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FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMVSS: 202 THE EFFECTIVENESS OF HEAD RESTRAINTS AND FMVSS: 207 SEATING SYSTEMS

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16. Abstract

This report covers the final design and implementation plan for evaluating the effectiveness of FMVSS 202: Head Restraints, and FMVSS 207: Seating Systems. The plan for the evaluation study considers measurability criteria, alternate statistical techniques, laboratory tests, data availability/collectability, resource requirements, work schedule and other factors. The overall purpose of FMVSS 202 is to reduce the frequency and severity of neck injury in rear end and other collisions. This purpose is to be achieved by establishing requirements for head restraints in passenger cars. The overall purpose of FMVSS 207 is to reduce the incidence of seat failures and their contributions to fatalities and injuries. This purpose is to be achieved by establishing strength requirements for seating systems and requiring a self-locking restraining device for folding seat backs. The integrated plan for evaluating the effectiveness of these two Standards, as described herein, contains eight separate evaluation programs, including one for additional costs due to the Standards. One program focuses on neck injury insurance claims. Another employs detailed accident data to evaluate both head restraints and seating systems. A third program analyzes fatalities to investigate the effects of self-locking seat backs. The fourth and fifth programs evaluate mass accident data and newly collected head restraint usage data. Both Standards are evaluated with laboratory tests in the sixth program, and through instrumenting vehicles in the field in the seventh program. The eighth program is for cost data acquisition. In summary, the entire program to evaluate both Standards would require 13 staff-years of effort over a six year period at an estimated cost of $1,355,000. However, early successful evaluation of FMVSS 202 and restricting the evaluation of FMVSS 207 to the effects of seat back locks could drastically reduce costs to only $268,000.

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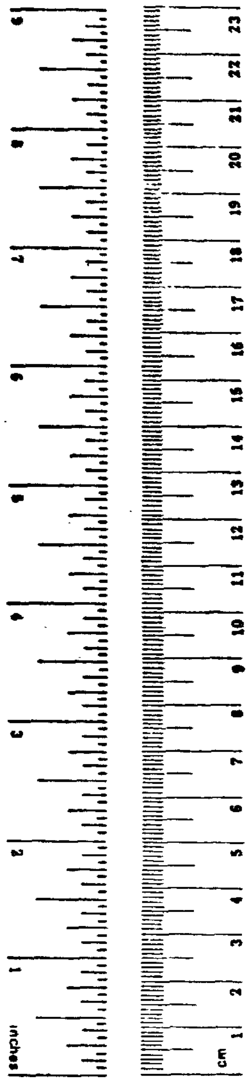
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

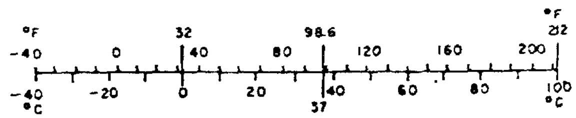
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



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ABBREVIATIONS USED

ANACOVA	Analysis of Covariance
AIS	Abbreviated Injury Scale
AMC	American Motors Company
BLS	Bureau of Labor Statistics
CDC	Collision Deformation Classification
CEM	The Center for the Environment & Man, Inc.
CPIR	Collision Performance and Injury Report
DOT	Department of Transportation
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GAO	General Accounting Office
GM	General Motors
GVWR	Gross Vehicle Weight Rating
HSRC	Highway Safety Research Center (U.of North Carolina)
HSRI	Highway Safety Research Institute (U. of Michigan)
IRPS	Institute for Research in Public Safety (U. of Indiana)
MDAI	Multi-Disciplinary Accident Investigation
MY	Model Year
NASS	National Accident Sampling System
NBS	National Bureau of Standards
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
RSEP	Restraint Systems Evaluation Program
SAE	Society of Automotive Engineers
VDI	Vehicle Damage Index
VMT	Vehicle Miles of Travel
VW	Volkswagen

TABLE OF CONTENTS

1.0 INTRODUCTION

This report is the first in a series of four reports which contain final design and implementation plans for evaluating the effects of selected Federal Motor Vehicle Safety Standards (FMVSS). The six selected FMVSS being examined are:

- FMVSS 202 - Head Restraints
- FMVSS 207 - Seating Systems
- FMVSS 213 - Child Seating Systems
- FMVSS 220 - School Bus Rollover Protection*
- FMVSS 221 - School Bus Body Joint Strength*
- FMVSS 222 - School Bus Seating and Crash Protection*

This report contains the final design and implementation plan for evaluating the effectiveness of FMVSS 202 (Head Restraints) and FMVSS 207 (Seating Systems).

1.1 Background for FMVSS 202: Head Restraints

FMVSS 202 originally went into effect on January 1, 1969, requiring passenger cars to be equipped with head restraints. Volkswagen had head restraints as standard equipment in their 1968 models, while Ford installed them on almost all their 1969 models. General Motors and Chrysler did not install head restraints on most vehicles until a mid-model year change. Two methods evolved for complying with the Standards. Some seats were manufactured with separate head restraints, some of which are adjustable. Other seats were manufactured with an integrated head restraint as part of a higher seat back. Initially, the foreign cars complied primarily with the integrated head restraint, while domestic manufacturers provided separate head restraints. This sharp difference no longer applies.

The purpose of the head restraint is to reduce neck injuries to front seat occupants in rear-end collisions. Initial analyses indicate that the head restraints are effective. Absolute levels of effectiveness are difficult to establish because of the difficulty in establishing consistent and reliable definitions of neck injury.

1.1.1 Purpose

The overall purpose of FMVSS 202 is to reduce the frequency and severity of neck injury in rear end and other collisions. This purpose is to be achieved by establishing requirements for head restraints in passenger cars which meet certain test criteria and other dimensional specifications.

*The final design and implementation plans for evaluating FMVSS 220, 221 and 222 will be combined in a single report.

1.1.2 General Requirements of FMVSS 202

As of January 1, 1969, all passenger cars had to have head restraints in the front left and right seating positions. The head restraint devices can be either an extension of the seat back or can be a separate device mounted on the seat. The head restraint device must conform to either a dynamic test in which the angular displacement of the manikin's head is measured or a static test where the rearward displacement of the test dummy head form is measured while applying a load to the head form. In the dynamic test, the acceleration has an amplitude of between 8.0 and 9.6 g and a duration of between 80 and 96 milliseconds. In the static test, the maximum load is 200 pounds (or less if the seat fails). Greater detail is given below.

Dynamic Test for Head Restraints

A test dummy with the weight and seated height of a 95th percentile male is used.* This dummy is not necessarily the anthropometric type used for crash testing; however, it must have an approved representation of a human, articulated neck structure.** The three-dimensional test dummy is placed in the seat. The SAE J826 two-dimensional manikin is placed next to the three-dimensional dummy to establish the torso and head reference lines on the three-dimensional dummy. The dummy is restrained with a seat belt and the seat is accelerated forward with a half sine wave pulse of between 8 and 9.6 g for a duration of 80 to 96 milliseconds. During the test the angular displacement of the head reference line to the torso reference line should not exceed 45 degrees.

Static Test for Head Restraints

The SAE J826 three-dimensional test manikin is placed in the manufacturer's recommended seated position. The head restraint is in its fully extended position. An initial load is applied to the manikin's back pan so that a 3300-in-lb moment is generated around the seat reference point. This initial load establishes the displaced torso reference line. Next, the manikin back pan is removed and a spherical or cylinderical head form is placed on the manikin. The head form is 6.5 inches in diameter. A load is applied rearward to the head form 2.5 inches below the top of the head restraint such that a 3300 in-lb moment is generated around the seating reference point. The rear-most portion of the head form should

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*217 lbs and 38.0 inches [1].

**SAE Recommended Practice J963 describes an anthropomorphic test device for dynamic testing and Part 57-2 of Title 49 of the Code of Federal Regulations establishes the specifications for the anthropomorphic test dummy for FMVSS 208.

not be displaced more than 4 inches rearward of the displaced torso reference line. In addition, the head restraint must withstand a load of up to 200 pounds before failing (unless the seat fails first).

Dimensions

If the head restraint complies under the dynamic test requirements, no specific dimensions for the head restraint are established. If the head restraint complies under the static test requirements, the dimensions of the fully extended head restraint must be as follows:

- The top of the restraint must be at least 27.5 inches above the seating reference point.
- The lateral width, when measured either 2.5 inches below the top of the restraint or 25 inches above the seating reference point, must be at least 10 inches for bench type seats or 6.75 inches for individual seats.

1.1.3 Measures of Effectiveness

The Standard sets specifications for head restraint devices which are intended to reduce the frequency and severity of neck injury to outboard front seat passengers in rear end and other collisions. The Standard requires head restraints in only the front left and right seats of passenger cars. Secondly, the Standard went into effect on January 1, 1969, and most earlier car models did not have this safety feature. Therefore, the conceptual measures of effectiveness include reductions in the frequency and severity of neck injury for (a) drivers and right front seat occupants from Pre-Standard to Post-Standard vehicles, and (b) drivers and right front seat occupants relative to other occupants in positions without head restraints.

Since manufacturers comply with the Standard using two basic head restraint systems (extended seat backs vs. adjustable head restraints), another measure would be the relative effectiveness of the different systems.*

A potential effect of the Standard which also should be considered is injury suffered from contact with head restraints by back seat occupants. This analysis would examine the different types of head restraints and the relative frequency and types of injury incurred.

A final measure of effectiveness of the Standard would be the relative performance of various head restraint systems in off-center impacts (loading). This type of measure would evaluate the range of circumstances where the head restraint would have an effect (including unadjusted).

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*Seat type may also have an effect and should be included in the analysis.

In summary, the basic quantitative measure of effectiveness of the Standard is the reduction in the frequency of neck injuries. Because of the difficulty in establishing the occurrence of neck injuries, since the occupant may not show or feel any difficulty until several hours or even days later, another grosser measure might be the rate of neck injury insurance claims per insured model year. This measure is less desirable for several reasons, one major one being that the claim is submitted by the individual and not based on accident investigation and independent corroboration.

Other measurements of the effectiveness of the Standard involve the relative performance of different types of head restraints (a) in reducing neck injuries, and (b) in lab tests involving off-center head restraint loadings. A final quantitative set of measures relating to the Standard is the "usage" of the head restraints--the number correctly adjusted and the frequency with which occupants are too tall or sit out of position. These measures do not evaluate the effectiveness of the Standard in reducing injuries; they show the degree to which the potential effectiveness of the Standard may be lowered because of improper usage on the part of motor vehicle occupants.

1.1.4 Means of Complying with the Standard

FMVSS 202 (Head Restraints for Passenger Cars) first went into effect on January 1, 1969. Its purpose was to require the use of head restraints and establish performance standards for head restraint systems in passenger cars. Head restraints reduce the frequency and severity of neck injuries in rear-end collisions.

Head restraints are required by the Standard at each front left and right seating position in passenger cars. Restraint systems must conform to the performance requirements designated in FMVSS 202 under a dynamic or static test.

There are basically two methods by which passenger cars comply with the head restraint requirements imposed by FMVSS 202:

(1) Adjustable head restraints which must be 10 inches wide for bench seats and 6.75 inches wide for bucket seats. The top of the restraint must be 27.5 inches above the seating reference point.

(2) High seat backs which have the head restraint built into the seat and require no adjustment.

The system actually employed is primarily a function of seating configuration (bench, bucket, etc.) which in turn is a function of make and model of vehicle. In general, most bench seating configurations are equipped with adjustable head restraints while most bucket seat arrangements employ fixed high seat backs.

1.1.5 Secondary Effects of the Standard

A potentially serious effect of the methods used to comply with the Standard is the reduction in visibility. Although properly adjusted rear-view and side-view mirrors should provide drivers with adequate information, the facts are that there are many cases where drivers chose to turn their heads to look. In some of these cases the driver's view can be blocked.* This problem could be simply a nuisance and drivers could learn to accommodate to these additional inconveniences. Some manufacturers (e.g., Saab) have constructed their high seat back restraints with an open design to reduce this problem. Another secondary effect of the Standard can result from the fact that rear seat occupants strike head restraints in frontal crashes.

1.1.6 Real World Performance of the Standard

Real world accident experience has shown that head restraints have a substantial effect in reducing neck injuries in rear-end accidents. States, *et al.*, found a 14 percent reduction in whiplash injuries and O'Neill, *et al.*, reported an 18 percent reduction in neck injury insurance claims [2,3]. In addition, O'Neill reported that the adjustable head restraints are rarely properly adjusted. Therefore, the effectiveness of properly used adjustable head restraints may be even higher.

The direction of rear-end impacts is <u>not</u> solely longitudinal, but is distributed around the longitudinal axis; also, drivers do not position themselves at all times squarely in the seat in front of the head restraint. These facts affect the performance of a head restraint designed for longitudinal stresses. Seats designed to hold the occupant in position and to limit lateral movement in an off-center crash may improve the effectiveness of the head restraints in reducing injury.

There is a negative side effect of head restraints, particularly adjustable ones, designed with exposed metal fixtures. These head restraints may increase certain types of injuries (such as lacerations) to rear seat passengers.

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*Trying to see the car behind in a parking situation, a vehicle to the right rear in a merging or crossing situation, trying to see (or reach) into the back seat.

1.2 Background for FMVSS 207: Seating Systems

FMVSS 207 originally went into effect on January 1, 1968, applying to passenger cars only. The Standard basically adapted SAE Recommended Practice J879 for Motor Vehicle Seating Systems, which was originally promulgated in November 1963. The major impact of the Standard was that it required a self-locking restraining device for folding seats and seat backs. The seating system strength requirements, as reflected in static loading tests, codified generally accepted engineering practices as reflected in SAE Recommended Practice J879.

The application of the Standard was extended to multipurpose passenger vehicles, trucks and buses as of January 1, 1972. Additional requirements were incorporated into the Standard, including the proviso that a seat remain in its adjusted track position during load application. Various aspects of the Standard were clarified and restructured. Table 1-1 describes the application by model year of Pre- and Post-Standard activities related to the Standard.

TABLE 1-1

APPLICABILITY OF FMVSS 207 BY MODEL YEAR

Model Year	Seating System Requirements
Pre-Standard	
1964	• Society of Automotive Engineers adopt Recommended Practice J879--Motor Vehicle Seating Systems--in November 1963. Procedures for static testing of seats are specified.
1966 and earlier	• Self-locking restraining device for folding seats on some foreign cars.
1967	• General Motors includes self-locking restraining devices on all 2-door models.
Post-Standard	
1968	• FMVSS 207, effective 1 January 1968, for all passenger cars.
	• All U.S.-produced passenger cars contain self-locking restraining devices on folding or hinged seats.
1972	• FMVSS 207, effective 1 January 1972, extended to multipurpose passenger vehicles, trucks and buses.
	• Standard clarified and specified in greater detail.

1.2.1 Purpose

The purpose of FMVSS 207 is to establish requirements for seats, their attachment assemblies, and their installation to minimize the possibility of their failure by forces acting on them as a result of vehicle impact. The general purpose is to reduce the incidence of seat failures and their contribution to fatalities and injuries in motor vehicle accidents.

1.2.2 General Requirements of FMVSS 207

The general requirements listed below apply to passenger cars, multipurpose passenger vehicles, trucks and buses.

1. Each occupant seat, with the exception of folding auxiliary jump seats and side-facing seats must be able to withstand specified loads in forward and rearward longitudinal directions. These loads include an amount equal to 20 times the weight of the seat and a load equal to a 3,300 inch pound moment about a defined seating reference point. The seat must remain in its adjusted position during the application of each force.

2. With the exceptions of a passenger seat in a bus or a seat having a back that is adjustable only for the comfort of its occupants, hinged or folding seats or seat backs must be equipped with a self-locking restraining device. Each device must have a release control. The device must not release or fail when (a) a force of 20 times the weight of the seat back is applied through the center of gravity of a forward facing seat back; or (b) a force of 8 times the weight of the seat back is applied through the center of gravity of a rearward facing seat back. Additionally, the restraining device must not release or fail when subjected to an acceleration of 20 g.

3. The control for releasing the restraining device must be readily accessible to the seat occupant. It must also be readily accessible to any occupant in a seat immediately to the rear.

4. Seats that are not designated for occupancy while the motor vehicle is in motion must be conspecuously labeled to that effect.

1.2.3 Measures of Effectiveness

The primary conceptual measure of effectiveness is: given the occurrence of an accident, was seat system failure avoided as a result of compliance with the seating system requirements of the Standard. Seating systems can fail in a variety of ways. The self-locking restraining device mechanism for folding seat backs can release or fail when subjected to a strong acceleration loading. Seats can fail to remain in their adjusted position in the track. The seat adjustment track and/or seat anchorage can pull out of the floor of the car. Seats can fail when impacted by occupants and/or cargo from the back seat area of the vehicle. Thus, the potential seat failure mode is related to type of seat,seat adjustment prior to accident, type of accident (e.g., rear end *vs.* front end) and resultant forces exerted and the distribution and characteristics of vehicle occupants and/or cargo.

It is also clear that a seat which breaks, tears loose or fails in some way is an added hazard to vehicle occupants. Thus, occupant injury is another conceptual measure to evaluate the effectiveness of the Standard. Both the injury severity and distribution (i.e., where it occurred--head, upper torso, legs, etc.) are of interest because these may vary with the type of seat, type of accident and occupant/cargo characteristics and distribution. The conceptual measures of seating system failure and occupant injury present immediate problems concerning the use of mass accident data to help evaluate the Standard. There may be no information at all on seat failure, not even a binary 0 or 1 indication as to whether the seating system is impaired by the accident. Furthermore, the information on injury may be coded only in the KABCO scale:

K = Killed
A = Incapacitated
B = Not Incapacitated
C = Possible Injury
0 = Not Injured

The abbreviated Injury Scale (AIS) in combination with other information such as was obtained in the National Crash Severity Study (NCSS) is of greater value.* The AIS is as follows:

0 = None
1 = Minor
2 = Moderate
3 = Severe (not life-threatening)
4 = Severe (life-threatening)
5 = Critical (survival uncertain)
6 = Fatal

In the NCSS study, information is provided on body region, aspect, lesion, system/organ, and injury source, as well as AIS severity.

Quantitative measures of seat system failure can, of course, be most conveniently determined in the laboratory. As will be discussed in Section 3, it is recommended that dynamic as well as static testing be conducted to determine more realistically the types of crash situations and forces that can be withstood by currently designed seating systems.

*The AIS will also be available in National Accident Severity Study (NASS) data.

The NCSS and Multidisciplinary Accident Investigation (MDAI) data file [4] contain detailed data on seating system failure. The NCSS contains the following for both front and rear seats:

- Seat type.
- Seat adjusters damage (front seat only)
- Back rest deformation--type and cause.
- Cushion damage.
- Seat back locks.

The MDAI file also contains data similar to the above and includes such detailed information as type of damage to seat adjusters (e.g., chucking, deformed and released, separated, etc.), location of seat separation and seat orientation relative to ground and vehicle after the accident.

1.2.4 Means of Complying with the Standard

Basically, FMVSS 207 imposes two types of requirements. The first requirement is that each occupant seat installation in the passenger vehicle be capable of withstanding certain specified forces. The second fundamental requirement is that hinged or folding seats or seat backs be equipped with a self-locking restraining device and a control for releasing the restraining device that is readily accessible to the occupant of the seat and the occupant of any seat immediately behind the seat. The restraining device must also withstand certain forces.

The strength of car seating systems to absorb these forces could be substantially affected by the following:

- Overall dimensions, contour and weight of seat and seat back.
- Car seat type (bench, bucket, etc.).
- Seat frames--both the structural characteristics of the metal used and the configuration.
- Seat spring assemblies
- Seat adjuster track--type and strength.
- Anchorage of seating system to floor of car.

Thus, potentially there could be a variety of compliance approaches involving the design of seating systems and the material used, if the requirements of the Standard so dictated.

However, the evidence suggests that the actual strength of seating systems before the effective date of the Standard (January 1, 1968) was little different from the strengths of seating systems after the Standard [5]. Therefore, it would appear that the principal compliance with the Standard has been directed toward the inclusion of a self-locking restraining device on folding seat backs, and a control for releasing the restraining device. Increased concern among the manufacturers for high quality control in the manufacture of seating systems may be an additional effect of the Standard [6].

In all seating systems, the seat back latch can be released manually by activating the seat back release control device (usually a handle; sometimes a pushbutton). In some systems, the front seat back latch releases automatically when either front door is opened [7]. This automatic electromechanical releasing feature is not required by the Standard.

1.2.5 Secondary Effects of Compliance

In prescribing seating system requirements, it is possible that at least two secondary or unintended effects may have resulted. These possible negative effects should be considered in evaluating the effects of the Standard.

The first potential negative effect relates to the inclusion of self-locking restraining devices in folding front seat backs in two-door vehicles. The Standard does prescribe that the control for releasing the seat back latch must be readily accessible to both the front seat occupant and any occupant in the rear. The question which is raised here relates to the frequency of back seat occupants becoming trapped in the vehicle, especially in the event of fire. If the back seat occupant puts pressure on the front seat back with hand or body before attempting to activate the control device with the other hand, the self-locking restraining device may not release.

A second potential negative effect is concerned with the impact that specific minimum strength requirements, as specified by the Standard, could have on specific seating systems which (prior to the Standard) well exceeded these test requirements. There might be a tendency to "design down" to Standard specifications (which results in reduced dynamic forces as weight goes down). Laboratory testing of specific seating systems as they evolved in model years, before and after the Standard implementation, might clarify this point. This static and dynamic testing should build on the work of previous investigators, such as Severy, *et al.* [5].

1.2.6 Real World Performance of the Standard

The determination of the real world performance of the Standard poses a number of difficulties because of the need for detailed information on seat failure and injury occurrence. Huelke [8] contended in 1976 that there were insufficient data to evaluate the real world effectiveness of FMVSS 207, as well as most of the other Standards in the 200 series.

Severy, *et al.* [5] have conducted 85 laboratory full-scale force deflection tests on passenger vehicle seats, both foreign and domestic, that have been manufactured during the past 30 years. On the basis of these tests, the authors concluded that the backrest strengths were very similar and all were incapable of effectively resisting the inertial forces of the motorist for anything but light impact without inducing excessive yield and/or component separation. The authors also found that production seats manufactured during the 1940's substantially exceeded some requirements of the Standard.

It appears that the major real world effect of the Standard was to introduce the requirement for a self-locking device for restraining hinged or folding seats. The introduction of the self-locking device is described in Table 1-2. In attempting to evaluate the effect of this aspect of the Standard, using either mass accident data or special data, the staggered implementation suggested in the table must be taken into account.

TABLE 1-2

INTRODUCTION OF SELF-LOCKING DEVICE FOR RESTRAINING HINGED OR FOLDING SEATS [9]

Model Year	Description
1966 & earlier	• Many foreign cars contained the self-locking device, including VW and Opel.
1967	• Most foreign cars contained the self-locking device, including VW, Opel, Fiat, Renault, Datsun, Sunbeam. • GM introduced the self-locking device into all lines. - Chevrolet - Oldsmobile - Buick - Pontiac
1968	• All 1968 MY passenger cars with folding seats have self-locking restraining device.

1.3 Summary of Evaluation, Cost Sampling and Work Plan

The plan to evaluate the effectiveness of FMVSS 202 and FMVSS 207 will be concerned with eight analyses. They are:

- Analysis of Insurance Claims (FMVSS 202)
- Analysis of Detailed Accident Data
- Analysis of Occupant Fatalities (FMVSS 207)
- Analysis of Mass Accident Data (FMVSS 207)
- Head Restraint Usage Survey (FMVSS 202)
- Dynamic Laboratory Tests
- Instrumented Vehicles Data Collection and Analysis
- Cost Data Analysis.

1.3.1 Analysis of Insurance Claims

This analysis is concerned with establishing whether a significant reduction in the frequency of neck injury complaints has occurred due to the FMVSS 202. Claims from the 1969-1970 calendar years would be investigated. The extraction of claim data does require considerable effort, but the relatively modest statistical analysis envisioned may permit a sample size of about 10,000 claims. It would be essential to the study to secure the cooperation of an automobile insurer with nationwide exposure. A data extraction plan and forms must be prepared after examining a sample of claims. Personnel would be trained in data extraction and a procedure for quality control monitoring of incoming data established. Initial data tabulations and statistical comparisons could be made as the data accumulate.

1.3.2 Analysis of Detailed Accident Data

The purpose of this analysis in terms of FMVSS 202 is to analyze the generation of neck injuries in accidents, primarily rear-end accidents. The study will require existing detailed accident data from MDAI, RSEP, and NCSS. The initial analysis is concerned with determining whether a significant reduction in the frequency of neck injuries for front seat occupants in vehicles with head restraints has occurred. In addition to injuries, variables of importance include type of collision, seating position, seat type, head restraint type, seat restraint, occupant age, sex, height and weight, and vehicle factors. A second analysis will attempt to determine if there is a difference in performance among different types of head restraints. Vehicle factors such as model year, type, weight and speed of impact must be considered, as well as the variables mentioned above.

In terms of FMVSS 207, the purpose is to analyze the incidence of occupant injury and seat failure as a function of accident type, vehicle occupancy, seat type and other relevant variables. Detailed accident data from MDAI and NCSS will be evaluated in a two-part analysis. First, occupant injury and front seat failure are analyzed in front-end and rear-end accidents. In front-end accidents, the data are stratified according to occupancy or no-occupancy in the back seat. Injuries to rear seat passengers are also investigated, as a function of seat failure. A similar analysis is performed in rear-end accidents except that rear seat occupancy is not considered. Second, the frequency and type of seating system failure is evaluated for different accident types, seat types, vehicle occupancy, etc.

1.3.3 Occupant Fatality Analysis

The main purpose of this evaluation is to study the fatality rate of front and rear seat occupants using FARS data. One aspect of the study is to investigate the possibility that the introduction of the self-locking device for folding front seat backs on 2-door cars may increase the possibility of a back seat occupant being trapped in a panic situation when quick emergency exit from the car is required. In addition to the FARS statistical analyses, a case-by-case clinical analysis of accidents involving fire in the MDAI and NCSS detailed accident data base will be made. The analysis will be concerned with type and severity of injury to occupants, whether front and back seat occupants escaped, car type, seat type, etc. Fatalities and injuries in FARS will be analyzed with respect to front and back seat occupants in 2-door and 4-door cars for Pre-Standard and Post-Standard model years. Comparison of make/model groupings will be undertaken. The results of the clinical analysis will be compared with the statistical analysis of the FARS data.

1.3.4 Analysis of Mass Accident Data

This part of the evaluation is concerned with determining if any effects of the Standard on injury avoidance can be determined from mass accident data. Suggested data sources are the HSRI data files as well as complete Texas, North Caroline, and New York accident data of 1968 through 1971. The analysis will be directed toward determining whether in front-end collisions there are any differences in driver and up-front passenger injuries between 2-door and 4-door cars in Pre-Standard and Post-Standard model years. Essentially, the analysis is investigating whether the injury rate in 2-door cars changes as a result of the requirement of the self-locking device for folding seats while no similar change is found in 4-door cars. Where appropriate, similar make/models will be compared.

1.3.5 Head Restraint Usage Survey

The purpose of this portion of the evaluation is to conduct a survey of misuse of head restraint systems. The survey would attempt to estimate the frequency of mispositioning of head restraints. This frequency could vary with a fairly large number of factors and this must be considered in the development of a survey plan that will be tested with a pilot study. The pilot study will test data processing procedures and initial data tabulations as well as data collection. The eventual selection of several data collection sites might be according to geographic diversity, highway type, and traffic density. Time of day must be considered in actual data collection. Other variables of interest include driver age, sex and height, seat type, and head restraint type. The conduct of the study will require training of personnel, monitoring data collection and processing and analyzing results, including standard errors of estimates.

1.3.6 Dynamic Laboratory Testing

This analysis is concerned with dynamic laboratory testing of head restraints and seating systems to establish performance characteristics. The purpose of the study with regard to FMVSS 202 is to establish the performance characteristics of different head restraint devices under off-center and angular impacts. The twisting of head restraints upon impact and great differences between rebound from the seat and head restraint are not desirable. Head restraints and seat backs can be instrumented to determine the degree of resistance--both longitudinal and in rotation. The critical factors in this study approach relate more to engineering and testing capabilities than to analytic sophistication. Past tests on head restraining devices and seating systems will be reviewed. Prior to the actual tests, considerable preparation is required. Selected seat/head restraint systems and instruments must be obtained. The results of the tests will be compared, analyzed and reported.

The purpose of this study with regard to FMVSS 207 is to conduct dynamic tests of selected seating systems, both Pre-Standard and Post-Standard, to evaluate the effects of the Standard on seating strength and to suggest possible additional criteria for the requirements of the Standard. Dynamic testing of a variety of seating system types from cars, multipurpose vehicles, trucks and buses will be undertaken for varying acceleration exposures, seating arrangements, occupant (dummy) dimensions, restraint usage and seat adjustment in track (if applicable). Free body analysis of the seating system comprised of the occupant seat with attachments and seat restraints will be carried out.

