frac{n_1}{n} + (c' - \bar{c})^2 \frac{(n-n_1)}{n} + \sum_{2}^{k} (c_i-c')^2 \frac{n_i}{n} ,$$

compared with

$$(c_1 - \bar{c})^2 .$$

But if $\frac{n_1}{n} > 1/2$ then $\bar{c}$ is closer to c_1 than to c'.

i.e., $(c_1 - \bar{c})^2 < (c' - \bar{c})^2$

or $(c_1 - \bar{c})^2 \frac{(n-n_1)}{n} < (c' - \bar{c})^2 \frac{(n-n_1)}{n}$

or $(c_1 - \bar{c})^2 < (c_1 - \bar{c})^2 \frac{n_1}{n} + (c' - \bar{c})^2 \frac{(n-n_1)}{n}$

Since the circled term is ≥ 0, selecting c_1 via n_1 clearly gives the smaller risk. If $\frac{n_1}{n} < \frac{1}{2}$, there is no "best" solution. The better choice can only be made knowing the c_i. If $\frac{n_1}{n}$ is close to $\frac{1}{2}$, the circled term should still be large enough to make selecting c_1 via n_1 the better choice.

On the other hand, if all the n_i are about the same, i.e.,

$$\frac{n_i}{n} \approx \frac{1}{k} \qquad \text{then}$$

$$\bar{c} \approx \frac{\Sigma c_i}{k} \qquad \text{and} \qquad \sum_i (c_i - \bar{c})^2 \frac{n_i}{n} \approx \sum_i (c_i - \bar{c})^2 \frac{1}{k}$$

i.e. , the "average" $(c_i-\bar{c})^2$ is no better than any particular $(c_i-\bar{c})^2$. Hence, again selecting c_1 via n_1 should still be as effective as randomizing.