1.3.7 Instrumented Vehicles Data Collection and Analysis

This part of the evaluation is directed toward improving the understanding of the performance of head restraints and seating systems in real world crashes. For this purpose, a fleet of selected vehicles, perhaps numbering 50,000 would be instrumented. This number of vehicles may be instrumented under a NHTSA program concerned with brake performance and vehicle handling. The basic additional information that would be useful relates to acceleration (lateral and longitudinal) of the vehicle's center of gravity, and accelerations or forces on the head restraint, seat back, seat anchors, seat tracks, and seat latches.

The rate of reportable accidents from 50,000 vehicles would require approximately a 2-year period of accident exposure, and special accident investigations would have to be conducted in order to use the crash reconstruction programs for accident data evaluation. The program plan must include (1) specification of sensing units required and instrumentation of vehicles; (2) data to be collected, data processing procedures and data usage; (3) pilot program for testing; (4) vehicle tracking program and special accident investigations; and (5) analysis of data.

1.3.8 Cost Sampling Plan

This analysis is concerned with the determination of direct costs to implement FMVSS 202 and FMVSS 207. 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 has been developed which assumes that the manufacturer's cost of compliance varies according to the manufacturer and vehicle weight or class. Additionally, in the evaluation of FMVSS 202, the sampling plan must consider adjustable and fixed restraints and in the evaluation of FMVSS 207, the sampling plan must differentiate between 2-door and 4-door cars.

1.3.9 Work Plan

The work plan for the evaluation study of FMVSS 202 and FMVSS 207 is divided into a total of eight Tasks. Assuming all Tasks are carried out, the estimated resources required for evaluating the effectiveness of both Standards is $1,355,000. This figure includes estimated requirements of over 13 staff years. Because of the length of the seventh Task (Instrumented Vehicles), the entire study would require almost six years.

Task 1 is concerned with establishing whether a reduction in neck injury complaints occurred due to FMVSS 202. It is estimated that six months will be required for the completion of Task 1, assuming that cooperation of an automobile insurer will permit rapid and efficient access to insurance claims. The total resources required for Task 1 are estimated to be $52,000. This total includes about 1.3 staff-years of effort and $2,000 for data processing.

Task 2 deals with the analysis of injuries, especially neck injuries, and seating system failure with detailed accident data. It is estimated that one year will be required for the completion of the Task 2 study. The total resources required for Task 2 are estimated to be $80,000. This total includes about 1.5 staff-years of effort and $5,000 for data processing.

Task 3 is directed toward studying fatality rates of front and rear seat occupants using FARS data. It is estimated that the modest effort under Task 3 can be completed in six months. The Task work can be completed during the first year of the overall study to evaluate FMVSS 202 and FMVSS 207. The total resources required for Task 3 are estimated to be only $37,000. This total includes accomplishing the Task effort with 0.7 staff-years and $2,000 for data processing costs.

Task 4 is concerned with the analysis of injuries from mass accident data. It is estiamted that six months will be required for the completion of the Task 4 effort. This estimate assumes prompt acquisition and/or accessing multiple mass accident data sources. The total resources required for Task 4 are estimated to be $42,000. This total includes accomplishing the Task effort with 0.8 staff-years and $4,000 for data processing.

Task 5 deals with the misuse of head restraint systems. It is estimated that six months will be required for the completion of the Task 5 effort. The Task is not scheduled to begin until 16 months after the start of the overall evaluation study. This will permit a revised assessment of the need for the Task 5 effort. The Task work should be undertaken only if the Task 2 study demonstrates a difference in the overall effectiveness of unadjusted and correctly adjusted head restraints. The total resources required for Task 5 are estimated to be $57,000. This total includes about 1.5 staff-years of effort and $2,000 for data processing.

Task 6 is directed toward the laboratory testing of head restraints and seating systems to establish performance characteristics. It is estimated that about nine months would be required for the completion of the Task 6 study which is scheduled to be undertaken during the third year of the overall FMVSS 202 and FMVSS 207 evaluation study. The total resources required for Task 6 are estimated to be $300,000. This total includes about four staff-years of effort, $67,000 for equipment costs, $50,000 for laboratory costs and $3,000 for data processing.

Task 7 is concerned with improving the understanding of the performance of head restraints and seating systems in real world crashes. It is estimated that at least two and one-half years would be required for the completion of the Task 7 effort. This plan allows for a 2-year data collection period. It is recognized that not all of the target 50,000 vehicles would necessarily be "in the field" during the entire two years (i.e., a greater lead time may be required in getting the selected instrumented vehicles into the field and some vehicles will be removed due to accidents). The costs for this Task are estimated with the assumption that the costs of the basic crash recorders for the 50,000 vehicles are assumed under another NHTSA program. It is assumed that the cost of manufacture and installation of the additional head restraint and seating system instruments is approximately $10/vehicle. Thus, the total resources required for Task 7 are estimated to be $730,000. This total includes about 2.5 staff-years of effort, $500,000 for equipment costs, $50,000 for field data costs, $50,000 for laboratory testing and $5,000 for data processing.

Task 8 is designed to determine the direct costs to implement FMVSS 202 and FMVSS 207. Task 8 will be completed in six months during the first year of the study. It is estimated that the total resources required are $57,000; this includes 1.0 staff-years of effort and $2,000 for computer processing.

In summary, the study to determine the effectiveness and costs of FMVSS 202 and FMVSS 207 could require resources of $1,355,000 and almost six years if all scheduled Tasks are carried out. However, it is quite conceivable that the evaluation of FMVSS 202 could be successfully completed at the end of the first year. It is also quite possible that the evaluation of FMVSS 207, in terms of the effects of seat back locks, can be completed during the second year of the study. If the above occur, and it is *not* required that the overall effect of FMVSS 207 on seating system strength be established, then the cost of the evaluation study would be drastically reduced to $268,000.

1.4 References for Section 1

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8. Huelke, D. F. "How Effective Are Occupant Protection Standards?" *Traffic Safety*, V. 76, No. 1, January 1976.

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2.0 APPROACHES TO THE EVALUATION OF FMVSS 202 AND FMVSS 207

The overall purpose of FMVSS 202 (Head Restraints) is to reduce the frequency and severity of neck injury in rear end and other collisions. This purpose is to be achieved by establishing requirements for head restraints in passenger cars which meet certain test criteria and other dimensional specifications. The purpose of FMVSS 207 (Seating Systems) is to establish requirements for seats, their attachment assemblies, and their installation to minimize the possibility of their failure by forces acting on them as a result of vehicle impact. The general purpose is to reduce the incidence of seat failures and their contribution to fatalities and injuries in motor vehicle accidents.

It became increasingly clear that many of the analytical approaches to evaluating the effectiveness of head restraints could most effectively be carried out if they were integrated with the analytical approaches which evaluate the effectiveness of the seating system Standard. Thus, several of the approaches described below provide information on the evaluation of both Standards.

2.1 Problems in Evaluating the Standard

Some problems that can be anticipated in evaluating the two Standards are:

1. There is considerable difficulty in establishing the occurrence of neck injuries, since the occupant may not show or feel any difficulty until several hours or even days later. Additionally, some individuals may be reluctant to complain about this type of injury, while others may be prone to exaggerate the severity.

2. Most bench seating configurations are equipped with adjustable head restraints while most bucket seat arrangements employ fixed high seat backs. Studies indicate that adjustable head restraints are rarely properly adjusted. The prior correctness of adjustment may be difficult to determine for many accidents.

3. Available evidence (discussed in Section 1) suggests that seat back strength on passenger vehicle seats has been very similar over the past 30 years.

4. It appears that the major real world effect of FMVSS 207 was to require a self-locking device for restraining hinged or folding seats in passenger cars.* Because this took place in MY67 or MY68 domestic cars, special detailed accident data are of limited value here because of the age of the seating systems and the small sample size.

*Some cars had seat latches before the Standard became effective.

5. Information to be derived from the controlled laboratory type experiments does not directly measure the effectiveness of either FMVSS 202 or FMVSS 207 in real world situations.

2.2 Proposed Evaluation Approaches

The nine approaches listed below have been proposed and studied for suitability in evaluating FMVSS 202 and/or FMVSS 207.

- Injury Analysis Using Mass Accident Data.
- Injury and Seat Failure Analysis Using Detailed Data.
- Occupant Fatality Analyses
- Analyses of Insurance Claims.
- Adjustable Head Restraint Usage Survey.
- Dynamic Tests.
- Instrumented Vehicles.
- Latch Release Tests.
- Multipurpose Vehicles Analysis.

The final two approaches listed above were *not* judged to be sufficiently promising to include in the evaluation plan described in Section 3. A description of these two approaches and the reasons for eliminating them are given in Section 2.1.

Tables 2-1 and 2-2 address the results of the evaluation approaches to FMVSS 202 and FMVSS 207 respectively. Some of the approaches will provide information on both Standards while other approaches are obviously directed only to one of the Standards.

TABLE 2-1

APPROACHES FOR EVALUATING THE EFFECTIVENESS OF FMVSS 202

Approach	Description Section	Results
• Injury Analysis Using Detailed Data	3.2	Estimates of neck injury rates as a function of the presence or absence of head restraints and the type of head restraint. The effects of collision type, seat type, occupant factors and vehicle factors will be included.
• Analysis of Insurance Claims	3.4	Estimates of the reduction in the frequency of neck injury insurance claims, due to the Standard.
• Adjustable Head Restraint Usage Survey	3.5	Estimate of the rate of misuse of adjustable head restraint systems. This estimate shows the degree to which the potential effectiveness of the Standard may be lowered because of improper usage on the part of the seat occupant.
• Dynamic Tests	3.6	Establish the performance characteristics of different head restraint devices during specified impact situations, including off-center and angular impacts.
• Instrumented Vehicles	3.7	Improve understanding of the performance of different types of head restraints in real world crashes by instrumenting vehicles in use. Impact forces on the head restraint will be related to vehicle accelerations and accident characteristics.

TABLE 2-2

APPROACHES FOR EVALUATING THE EFFECTIVENESS OF FMVSS 207

Approach	Description Section	Results
• Injury Analysis Using Mass Accident Data	3.1	Estimates of the effectiveness of seat back locks in reducing injury. Differences in injury rate for drivers and up-front occupants will be determined for Pre-Standard and Post-Standard 2-door and 4-door cars.
• Injury and Seat Failure Analysis Using Detailed Data	3.2	Estimates of injury rates and injury severity and different types of seat failure will be determined, especially as these relate to the presence or absence of seat back locks (bench *versus* bucket seats) in Post-Standard cars.
• Occupant Fatality Analysis	3.3	Estimates of front and rear seat occupant fatalities will be made to assess the effects of seat back locks on fatalities and evaluate the question of trapping a rear seat occupant.
• Dynamic Testing	3.6	Establish the performance characteristics of different seating system types during specified impact situations, including off-center and angular impacts.
• Instrumented Vehicles	3.7	Improve understanding of the performance of different types of seating systems in real world crashes by instrumenting vehicles in use. Impact forces on the seat will be related to vehicle accelerations and accident characteristics.

Approaches Not Recommended

Latch Release Testing

The purpose of this approach would be to conduct tests of various latch release controls for folding front seat backs. Specifically, the testing is directed toward determining the ability of rear seat occupants to locate and activate the control release device.

In two-door cars, a back seat occupant can normally exit from the vehicle only by mechanically activating the control device to release the self-locking device which permits the seat back of the front seat to be folded. Although there are alternatives to this system (such as a system whereby opening either front door automatically disengages the locking device), most systems are solely dependent on the mechanical action of the control for release. Under emergency conditions, there is the possibility that a back seat occupant will be unable to activate the control device because it cannot be located (due to confusion), or it cannot be operated properly. If such situations occur, the rear seat occupant will be trapped. In a panic situation, location of the release control device can become a very difficult task, especially since several variations of control release types and locations exist. This situation would certainly be helped by greater standardization of the control release type, appearance and locations. The latch release testing would be directed toward establishing which control release type, appearance and location are most accessible to a back seat occupant.

Another dangerous situation during emergency exiting occurs when the back seat occupant has located the control release device but is unable to activate it because he or she is pressing against the seat back in an effort to push the seat back forward before activating the release control. In this case, it is assumed that for most seating systems, the latch mechanism will lock up with only a minimal amount of force applied to the seat back. Therefore, laboratory testing to determine the load (on seat back) sufficient to prevent mechanical release is unnecessary.

To obtain the desired data on latch system recognition, a very simple test could be performed. Selected volunteers would be blindfolded and placed in a compartment which simulates the back seat of a vehicle. The blindfold is used so that the volunteer will not become familiar with the type and location of the control release device being tested before the test begins. The blindfold will then be removed and the time it takes for the occupant to locate and successfully operate the control release device will be recorded. This step will be repeated for each of the various latch devices being tested. The vehicle interior simulator will be designed so as to allow rapid interchanging of the various control release devices. Volunteers should be carefully selected so as to be representatie of the overall population.

At least two objections can be expressed against including the above approach as part of the FMVSS 207 evaluation plan. The above tests would provide information about ease of recognition and operation of latch release controls but these data would not necessarily apply directly to a real world emergency situation. Perhaps more importantly the tests are really concerned with the desirability of standardizing the design of the seat back lock release mechanism and this is outside the purview of a plan to evaluate FMVSS 207.

Multipurpose Vehicles

Multipurpose vehicles such as vans and general utility vehicles constitute a rather small percentage of the vehicle population--less than 5%. It was felt that a special study of the effects of FMVSS 207 on seat failure and injuries in multipurpose vehicles might be warranted, especially in terms of the requirement for self-locking devices for folding seats. However, since adequate information on seating system failure is present only in the detailed data sample of the NCSS and MDAI, a problem is immediately apparent. These limited samples contain very few multipurpose vehicles. For example, in the MDAI sample there are 16 utility (jeep, bronco) vehicles and 28 carryall/panel trucks and only a small fraction of these were involved in accidents with seating system failure.

*Highway Safety Research Institute, CPIR Revision 3 No. 77-2, The University of Michigan, April 1977.

2.3 Organization of the Effectiveness Evaluation Plan

The general approach to evaluating the effectiveness of any Standard is to undertake first those evaluation tasks which:

- Can be done early.
- Show significant promise of achieving success in evaluating the effectiveness of the Standard.
- Can be performed relatively inexpensively.

If appropriate data are available in the mass accident data files available from states, and detailed accident data bases such as RSEP, MDAI, NCSS and (in the future) NASS, then statistical analyses are usually the first recommended task(s). In some instances, clinical analyses of available data, surveys, and/or preliminary field or laboratory tests may be appropriate to augment and/or enhance the results expected from the first round of statistical data analyses.

The initial statistical and supporting analyses and tests usually occupy approximately the first year of the evaluation program (time for preparation of Requests for Proposals, proposal review, and contracting is included). The first major decision point is then reached. For some Standards, the initial analyses may be adequate to evaluate the Standard with satisfactory statistical confidence levels. In the case of other Standards, the initial analyses will only provide the basis for conducting surveys, field and laboratory tests, and additional detailed data collection and analysis efforts. As much as two, three or more years of work may be required, and there may be several additional decision points, where NHTSA can decide whether the evaluation process is adequate or should be continued.

CEM has outlined evaluation programs lasting from three to six years. In each case, it is CEM's judgment that there is a reasonably high probability that, by the end of the program, the effectiveness of the Standard will have been satisfactorily evaluated. However, in the event the issue remains in doubt, a number of "Next Possible Steps" are outlined.

The evaluations of FMVSS 202 (Head Restraints) and FMVSS 207 (Seating Systems) have been combined because of the strong interaction between the two Standards. Separate evaluation program flowcharts/decision trees are presented in Figures 2-1 and 2-2. An integrated evaluation Work Plan is presented in Section 5. Some Tasks apply to both Standards and some apply to only one.

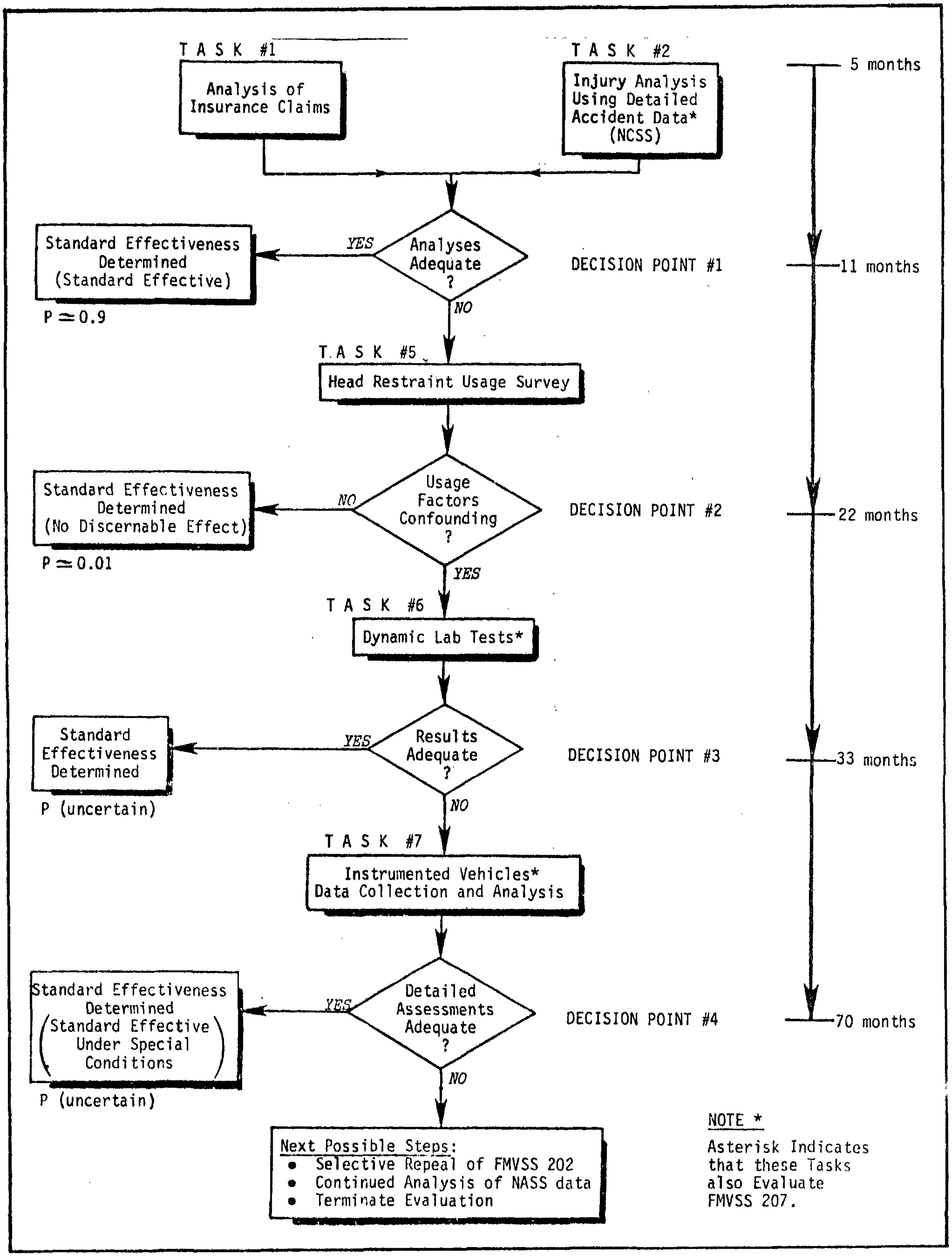


Figure 2-1. Flow chart for proposed evaluation of FMVSS 202: Head Restraints.

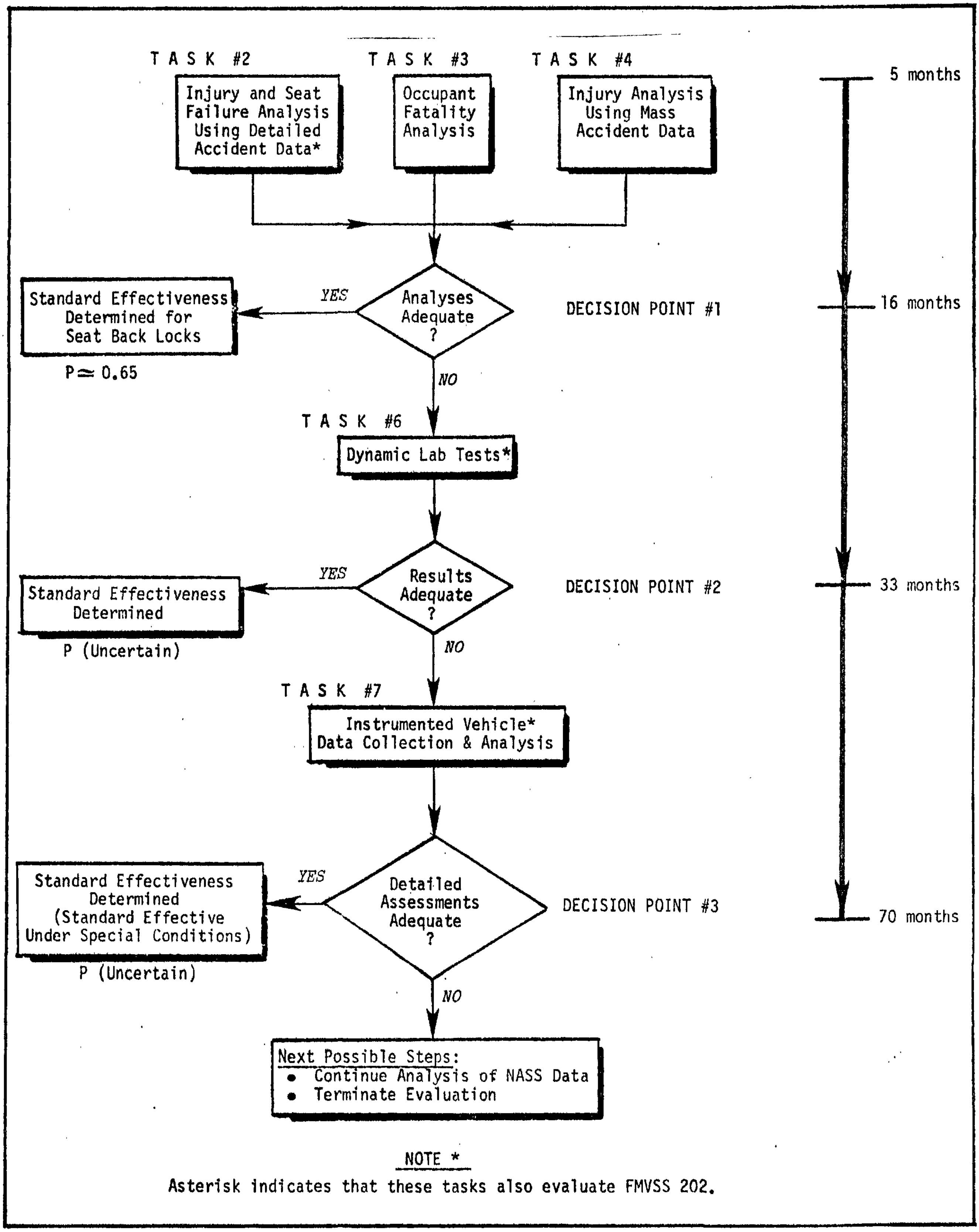


Figure 2-2. Flow chart for proposed evaluation of FMVSS 207: Seating Systems.

HEAD RESTRAINTS

Task #1: Analysis of Insurance Claims

This study is an updated and broadened version of a 1970 study which showed that head restraints significantly reduced the frequency of neck injury claims. This Task is a complementary study to Task #2 (Injury Analysis using Detailed Accident Data). It is important to do both of these Tasks early and together so that the results can reinforce one another.

Task #2: Injury Analysis Using Detailed Accident Data (NCSS)

This task will focus on determining the effectiveness of the head restraints through the analysis of detailed accident data. There is a problem in most accident data concerning neck injuries because of generally lower severity and unreporting. The problems of identifying neck injury and head restraint adjustment are the major constraints to sucessfully evaluating the effectiveness of the head restraints.

Decision Point #1

At the end of Month 11, NHTSA will review the results of Task #1 and Task #2 and decide whether the results are sufficiently definitive to terminate the evaluation and say that the effectiveness has been determined. CEM feels that there is a very high likelihood that the two studies taken together will show that the Standard is effective (though the effectiveness depends on the definition of injury). If the initial analyses are not successful it will be necessary to embark on a much more costly and time consuming effort to evaluate the effectiveness of head restraints. Although it is likely that all remaining tasks (#5,6 & 7) will have to be done, they are programmed sequentially to maximize the utilization of new information and provide controlled pace of research.

Task #5: Head Restraint Usage Survey

Given that the previous analyses did not reveal that head restraints were effective, or did not give as accurate an estimate of effectiveness as desired, it is then necessary to learn more about head restraints. The first task for this is Task #5 (Head Restraint Usage Survey). The question which will be addressed concerns mispositioning of head restraint, the frequency, degree and type.

Decision Point #2

At the end of Month 22, NHTSA will review the results of the above tasks to determine whether mispositioning/misusage of head restraints is the probable reason for failing to find an effect of the Standard. The most likely result will be that there is considerable misusage but that there still is some effect of head restraints. In order to gain more knowledge on the effectiveness given different types of positioning of head restraint vis-a-vis the occupant head, the next Task will be required.

Task #6: Dynamic Laboratory Tests

The Dynamic Laboratory Tests will provide results for the evaluation of both FMVSS 202 and 207. Most of the tests will evaluate head restraint and seating systems simultaneously. If FMVSS 202 or 207 was satisfactorily evaluated by this point, this task could be scaled back somewhat. However, the interaction between head restraint and seating system would still be important to examine even in a somewhat reduced set of laboratory tests.

This task will provide detailed information on how different head restraint systems react in controlled dynamic sled tests in which the angle and severity are varied.

Decision Point #3

At the end of Month 33, NHTSA will review the results of the Dynamic Lab Tests to determine (a) if reanalysis of previous data is warranted, i.e., if special circumstances indicate higher effectiveness and (b) what instrumentation and data collection is needed for Task #7 (Instrumented Vehicles Data Collection and Analysis). If the dynamic tests reveal particular information which leads to satisfactorily determining the effectiveness of head restraints, one will not have to procede with the expensive instrumented vehicle program (Task #7). Therefore considerable time is put in the evaluation program work plan (See Section 5) for review and revaluation.

Task #7: Instrumented Vehicles Data Collection and Analysis*

Given that all the previous analyses have been unable to satisfactorily determine the effectiveness of the head restraints, the conclusion is that the only way to establish the effectiveness is to take actual measurements of accelerations and impact forces of a large sample of vehicles in crashes. The seat and head restraint instrumentation would have been developed in the previous task; the crash recorder instrumentation would be provided by the NHTSA Crash Recorder Program; the data collection would be carried out by NASS teams; therefore, the reliability, accuracy and detail of this information is potentially very high. Such a study will also be very expensive and time consuming; CEM estimates over $700 thousand and two and one-half years.

* Results of this task also help evaluate seating systems.

Decision Point #4

It is highly unlikely that the results of all the previous analyses will have not adequately determined the effectiveness of the head restraints by the end of Month 70. However, CEM is uncertain as whether the later task will be sufficient to evaluate the Standard given earlier analyses fail. To a great extent the likelihood of success in the later analyses depends on the reasons for failure in the earlier analyses.

Next Possible Steps

Given the unlikely event that all previous analyses (and potential reanalyses) have failed to determine the effectiveness of head restraints there are several possible steps which might be taken next. NHTSA might decide to selective repeal (or modify) the head restraint Standard requirements. If no effect was shown, and no difference found between types of head restraints, the Standard might be dropped for some vehicles selectively. If some types of head restraints showed more promise then others, the Standard might be modified to require this type. NHTSA could also decide to use NASS data to analyze neck injuries on a continuing basis. Finally, NHTSA could decide to terminate the evaluation program.

SEATING SYSTEMS

Task #2: Injury and Seat Failure Analysis Using Detailed Accident Data

The purpose of this Task is to analyze the incidence of occupant injury and seat failure as a function of accident type, vehicle occupancy, seat type and other relevant variables. Detailed accident data from MDAI and NCSS will be used in both clinical and statistical analyses.

Task #3: Occupant Fatality Analysis

This Task is designed to study the fatality rate of front and rear seat occupants using FARS data. An important aspect of the analysis is to investigate the possibility that the introduction of the self-locking device for folding front seat backs on 2-door cars may increase the possibility of a back seat occupant being trapped in an emergency situation.

Task #4: Injury Analysis Using Mass Accident Data

The mass accident data sources including the HSRI data files, Texas, North Carolina and New York State will be analyzed to determine if any effects of the Standard on injury avoidance can be determined. Essentially, the analysis is investigating whether the injury rate in 2-door cars changes as a result of the requirement of the self-locking device for folding seats while no similar change is found in 4-door cars.

Decision Point #1

At the end of Month 16, NHTSA would have to make a decision based on the results of Tasks 2, 3 and 4. It is estimated that the probability of adequately evaluating FMVSS 207 with regard to seat back locks using FARS data, mass and detailed accident data is better than half ($p \simeq 0.65$). The primary effect of the Standard that is expected to be detected is the requirement for self-locking devices for folding seats. If NHTSA determines that the analyses were not adequate, laboratory testing is required to examine the performance of seating systems under controlled conditions.

Task #6: Dynamic Tests

This Task is designed to conduct dynamic tests of selected seating systems, both Pre-Standard and Post-Standard, to evaluate the effects of the Standard on seating system strength. Tests will be conducted with a variety of seating systmes, acceleration exposures, seating arrangements, seat track adjustment, etc.

Decision Point #2

At the end of Month 33, NHTSA will be faced with the decision as to whether the dynamic tests have produced additional results that allow the determination that the Standard is effective. The dynamic tests could provide results that might permit a re-evaluation or re-analysis of the information derived from Tasks 2, 3 and 4. The probabilities of determining the Standard effectiveness at this point are quite uncertain and are not estimated. If NHTSA determines that the analyses are still not adequate, new data collection is the next logical approach for attempting to evaluate the Standard.

Task #7: Instrumented Vehicle Data Collection and Analysis

This Task is directed toward improving the understanding of the performance of seating systems in real world crashes. The program would begin in Month 40 and last two and one-half years. The costing of $730,000 assumes that the costs of basic crash recorders for 50,000 vehicles are provided under another NHTSA program and that the data would be collected within the NASS data collection effort. It should be noted that costing reflects data collection and analysis to evaluate both FMVSS 202 and FMVSS 207.

Decision Point #3

At the end of Month 70, NHTSA will decide whether the data collected under the instrumented vehicle program permit the determination of FMVSS 207 effectiveness. The probability of this occurring at the third Decision Point is quite uncertain and is not estimated at this time.

Next Possible Steps

If the effectiveness of FMVSS 207 has not been determined, it is suggested that the two possible additional courses of action are to continue the analysis of instrumented vehicle data as more becomes available, or to terminate the evaluation.

3.0 EVALUATION PLAN

3.1 Injury Analysis Using Mass Accident Data

3.1.1 Introduction

The purpose of this section is to establish what information regarding the effectiveness of seat back locks is available in the mass accident data files. We expect the mass accident data to provide useful information with respect to FMVSS 207 only.* This is because this data base does not provide sufficient detail on injuries for evaluation of head restraints. The typical minor injury recorded by police in an accident investigation of a rear end collision corresponds to whiplash. But this complaint is noted at the scene of the accident and is not recorded as neck injury which emerges later. Such injuries are most crucial to an evaluation of the effectiveness of head restraints and an analysis of such injury must be deferred to the more detailed data bases discussed in Section 3.2.

Although the suggested approach to evaluating FMVSS 207 is certainly speculative, it can probably be justified because of the availability of the data and the relatively modest cost of conducting the study. The proposed analysis will investigate whether there are any differences in Pre-Standard and Post-Standard cars, with relation to the injury frequency of the driver and front seat passenger.

The basic question to be investigated is the following: in front-end collisions, are there any differences in driver and front seat passenger injuries between 2-door and 4-door cars in Pre-Standard and Post-Standard model years? If the self-locking restraining device for folding seat backs is an important deterrent to injury, injury rates may differ between Pre-Standard and Post-Standard model years in 2-door cars. The same effect would not be seen in 4-door cars, where fixed-back seats predominate. The analysis will have to consider the effects of seat belt use in Pre-Standard cars; their use may increase injuries.

It is recognized that a variety of other effects can influence the above suggested analysis. To eliminate some of these effects, it is suggested that the analyses be conducted by matching selected make/models as follows:

- Similar GM models - MY66 and earlier *vs.* MY67 and later.
- Similar AMC/Ford/Chrysler models - MY67 and earlier *vs.* MY68 and later.
- For similar models in MY67 - GM *vs.* AMC/Ford/Chrysler.

Driver (or occupant) age and sex must be considered. Other information such as seat belt usage, driver height, and car weight would be desirable, but some of these variables cannot be obtained reliably from mass accident samples.

*Mass accident data have some potential for evaluating FMVSS 202; however the other approaches detailed in this report will give better estimates of effectiveness.

3.1.2 Data Required

The crudeness of the mass accident data limits the number of variables that can be studied and hence the number of "crash circumstances" which can be controlled. Nonetheless, the data bases are quite large, so that sample size consideration will not likely be a problem. The variables required are:

Vehicle Data	Driver Data	Accident Type
Make	Age	Front End
Model	Sex	Rear End
2-door, 4-door		Side
Model Year		

Any other vehicle or driver data, and even more important, any data concerning vehicle occupancy configuration at the time of the accident (which may be available over a substantial subset of the data base) will be worth obtaining.

3.1.3 Data Acquisition

It is not likely to prove worthwhile attempting to access all of the mass accident data bases. The most promising sources are the HSRI data files, as well as the complete Texas, North Carolina and New York accident files for 1968-1971. The set of variables listed in Section 3.1.2 are available in these files.

3.1.4 Preliminary Results

No preliminary analysis of such injury rates as described in Section 3.1.1 exists at present. Hence, the most useful preliminary data which might be acquired would be concerned with relative accident exposure of vehicle classes (i.e., a particular make and model year in a particular accident year). The exposure would be reflected in a comparison of the relative numbers of vehicles in the given vehicle classes which are driven in a given year. These numbers may be estimated from data on the number of vehicles originally manufactured, adjusted by data on annual attrition rate. However, accident exposure is not an important issue in the analysis of Section 3.1.5. It is an issue in Section 3.2 and even more so in Section 3.3, where it becomes a crucial factor.

3.1.5 Analysis

The most effective statistical analysis that can be performed with mass accident data will be a fairly gross seat back effectiveness study, using a log-linear model approach. More specifically, after controlling for appropriate variables within the mass accident samples, and also matching selected makes/models as indicated already (i.e., similar GM models--MY66 and earlier *versus* MY67 and later, etc.), one will ultimately arrive at the following subset of observed numbers.

N_{2B} = No. of Pre-Standard 2-door cars involved in front end collisions.

N_{4B} = No. of Pre-Standard 4-door cars involved in front end collisions.

N_{2A} = No. of Post-Standard 2-door cars involved in front end collisions.

N_{4A} = No. of Post-Standard 4-door cars involved in front end collisions.

Similarly, there is:

M_{2B} = No. of Pre-Standard 2-door cars involved in front end collisions and injury occurred to driver or front seat passenger.

M_{4B} = No. of Pre-Standard 4-door cars involved in front end collisions and injury occurred to driver or front seat passenger.

M_{2A} = No. of Post-Standard 2-door cars involved in front end collisions and injury occurred to driver or front seat passenger.

M_{4A} = No. of Post-Standard 4-door cars involved in front end collisions and injury occurred to driver or front seat passenger.

One may distribute these numbers in two sets of 2 x 2 tables, as shown below.

Table A-1

Two-Door Cars

	Injuries	None	
Pre-Stand.	M_{2B}	$N_{2B}-M_{2B}$	N_{2B}
Post-Stand.	M_{2A}	$N_{2A}-M_{2A}$	N_{2A}
	$M_{2B}+M_{2A}$	$N_{2A}+N_{2B}$ $-(M_{2A}+M_{2B})$	$N_{2B}+N_{2A}$

Table B-1

Four-Door Cars

	Injuries	None	
Pre-Stand.	M_{4B}	$N_{4B}-M_{4B}$	N_{4B}
Post-Stand.	M_{4A}	$N_{4A}-M_{4A}$	N_{4A}
	$M_{4B}+M_{4A}$	$N_{4B}+N_{4A}$ $-(M_{4B}+M_{4A})$	$N_{4B}+N_{4A}$

Table A-2

Pre-Standard

	Injuries	None	
2-Door	M_{2B}	$N_{2B}-M_{2B}$	N_{2B}
4-Door	M_{4B}	$N_{4B}-M_{4B}$	N_{4B}
	$M_{2B}+M_{4B}$	$N_{2B}+N_{4B}$ $-(M_{2B}+M_{4B})$	

Table B-2

Post-Standard

	Injuries	None	
2-Door	M_{2A}	$N_{2A}-M_{2A}$	N_{2A}
4-Door	M_{4A}	$N_{4A}-M_{4A}$	N_{4A}
	$M_{2A}+M_{4A}$	$N_{2A}+N_{4A}$ $-(M_{2A}+M_{4A})$	

Consider the first set, Tables A-1 and B-1. The first thought is that in Table B-1, since no change occurred from Pre- to Post-Standard 4-door vehicles, a chi-squared test of homogeneity might be accepted for this table. However, given N_{4B} and N_{4A}, the hypothesis of homogeneity is equivalent to the hypothesis of independence. But independence of injury incidence and age may be suspect--i.e., there is evidence that with increasing vehicle age the probability of occupant injury in an accident increases. The degree of dependence in the table can be measured by the probability odds cross ratio; the closer this ratio is to one, the closer the table is to independence. For Table B-1 the underlying odds cross-ratio can be estimated by:

$$\hat{\lambda}_2 = \frac{M_{4B}\ (N_{4A} - M_{4A})}{M_{4A}\ (N_{4B} - M_{4B})}\ .$$

This quantity is closely connected with the chi-squared test for independence, which in two-by-two tables is based on the appropriately standardized determinant:

$$M_{4B}(N_{4A} - M_{4A}) - M_{4A}(N_{4B} - M_{4B}),$$

whose terms are the numerator and denominator of $\hat{\lambda}_2$. If homogeneity is of interest, one can test for it. What is of interest is the degree of dependence in Table A-1, as measured by its underlying odds ratio, which is estimated by:

$$\hat{\lambda}_1 = \frac{M_{2B}\ (N_{2A} - M_{2A})}{M_{2A}\ (N_{2B} - M_{2B})}.$$

In particular, if the degree of dependence in the two tables A-1 and B-1 is not the same, the implication is that the relationship between age of vehicle and chance of injury is different in these tables. The equality of the amount of dependence in the two tables can be examined using the ratio $\hat{\lambda}_1/\hat{\lambda}_2$. If this ratio is close to one, the dependence is the same. The precise analysis is given later in this section. This difference can crudely be attributed to the Standard--i.e., seat back locks on two-door vehicles are having an effect on injury rate in accidents. An alternative to studying these ratios is to attempt to control for age effects by viewing the set of one-year old vehicles involved in accidents, the set of two-year old vehicles involved in accidents, etc. Within these sets, one may develop tables comparable to Tables A-1 and B-1 and proceed as above. This alternative may not prove effective if the resulting tables have too few entries to run reliable chi-squared tests.

Consider now Tables A-2 and B-2. Within each table, age effects are ignored. A test of homogeneity in Table B-2, if accepted, asserts that injury rate does not change between two-door and four-door Post-Standard vehicles. A similar test on Table A-2, if rejected, would suggest that the seat back locks imposed by the Standard are forcing the injury rate for two-door vehicles to be essentially that of four-door vehicles--i.e., the Standard is having an effect. Again, estimates of the probability odds ratio for each table should be helpful. They are:

$$\hat{\lambda}_3 = \frac{M_{2B}\ (N_{4B} - M_{4B})}{M_{4B}\ (N_{2B} - M_{2B})}$$

$$\hat{\lambda}_4 = \frac{M_{2A}\ (N_{4A} - M_{4A})}{M_{4A}\ (N_{2A} - M_{2A})}$$

If homogeneity is accepted in Table B-2, $\hat{\lambda}_4$ will be close to one, while if it isn't accepted in Table A-2, $\hat{\lambda}_3$ will be significantly different from one. As above, homogeneity is not really relevant. The main interest is the amount of dependence, and whether it is the same in both tables. This equality is evaluated *via* the ratio $\hat{\lambda}_3/\hat{\lambda}_4$. If it differs significantly from one, this suggests that the dependence between probability of injury and number of doors differs between the tables and this difference may be crudely attributed to the Standard.

Lastly, notice that:

$$\hat{\lambda}_1/\hat{\lambda}_2 = \hat{\lambda}_3/\hat{\lambda}_4$$

That is, in terms of the ratios, the analyses for Tables A-1 and B-1 and for Tables A-2 and B-2 are equivalent.

If a more detailed injury frequency variable is to be considered, say by K, A, B, C, O, which is available in the mass accident file, the pattern of the preceding discussion may still be followed. This just necessitates comparing a collection of ratio estimates for each table instead of just one table, and making corresponding comparisons. Given the fact that seat failure is usually associated with severe injury, the injury criteria might be grouped into K + A and Other.

In order to be a bit more precise about the analysis, first note that a simple addition of 1/2 to each cell in the body of the table is a convenient way of smoothing cell frequencies, particularly in small data samples. There are more sophisticated smoothing procedures, but they should not be needed for this simple 2 x 2 analysis.

Redefining $\hat{\lambda}_1,\ldots,\hat{\lambda}_4$ in terms of the smoothed counts, note that the estimates of their respective odds ratios, λ_i (and thus $\log \lambda_i$), estimates the corresponding log odds ratio. In particular, if the entries in the four cells of the i^{th} table are denoted by i

a_i	b_i
c_i	d_i

$n_i=a_i+b_i+c_i+d_i$

then

$$\log \hat{\lambda}_i = \log \frac{(a_i+1/2)(d_i+1/2)}{(b_i+1/2)(c_i+1/2)}$$

and

$$E \log (\hat{\lambda}_i) = \log (\lambda_i) + \text{terms of order of } (n_i^{-2}).$$

Let

$$s_i = \frac{1}{a_i+\frac{1}{2}} + \frac{1}{b_i+\frac{1}{2}} + \frac{1}{c_i+\frac{1}{2}} + \frac{1}{d_i+\frac{1}{2}}$$

Then

$$E\{s_i\} = \text{var}(\log \hat{\lambda}_i) + \text{terms of order of } (n_i^{-3}).$$

under either Poisson or Multinomial sampling. Thus, $\log(\hat{\lambda}_1/\hat{\lambda}_2)$ has variance $\text{var}(\log \hat{\lambda}_1) + \text{var}(\log \hat{\lambda}_2)$, which is approximately

$$\tau = s_1 + s_2.$$

Under the null hypothesis of no high order interaction, (i.e., $\lambda_1=\lambda_2$) $\log(\lambda_1/\lambda_2) = 0$ so that

$$\frac{\log(\hat{\lambda}_1/\hat{\lambda}_2)}{\sqrt{\tau}}$$

is approximately distributed as N(0,1). If $n_1=n_2=n$ is assumed, the sample size needed to detect a difference $\lambda_1/\lambda_2 = k$ at level α with power β at this alternative is:

$$n = \left[Z_{1-\alpha/2} + Z_{(1+\beta)/2} \right]^2 \frac{2}{(\log k)^2} \ .$$

If the $n_1 \neq n_2$, it is conservative to take the smaller value to be at least n. Similar remarks hold for the analysis of λ_3 and λ_4.

One final remark should be made. Tables A-1 and B-1 together may be viewed as a 2 x 2 x 2 contingency table, as may Tables A-2 and B-2. This suggests that one can fit a three factor loglinear model to each pair and examine the fit of reduced hierarchical models without a second order interaction between "Pre - Post" and "Injury - No Injury" for Tables A-1, B-1, or without a second order interaction between "2-door - 4-door" and "Injury - No Injury" for Tables A-2, B-2 (and thus without third order interaction in either case). The log goodness of fit statistic for the reduced model(s) tested against a chi-square distribution with one degree of freedom measures the fit of the reduced model(s).

A bad fit indicates the interactions are significantly different from zero, i.e., incidence of injury will depend on whether the vehicle is "Pre" or "Post" Standard in Tables A-1, B-1 or on whether the vehicle is "2-door" or "4-door" in Tables A-2, B-2.

A moment's reflection on all of the previous analyses reveals that the 4-door vehicles "Pre" and "Post" are being employed as a "control" against 2-door vehicles "Pre" and "Post." This thought suggests looking into other possible control groups with the same intent. Suppose in place of

{ 4-door vehicles Pre-Standard in <u>front</u> end collisions, and
4-door vehicles Post-Standard in <u>front</u> end collisions

we consider

{ 2-door vehicles Pre-Standard in <u>rear</u> end collisions
2-door vehicles Post-Standard in <u>rear</u> end collisions

and again develop tables analogous to A-1, B-1 and A-2, B-2. Suppose that seat back locks are expected to be effective primarily in front end accidents. Then for the resultant table corresponding to B-1, a chi-square test of homogeneity might be accepted, while such a test on the resultant table corresponding to A-1 will not. Or if necessary, an examination of whether or not the corresponding ratio λ_1/λ_2 differs significantly from one might be considered. Detecting a difference in dependence of injury rate and accident type may crudely be attributed to the introduction of seat back locks.

The effectiveness of the Standard which this analysis might imply is more tentative than that using 4-door vehicles as the control group. For the former, "accident type" is used as a surrogate for "seat back lock effect" while this is not so in the latter. Nevertheless, confirmatory findings in both analyses would provide strong support for the presence of seat back lock effects.

The analysis described above can, with minor changes of detail mainly concerned with smoothing the frequencies, be incorporated into a full loglinear analysis (see Appendix B). GM's early compliance with some of the provisions of the Standard can then be included in one big analysis, rather than being examined separately.

Major steps required to analyze injuries using mass accident data are summarized in Figure 3-1.

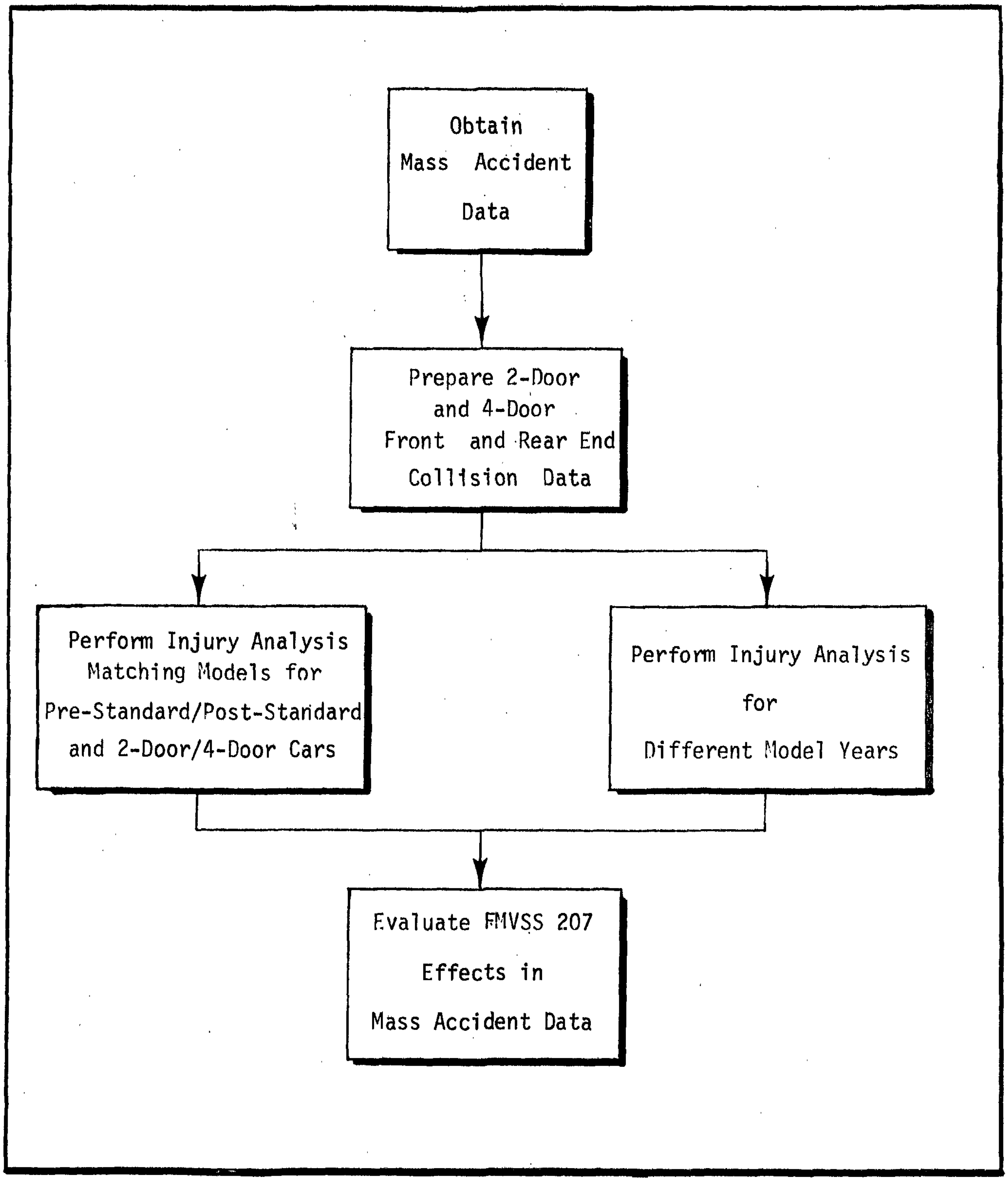


Figure 3-1. Injury Analysis Using Mass Accident Data.

3.2 Injury and Seat Failure Analysis Using Detailed Data

3.2.1 Introduction

The intent of this section is to establish what information regarding the effectiveness of head restraints and seat back locks is available in the detailed accident data files.

The rather crude analysis we would initially attempt is a comparison of injury rates with respect to the following:

(a) Presence or absence of head restraints

(b) Type of head restraint

(c) Presence or absence of seat back locks

(d) Seat back failure or not.

If sufficient data are available, these comparisons would be made under a variety of controls. In particular, rear end and front end collisions must be separated.

A more specific injury analysis for head restraints would involve a study of neck injuries according to the following:

- Type of collision
- Seating position,seat type, head restraint type, seat restraint
- Occupant injuries
- Occupant factors (age, sex, height/weight, etc.)
- Vehicle factors (model year, type, weight, impact speed, etc.)

Also, a study of rear end collision for occupant injury would be required, according to:

- Occupant height/weight, sex, age, etc.
- Head restraint type,seat type, seat restraint, seating position
- Vehicle factors (model year, type,weight, speed of impact, etc.)

The more detailed analysis for seat back locks would consider the effect of front end collisions on seat failure and on driver and occupant (sitting in front or in back) injury with more detailed seat classifications. The analysis of rear end accidents will be quite similar. However, because of the rearward forces exerted in rear end collisions, rear seat occupancy is a less critical question and need not be considered. Hence, the basic purpose of the analysis will be to examine the effects of the different seat types on injuries to front seat occupants. The seat classifications would include bucket seats, folding individual seat backs, folding bench seats, etc.

The specialized data bases provide the level of detail necessary to obtain observations on the type of variables that have been discussed. Unfortunately, these data bases consist in large part of information on Post-Standard (with respect to both FMVSS 202 and FMVSS 207) vehicles. Hence, while a comparison of Pre-Standard and Post-Standard model cars will be attempted, the primary statistical analysis will have to deal with Post-Standard 2-door and 4-door vehicles. For example, studying such variables enables only a comparison of self-locking *vs.* rigid seat backs as opposed to the primary intent of FMVSS 207 to improve the performance of 2-door vehicle seats, from non-locking to self-locking seat backs *via* the imposition of this Standard. That is, if Post-Standard 2-door vehicles perform as well as Post-Standard 4-door vehicles under sufficient control of other variables, we would not know if they performed equivalently before the Standard. And if Post-Standard 2-door vehicles did not perform as well as Post-Standard 4-door vehicles, this does not mean that they are still not better than Pre-Standard 2-door vehicles. Hence, the conclusions of such an analysis are only relative, not absolute.

With respect to head restraints, neck injuries are, of course, the primary injury type to be studied. However, there are inherent difficulties in discussing such injuries. The nature of neck injury, commonly described as whiplash, makes it difficult to establish an injury rate. Symptoms of injury resulting from rear end impacts are often delayed hours or days. Also, objective clinical evidence of injury does not exist in a typical case [1].

The neck injury is generated in an accident when there is hyperflexion of the neck. The normal ranges of flexion of the neck are:

- Forward: 61-93 degrees
- Backward: 54-67 degrees
- Sidewise: 41 degrees
- Rotation: 73-76 degrees [1,2].

However, these ranges of motion are based on "normal" subjects, mostly males between 18 and 40 years old. There are major differences in individuals due to sex*, age, body build, and cervical spine arthritis. Other factors which affect the incidence of neck injury are the seat position (e.g., left-front); position at the moment of impact (e.g., turned, leaning, etc.); seat and head restraint type; vehicle cruch characteristics; and whether the seat back fails. Seat back failure and vehicle crush both absorb energy and reduce the acceleration forces on the occupant. The neck is susceptible to injury in rear end collisions when

*Women seem to have a greater incidence of whiplash injuries, despite the smaller stature and greater flexibility. This may occur because more women appear to sit forward in the seat while driving (to achieve better visibility), thus traveling farther back and achieving higher rearward velocities, when their car is struck from behind.

there is no head restraint present. The head is not blocked anatomically in its rearward displacement as it is to the front by the chest (or steering wheel). The various physical trauma which can be experienced include:

- Muscle tears and separations of ligaments.
- Cerebral disturbances due to bruising from accelerations; as well as causing pain, these injuries can affect many sensory functions.
- Spinal injuries to the disk or bone.

However, in most cases the injury is not immediately perceivable, and, indeed, its presence may not be noted for several hours. Entrance of information on neck injury in police reports will depend on many factors such as public awareness of the problem,individual sensitivity and knowledge of potential problems,etc. There is the possibility that certain socioeconomic groups may ignore medical treatment for such minor, non-visible injury. Therefore, even though NASS specified driver interviews as a source of data on injuries and other accident information, collection of data on neck injuries is a difficult problem.

A further complication to the analysis of neck injuries arises because occupants in motor vehicles do not necessarily sit perfectly positioned in front of the head restraints. Since head restraints are not hit exactly in a longitudinal direction, there is a need to examine the performance of different types of head restraints (with different seat types). Those head restraints (and seats) which hold the occupant and resist the rotation (as well as flexion) of the neck will presumably exhibit fewer neck injury complaints. The individual bucket seat with an extended seat back should have greater effectiveness than the bench seat with an adjustable head restraint mounted on a single pillar. One problem in the analysis will be that the individual bucket seat/high seat back configuration occurs most frequently on smaller compact and subcompact vehicles, while the bench seat/adjustable head restraint has been the configuration on older and/or larger vehicles. The different types of vehicles and types of drivers will have to be considered in the effectiveness comparisons.

With respect to seat back locks a solely dichotomous variable recording presence or absence of injury will be less than satisfactory. One would likely prefer injury level categorized by AIS number with possible further classification by area of bodily injury. This would enable the study of reduction of injury severity rather than just reduction of injury. However, given the difficulties in establishing effects in multinomial distributions, various two-way comparisons should be attempted.

3.2.2 Data Requirements

At least the following variables will be required for the proposed analysis:

- Injury - severity and location on body.
- Type of Collision - front, rear
- Seating Position, Seat Type, Seating System Failure.
- Head Restraint Type, Usage.
- Lap/Shoulder Belt Usage.
- Number and Distribution of Vehicle Occupants.
- Vehicle Factors (model year, type, weight, impact speed, or ΔV, etc.).
- Occupant Factors (height, weight, sex, age, etc.).

Many of these variables are available in NCSS.

3.2.3 Data Acquisition

The existing detailed data files, especially MDAI, RSEP, and NCSS will be utilized for the initial analysis. Analysis should be performed on each data base separately because of the differing procedures used to collect the data and the differing variables contained therein. Newly collected NASS data will be needed if the initial analysis is unsatisfactory, i.e., if it does not provide significant or consistent results. Synthesizing the various analyses will enable a determination of whether existing sample sizes are large enough or whether additional data collection is necessary.

3.2.4 Preliminary Analysis

Some preliminary evidence regarding the effectiveness of head restraints exists. There were approximately 3.4 million rear end collisions in the United States in 1975 out of 12.9 million two-vehicle collisions--26 percent [3]. These rear end collisions accounted for 12 percent of the fatalities in two-vehicle collisions. They also account for approximately 85 percent of the neck injuries due to motor vehicle accidents [4].

Various estimates of the incidence of injury are reported by States *et al.* [1]. Estimates ranged from 24 to 33 percent of rear end accidents, with one low estimate of 15 percent when the determination of injury was restricted to 24 hours after the accident. States estimated that head restraints reduced whiplash frequency by 14 percent [1]. This disappointing result is attributed partially to the failure of users to adjust their head restraint. In the multidisciplinary accident investigation files, about 15 percent of occupants recorded have some neck injuries [5]. The Restraint Systems Effectiveness Project reported between 5.7 and 1.3 percent injuries to the neck region among the first three injuries recorded for front seat occupants of mostly Post-Standard vehicles [6].

To date, there is no field evidence supporting the effectiveness or non-effectiveness of seat back locks.

3.2.5 Analysis

All of the crude injury data comparisons can be made using χ^2 tests of homogeneity. For example, consider the following simple 2 x 2 table for 2-door vehicles appropriately controlled for other variables.

		Driver or Front Passenger		
		Injury	No Injury	
Seat Back	Failure	a	b	n_1
	No Failure	c	d	n_2

With these data there is no need to adjust the row populations for accident exposure. Simple tests would at least reveal crash circumstances under which the incidence of injury is affected by seat back performance. Of course, such evidence does not establish causality in the given crash circumstance. It is recommended that the Yates continuity correction be employed when sample sizes in the tables are small, or better, that Fisher's exact hypergeometric test be used.

The same method of analysis is also appropriate for the following simple 2 x 2 table.

		Driver or Front Passenger		
		Injury	No Injury	
Striking Vehicle in Front End Accident	Post-Standard 2-door	a	b	n_1
	Post-Standard 4-door	c	d	n_2

This analysis readily provides sample sizes to establish a given difference in accident rate percentages.

Specifically, the sample size necessary to detect a difference in conditional injury probability p_1-p_2 at level α with specified probability of Type II error β (if $n_1=n_2=n$) is:

$$n = (Z_{1-\beta/2}+Z_{1-\alpha/2})^2 \frac{2}{(\theta_1-\theta_2)^2}$$ where z_δ is the δ^{th} percentile of the unit normal distribution and $\theta_1 = 2 \sin^{-1}\sqrt{p_1}$, $\theta_2 = 2 \sin^{-1}\sqrt{p_2}$.

Conservatively, then, we require the smaller of the two sample sizes to be at least n.

This approach may still be attempted with the more specific analyses. However, after immediately stratifying by front end and rear end accidents, a loglinear model approach or analysis of covariance (ANACOVA) approach is better.

The loglinear model approach would consider a multidimensional table with cells (i,j,k,...) having probability of occurrence p_{ijk}..., where for example i indicates injury classification (might be just "Yes," or "No" or more detailed by AIS), j indicates the front seat type, k indicates vehicle weight, etc. The quantities N_{ijk}... would represent the number observed in each cell. There would be interest in the effect of varying j, on "p_{ij} interactions", etc., all of which can be studied by means of a loglinear model analysis.

In addition to the above suggested statistical analyses, it may be desirable to conduct case-by-case clinical analyses of seat failure types and injuries to rear seat passengers using the NCSS and MDAI data bases. An attempt should be made to make rough overall estimates (national) of seating system failure using the NCSS data.

The analysis of injuries to rear seat passengers is proposed because adjustable head restraints have metal fixtures at the top of the seat that are small with sharp corners. In a front end collision a rear passenger could contact these parts, and be badly cut. These injuries need to be balanced against those that might have occurred had the rear passenger not been blocked by the restraint but had been thrown over the front seat. A clinical case analysis of injured rear seat passengers in the MDAI accidents is suggested, to find the kind of injuries caused by the head restraints, and to determine if remedial action is necessary in future versions of FMVSS 202.

A summary of the major steps to be taken in analyzing injuries and seat failure with detailed data is given in Figure 3-2.

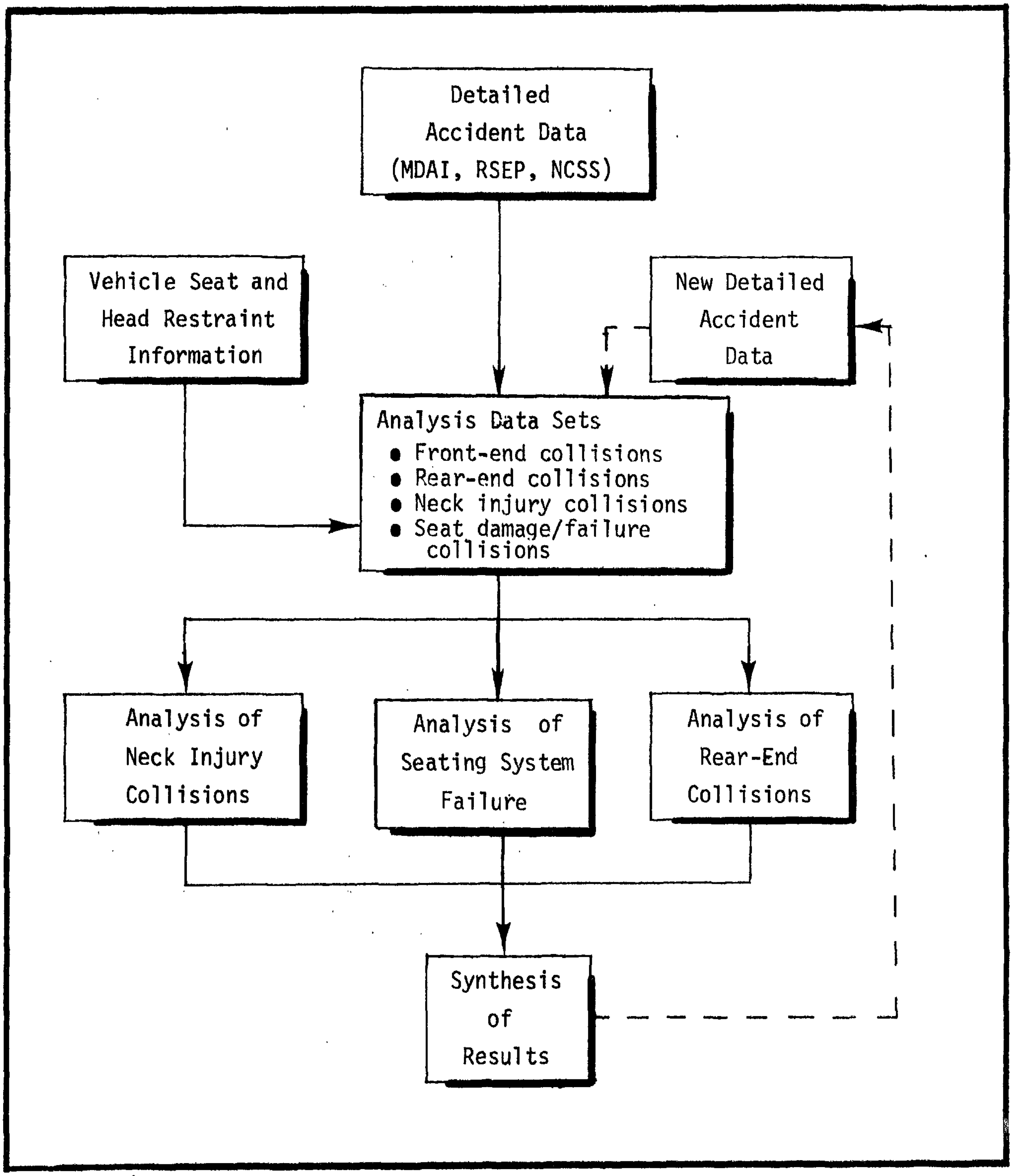


Figure 3-2. Injury and Seat Failure Analysis Using Detailed Data.

3.3 Occupant Fatality Analysis

3.3.1 Introduction

The intent of this analysis is to examine occupant data in motor vehicle accidents to reveal the effects of seat back locks imposed by FMVSS 207. The effort will discern relative fatality rate differences. Fatalities of rear seat and of front seat occupants will be examined relative to the following:

(i) Respective 2-door and 4-door vehicle populations.
(ii) Respective 2-door and 4-door accident populations.
(iii) Respective 2-door and 4-door fatal accident populations.
(iv) Respective Pre- and Post-Standard vehicle populations.
(v) Respective Pre- and Post-Standard accident populations.
(vi) Respective Pre- and Post-Standard fatal accident populations.

This study will delineate changes in both the front and rear seat occupant fatality rates as it progresses from Pre-Standard to Post-Standard 2-door vehicles. On the other hand, such changes are not expected in going from Pre-Standard to Post-Standard 4-door vehicles.

The notion of "rate" as used above (and in all that follows) is clarified: It refers to the Poisson intensity parameter governing the arrival rate of occupant fatalities within the particular defined group (2-door,4-door, Pre-, Post-Standard, etc.). Comparisons of rates are therefore accomplished by conditional binomial tests as described in Section 3.3.4. It is crucial to recognize that in comparing counts of occupant fatalities from one group to another, one must adjust for the relative exposure of the different groups. Originally this approach was based on the hypothesis that the seat back locks might lead to increased rear seat fatalities due to trapping in the event of fire or explosion. The preliminary analysis of FARS data with regard to this issue did not support the hypothesis. However,a larger analysis of the FARS file seemed reasonable from a speculative point of view.

3.3.2 Data Requirements

Most of the data needed for this approach appears readily available. A small subset has already been obtained and analyzed by CEM. The preliminary results are given in Section 3.3.4. The total set of variables required is listed below. Each variable will consist of a categorical count. The variables are as follows:

(1) Number of 2-door vehicles manufactured by model year in a given accident year.
Number of 4-door vehicles manufactured by model year in a given accident year.

(2) Number of 2-door vehicles in accidents by model year by accident year.
Number of 4-door vehicles in accidents by model year by accident year.

(3) Number of 2-door vehicles in accidents with rear seat fatality by model year by accident year.
Number of 4-door vehicles in accidents with rear seat fatality by model year by accident year.

(4) Number of 2-door vehicles in accidents with front seat fatality by model year by accident year.
Number of 4-door vehicles in accidents with front seat fatality by model year by accident year.

(5) Number within each count in (3) and (4) in which the vehicle either caught fire or exploded.

If the data base is large enough, the counts in (3), (4), and (5) can perhaps be controlled for vehicle characteristics (size, weight) and/or driver characteristics (age, sex).

3.3.3 Data Acquisition

An adequate sampling of occupant fatality data is available through the FARS data file. Hence, the counts in (3), (4) and (5) may be readily drawn from an existing base. The data for (1) are available in, for example, *Ward's Automotive Yearbook* [7], and data for (2) are available in mass accident data bases in states such as New York, Texas, and North Carolina.

3.3.4 Preliminary Results

The tabulation of rear seat occupant fatalities given in Table 3-1 was drawn from the FARS data base. For FMVSS 207 model year 1967 data are deleted, because in this model year some vehicles were equipped with seat back locks (which likely met the Standard) where others were not. Further, all pre-1967 accident years are collapsed to one category and all post-1967 accident years to one category. The argument for this procedure is that in a preliminary analysis it is assumed that age effects do not play a significant role in the performance of seat back locks. Moreover, age effects certainly do not enter into the effectiveness of non-locking seat backs. The collapsed data are given in Table 3-2.

An initial analysis is made to see if the incidence of fire or explosion is important. The incidence rate of rear seat fatalities for 4-door vehicles where fire or explosion occurred is probably not affected by the Standard. For 2-door vehicles this probably will not be true. Rather, the Post-Standard 2-door vehicles may have a higher rate of fatality when fire or explosion occurred. By virtue of the presence of seat back lock, the rear seat occupant may be trapped and be unable to escape as easily as when there were no seat back locks.

The data in Table 3-3 are obtained by collapsing over the accident years 1975, 1976. They reveal that:

- The number of fire or explosion cases is small.
- The 4-door Pre-Standard vehicles differ at least as much as the 2-door Pre-Standard vehicles from the respective Post-Standard vehicles.

TABLE 3-1

REAR SEAT OCCUPANT FATALITIES

Model Year	1975 Accident Year						1976 Accident Year					
	2-Door			4-Door			2-Door			4-Door		
	Fire or Explosion	None	Total	Fire or Explosion	None	Total	Fire or Explosion	None	Total	Fire or Explosion	None	Total
1976	0	3	3	0	1	1	5	56	61	0	20	20
1975	2	28	30	1	12	13	6	50	56	3	18	21
1974	1	83	84	1	34	35	3	84	87	1	25	22
1973	7	103	110	1	49	50	2	84	86	1	48	49
1972	2	74	76	2	21	23	3	82	85	3	33	36
1971	2	77	79	0	48	48	10	67	77	2	30	32
1970	1	94	95	0	30	30	2	82	84	0	40	40
1969	1	90	91	0	44	44	7	70	77	0	40	40
1968	6	75	81	0	46	46	6	67	73	0	38	38
1967	3	59	62	0	52	52	0	48	48	1	32	33
1966	1	64	65	0	39	39	1	35	36	0	32	32
1965	2	47	49	0	30	30	0	30	30	0	20	20
1964	1	21	22	0	18	18	1	13	14	0	7	7
1963	1	12	13	0	29	29	0	10	10	0	11	11
1962	2	9	11	0	16	16	0	7	7	0	2	2
1961	0	5	5	0	4	4	0	4	4	0	6	6
1960	0	1	1	0	2	2	0	4	4	0	3	3
1959	0	1	1	0	1	1	0	2	2	0	0	0
1958	0	0	0	0	3	3	0	0	0	0	1	1
Pre-1958	0	4	4	0	3	3	0	0	0	0	2	2

However this crude analysis fails to adjust for the relative differences in accident exposure i.e. the relative accident rates of 2-door and 4-door Pre-Standard vehicles and 2-door and 4-door Post-Standard vehicles in a given accident year. We will return to this point shortly.

TABLE 3-2

COLLAPSED TABLE OF REAR SEAT OCCUPANT FATALITIES

	(a) 1975 Accident Year					
	2-Door Vehicle			4-Door Vehicle		
	Fire or Explosion	None	Total	Fire or Explosion	None	Total
Pre-Standard	7	164	171	0	145	145
Post-Standard	22	627	649	5	285	290
Total	29	791	820	5	430	435

	(b) 1976 Accident Year					
	2-Door Vehicle			4-Door Vehicle		
	Fire or Explosion	None	Total	Fire or Explosion	None	Total
Pre-Standard	3	104	107	3	84	87
Post-Standard	44	643	687	10	292	302
Total	47	747	794	13	376	389

TABLE 3-3

FIRE OR EXPLOSION DATA COLLAPSED OVER ACCIDENT YEAR

	2-Door Vehicle			4-Door Vehicle		
	Fire or Explosion	None	Total	Fire or Explosion	None	Total
Pre-Standard	10	268	278	3	229	232
Post-Standard	66	1270	1336	15	577	592
Total	76	1538	1614	18	806	824

Delete the fire or explosion data with the presumption that it may be confounding Pre- and Post-Standard effects. That is, removing the incidence of fire or explosion gives a clearer measure of rear seat occupant fatality rates. The resulting data may be displayed in three sets, each consisting of two 2 x 2 tables, as given in Table 3-4 below. An examination of the various cross-product ratios (0.514, 0.562 for the first pair, 1.617, 1.768 for the second pair and 0.913, 0.994 for the third pair) suggests that "Pre-" and "Post-" are not independent of accident year; (obviously so since the later accident year would have relatively more Post-Standard vehicles on the road); that "Pre-" and "Post-" are not independent of 2-door and 4-door vehicles (again apparent, since a higher percentage of 2-door vehicles was sold after 1967 than was sold prior to 1967); and that 2-door and 4-door vehicles are independent of accident year (quite plausible). These computations suggest that an effective hierarchical loglinear model can be fit to these data, which will delete the second order interaction between vehicle type and/or accident year and will also delete the third order interaction term.

Looking at the marginal row totals in the second set of tables in Table 3-4, it is tempting to argue that the number of Post-Standard 2-door vehicles where a rear occupant fatality occurred relative to the total number of 2-door vehicles where this occurred (1270 relative to 1538) is significantly larger than that for 4-door vehicles (577 relative to 806). Hence, one might infer the presence of a "trapping effect" due to the introduction of seat back locks.

Again, this conclusion is at present unwarranted since we have failed to adjust for accident exposure as mentioned earlier.

TABLE 3-4

VARIOUS 2 x 2 TABLES
COLLAPSED FROM TABLE 3-1

(1)	1975 Accident Year			1976 Accident Year		
	2-Door	4-Door	Total	2-Door	4-Door	Total
Pre-Standard	164	145	309	104	84	188
Post-Standard	627	185	912	643	292	935
Total	791	430	1221	747	376	1123
(2)	**2-Door Vehicles**			**4-Door Vehicles**		
	1975	1976	Total	1975	1976	Total
Pre-Standard	164	104	268	145	84	229
Post-Standard	627	643	1270	285	292	577
Total	791	747	1538	430	376	866
(3)	**Pre-Standard Vehicles**			**Post-Standard Vehicles**		
	1975	1976	Total	1975	1976	Total
Two Door	164	104	268	627	643	1270
Four Door	145	84	229	285	292	577
Total	309	188	497	912	935	1847

Now consider the question of how to adjust for accident exposure. Returning to Table 3-3, compare the counts 10 and 66 and the counts 3 and 15. Similarly, from Table 3-4, compare the counts 164 and 627 (for accident year 1975); the counts 104 and 643 (in accident year 1976) and the counts 268 and 1270 (for the year combined). In all cases, the necessary adjusting ratio of "Pre" to "Post-" is the number of Post-Standard 2-door accidents over the number of Pre-Standard 2-door accidents in a given accident year or combination of accident years. If these counts are available, this ratio r will be known exactly. At present, one can *crudely* estimate it using three simplifying assumptions. In each case the assumptions are for a given accident year or combination of years.

$$\text{A:}\quad \frac{\text{Number of Rear Seat Occupant Fatalities for Pre-Standard 4-Door Vehicles}}{\text{Number of Pre-Standard 4-Door Vehicle Accidents}} \approx \frac{\text{Number of Rear Seat Occupant Fatalities for Post-Standard 4-Door Vehicles}}{\text{Number of Post-Standard 4-Door Vehicle Accidents}}$$

$$\text{B:}\quad \frac{\text{Number of Pre-Standard 2-Door Vehicle Accidents}}{\text{Number of Pre-Standard 4-Door Vehicle Accidents}} \approx \frac{\text{Number of Pre-Standard 2-Door Vehicles Manufactured}}{\text{Number of Pre-Standard 4-Door Vehicles Manufactured}}$$

$$\text{C:}\quad \frac{\text{Number of Post-Standard 2-Door Vehicle Accidents}}{\text{Number of Post-Standard 4-Door Vehicle Accidents}} \approx \frac{\text{Number of Post-Standard 2-Door Vehicles Manufactured}}{\text{Number of Post-Standard 4-Door Vehicles Manufactured}}$$

Assumption A may be plausible; assumptions B and C are probably much less so. Given these assumptions, both numerators in A are known and from the data in [7], the ratio on the right hand side of B is approximately 1/4 while the ratio on the right hand side of C is approximately 7/13. Hence, manipulating these assumptions gives:

$$\hat{r}_{1975} = \frac{7/13}{1/4} \cdot \frac{285}{145} = 4.23$$

$$\hat{r}_{1976} = \frac{7/13}{1/4} \cdot \frac{292}{84} = 7.49$$

$$\hat{r}_{\text{combined}} = \frac{7/13}{1/4} \cdot \frac{577}{229} = 5.43$$

For the fire or explosion cases combined over 1975 and 1976, adjust 10 to 10 x 5.43 = 54.3 compared with 66. For the non-fire or explosion cases, adjust the 1975 figure of 164 to 164 x 4.23 = 693.7 compared with 627, the 1976 figure of 104 to 104 x 7.49 = 778.7 compared with 643 and the combined figure of 268 to 268 x 5.43 = 1454.4 compared with 1270. Formally conducting the conditioned Poisson tests of the original counts gives:

Case	x_1	x_2	$\hat{r}$	$\hat{p} = \frac{1}{\hat{r}+1}$	$(x_1+x_2)\hat{p}$	$\sqrt{(x_1+x_2)p(1-p)} = \hat{r}$
i	10	66	5.43	0.1555	11.8	3.1594
ii	164	627	4.23	0.1912	151.2	11.0601
iii	104	643	7.49	0.1178	88.0	8.8103
iv	268	1270	5.43	0.1555	239.2	14.2116

Cases (i) and (ii) are not all significant. Against one sided alternatives, cases (iii) and (iv) have descriptive levels 0.035 and 0.02 respectively.

Hence, the preliminary analysis suggests that:

(1) Seat back locks do not trap rear seat occupants in the case of fire or explosion.

(2) Pre-Standard 2-door vehicles seem to have a slightly higher rate of rear seat occupant fatalities in accidents than Post-Standard 2-door vehicles relative to 4-door cars even after controlling for the age effect. The analyses still has not controlled for effects of marketing differences through the years in 2-door and 4-door cars.

3.3.5 Data Analysis

The analysis proposed here consists of carrying out the same procedure as in the previous section, with the true r known. In fact, if the data permit, this analysis can be conducted for each of the Post-Standard years.

Another use to which the knowledge of the data in Item (2) of Section 3.3.2 may be put is adding a fourth dimension to the tabulations in Table 3-4. One can then observe the incidence of rear seat occupant fatality or not in a given 2-door vehicle or 4-door vehicle accident. This permits examination of changes in the probability of rear occupant fatalities for Pre-Standard and Post-Standard 2-door vehicles and for Pre-Standard and Post-Standard 4-door vehicles. The analysis will be much like that of the previous section. Surely these probabilities are of interest. However, use of the FARS data shows that a fatality has occurred and thus one cannot examine these probabilities.

The identical analysis of the previous section can be performed using the data in Item (4) of Section 3.3.2. Now consider whether or not there is a change in performance of Post-Standard 2-door vehicles relative to Pre-Standard 2-door vehicles with respect to front seat occupant fatalities. Presumably no change should occur for 4-door vehicles. Apply this analysis with $\hat{r}$ or r, if available. Also, add a fourth dimension to this analysis to again examine the probability of front seat occupant fatality.

In addition to the above outlined statistical analysis of FARS data, it may be desirable to conduct a case-by-case clinical analysis of selected occurrences of fire- or explosion-involved motor vehicle injuries or fatalities as these are available in detailed accident data or some mass accident data bases.

The major steps in the occupant fatality analysis of FARS data supplemented by the selective clinical analysis are summarized in Figure 3-3.

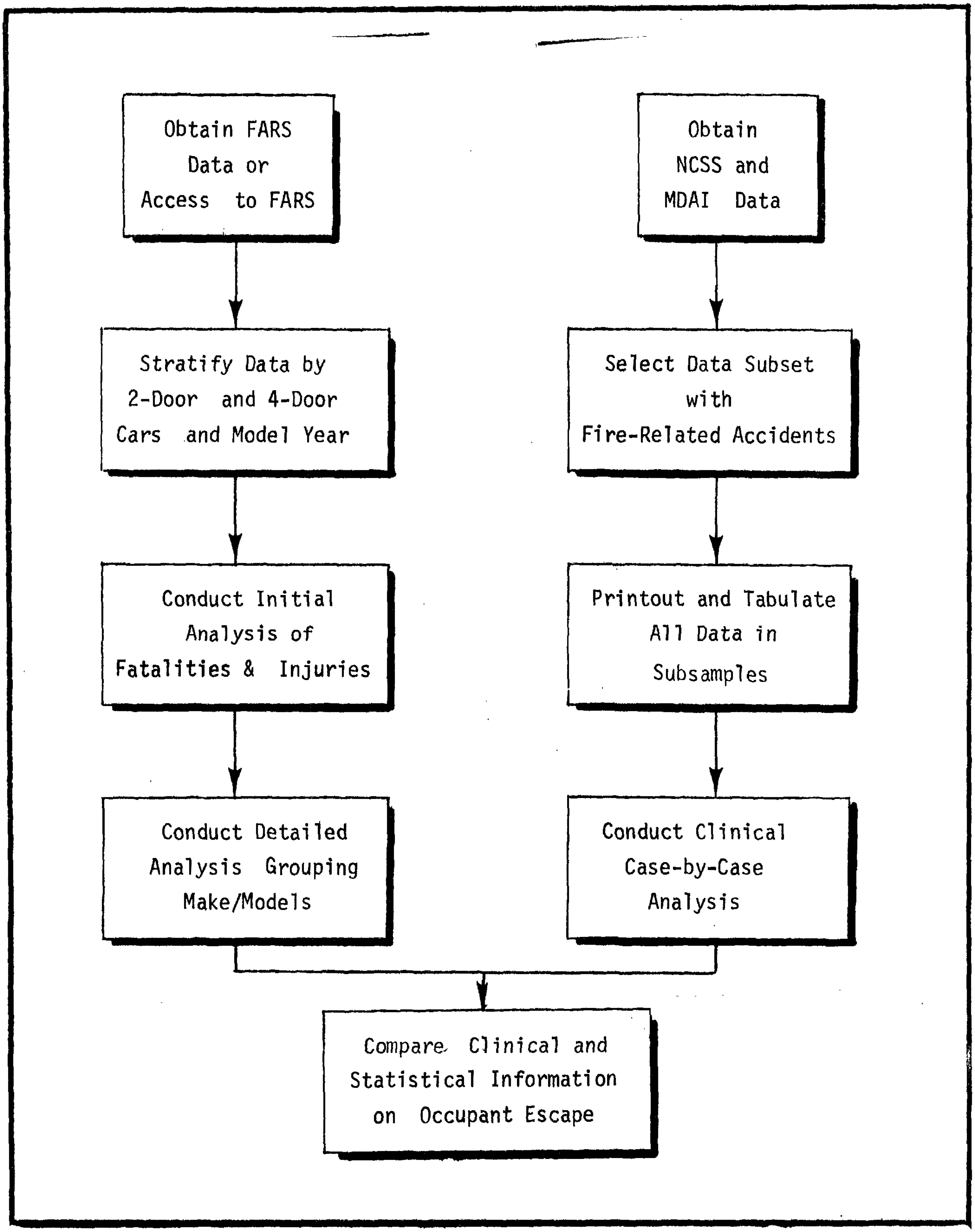


Figure 3-3. Occupant Fatality Analysis and Clinical Studies.

3.4 Analysis of Neck Injury Insurance Claims

3.4.1 Introduction

The purpose of this study is to estimate the reduction in the frequency of neck injuries by head restraints through analysis of neck injury insurance claims.

This study is based largely on an earlier study by O'Neill, *et al.* in 1971 [4] . Because neck injury symptoms are often not apparent at the time of the accident, the frequency of neck injury is understated in regular accident data. In this early study injury claims rather then settlements were used because of the length of time necessary to settle many claims. In this proposed study settled claims from about that same period (1969-1971) will be used in order to give some measure of severity of neck injury and its reduction.

3.4.2 Data Requirements

Because the data will be derived from insurance files rather then police accident files one will not have the same accident detail or quality of reporting. In general, data will be required on the driver, vehicles, accident type, injury severity. Specifically the variables are:

- Driver
  - Age
  - Sex
  - Height (if available)
  - Socioeconomic background (Speculative: different ethnic and income groups might report injury claims differently).

- Vehicle(s)

  (Information on the striking vehicle would be desirable because the relative weight of the vehicles influences injury severity of occupants in each vehicle).
  - Vehicle make, model and model year. (This will yield vehicle weight and standard head restraint type.)

- Accident type
  - Only claims from drivers struck from the rear are desired.

- Injury Severity
  - Settlement amount for neck injury claim by the driver.

3.4.3 Data Acquisition and Preparation

Data would be extracted from insurance claim files of first party coverage. The files should be from the 1969-1971 period as head restraints began to be installed in that period and secondly those cases will now be settled. Because of the extremely large number of accident claims a typical large insurer closes per year, one should sample from them.* The sampling rate can be relatively low given that approximately 3000 - 5000 cases should suffice. (The previous study had 6,333 accident claims and found a reduction that was significantly at $p < 0.001$). In order to get that number of cases, from 30,000 to 50,000 insurance claims need to be sampled. (Again, that rate is based on the previous O'Neill study.)

The cases would be sampled so that the time and location of the case was random. Each claim file selected would first be reviewed as to relevance, i.e., car struck in the rear. For those cases the required data would be recorded and subsequently keypunched.

3.4.4 Preliminary Results

O'Neill, *et al.*, found a reduction of 18 percent, from 29 percent to 24 percent, in the frequency of claimed neck injuries for drivers in cars with head restraints as standard equipment [4]. This study did not consider whether the head restraints were properly adjusted or not. However, part of the study was an observational survey which found the great majority of head restraints improperly positioned--up to 93 percent for male drivers in Washington, D.C.

Insurance data, especially of the early Seventies, are not totally representative of the driver population because of self selection on the part of the insured.

3.4.5 Analysis

The analysis is very straightforward. The rate of driver neck injury claim in rear end collisions would be compared for cars with head restraints as standard equipment and those without them. The analysis would be further refined by examining these rates for males and females separately and perhaps for those of different heights if possible. Dividing the data into different vehicle groups will provide other comparisons--for instance differences between vehicle manufacturers, or between different weight vehicles, or perhaps between categories of weight ratios or restraint types (fixed *vs.* adjustable). The analysis will be done initially for all neck injury claims and subsequently for more serious neck injury levels as determined by the settlement amount. Because there might be possible age effects, the rates for the same model year in different accident

*Travelers Insurance closed approximately 150,000 accident claims/year in the early Seventies.

years should be examined;however,there is little reason to suspect the effectiveness of the head restraints to decrease much with time. A summary of the major steps to be carried out in the analysis of neck injury insurance claims is given in Figure 3-4.

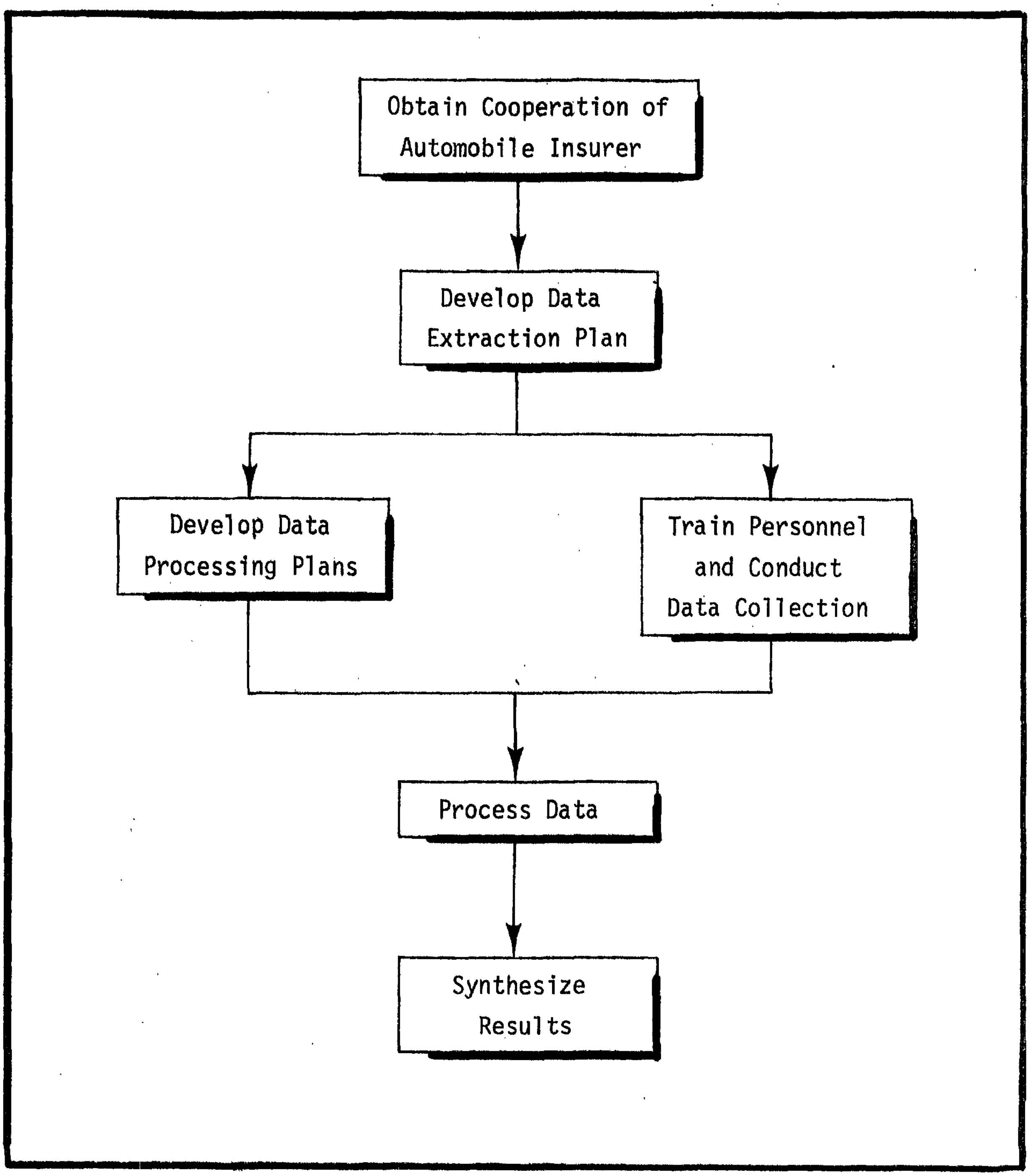


Figure 3-4. Analysis of Neck Injury Insurance Claims.

3.5 Head Restraint Usage Survey

3.5.1 Introduction

The purpose of this survey is to estimate the rate of improper usage of head restraint systems. This study need not be done if other analyses do indicate that adjustment of the head restraint is unimportant in injury severity.

As with all "voluntary" safety devices, the potential effectiveness of a device is limited by the rate of usage. In the earlier O'Neill study, a consistent sizable rate of improper usage was reported--84 percent for male drivers and 71 percent for females [4]. But misuse of head restraints is not limited to the fact the head restraint of the driver is unadjusted. Improper usage also applies to the occupants' positions in the seat. If drivers consistently lean against the car door, their head will not be in front of the head restraint.

Much data can be derived from existing or proposed data collection efforts about the adjustment of head restraints of those vehicles in accidents (NCSS and NASS). However, additional observations are desired in order to determine the rate of lateral mispositioning of the driver and other occupants and,additionally, as a check on the rate of unadjusted head restraints in accident vehicles.

3.5.2 Data Requirements

Observers would collect data on:

- Driver
  - Sex
  - Age (Young, middle aged, elderly)
- Vehicle
  - Type (2 door, 4 door, station wagon, etc.)
  - Size (Subcompact, compact, intermediate, full size, luxury, sports)
- Seat/head restraint type
  - Bench seat/adjustable restraints
  - Bucket seats/fixed restraints
  - Bucket seats/adjustable restraints
- Usage
  - Vertical position (proper/improper)
  - Lateral position (proper/improper)
- Ambient Conditions
  - Time
  - Location.

*People who drive (or ride in the front right seat) with their elbow resting on the bottom of the window frame are off-center,relative to the headrest in many cars,especially large cars of the 1968-1975 period.

3.5.3 Data Acquisition and Preparation

The data will be acquired in the NASS data collection areas from very short observations of traffic. In the O'Neill study, 5,000 observations were collected. This number should provide a sufficiently small error. Given the initial ten NASS sites and a rate of observation of 50 vehicles per hour, then the total number of hours of observing for each NASS team would be 10 hours.

The observations should be made by two-person teams in 20 one-half hour sessions at a variety of typical sites with relatively high density of traffic. The observations should be conducted at points where vehicles are moving relatively slowly, such as at intersections near highways or shopping centers or industrial parks, etc.

The data would be recorded on tape recorders for later transcription and key punching.

3.5.4 Preliminary Results

As stated earlier, the O'Neill Study found an overwhelming amount of improper usage of head restraint devices. The amount was greater for men than for women drivers (84 to 71 percent). This result seems largely due to the size of men and women. The O'Neill Study also found higher misusage in Washington, D.C. than in Los Angeles. Since the size of drivers is not significantly different in these two areas, it appears likely to be differences due to locale.

3.5.5 Analysis

The analysis of the results of the survey will be basic tabulations of the rate and kind of misusage for men and women by geographic location, type of highway, traffic density, time of day, vehicle type, etc. An analysis of head restraint adjustment should be run on both NCSS and existing NASS data and comparisons made to the adjustment rates derived from the observational surveys. One might hypothesize that more careless drivers will not adjust head restraints and also be overinvolved in accidents. However, the NCSS and NASS data will not give information on lateral mispositioning. A summary of the major steps to be carried out in the head restraint usage survey and analysis is given in Figure 3-5.

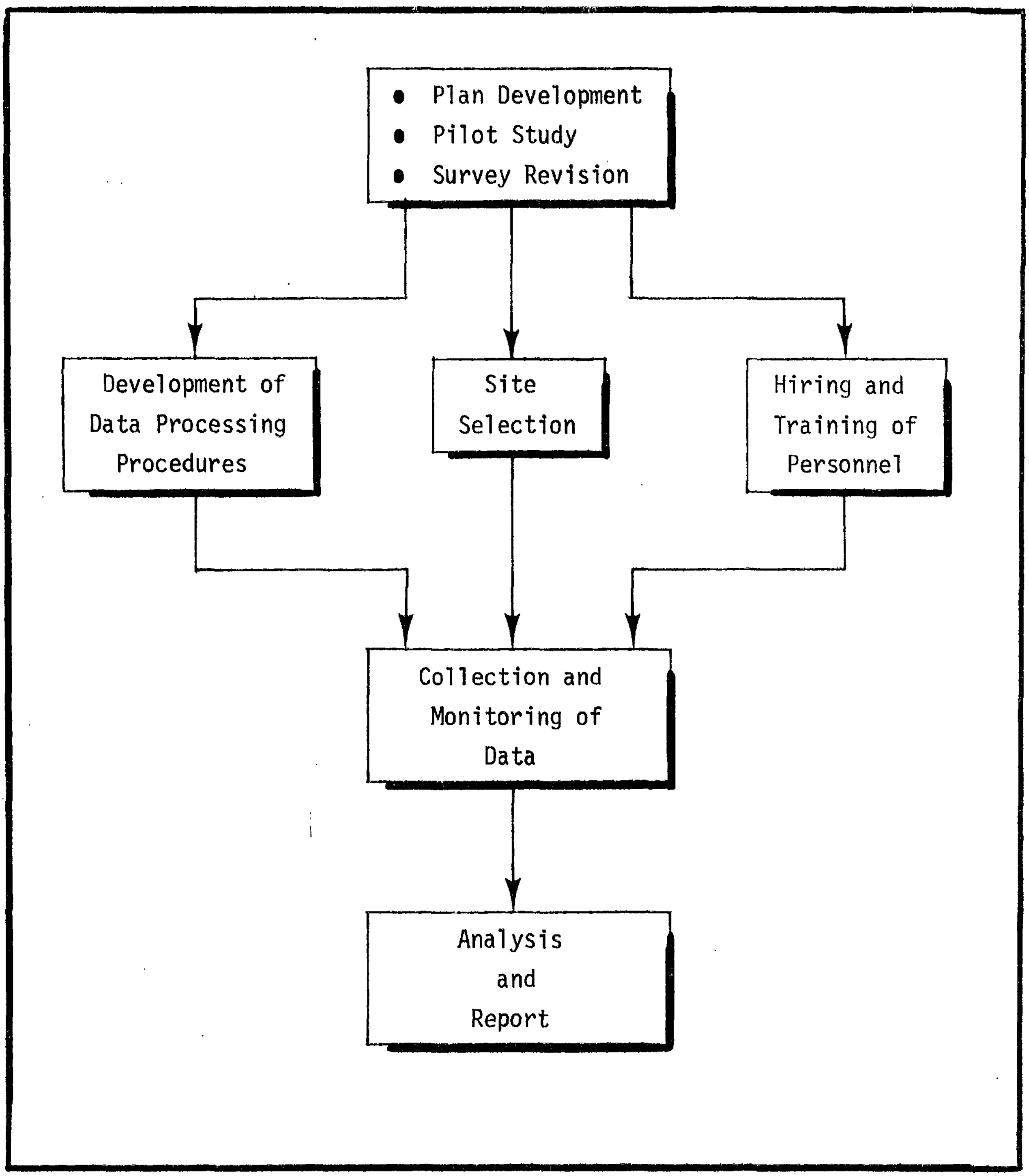


Figure 3-5. Head Restraint Usage Survey.

3.6 Dynamic Laboratory Tests

3.6.1 Introduction

The purpose of these tests is to establish the performance of different head restraint devices and seating system types during various impact situations including off-center and angular impacts.

In the testing of head restraints, seat characteristics are important because of the way the seat holds the occupant in place. In addition, elastic or rebound characteristics of the seat back might influence the effectiveness of the head restraint. Seat back failure may protect occupants from neck injury by allowing the torso and shoulders to move rearward, as energy is absorbed. Since seat characteristics may influence the effectiveness of head restraints, it is desirable to combine certain aspects of the head restraint and seating system test procedures.

The dynamic tests will be performed using a test platform that can be accelerated with considerable control. There are four crash modes that will be used for the seating and they are listed below in decreasing order of importance:

- Rear Collision; with dummy (prime mode of interest for testing).
- Frontal Collision; with dummy (effects of the Standard are speculative).
- Frontal Collision; without dummy (for test calibration purposes only).
- Rear Collision; without dummy (for test calibration purposes only).

The results of these tests should establish performance measures for the various head restraint devices and seating system types. The data obtained from these tests will be analyzed to see if certain types of head restraints or seat types (or combinations of the two) are more effective than others in avoiding injury or reducing the severity of injury during crash situations.

3.6.2 Data Requirements

There are certain data that are required before testing of head restraints and seating systems can proceed. Since it would not be feasible to test every type of head restraint or seating system configuration existing in the automobile population, testing will be limited to the systems that are the most popular and the most unusual (for both head restraints and seating systems). In order to establish the types of seating systems and head restraints to be tested, a study of head restraint and seating system characteristics of the automobile population dating back to the early 1960's will be made. The following list describes the variables that will be considered in such a study.

- <u>Seating System Characteristics</u> (in order of decreasing importance)
  - Seat Type (Bench *vs.* bucket)
  - Track configurations
    - -- Flat
    - -- Inclined
    - -- Other
  - Anchor characteristics
  - Hinging characteristics
  - Latch mechanisms
  - Seat track type
    - -- Manually *vs.* electrically adjusted
  - Seat back angles
    - -- Reclining *vs.* non-reclining seats.

- <u>Head Restraint Characteristics</u>
  - Adjustable*
  - Non-adjustable
  - See-through type.

These data will be analyzed to determine types of head restraints and seating systems that are most representative of the vehicle population. It might also be desirable to test systems that are unusual or new to the market.

Information on driver characteristics will also be required for the test. The driver characteristics listed below might influence the effectiveness of both head restraints and seating systems.

- <u>Driver Characteristics</u>
  - Height
  - Weight
  - Sex
  - Age.

During the test, the seating system, head restraint, and (when used) dummy will be instrumented according to the type of information that is desired. The following describes the variables that will be measured during the various tests.

- <u>Seating System Measurements</u>
  - Movement of seat
    - -- Seat back forward movement
    - -- Seat movement on track
  - Acceleration, deceleration of seat back
  - Weight of seat back (obtained from manufacturer)
  - Location of seat failure
  - Type of seat failure

---

*Adjustable head restraints will be tested in both adjusted and non-adjusted positions. Misuse of head restraints obviously will have an impact on the effectiveness of head restraints. Therefore, usage rates for head restraints (rates of mispositioning) will be required for analysis of the head restraint test data.

- Seat back rotation
- Acceleration, deceleration time (secondary)
- Maximum force on seat back (at predetermined locations) from dummy impact.

- <u>Head Restraint Measurements</u>*
  - Movement of head restraint (or high seat back) relative to seat back
  - Acceleration, deceleration of head restraint
  - Type of head restraint failure (adjustable)
  - Head restraint rotation
  - Acceleration, deceleration time (secondary)
  - Impact from dummy's head.

- <u>Dummy Measurements</u>*
  - Distance head travels backwards
  - Acceleration, deceleration of head
  - Impacts on head from head restraint
  - Impacts on dummy's torso from seat back
  - Acceleration, deceleration of torso.

Other variables that will be included in the dynamic test are:

- <u>Test Platform Characteristics</u>
  - Angle adjustment: the tests will attempt to establish the performance of different head restraint and seating system types during off-center and angular impacts, so that the sled will have the capability of adjusting for various impact angles. The maximum angle of impact will be $\pm$ 15° and the increment will be 7.5°.
  - Acceleration control: the test will involve various levels of deceleration (5, 10, 15, and 20 g's) so that the platform will be designed to simulate these impacts.
  - Steering wheel and dashboard mockup: this will be required for the test involving a frontal collision (with dummy). The purpose is to measure the impact of a dummy with the seat back and head restraint after rebounding from an impact with the steering wheel and dashboard. Only a partial dashboard (on driver's side) is required. The mockup design will follow the SAE design criteria for distance between the seat back and the steering wheel.

- <u>Dummy Characteristics</u>
  - 50th percentile male
  - 95th percentile male.

3.6.3 Data Acquisition

The data will be acquired from a series of highly controlled dynamic tests A test platform (sled), which will be designed to allow for adjustment of deceleration rates and impact angles, will be used. Because of the interrelationship between seating systems and the effectiveness of head restraints, testing of head restraints will be combined with the testing of seating systems. However, there will be some test crash situations where the acquisition of seating system data alone is desired.

*Only included during rear and frontal collisions (with dummy). Dummy measurements will be obtained only from the dummy located in the driver seat.

As mentioned before, there are four crash modes that will be used in the testing. They are listed below:

- Frontal Collision; with dummy* (effects of Standard are speculative).
- Frontal Collision; without dummy (for test calibration purposes only).
- Rear Collision; with dummy* (prime mode of interest for seating).
- Rear Collision; without dummy (for test calibration purposes only).

The crash mode of prime interest for this study is the rear collision in which a dummy is used. This mode is most likely to reveal the greatest amount of information on the performance of head restraints and seating systems during a crash situation. Therefore, extensive testing will be required under this crash mode in order to obtain the amount of data necessary to analyze the performance of the different types of head restraints and seating systems.

The amount of information obtainable for our purposes from each of the other three crash modes is small. To obtain this information, only a small number of tests will have to be performed, within each crash mode. In each of the two frontal collision modes (with and without a dummy), tests will be performed with and without a rear seat dummy occupant, in order to study the effects of the dummy impacting with the seat back during a frontal collision. To simplify the testing, rear seat dummies will be used only in the testing of bench seats. According to the MDAI files, about 20 percent of all accidents involving vehicles containing back seat passengers incur some sort of seating system damage [8]. The seating position of the rear seat dummy will be varied in order to examine the impact effects at various locations of the front seat back.

The crash modes without a dummy (both frontal and rear) are tested for the purpose of calibrating the other tests and, therefore, only require a minimal amount of testing. We are interested in determining seating system failure rates due to its own weight during a crash situation.

For each of these four crash situations, several variations of the test conditions will be made. Variations that will be made are listed below:

- Impact angles
- Deceleration rates
- Seating system characteristics
- Head restraint characteristics (if applicable)
- Dummy characteristics (if dummy is used)
- Restraint system type (if applicable).

Crash simulation facilities exist that are capable of simulating various deceleration levels that may occur in crash situations. One such facility is

* These dummies will be located in the driver's seat.

the Transportation Research Center of Ohio which has a crash simulator that can create accelerations typical of those experienced by occupants of 5,000 lb vehicles during collisions up to 100 mph. We are interested in testing four rates of deceleration (5, 10, 15, 20 g's).

To obtain data on head restraint and seating system performance during angular impacts, the effective angle of acceleration relative to the seats will be varied. The tests will be conducted for acceleration angles incremented by 7.5 degrees up to a maximum of $\pm$ 15 degrees from the longitudinal axis.

In addition to variations in the type of seating system (bench *vs.* bucket), other seating characteristics will be varied in order to study their performance. The position of the seat in its track will be examined. Testing of the seat positioned in its extreme frontward and rearward positions will be done. The various types of seat tracks will also be tested. There are some seat tracks that not only allow the seat to move forward and backward, but also up and down.

The position of the dummy in the seat will also be examined. The dummy position will be varied (several inches to the left or right) to examine the tolerances of the head restraint and the effect on seat strength.

The dummy will be tested both restrained (lap belt restraint) and unrestrained.

In tests utilizing a dummy, two dummy sizes will be used. The dummy sizes will represent the 50th percentile male and the 95th percentile male in the driver population.

In order to obtain the results of the tests, data collection and recording equipment will be used. To visually record the test results, cameras* will be placed above and alongside of the test platform. The videotape or film will be used to measure travel distances for the dummy's head, head restraint and seat back. The videotape will also be used to measure the rotation of the head restraint and seat back. A secondary measure that can be obtained from the videotape is the time for acceleration and deceleration to occur for the dummy's head, head restraint and seat.

Other instrumentation that will be used to obtain data include accelerometers, pressure transducers, displacement devices** and strain gauges.

*Videotape could be used so that a quick review of the test can be made to see if the data that were desired were obtained. It is also less expensive than film.

**These devices are collapsible tubes (e.g., portable radio antennae) that will be used to measure the impact forces of the dummy's head on the head restraint and also the dummy's torso on the seat back. The amount of displacement will be a direct measure of the applied force.

Accelerometers will be used to measure the accelerations (decelerations) of the dummy's head and torso, head restraint, and seat. They will be placed in positions where maximum accelerations are expected to occur. Displacement devices will be used to measure the maximum force of the dummy's head on the head restraint and the maximum force of the dummy's torso on the seat back. These devices will be inserted into the seat back and head restraint at predetermined locations. To measure the impact of the seat back on the dummy's torso, a thin metal plate with pressure transducers in each corner will be placed on the upper portion of the dummy's back. Another transducer will be placed on the back of the dummy's head to measure the impact on the head by the head restraint. Measurements obtained from the transducers will be continuous through the time sequence of the crash, whereas only one measurement (maximum force) will be obtained from the displacement devices. Strain gauges will be placed on the seat tracks, seat hinges and seat latches, and on the head restraint bar (for adjustable head restraints). They will measure the straining (due to twisting) that is experienced by the seat tracks, hinges, latches, etc., during crash situations.

In each test, failures of both the head restraint device and the seating system should be noted. Areas of possible failure in the seating system could be the seat anchor, track, hinge, or latch. Adjustable head restraints may experience a failure in the support bar.

SUMMARY:

- Frontal Collision; with Dummy (effects of Standard are speculative)

  Both seating systems and head restraints will be tested. A steering wheel and dashboard mockup is required.
  - Test Variations
    - -- Velocity
    - -- Impact angles
    - -- Deceleration rates
    - -- Seating characteristics (Front vs. rear: Position in seat--lateral, vertical)
    - -- Head restraint characteristics
    - -- Dummy sizes
  - Variables to be Measured
    - -- Dummy head travel (backwards)
    - -- Seat movement on track
    - -- Seat back movement
    - -- Head restraint movement
    - -- Acceleration, deceleration of dummy head, head restraint, seat back and dummy torso
    - -- Seat anchor, track, latch, and hinge failures
    - -- Head restraint failures (adjustable only)
    - -- Rotation of head restraint and seat back
    - -- Impacts on head restraint by head (maximum force)
    - -- Impacts on seat back by dummy torso (maximum force)
    - -- Impacts on dummy's head by head restraint
    - -- Impacts on dummy's torso by seat back
    - -- Impact of rear seat occupant with head rest.
  - Instrumentation
    - -- Accelerometers
    - -- Pressure transducers
    - -- Strain gauges
    - -- Videotape cameras
    - -- Displacement devices

- Frontal Collision; without Dummy (for test calibration purposes only)

  Only data on seating system performance will be obtained.
  - Test Variations
    - -- Impact angles
    - -- Deceleration rates
    - -- Seating characteristics
  - Variables to be Measured
    - -- Seat movement on track
    - -- Seat back movement
    - -- Acceleration, deceleration of seat back
    - -- Seat anchor, track, latch and hinge failures
    - -- Rotation of seat
  - Instrumentation
    - -- Accelerometers
    - -- Strain Gauges
    - -- Videotape cameras

- Rear Collision; with Dummy (prime mode of interest for testing)

  Data on both seating systems and head restraints will be obtained.
  - Test Variations
    (same as frontal collision; with dummy)
  - Variables to be Measured
    (same as frontal collision; with dummy)
  - Instrumentation
    (same as frontal collision; with dummy)

- Rear Collision; without Dummy (for test calibration purposes only)

  Data obtained on seating systems only.
  - Test Variations
    (same as frontal; without dummy)
  - Variables to be Measured
    (same as frontal; without dummy)
  - Instrumentation
    (same as frontal; without dummy)

3.6.4 Data Analysis

The acceleration curves in the various testing modes will at best only approximate the accelerations produced in actual crash situations. It is not possible or practical to simulate with a test sled the crushing of the front of a vehicle, and in rear end collisions the repeatable results for the joint crush of a front (striking car) and rear end (struck car) are even more difficult. The crushing varies by type of vehicle, the object struck, the direction of crush, momentum, etc.

The accelerations produced to relate to the crash history of the passenger compartment. The strains measured in the various seat components enable calibration of sled accelerations to real crash situations (see Section 3.7 on Instrumented Vehicles).

The direct comparison of seating systems on the basis of these strains is not immediately possible, since seats that fail at relatively low accelerations and/or strains may only be used in large, heavy vehicles which will undergo lower accelerations than smaller cars crashing at the same speed. After adjusting for this factor, the different seating and head restraint systems can be compared. This adjustment for differing crushability is the major difficulty in an otherwise straightforward analysis of the experimental data.

A summary of the major steps to be carried out in the conduct of the dynamic laboratory tests and evaluation of the results is given in Figure 3-6.

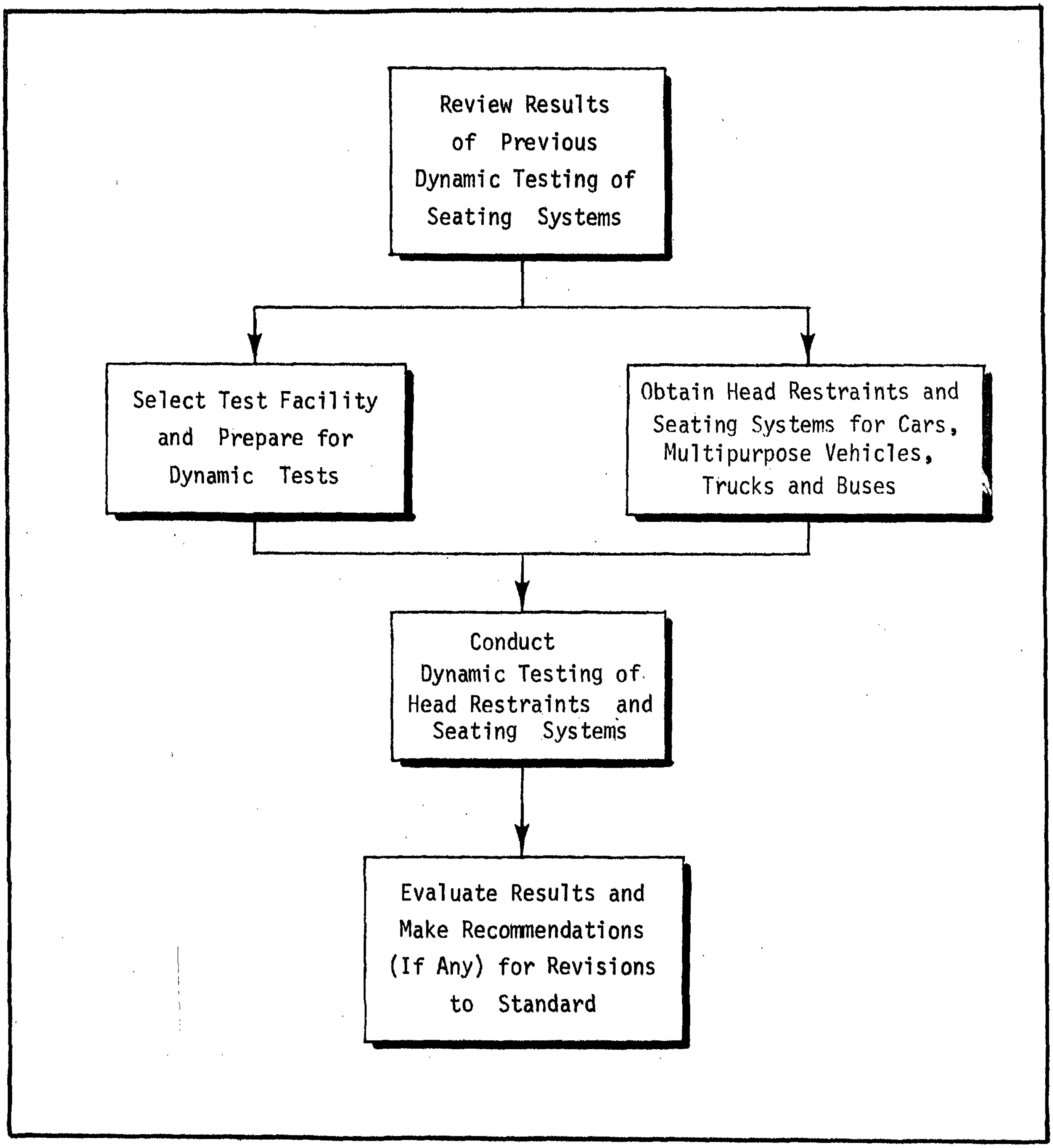


Figure 3-6. Dynamic Laboratory Testing.

3.7 Instrumented Vehicles

3.7.1 Introduction

The purpose of this study is to improve the understanding of the performance of head restraints and seating systems in real world crashes by instrumenting vehicles in use. Instrumentation will be used to measure the maximum forces exerted on the head restraints and seat backs from impacts with the head and torso during a collision. The head restraint support bars (adjustable only), seat latches, seat tracks, and seat anchors will also be instrumented to measure the amount of rotation (or twisting) experienced during a crash situation. In addition, instrumentation will be used to measure and record the vehicle's acceleration/time history during a collision. The crash data obtained, along with the data obtained from the dynamic tests, can be used to refine the crash reconstruction and occupant computer programs. Also, these data can be used to help improve the understanding about the relationship of acceleration to neck injury.

The basic thrust of this approach will be to instrument a group of vehicles. Currently, NHTSA is funding the development of a vehicle instrumentation program that involves instrumenting approximately 50,000 vehicles with a crash recorder [9]. These recorders, on which NHTSA has put a $50 per recorder price limit, will record accelerations experienced by a vehicle in the x, y direction during a crash. For our study, it will be necessary to include additional instrumentation to obtain the effects of a crash on various seating systems and head restraints. This, however, should represent only modest added costs (e.g., perhaps $5-$10 per vehicle). Our study will be most economical if it can be included in this larger instrumentation project.*

There are some problems associated with this approach. The exact cost and accuracy of such recording equipment is unknown; the rate of reportable accidents from 50,000 vehicles would require an accident exposure period of about two years, and special accident investigations would have to be conducted by trained personnel in order to use the crash reconstruction programs. Only limited knowledge may be obtained relative to the performance of head restraints and seats in accidents. Despite these problems, there is still the potential for improving the simulation of vehicle and occupant dynamics in crash situations.

*This study can be conducted independently of NHTSA's vehicle instrumentation program by using carefully located, inexpensive accelerometer packages in place of the crash recorders. However, the recommended instrumentation program in this case would be quite similar to the program now being developed for NHTSA.

3.7.2 Data Requirements

The objective of this study is to obtain information on vehicle accelerations and impact forces on both the head restraint and seat back during a crash situation. To accomplish this, a fleet of vehicles will be instrumented. The following is a list of the instrumentation required for this study:

- Required Instrumentation
  - Accelerometers } Contained in the crash recorder being
  - Recording devices } developed by NHTSA
  - Displacement devices*
  - Strain gauges

The crash reconstruction and occupant dynamic computer programs will be used to evaluate the actual crash data along with the dynamic test data. Therefore, detailed information on the accident is needed in order to execute the crash reconstruction programs. Information collected on the accident will be the same as in the current NASS forms, and includes the following:

- Vehicle make, model, model year.
- Vehicle size.
  - Subcompact
  - Compact
  - Intermediate
  - Full size
- Vehicle weight.
- Accident year.
- Crash configuration.
  - Front
  - Rear
  - Side
- Impact speed.
- Occupant characteristics.
  - Age
  - Sex
  - Height
  - Weight
- Occupant injuries.
- Weather conditions.
- Road surface conditions.
  - Wet
  - Dry
- Head restraint type.
  - Adjustable
  - Non-adjustable

---

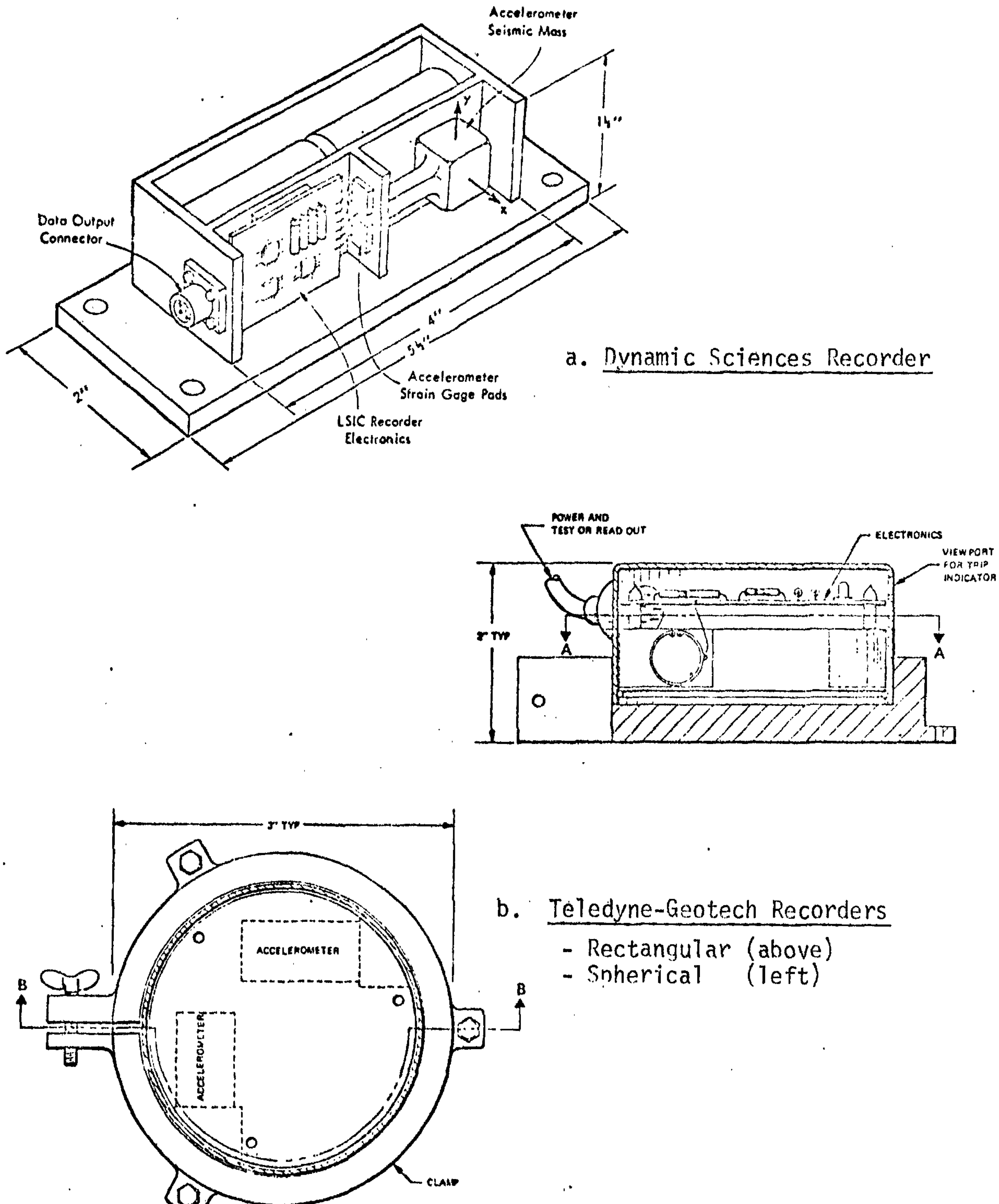
*Described in Section 3.7.3.

Accelerations for the adjustable restraints can be deduced from the displacement, strains and the dynamic tests. These accelerations can then be related to head and brain injuries in a similar manner.

Seating Failure

Here the information on strains, etc., can be related to the crash severity. The effect of passenger weight and seat belt use should be examined if sample sizes allow it. From an external distribution of crash severity, the overall strain distribution can be estimated. This estimate can then be used to evaluate the effect of any proposed changes in FMVSS 207.

The major steps to be carried out in the study of instrumented vehicles are summarized in Figure 3-8.



Source: Tally Industries (formerly Utra Systems) Proposal No. 6155 and Teledyne Geotech Proposal PI-2732 [10,11].

Figure 3-7. Schematic description of crash recorders being developed for NHTSA's vehicle instrumentation program.

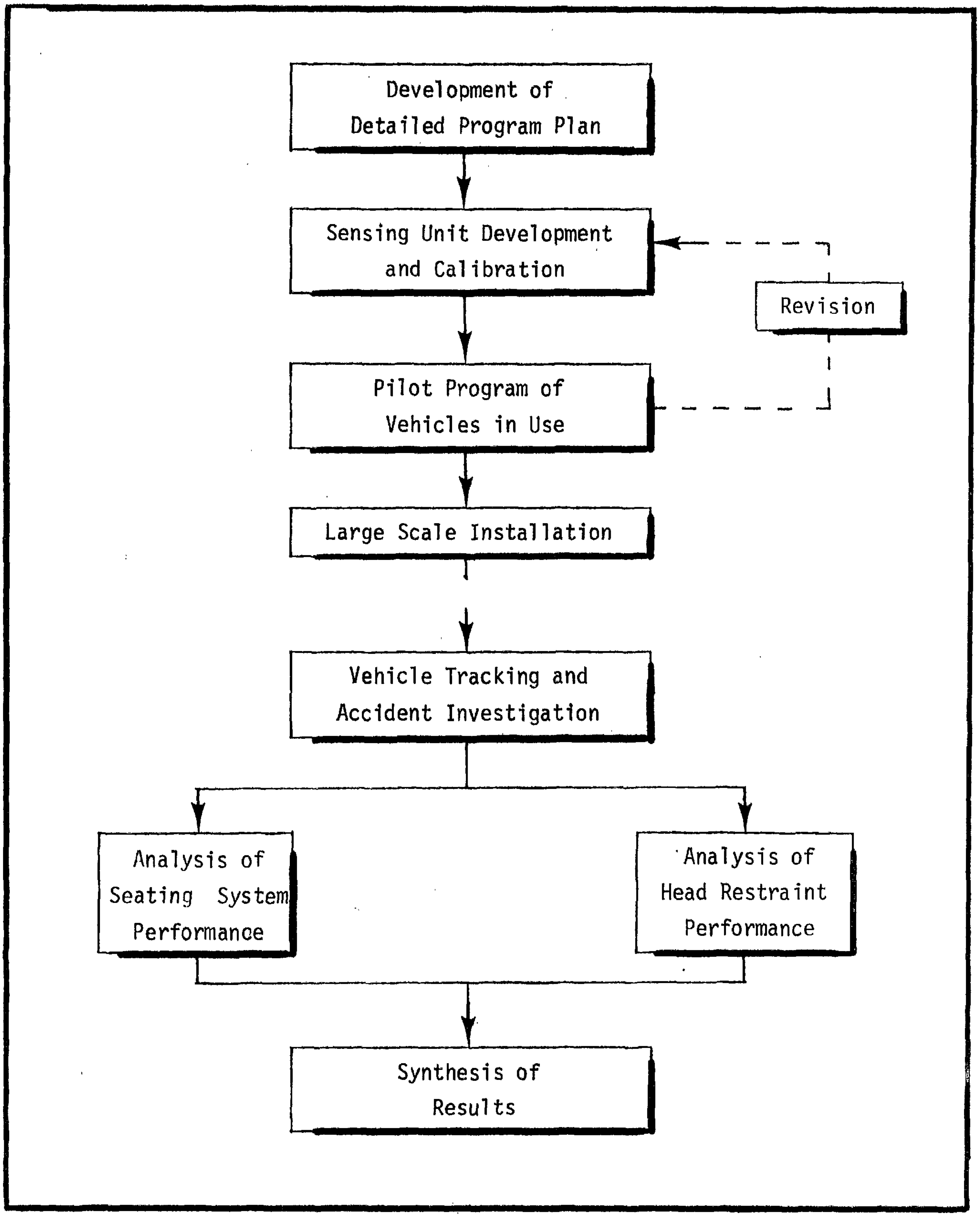


Figure 3-8. Approach for Analysis of Instrumented Vehicle Data.

3.8 References for Section 3

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2. Snyder, R.G., *et al.* *Bioengineering Study of Basic Physical Measurements Related to Susceptibility to Cervical Hyperextension-Hyperflexion Injury*, Highway Safety Research Institute, Ann Arbor, Michigan, September 1975.

3. *Accident Facts* (1976 Edition), National Safety Çouncil, Chicago, Illinois, 1976.

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6. Mungenast, J.S. and C. J. Kahane. *Restraint Systems Evaluation Project Codebook*, National Center for Statistics and Analysis (NHTSA), Washington, D.C., March 1977 (Technical Note N43-32-2)

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8. __________. *Collision Performance and Injury Report*, Long Form, Revision Number 3, General Motors Corporation, January 1975.

9. __________. NHTSA Statement of Work for RFP No. NHTSA-6-B349 to Teledyne Goetech, 1977.

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4.0 COST DATA AND SAMPLING PLAN

4.1 Background for FMVSS 202: Head Restraints

FMVSS 202 (Head Restraints for Passenger Cars) first went into effect on January 1, 1969. Its purpose was to require the use of head restraints and establish performance standards for head restraint systems in passenger cars. Use of head restraints reduces the frequency and severity of neck injuries in rear end and other collisions.

Head restraints are required by the Standard at each front left and front right seating position in passenger cars. Restraint systems must conform to the performance requirements designated in FMVSS 202 under a dynamic or static test.

There are basically two methods by which passenger cars comply with the head restraint requirements imposed by FMVSS 202:

(1) Adjustable head restraints which must be 10 inches wide for bench seats and 6.75 inches wide for bucket seats. The top of the restraint must be 27.5 inches above the seating reference point.

(2) High seat backs which have the head restraint capability designed into the seat and require no adjustment.

The system actually employed is primarily a function of seating configuration (bench, bucket, etc.) which in turn is a function of make and model of vehicle. In general, most bench seating configurations are equipped with adjustable head restraints while most bucket seat arrangements employ fixed high seat backs. Typical examples are shown below in Figures 4-1 and 4-2.

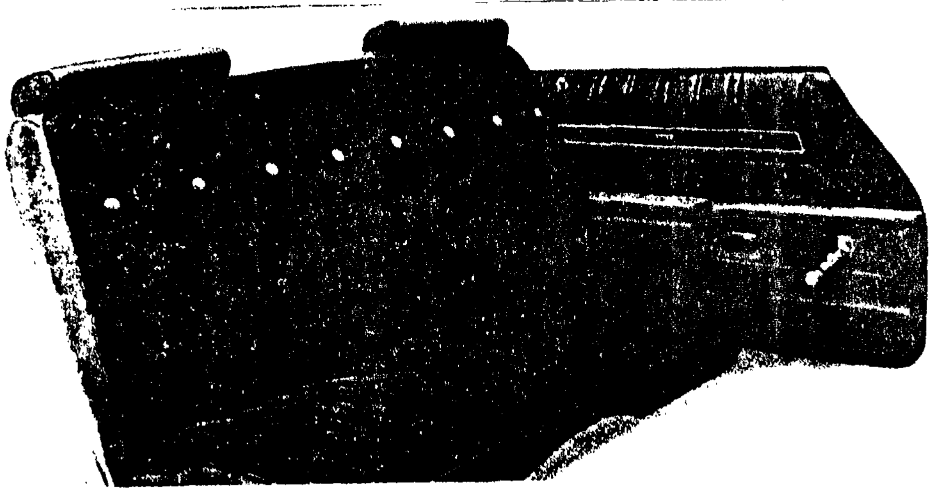


Figure 4-1. Bench seating with adjustable head restraints.

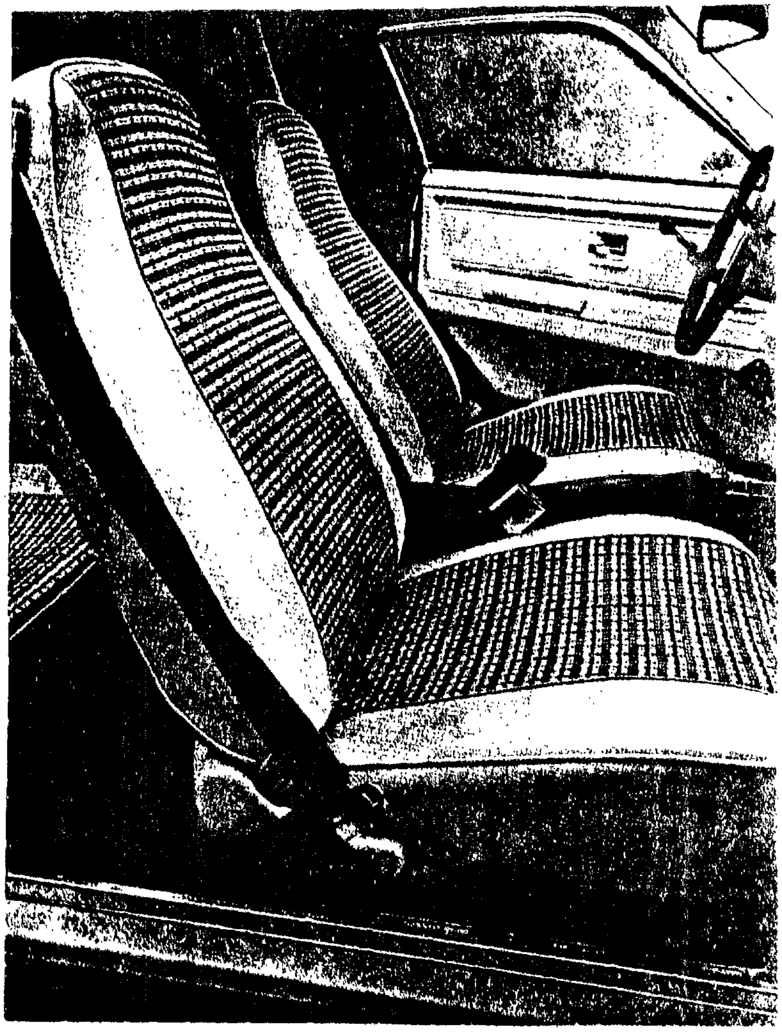
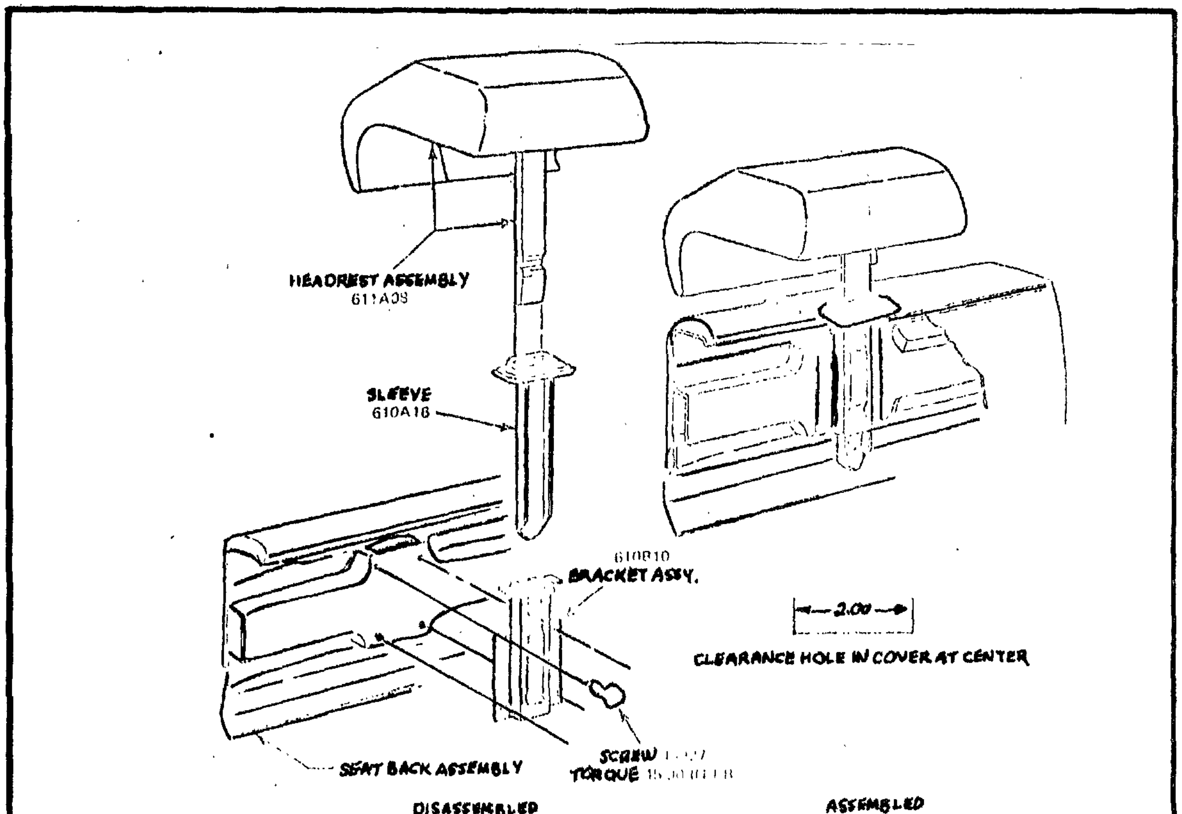


Figure 4-2. Bucket seats with high seat backs (fixed head restraints).

The fixed head restraint is a structural extension of the standard seat back into a high seat back. A typical adjustable headrest and associated components are shown in Figure 4-3. This type of head restraint generally has a single post with notch to engage a spring-loaded catch in the mounting bracket. The mounting bracket retains the post and guide sleeve. The mounting itself is part of the seat back assembly.

Manufacturers seem to prefer the adjustable head restraints. These are active restraint systems in that they require a position adjustment by the seat occupant. This preference, is, in part, due to the visibility restrictions imposed by high seat backs, particularly in bench seat configurations. To alleviate this visibility problem, some manufacturers have designed open space (see through) fixed head restraints [1].



Source: *Ford Auto Repair Manual*, 41-40-1, 1974 [1]

Figure 4-3. Adjustable headrest and associated components.

Before the Standard became effective on January 1, 1969,few manufacturers provided head restraints. Volkswagen provided them as standard equipment on their 1968 models. Ford complied with FMVSS 202 on approximately 99 percent of their 1969 models with General Motors and Chrysler following the later part of the 1969 model year.

General Accounting Office estimates of the average cost per car incurred in complying with FMVSS 202 and FMVSS 207 (Seating Systems) are combined for model years 1969 through 1974. These estimates represent the incremental cost in a model year of introducing a head restraint system and design changes to seating systems to comply with performance standards established by FMVSS 202 and 207. These costs are as follows [1]:

1967	$3/car	1971	$18/car
1968	$5/car	1972	$18/car
1969	$19/car	1973	$19/car
1970	$19/car	1974	$19/car.

Since FMVSS 202 was not in effect for vehicles manufactured before January 1, 1969, the 1967 and 1968 costs must be attributed to compliance with the Seating Standard. Subtracting these costs from the total cost for the succeeding model years will yield a rough estimate of the average cost of compliance with FMVSS 202.

4.2 Background for FMVSS 207: Seating Systems

FMVSS 207, which became effective for passenger car seating systems on January 1, 1968, basically imposes two types of requirements. The first requirement is that each occupant seat installation in the passenger vehicle be capable of withstanding certain specified forces described in detail in Section 1. The second fundamental requirement is that hinged or folding seats or seat backs be equipped with a self-locking restraining device and a control for releasing the restraining device that is readily accessible to the occupant of the seat and the occupant of any seat immediately behind the seat. The restraining device must also withstand certain forces, discussed in Section 1.

It is possible to envision a number of approaches that could be undertaken to strengthen seating systems and their ability to withstand forces such as those specified by the Standard. The strength of car seating systems to absorb these forces could be substantially affected by the following.

- Overall dimensions, contour and weight of seat and seat back.
- Car seat type (bench, bucket, etc.).
- Seat frames--both the structural characteristics of the metal used and the configuration.
- Seat spring assemblies.
- Seat adjuster track--type and strength.
- Anchorage of seating system to floor of car.

Thus, potentially there could be a variety of compliance approaches involving the design of seating systems and the material used, if the requirements of the Standard so dictated. However, Severy *et al.* [3] have conducted laboratory tests of production seats from large and small cars of both foreign and domestic design that have been manufactured over the past 30 years (post World War II to the near present). They have found that the backrest strengths are remarkably alike and all would be "incapable of effectively resisting motorist inertial forces for any but light impact exposures without inducing excessive yield and/or component separation." Severy *et al.* [3] go on to note that while the 3300 in-lbs moment feature of the Standard appears impressive, production seats from the forties and fifties that were tested substantially exceeded this criterion. A more detailed discussion of seating system strength and failure modes is given in Appendix D.

Thus, the evidence suggests that the actual strength of seating systems before (and, indeed, long before) the effective date of the Standard (January 1, 1968) was little different from the strengths of seating systems after the Standard. Therefore, it would appear that the principal compliance with the Standard has been directed toward the inclusion of a self-locking restraining device on folding seat backs, and a control for releasing the restraining device. There remains the possibility that seats are now being "designed down" to meet the Standard.

One method of complying with the requirement for a self-locking restraining device and manual releasing control is described in a Ford manual [4] for most Ford 1974 model year cars. The front seat back latches can be operated either automatically or manually. The front seat back latches release automatically when either front door is opened. Opening the door energizes a relay switch which sends power to two solenoids, one mounted on each seat back. An actuating rod of the solenoid is connected to a latch pawl. The actuating rod operates the pawl to release the seat back latch upon energization of the solenoid. If the electric system is not operating, the seat back latch can be released manually by moving the seat back release handle control. The mechanical release of the self-locking restraining device for folding seat backs is the common and required feature of all such systems. The automatic electronic releasing feature is not required by the Standard.

Generally speaking, seat back latch mechanisms are constructed of formed sheet metal and cast components in some instances, having latching or holding points that receive highly concentrated loading under collision circumstances. The design of these localized, small contact area restraining latch systems cannot be considered crashworthy in the sense that they can provide seat back holding strength comparable to fixed tubular and structural framing that forms an integral structure of bench and seat backs commonly employed in aircraft and race car seating systems. A tradeoff between seat strength and the necessary convenience of a "tilt forward" seat for two-door cars must be made. The actual latch and striker parts of the fold-forward seats are generally commensurate with the strength of the simple latch activating rods and seat pivots used in most vehicles. The strength of the latch system which must necessarily include the seat back pivots and seat back framing configuration must be treated as an integrated entity and (although the latch and striker may remain engaged under collision conditions), if the seat back displaces sharply forward or rearward, the seating system must be considered to have failed.

NHTSA has made estimates of the average cost per car for the combined compliance with FMVSS 202 (Head Restraints) and FMVSS 207 (Seating Systems) for model years 1966 through 1974. The combined costs are summmarized as follows [1]:

1966	-
1967	$3/car
1968	$5/car
1969	$19/car
1970-1974	$18-19/car

Recall that FMVSS 207 became effective on January 1, 1968 (required for 1968 MY cars) while FMVSS 202 became effective on January 1, 1969 (required for 1969 MY cars). Remember also that General Motors chose to anticipate the requirement for a self-locking restraining device on hinged seats by introducing this feature into all their 1967 model year cars and also that this feature was included in most foreign cars [5].* The implication from the table and above text is that average cost per car of complying with FMVSS 207 is about $5. If most (or all) of this cost is associated with the self-locking mechanism for hinged front seat backs, obviously the compliance cost per car will vary with the ratios of 2-door and 4-door cars. For example, in the 1974 MY, 66 percent of the cars were a 2-door body style compared with 54 percent and 58 percent in 72 MY and 73 MY cars,respectively [6].

*It is noted that General Motors accounts for approximately half the automotive vehicles manufactured in the U. S.

4.3 Relevant Cost Items

The components of adjustable head restraints that must be included in the cost determination of FMVSS 202 include:

- Headrest assembly
- Sleeve
- Bracket assembly
- Seat back assembly.

For the high seat back equipped vehicles, no new components are added--only additional materials and design changes.

The major components of seating systems that could be affected by the general performance tests and the tests for folding or hinged seats or seat backs restraining devices are summarized in Table 4-1 [4, 7]. Costs related to changes in these items which were made as a result of FMVSS 207 should be included. It must be recalled, however, that in the real world, the main effect of FMVSS 207 was to introduce the requirement for a self-locking restraining device and control for hinged seats.

To establish total costs, at the very least, direct and indirect manufacturing, and capital investments must be considered. Consumers certainly pay for manufacturer's markup and taxes when they purchase the vehicle. The NHTSA methodology also includes lifetime operating and maintenance costs as part of the total costs of the design change. We will not include these lifetime costs.

The manufacturing costs are a function of:

- Material amount
- Material cost
- Labor required for component assembly
- Wage rate
- Overhead rate (indirect labor and material)
- Labor required for component installation.

Capital investments should be amortized over the useful life of the equipment and estimated level of production. Manufacturer and dealer markups and taxes are percentage amounts applied to the base costs. Additional discussion of Standard implementation cost categories appears in Appendix C.

TABLE 4-1

MAJOR COMPONENTS OF SEATING SYSTEMS [4,7]

Motor Vehicle Seat Types

Typical Front Seats	Typical Rear Seats
Bench seat	Seat with folding arm rest (in middle)
Bench seat-split back	Folding seat for cargo space
Bucket seat	Fixed seat
Individual adjustable seat	Contoured seat with folding arm rest

Seat Adjusters

Type	Design
Manual	Two-way straight adjuster
Power	Two-way inclined straight adjuster
	Two-way curved adjuster
	Four-way elevating adjuster
	Six-way adjuster

Seat Frames - Structural Classifications

- Tubular
- Stamped or rolled
- Wire or sheet metal assemblies
- Wood
- Combination of above

Seat Spring Assemblies

- Spring element types - Zigzag and formed wire
  - Coil
- Jack stringer (flexible base element)
- Stabilizer brace
- Border wire
- Hog rings
- Spring retainers

Seat Padding

- Foundation pad
- Intermediate pad
- Topper pad
- Trim cover filler pads

Seat Covering Materials Type

- Textile Fabrics
- Coated fabrics
- Genuine leather

TABLE 4-1 (continued)

<u>Trim Fastening for Cushion, Padding, Covers, etc.</u> Tasks and Wire Staples Hog rings Trim tabs Cover retainer Adhesives
<u>Self-Locking Restraining Device and Control</u> Electronic relay switch Solenoid Actuating rod Seat back latch pawl Seat back release handle
<u>Seating System Anchorage</u> Tract assembly Floor pan Sealer Studs, nuts, washers, etc.

4.4 Cost Data Acquisition Plan

The purpose of this activity is to obtain reliable estimates of the incremental costs incurred by manufacturers in complying with FMVSS 202 and FMVSS 207. Since both of these Standards apply to seating systems, the sampling schemes for each Standard should overlap as much as possible in the interests of economy.

The cost of various components of seating systems and head restraints can be determined from information supplied by the manufacturer. When this information on various models for years both before and after each Standard became effective is compiled, the incremental cost of compliance can be ascertained by extrapolation. Acquiring the necessary information for all models produced, in all relevant variations, is costly and unnecessary. If we assume some structure for the cost of compliance, it is then possible to design a sampling scheme whereby only some automobile models are examined. Since FMVSS 207 first went into effect in 1968, and FMVSS 202 went into effect in 1969, any overlap in models sampled for both Standards reduces both the cost of acquiring physical components and the work necessary to determine component costs. The particular structure assumed for the cost will lead to the sampling plan, and the stronger the assumptions, the smaller the sample size needed; if it is assumed that costs are the same for all models and manufacturers, only one model needs to be examined. However, different manufacturers have different design philosophies and different accounting procedures, so that costs will certainly vary among them. For each manufacturer we expect the costs to vary according to the market class of the automobile. Since the major means of compliance with FMVSS 207 has been the addition of lock and release mechanisms to folding seats, and almost all folding seats are to be found in two door cars, it is proposed that the majority of the models sampled for this Standard be two door models. For FMVSS 202, the different head restraint types (adjustable *vs* fixed) will be important.

The manufacturers and market classes to be considered are shown in Table 4-2. The manufacturers represent approximately 90% of the total market. Specific figures for two door *vs* four door models or adjustable *vs* fixed head restraints are not readily available. Using these 7 manufacturers and 7 market classes, let the incremental cost of compliance be c_{ijk}, where i denotes the manufacturer, j the market class and k pertains to the Standard. Values of i are 1 for GM, 2 for Ford, ... , 7 for Datsun; values of j are 1 for luxury, 2 for medium,..., 7 for sportstype. Values for k are 1 for an adjustable head restraint, 2 for a fixed head restraint, 3 for two door vehicles, 4 for four door vehicles. Thus values 1 or 2

TABLE 4-2

VEHICLE TYPE BY MANUFACTURER, 1974

Market Class	Manufacturer						
	GM	Ford	Chrysler	AMC	VW	Toyota	Datsun
Luxury	5.0	1.7	1.0	--	--	--	--
Medium	14.5	3.8	13.2	--	--	--	--
Full size	15.3	18.9	8.9	4.9	--	--	--
Intermediate	24.5	15.9	20.4	23.2	--	--	--
Compact	13.0	17.9	53.3	35.4	11.1	--	--
Subcompact	8.9	16.2	--	31.3	88.8	100.	81.6
Sports type	18.7	25.5	3.2	5.2	0.1	--	18.4
Overall share of market	41%	25%	13%	4%	4%	3%	3%

Source: Derived from *Wards 1975 Automotive Yearbook*, using their market class categories.

for k correspond to FMVSS 202, while k being 3 or 4 indicates FMVSS 207.

Assume now that the cost of compliance can be represented as the sum of two components, one depending solely on the manufacturer, the other depending only on the market class. For FMVSS 202, these components will probably differ according to restraint type. For FMVSS 207, assume that the cost of compliance for four door vehicles has no market class component. Then the cost c_{ijk} can be written as

$$c_{ijk} = \begin{cases} \alpha_{ik} + \beta_{jk} & k = 1,2,3 \\ \alpha_{ik} & k = 4, \end{cases}$$

where for each appropriate value of k, α_{ik} is the manufacturers component and β_{jk} is market class component of the cost. Once these components are estimated, cost estimates for all vehicles under consideration are immediately available. It should be noted that since the subscript k appears throughout, the estimates for each k are not related. A more complex model for the costs might link the estimates. but building such a model requires much more detailed knowledge of the manufacturers and their means of compliance with the Standards.

The particular cells of Table 4-2 to be sampled can now be chosen. The cells should be picked according to their importance in the market (sales volume) and also to achieve economy, so that physical components can, whenever possible, be used for both standards. At least forty-six automobile models need to be sampled; for example, for two door vehicles and each of two head restraint types one model from each market class for GM and then one model from each of the other six manufacturers, and for four door vehicles one from each of the seven manufacturers. Costs for all permissible combinations follow directly from the assumed cost structure. It is also clear that unless more models are sampled, these assumptions cannot be checked, so that while the costs for GM are known, cost estimates for the other manufacturers may be way off. When it is possible to gather more data by suitable sampling, much additional information can be acquired, enabling checking of assumptions and nearly uniformly optimal precision in the estimates of cost. The theory of experimental design, a highly specialized branch of regression and analysis of variance guides the selection of models. One way of reducing the number of samples needed is to collapse market classes--consider the components of the cost of compliance for Luxury, Medium (price), and Full-Size market classes to be the same (i.e., take $\beta_{1k} = \beta_{2k} = \beta_{3k}$). Another possibility is to consider only one foreign manufacturer, and using its costs for all foreign cars. Little is lost assuming that for foreign manufacturers the cost of compliance with FMVSS 202 does not depend on head restraint type, and that the incremental cost of compliance with FMVSS 207 does not depend on the number of doors.

Collapsing the first three market classes and using Volkswagen as the one foreign manufacturer, the following sampling plan is proposed:

For each of the classes listed, collect cost information on one model, which is taken as representative of the entire class.

For two door cars, adjustable head restraints and fixed head restraints:

- GM: Lumped class, Intermediate, Subcompact, Sports type.
- Ford: Lumped class, Compact, Sports type.
- Chrysler: Intermediate, Compact.
- AMC: Compact, Subcompact.

For two door cars, any head restraint type:

- VW: Subcompact

For four door cars:

- GM: Any
- Ford: Any
- Chrysler: Any
- AMC: Any

This sampling plan uses eleven models with adjustable restraints, eleven with fixed head restraints and eleven with two doors, in the first group. In the last group four models are picked, and for Volkswagen, only one. In all, thirty eight models are sampled. With cost information on these models, the reduced set of α and β parameters can be estimated. Also, some testing of the cost of compliance between adjustable and fixed head restraints does not depend on the manufacturer, or perhaps does not depend on the market class. If this is discovered early in the cost information acquisition, then the sampling plan should be modified appropriately, and fewer models sampled. If more observations can be taken, either more classes can be selected (GM Compacts, Ford Intermediate...) or more than one model can be chosen in a class, or both of these can be done. Selection of more than one model is a class (say in the GM Intermediate Class, Chevelle and Cutlass), gives an estimate of cost variability within a class.

4.5 References for Section 4

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3. Severy, D.M., D. M. Blaisdell and J. F. Kirkhoff. "Automotive Seat Design and Collision Performance," *Twentieth Stapp Car Crash Conference,* Dearborn, Michigan, 1976: 303-334. (SAE 760 810)

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6. ____________. *Ward's 1975 Automotive Yearbook,* 37th Edition, Detroit, Michigan, 1975.

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5.0 WORK PLAN

The Work Plan for the evaluation study of FMVSS 202 and FMVSS 207 is divided into eight Tasks. They are:

- Task 1: Analysis of Insurance Claims (FMVSS 202)
- Task 2: Analysis of Detailed Accident Data
- Task 3: Analysis of Occupant Fatalities (FMVSS 207)
- Task 4: Analysis of Mass Accident Data (FMVSS 207)
- Task 5: Head Restraint Usage Survey (FMVSS 202)
- Task 6: Dynamic Laboratory Tests
- Task 7: Instrumented Vehicles Data Collection and Analysis
- Task 8: Cost Data Analysis.

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 are given in Figure 5-2 and Figure 5-3. The Tasks are grouped into three classes: those Tasks designed to evaluate FMVSS 202 only, those Tasks designed to evaluate both FMVSS 202 and FMVSS 207, and those Tasks which evaluate only FMVSS 207. For the purpose of developing this Work Plan, the entire study is assumed to start on January 1, 1979.

During the first year and one-half, in addition to the cost data analysis (Task 8), four Tasks are scheduled. The analysis of insurance claims (Task 1) is completed within the first year and together with the analysis of detailed accident data (Task 2) and are the bases for the first Decision Point to evaluate FMVSS 202. It is considered highly probable that analyses in these two Tasks will be sufficient to evaluate FMVSS 202 and further work directed toward the evaluation of this Standard will not be required.

The analysis of detailed accident data, together with the analysis of fatalities from FARS data (Task 3) and mass accident data analysis (Task 4) form the basis for the first Decision Point to evaluate FMVSS 207, 16 months after the start of the study. It is estimated that the effect of seat back locks could be determined at this point, but the overall question of the effect of the Standard on seating system strength is unlikely to be resolved. During the second year, the head restraint usage survey (Task 5) is scheduled for completion and the results form the basis for a second Decision Point to evaluate FMVSS 202.

Dynamic laboratory testing (Task 6) is scheduled for nine months during the third year of the evaluation study. The testing can apply to both Standards and

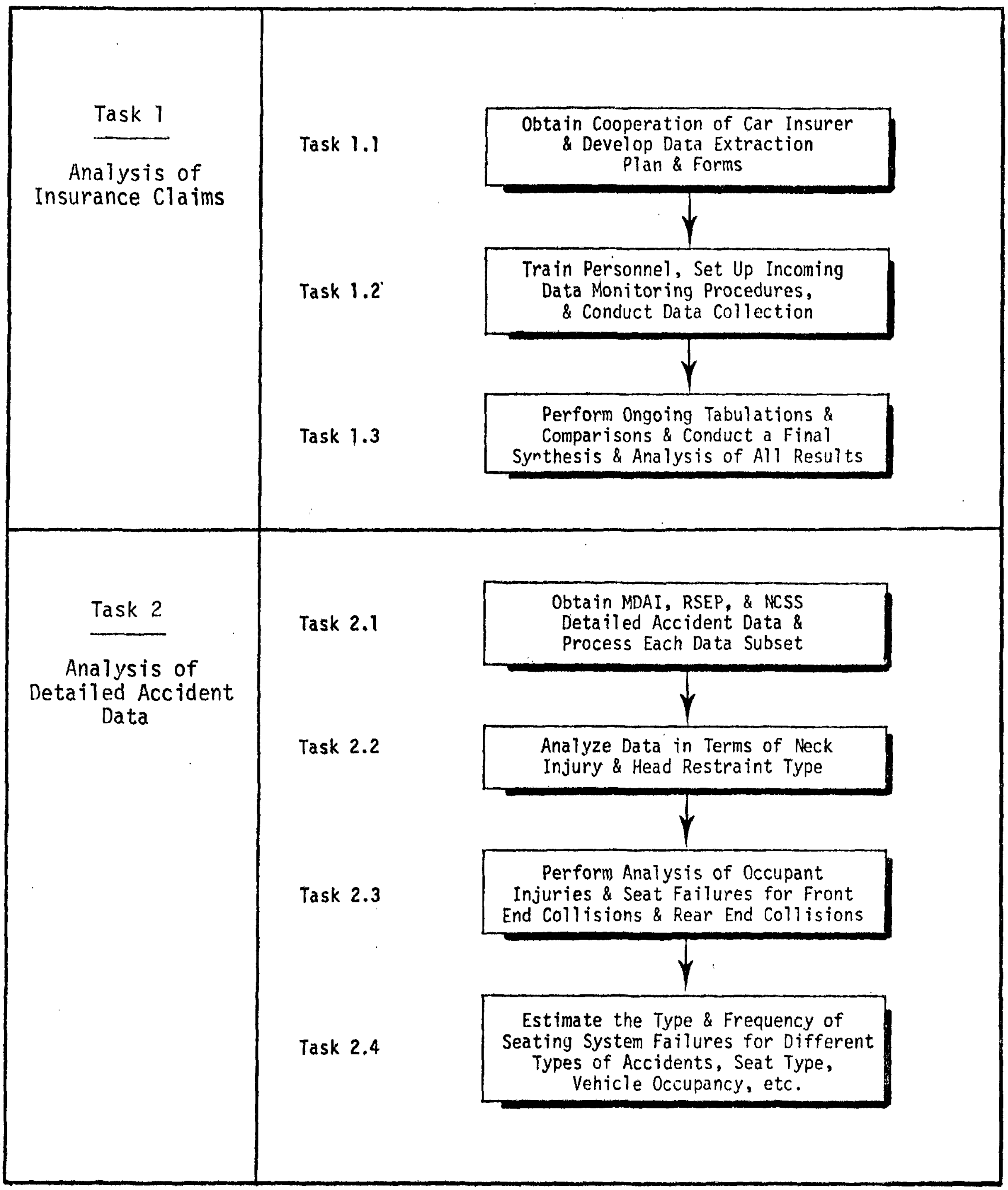

Figure 5-1. Flow chart for proposed study to evaluate FMVSS 202/207: Head Restraints/Seating Systems.

Task 3 Analysis of Occupant Fatalities	Task 3.1	Conduct Clinical Analyses of Fire-Related Accidents from MDAI, NCSS & Other Data Sources
	Task 3.2	Obtain or Access FARS Data Files & Extract & Process Required Subsets of Data
	Task 3.3	Analyze Fatality & Injury Rates as a Function of Seat Occupancy & Car Type (2-Door *vs.* 4-Door) for Pre- and Post-Standard Cars
Task 4 Analysis of Mass Accident Data	Task 4.1	Obtain Mass Accident Data Bases (or Access) for Texas, North Carolina, & New York for 1968 through 1971
	Task 4.2	Prepare Data Subset to Analyze Driver & Front Seat Occupants in Front End Collisions
	Task 4.3	Perform Analysis Proceeding from Pre-Standard *vs.* Post-Standard to More Detailed Categorization

Figure 5-1 (Continued).

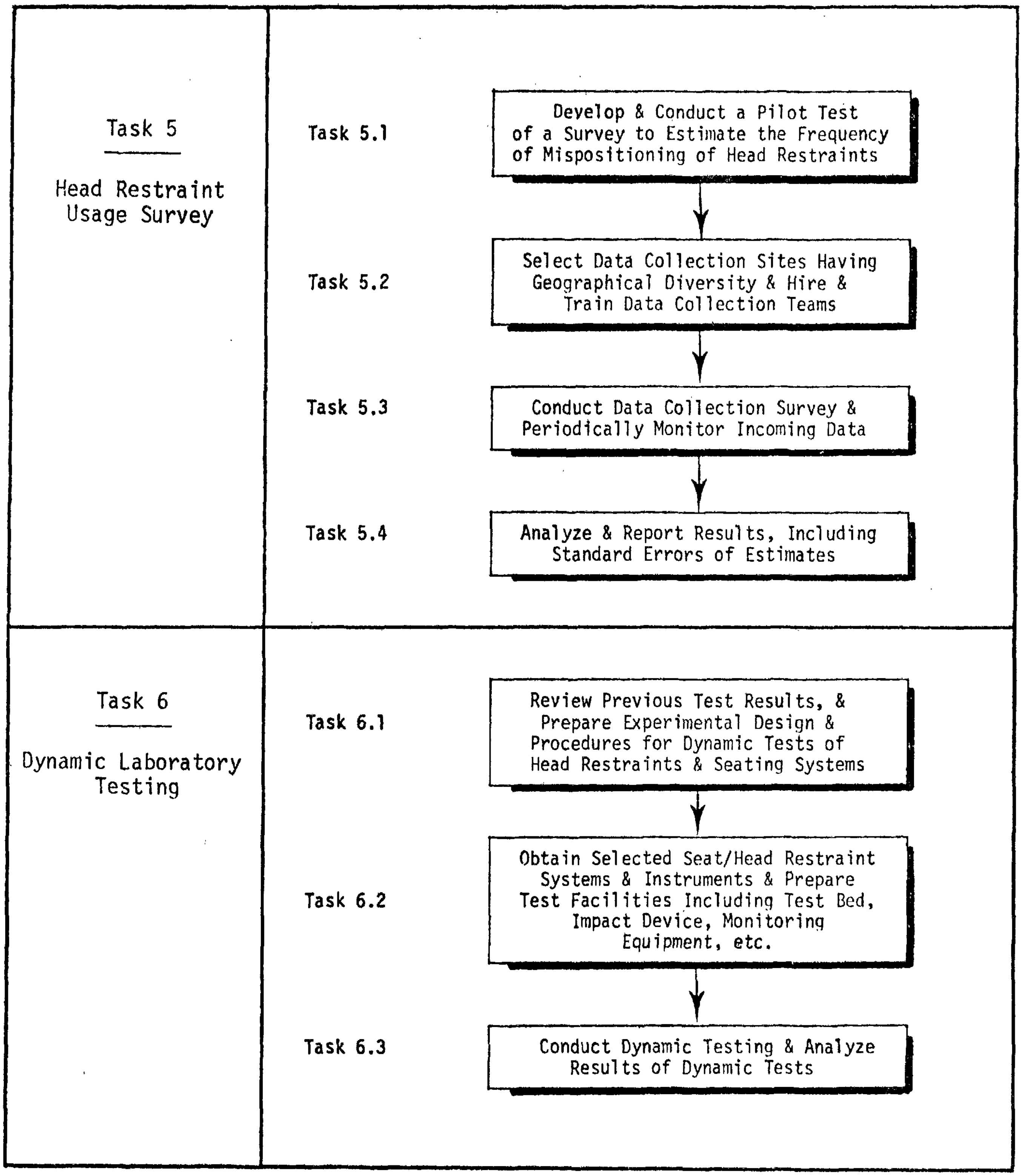

Figure 5-1 (Continued).

Task	Subtask	Description
Task 7 Instrumented Vehicles Data Collection and Analysis	Task 7.1	Plan & Conduct Pilot Study to Assess Sensing Units Required & Calibration Procedures, Data to be Collected, & Processing Procedures to be Followed
	Task 7.2	Install Instrumentation in 50,000 Vehicles in NHTSA Program & Plan Vehicle Tracking Program
	Task 7.3	Conduct Vehicle Tracking & Special Accident Investigations Over a Two-Year Period of Vehicle Exposure & Process Data
	Task 7.4	Analyze Data on Acceleration, Head Restraint Performance, Neck Injuries & Other Injuries & Seating System Damage & Failure
Task 8 Cost Data Analysis	Task 8.1	Review Frequency Sampling Plan to Obtain Cost Data to Evaluate Cost of FMVSS 202 & FMVSS 207
	Task 8.2	Acquire Cost Data from Manufacturers, NHTSA, & Other Relevant Sources
	Task 8.3	Establish Costs of Compliance with FMVSS 202 & FMVSS 207 by Manufacturer & Market Class

Figure 5-1 (Concluded).

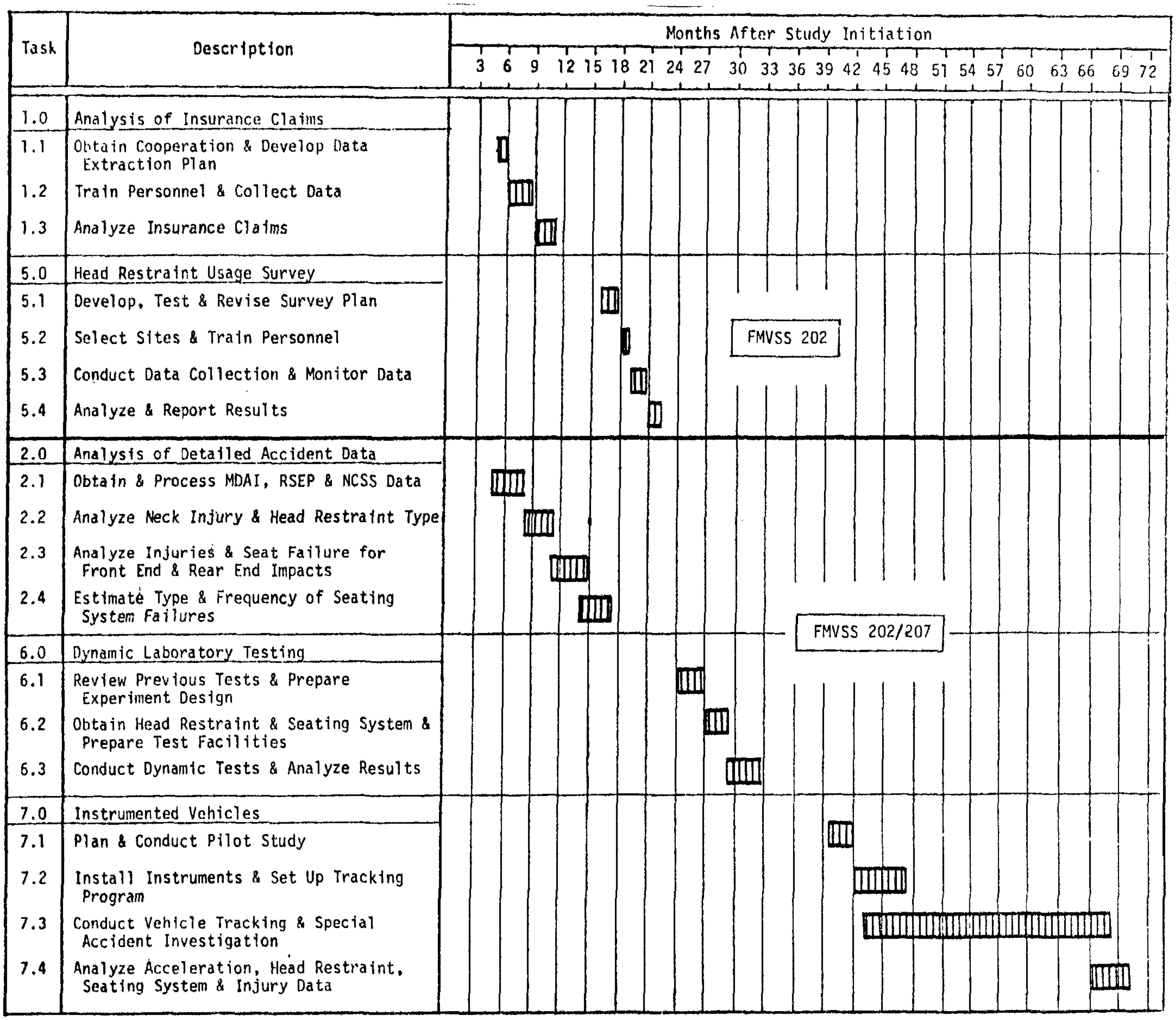

Figure 5-2. Schedule of tasks for evaluation of FMVSS 202/207: Head Restraints/Seating Systems.

Task	Description	Staff Years	Staff Cost ($)	Data Processing Cost ($)	Lab Cost ($)	Equip-ment Cost ($)	Field Data Cost ($)	Total Cost ($)
1.0	Analysis of Insurance Claims							
1.1	Obtain Cooperation & Develop Data Extraction Plan	0.2	10K	-	-	-	-	10K
1.2	Train Personnel & Collect Data	0.7	20K	-	-	-	-	20K
1.3	Analyze Insurance Claims	0.4	20K	2K	-	-	-	22K
	Total	1.3	50K	2K	-	-	-	52K
5.0	Head Restraint Usage Survey							
5.1	Develop, Test & Revise Survey Plan	0.3	12K	-	-	-	-	12K
5.2	Select Sites & Train Personnel	0.2	10K	-	-	-	-	10K
5.3	Conduct Data Collection & Monitor Data	0.7	20K	1K	-	-	-	21K
5.4	Analyze & Report Results	0.3	13K	1K	-	-	-	14K
	Total	1.5	55K	2K	-	-	-	57K
2.0	Analysis of Detailed Accident Data							
2.1	Obtain & Process MDAI, RSEP & NCSS Data	0.3	15K	1K	-	-	-	16K
2.2	Analyze Neck Injury & Head Restraint Type	0.4	20K	1K	-	-	-	21K
2.3	Analyze Injuries & Seat Failure for Front End & Rear End Impacts	0.4	20K	2K	-	-	-	22K
2.4	Estimate Type & Frequency of Seating System Failures	0.4	20K	1K	-	-	-	21K
	Total	1.5	75K	5K	-	-	-	80K
6.0	Dynamic Laboratory Testing							
6.1	Review Previous Tests & Prepare Experiment Design	0.4	20K	-	-	-	-	20K
6.2	Obtain Head Restraint & Seating System & Prepare Test Facilities	0.4	20K	-	-	67K	-	87K
6.3	Conduct Dynamic Tests & Analyze Results	3.2	140K	3K	50K	-	-	193K
	Total	4.0	180K	3K	50K	67K	-	300K
7.0	Instrumented Vehicles							
7.1	Plan & Conduct Pilot Study	0.3	15K	-	50K	-	-	65K
7.2	Install Instruments & Set Up Tracking Program	0.2	10K	-	-	500K	-	510K
7.3	Conduct Vehicle Tracking & Special Accident Investigation	1.5	75K	-	-	-	50K	125K
7.4	Analyze Acceleration, Head Restraint, Seating System & Injury Data	0.5	25K	5K	-	-	-	30K
	Total	2.5	125K	5K	50K	500K	50K	730K

Figure 5-3. Schedule of required resources for evaluation of FMVSS 202/207.

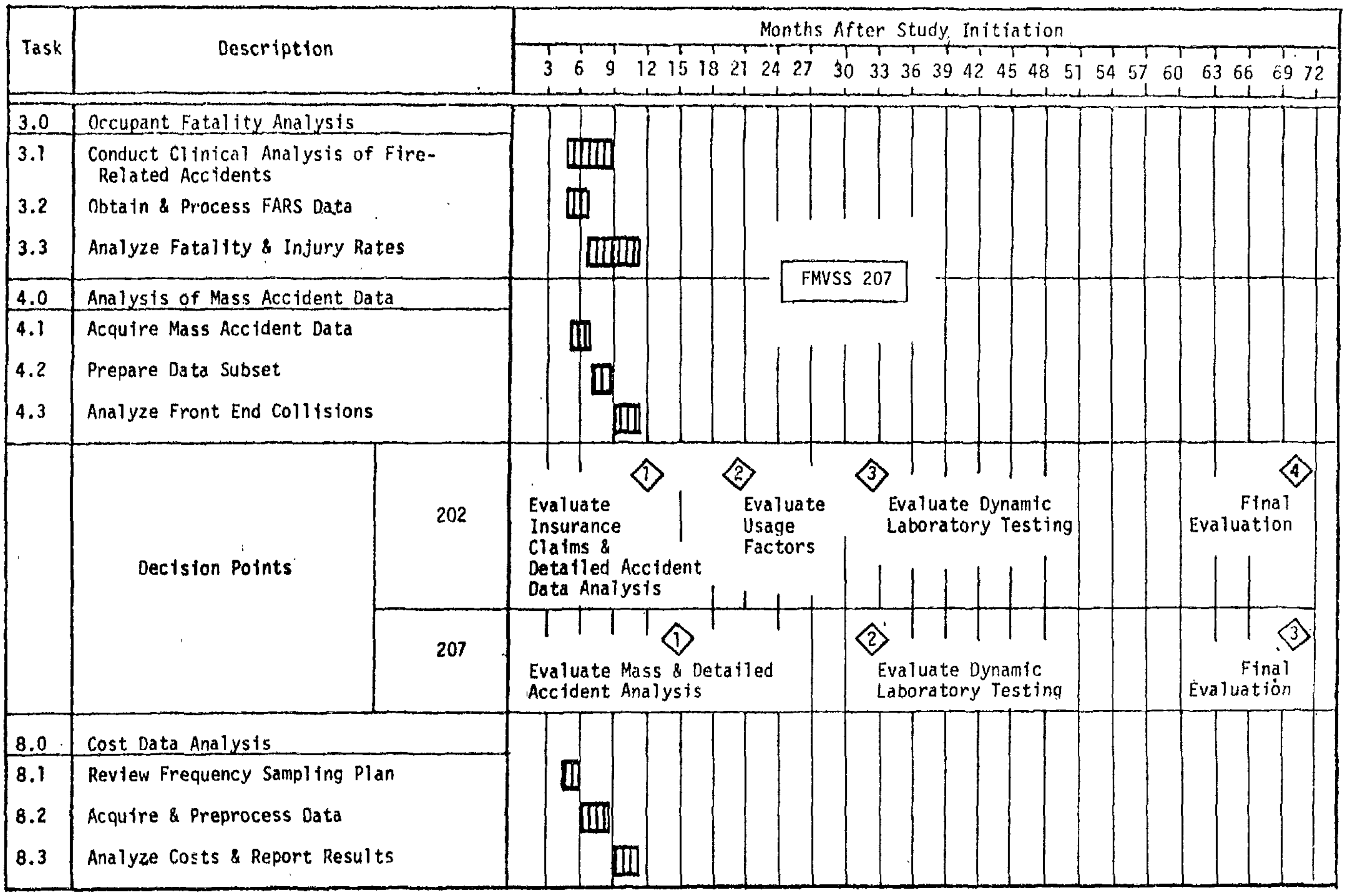

Figure 5-2 (Continued).

Task	Description	Staff Years	Staff Cost ($)	Data Processing Cost ($)	Lab Cost ($)	Equip-ment Cost ($)	Field Data Cost ($)	Total Cost ($)
3.0	Occupant Fatality Analysis							
3.1	Conduct Clinical Analysis of Fire-Related Accidents	0.2	10K	-	-	-	-	10K
3.2	Obtain & Process FARS Data	0.2	10K	1K	-	-	-	11K
3.3	Analyze Fatality & Injury Rates	0.3	15K	1K	-	-	-	16K
	Total	0.7	35K	2K				37K
4.0	Analysis of Mass Accident Data							
4.1	Acquire Mass Accident Data	0.2	10K	-	-	-	-	10K
4.2	Prepare Data Sheet	0.2	8K	2K	-	-	-	10K
4.3	Analyze Front End Collisions	0.4	20K	2K	-	-	-	22K
	Total	0.8	38K	4K	-	-	-	42K
8.0	Cost Data Analysis							
8.1	Review Frequency Sampling Plan	0.1	5K	-	-	-	-	5K
8.2	Acquire & Preprocess Data	0.4	20K	1K	-	-	-	21K
8.3	Analyze Costs & Report Results	0.5	30K	1K	-	-	-	31K
	Total	1.0	55K	2K	-	-	-	57K
	Grand Total	13.3	613K	25K	100K	567K	50K	1,355K

Figure 5-3 (Continued).

the results are evaluated at Month 33 (Decision Point #3 for FMVSS 202 and Decision Point #2 for FMVSS 207). If the Standards cannot be evaluated at this point, a two and one-half year effort to instrument vehicles and collect and analyze the data under Task 7 is scheduled as the final Task. The results of this Task will permit a final evaluation at Month 70.

Assuming all Tasks are carried out, the estimated resources required for evaluating the effectiveness of both Standards is $1,355,000. This figure includes estimated requirements of over 13 staff years. Because of the length of the seventh Task (Instrumented Vehicles), the entire study would require almost six years. If Task 7 is not performed, the cost of the entire study would be reduced to $625,000 and could be completed in less than three years.

5.1 Task 1 - Analysis of Insurance Claims

Task 1 is concerned with establishing whether a significant reduction in the frequency of neck injury complaints has occurred due to the FMVSS 202. Claims from the 1969-1970 calendar years would be investigated. The extraction of claim data does require considerable effort, but the relatively modest statistical analysis envisioned may permit a sample size of about 10,000 claims. It would be essential to the study to secure the cooperation of an automobile insurer with nationwide exposure. A data extraction plan and forms must be prepared after examining a sample of claims. Personnel would be trained in data extraction and a procedure for quality control monitoring of incoming data established. Initial data tabulations and statistical comparisons could be made as the data accumulate.

It is estimated that six months will be required for the completion of Task 1, assuming that cooperation of an automobile insurer will permit rapid and efficient access to insurance claims. The total resources required for Task 1 are estimated to be $52,000. This total includes about 1.3 staff-years of effort and $2,000 for data processing.

5.2 Task 2 - Analysis of Detailed Accident Data

The purpose of Task 2 in terms of FMVSS 202 is to analyze the generation of neck injuries in accidents, primarily rear-end accidents. The study will require existing detailed accident data from MDAI, RSEP, and NCSS. The initial analysis is concerned with determining whether a significant reduction in the frequency of neck injuries for front seat occupants in vehicles with head restraints has occurred. In addition to injuries, variables of importance include type of collision, seating position, seat type, head restraint type, seat restraint, occupant age, sex, height and weight, and vehicle factors. A second analysis will attempt to determine if there is a difference in performance among different types of head restraints. Vehicle factors such as model year, type, weight and speed of impact must be considered, as well as the above-mentioned variables.

The purpose of Task 2 in terms of FMVSS 207 is to analyze the incidence of occupant injury and seat failure as a function of accident type, vehicle occupancy, seat type and other relevant variables. Detailed accident data from MDAI and NCSS will be evaluated in a two-part analysis. First, occupant injury and front seat failure are analyzed in front-end and rear-end accidents. In front-end accidents, the data are stratified according to occupancy or no-occupancy in the back seat. Injuries to rear seat passengers are also investigated, as a function of seat failure. A similar analysis is performed in rear-end accidents except that rear seat occupancy is not considered. Second, the frequency and type of seating system failure is evaluated for different accident types, seat types, vehicle occupancy, etc.

It is estimated that one year will be required for the completion of the Task 2 study. The total resources required for Task 2 are estimated to be $80,000. This total includes about 1.5 staff-years of effort and $5,000 for data processing.

5.3 Task 3 - Occupant Fatality Analysis

The main purpose of Task 3 is to study fatality rate of front and rear seat occupants using FARS data. One aspect of the study is to investigate the possibility that the introduction of the self-locking device for folding front seat backs on 2-door cars may increase the possibility of a back seat occupant being trapped in a panic situation when quick emergency exit from the car is required. In addition to the FARS statistical analyses, a case-by-case clinical analysis of accidents involving fire in the MDAI and NCSS detailed accident data base will be made. The analysis will be concerned with type and severity of injury to occupants, whether front and back seat occupants escaped, car type, seat type, etc. Fatalities and injuries in FARS will be analyzed with respect to front and back seat occupants in 2-door and 4-door cars for Pre-Standard and Post-Standard model years. Comparison of make/model groupings will be undertaken. The results of the clinical analysis will be compared with the statistical analysis of the FARS data.

It is estimated that the modest effort under Task 3 can be completed in six months. The Task work can begin during the first year of the overall study to evaluate FMVSS 202 and FMVSS 207. The total resources required for Task 3 are estimated to be only $37,000. This total includes accomplishing the Task effort with 0.7 staff-years and $2,000 for data processing costs.

5.4 Task 4 - Analysis of Mass Accident Data

Task 4 is concerned with determining if any effects of the Standard on injury avoidance can be determined from mass accident data. Suggested data sources are the HSRI data files as well as complete Texas, North Carolina, and New York accident data of 1968 through 1971. The analysis will be directed toward determining whether in front-end collisions there are any differences in driver and upfront passenger injuries between 2-door and 4-door cars in Pre-Standard and

Post-Standard model years. Essentially, the analysis is investigating whether the injury rate in 2-door cars changes as a result of the requirement of the self-locking device for folding seats while no similar change is found in 4-door cars. Where appropriate, similar make/models will be compared.

It is estimated that six months will be required for the completion of the Task 4 effort. This estimate assumes prompt acquisition and/or accessing multiple mass accident data sources. The total resources required for Task 1 are estimated to be $42,000. This total includes accomplishing the Task effort with 0.8 staff-years and $4,000 for data processing.*

5.5 Task 5 - Head Restraint Usage Survey

The purpose of Task 5 is to conduct a survey of misuse of head restraint systems. The survey would attempt to estimate the frequency of mispositioning of head restraints. This frequency could vary with a fairly large number of factors and this must be considered in the development of a survey plan that will be tested with a pilot study. The pilot study will test data processing procedures and initial data tabulations as well as data collection. The eventual selection of several data collection sites might be according to geographic diversity, highway type, and traffic density. Time of day must be considered in actual data collection. Other variables of interest include driver age, sex and height, seat type, and head restraint type. The conduct of the study will require training of personnel, monitoring data collection and processing and analyzing results, including standard errors of estimates.

It is estimated that six months will be required for the completion of the Task 5 effort. The Task is not scheduled to begin until 16 months after the start of the overall evaluation study. This will permit a revised assessment of the need for the Task 5 effort. The Task work should be undertaken only if the Task 2 study demonstrates a difference in the overall effectiveness of unadjusted and correctly adjusted head restraints. The total resources required for Task 5 are estimated to be $57,000. This total includes about 1.5 staff-years of effort and $2,000 for data processing.

*CEM's estimates are based on the assumption that this work will be conducted by a contractor who already has most of the data tapes. We recognize that there is a certain likelihood that this work will be done in-house by NHTSA, with appropriate cost savings.

5.6 Task 6 - Dynamic Laboratory Testing

Task 6 is concerned with dynamic laboratory testing of head restraints and seating systems to establish performance characteristics. The purpose of the study with regard to FMVSS 202 is to establish the performance characteristics of different head restraint devices under off-center and angular impacts. The twisting of head restraints upon impact and great differences between rebound from the seat and head restraint are not desirable. Head restraints and seat backs can be instrumented to determine the degree of resistance--both longitudinal and in rotation. The critical factors in this study approach relate more to engineering and testing capabilities than to analytic sophistication. Past tests on head restraining devices and seating systems will be reviewed. Prior to the actual tests, considerable preparation is required. Selected seat/head restraint systems and instruments must be obtained. The test facilities, including test bed, impact device, monitoring equipment, etc. must be prepared. The results of the tests will be compared, analyzed and reported.

The purpose of this study with regard to FMVSS 207 is to conduct dynamic tests of selected seating systems, both Pre-Standard and Post-Standard, to evaluate the effects of the Standard on seating strength and to suggest possible additional criteria for the requirements of the Standard. Dynamic testing of a variety of seating system types from cars, multipurpose vehicles, trucks and buses will be undertaken for varying acceleration exposures, seating arrangements, occupant (dummy) dimensions, restraint usage and seat adjustment in track (if applicable). Free body analysis of the seating system comprised of the occupant seat with attachments, and seat restraints will be carried out.

It is estimated that about nine months would be required for the completion of the Task 6 study which is scheduled to be undertaken during the third year of the overall FMVSS 202 and FMVSS 207 evaluation study. The total resources required for Task 6 are estimated to be $300,000. This total includes about four staff-years of effort , $67,000 for equipment costs, $50,000 for laboratory costs and $3,000 for data processing.

5.7 Task 7 - Instrumented Vehicles Data Collection and Analysis

Task 7 is directed toward improving the understanding of the performance of head restraints and seating systems in real world crashes. For this purpose, a fleet of selected vehicles, perhaps numbering 50,000 would be instrumented. This number of vehicles may be instrumented under a NHTSA program concerned with brake performance and vehicle handling. The basic additional information that would be useful relates to acceleration (lateral and longitudinal) of the vehicle's center of gravity, and accelerations or forces on the head restraint, seat back, seat anchors, seat tracks, and seat latches.

The rate of reportable accidents from 50,000 vehicles would require approximately a 2-year period of accident exposure,and special accident investigations would have to be conducted in order to use the crash reconstruction programs for accident data evaluation. The program plan must include (1) specification of sensing units required and instrumentation of vehicles; (2) data to be collected, data processing procedures and data usage; (3) pilot program for testing; (4) vehicle tracking program and special accident investigations; and (5) analysis of data.

It is estimated that at least two and one-half years would be required for the completion of the Task 7 effort. This plan allows for a 2-year data collection period. It is recognized that not all of the target 50,000 vehicles would necessarily be "in the field" during the entire two years (i.e., a greater lead time may be required in getting the selected instrumented vehicles into the field and some vehicles will be removed due to accidents). The costs for this Task are estimated with the assumption that the costs of the basic crash recorders for the 50,000 vehicles are assumed under another NHTSA program. It is assumed that the cost of manufacture and installation of the additional head restraint and seating system instruments is approximately $10/vehicle. Thus, the total resources required for Task 7 are estimated to be $730,000. This total includes about 2.5 staff-years of effort, $500,000 for equipment costs, $50,000 for field data costs, $50,000 for laboratory testing and $5,000 for data processing.

5.8 Task 8 - Cost Data Analysis

Task 8 is concerned with the determination of direct costs to implement FMVSS 202 and FMVSS 207. 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 has been developed which assumes that the manufacturer's cost of compliance varies according to the manufacturer and vehicle weight or class. The two levels of interest for both Standards are:

1. Manufacturer: GM, Ford, Chrysler, AMC, VW, Toyota.
2. Size: Subcompact, Compact, Intermediate, Full Size, Luxury, and Other.

Additionally, in the evaluation of FMVSS 202, the sampling plan must consider adjustable and fixed restraints and in the evaluation of FMVSS 207, the sampling plan must differentiate between 2-door and 4-door cars.

The cost of compliance is of interest in two aspects: total cost and cost per vehicle. For total cost, models should be assigned on the basis of their dollar share of the market, and for per vehicle costs, models should be chosen on the basis of vehicle share of the market. In this way, the standard error of the overall cost estimates is minimized.

Task 8 will be completed in six months during the first year of the study. It is estimated that the total resources required are $57,000; this includes 1.0 staff-years of effort and $2,000 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

FEDERAL MOTOR VEHICLE SAFETY STANDARDS 202/207:

HEAD RESTRAINTS/SEATING SYSTEMS

MOTOR VEHICLE SAFETY STANDARD NO. 202

Head Restraints—Passenger Cars

S1. Purpose and Scope. This standard specifies requirements for head restraints to reduce the frequency and severity of neck injury in rear-end and other collisions.

S2. Application. This standard applies to passenger cars.

S3. Definitions. "Head restraint" means a device that limits rearward angular displacement of the occupant's head relative to his torso line.

S4. Requirements. A head restraint that conforms to either (a) or (b) shall be provided at each outboard front designated seating position—

(a) It shall, when tested in accordance with S5.1, during a forward acceleration of at least 8g on the seat supporting structure, limit rearward angular displacement of the head reference line to 45° from the torso reference line; or

(b) It shall, when adjusted to its fully extended design position, conform to each of the following—

(1) When measured parallel to torso line, the top of the head restraint shall not be less than 27.5 inches above the seating reference point;

[(2) When measured either 2.5 inches below the top of the head restraint, or 25 inches above the seating reference point, the lateral width of the head restraint shall be not less than—

(i) 10 inches for use with bench-type seats; and

(ii) 6.75 inches for use with individual seats; (33 F.R. 15066—Oct. 9, 1968)]

(3) When tested in accordance with S5.2, the rearmost portion of the head form shall not be displaced to more than 4 inches perpendicularly rearward of the displaced entended torso reference line during the application of the load specified in S5.2(c); and

(4) When tested in accordance with S5.2, the head restraint shall withstand an increasing load until one of the following occurs—

(i) Failure of the seat or seat back; or

(ii) Application of a load of 200 pounds.

S5. Demonstration Procedures.

S5.1 [Compliance with S.4(a) shall be demonstrated in accordance with the following with the head restraint in its fully extended design position:

(a) On the exterior profile of the head and torso of a dummy having the weight and seated height of a 95th percentile adult male with an approved representation of a human, articulated neck structure, or an approved equivalent test device, establish reference lines by the following method:

(1) Position the dummy's back on a horizontal flat surface with the lumbar joint in a straight line.

(2) Rotate the head of the dummy rearward until the back of the head contacts the same horizontal surface in (1).

(3) Position the SAE J-826 two-dimensional manikin's back against the flat surface in (1), alongside the dummy with the h-point of the manikin aligned with the h-point of the dummy.

(4) Establish the torso line of the manikin as defined in SAE Aerospace-Automotive Drawing Standards, Sec. 2.3.6, P. E1.01, September 1963.

(5) Establish the dummy torso reference line by superimposing the torso line of the manikin on the torso of the dummy.

(6) Establish the head reference line by extending the dummy torso reference line onto the head.

(b) At each designated seating position having a head restraint, place the dummy, snugly restrained by a Type 1 seat belt, in the manufacturer's recommended design seated position. (33 F.R. 5793—April 16, 1968)]

[(c) During a forward acceleration applied to the structure supporting the seat as described below, measure the maximum rearward angular displacement between the dummy torso reference line and the head reference line. When graphically depicted, the magnitude of the acceleration curve shall not be less than that of a half-sine wave having the amplitude of 8g and a duration of 80 milliseconds and not more than that of a half-sine wave curve having an amplitude of 9.6g and a duration of 96 milliseconds. (33 F.R. 15066—Oct. 9, 1968)]

[S5.2 Compliance with § 4.(b) shall be demonstrated in accordance with the following with the head restraint in its fully extended design position:

(a) Place a test device, having the back pan dimensions and torso line, (centerline of the head room probe in full back position) of the three dimensional SAE J-826 manikin, at the manufacturer's recommended design seated position.

(b) Establish the displaced torso reference line by applying a rearward moment of 3300 in. lb. about the seating reference point to the seat back through the test device back pan located in (a).

(c) After removing the back pan, using a 6.5 inch diameter spherical head form or a cylindrical head form having a 6.5 inch diameter in plain view and a 6-inch height in profile view, apply, perpendicular to the displaced torso reference line, a rearward initial load 2.5 inches below the top of the head restraint that will produce a 3300 in. lb. moment about the seating reference point.

(d) Gradually increase this initial load to 200 lbs. or until the seat or seat back fails, whichever occurs first. (33 F.R. 5793—April 16, 1968)]

33 F.R. 15065
October 9, 1968

MOTOR VEHICLE SAFETY STANDARD NO. 207

Seating Systems—Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses (Docket No. 2–12; Notice No. 3)

S1. *Purpose and scope.* This standard establishes requirements for seats, their attachment assemblies, and their installation to minimize the possibiilty of their failure by forces acting on them as a result of vehicle impact.

S2. Application. This standard applies to passenger cars, multipurpose passenger vehicles, trucks and buses.

S3. Definition. "Occupant seat" means a seat that provides at least one designated seating position.

S4. Requirements.

S4.1 Driver seat. Each vehicle shall have an occupant seat for the driver.

S4.2 General performance requirements. When tested in accordance with S5, each occupant seat, other than a side-facing seat or a passenger seat on a bus, shall withstand the following forces:

(a) In any position to which it can be adjusted—20 times the weight of the seat applied in a forward longitudinal direction;

(b) In any position to which it can be adjusted—20 times the weight of the seat applied in a rearward longitudinal direction;

(c) For a seat belt assembly attached to the seat—the force specified in subparagraph (a), if it is a forward facing seat, or subparagraph (b), if it is a rearward facing seat, in each case applied simultaneously with the forces imposed on the seat by the seat belt assembly when it is loaded in accordance with section S4.2 of Federal Motor Vehicle Safety Standard No. 210; and

(d) In its rearmost position—a force that produces a 3,300 inch-pound moment about the seating reference point for each designated seating position that the seat provides, applied to the upper cross-member of the seat back or the upper seat back, in a rearward longitudinal direction for forward-facing seats and in a forward longitudinal direction for rearward-facing seats.

S4.2.1 Seat adjustment. Except for vertical movement of nonlocking suspension type occupant seats in trucks or buses, the seat shall remain in its adjusted position during the application of each force specified in S4.2.

S4.3 Restraining device for hinged or folding seats or seat backs. Except for a passenger seat in a bus or a seat having a back that is adjustable only for the comfort of its occupants, a hinged or folding occupant seat or occupant seat back shall be equipped with a self-locking device for restraining the hinged or folding seat or seat back and a control for releasing that restraining device.

S4.3.1 Accessibility of release control. [If there is a designated seating position immediately behind a seat equipped with a restraining device, the control for releasing the device shall be readily accessible to the occupant of the seat equipped with the device and, if access to the control is required in order to exit from the vehicle, to the occupant of the designated seating position immediately behind the seat. (36 F.R. 7419—April 20, 1971. Effective: 1/1/72)]

S4.3.2 Performance of restraining device.

S4.3.2.1 Static force.

(a) Once engaged, the restraining device for forward-facing seat shall not release or fail when a forward longitudinal force equal to 20 times the weight of the hinged or folding portion of the seat is applied through the center of gravity of that portion of the seat.

(b) Once engaged, the restraining device for a rearward facing seat shall not release or fail when a rearward longitudinal force equal to 8 times the weight of the hinged or folding portion of the seat is applied to the center of gravity of that portion of the seat.

S4.3.2.2 Acceleration. Once engaged, the restraining device shall not release or fail when the device is subjected to an acceleration of 20 g. in the longitudinal direction opposite to that in which the seat folds.

S4.4 Labeling. Seats not designated for occupancy while the vehicle is in motion shall be conspicuously labeled to that effect.

S5. Test procedures.

S5.1 Apply the forces specified in S4.2(a) and S4.2(b) as follows:

S5.1.1 If the seat back and the seat bench are attached to the vehicle by the same attachments,

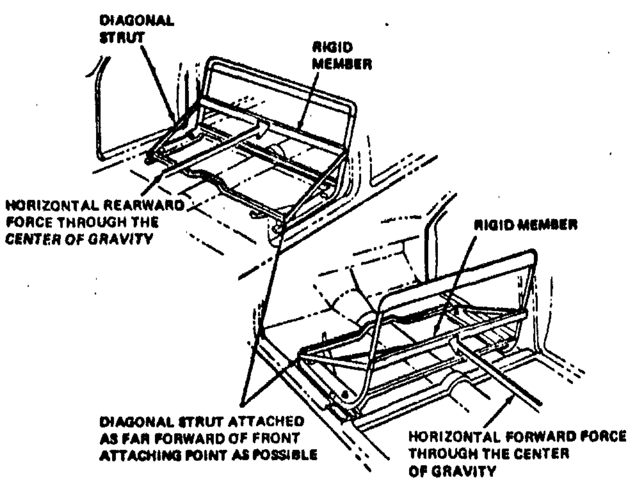

FIGURE 1

secure a strut on each side of the seat from a point on the outside of the seat frame in the horizontal plane of the seat's center of gravity to

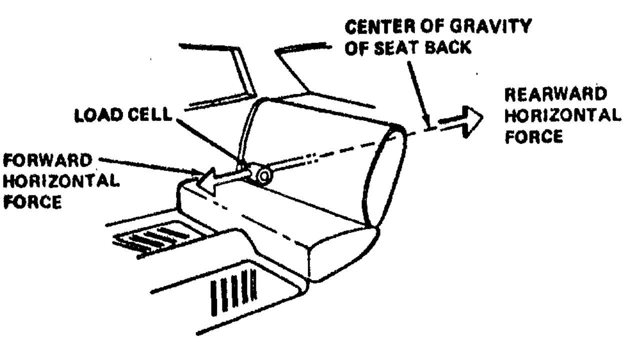

FIGURE 2

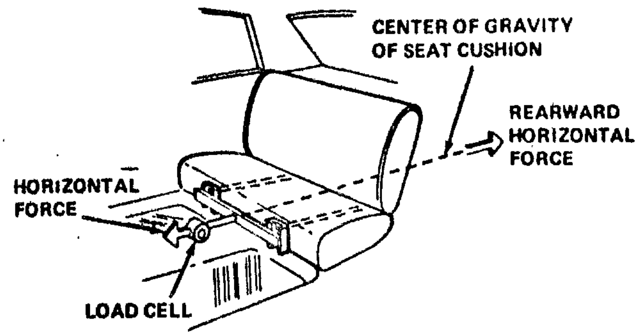

FIGURE 3

a point on the frame as far forward as possible of the seat anchorages. Between the upper ends of the struts place a rigid cross-member, in front of the seat back frame for rearward loading and behind the seat back frame for forward loading.

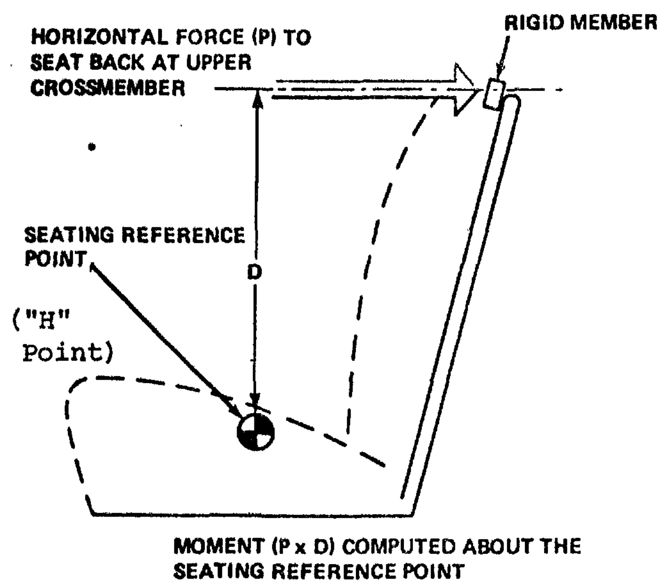

FIGURE 4

Apply the force specified by S4.2(a) or S4.2(b) horizontally through the rigid cross-member as shown in figure 1.

S5.1.2 If the seat back and the seat bench are attached to the vehicle by different attachments, attach to each component a fixture capable of transmitting a force to that component. Apply forces equal to 20 times the weight of the seat back horizontally through the center of gravity of the seat back, as shown in figure 2, and apply forces equal to 20 times the weight of the seat bench horizontally through the center of gravity of the seat bench, as shown in figure 3.

S5.2 Develop the moment specified in S4.2(d) as shown in figure 4.

S5.3 Apply the forces specified in S4.3.2.1 (a) and (b) to a hinged or folding seat as shown in figure 1 and to a hinged or folding seat back as shown in figure 5.

S5.4 Determine the center of gravity of a seat or seat component with all cushions and upholstery in place and with the head restraint in its fully extended design position.

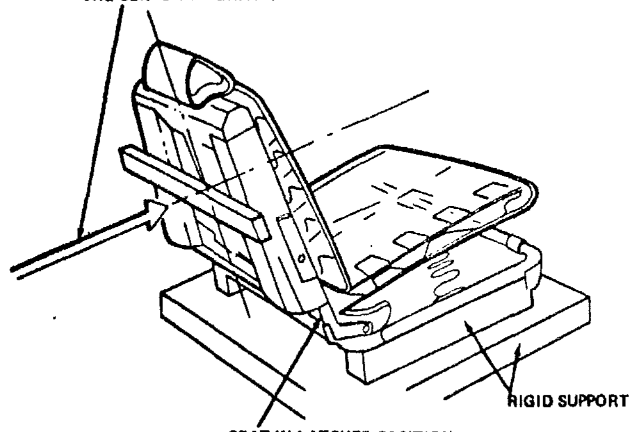

FIGURE 5

35 F.R. 15290
October 1, 1970

APPENDIX B

DISCUSSION OF
STATISTICAL TECHNIQUES

DISCUSSION OF STATISTICAL TECHNIQUES

INTRODUCTION

The field of statistics has grown out of a variety of disciplines such as political science, economics, biology, geology and agricultural genetics. Statistical techniques address a variety of problems faced by each of these disciplines. During this century, various mathematical foundations have been constructed for the field of statistics and many of the seemingly disparate techniques have been shown to be closely related in terms of their mathematical content. This similarity between techniques developed in different fields is due to the underlying similarity of the problems addressed in these fields: namely, successfully making inferences about a larger parent population, given the tremendous variation in the sampled data.

Statistics involves reducing the complexity of large amounts of data, so hypothesized relationships can be tested, while controlling for possible sources of error and extraneous variation. Some researchers emphasize statistical use of sample characteristics to make inferences about population characteristics. Some emphasize statistical use of hypothesized models and the concomitant techniques of parameter estimation, parameter testing and assessment of "goodness of fit."

Irrespective of particular emphasis, statistics is useful for the simple reason that many of the facts we wish to know are only knowable at great cost in time and effort and so we are *forced* to use a "sample" of manageable size to provide us with an approximate understanding of the situation. Economically, statistics allows us to arrive at highly probable answers by analyzing only a small subset of information on the total population considered.

In a field such as statistics where techniques have been developed from many different perspectives,it is not surprising to find that supposedly different techniques overlap in applicability and indeed sometimes may be shown to be equivalent. With the advent of readily available computers and statistical software, numerous investigators in the life sciences and natural sciences are discovering for themselves the usefulness of using a multiplicity of techniques to explore their data. For, while it is the rare data set that can satisfy all the technical assumptions of any given statistical technique, it is *also* the rare statistical technique that is so "unstable" as to demand that all of its technical assumptions be met exactly. This property of being "robust," i.e., continuing to produce reasonable answers under a variety of unreasonable conditions, is enjoyed by many of the statistical techniques that are applicable to the data bases available for the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards (FMVSS). Indeed, today many of the classical statistical techniques are being rebuilt in more robust form and there are available a variety of robust modifications to the processes of estimation that are amenable to any linear model situation, e.g., regression, analysis of variance, and loglinear analysis [1].

Besides both the creation of software packages supplying a variety of high quality statistical procedures and the development of robust techniques of inference, the last decade has also seen the development of new techniques, new software and, indeed, a new way of thinking about data analysis. John Tukey was one of the first to call attention to the split in statistical analysis between those textbook techniques that are perfect for well controled experiments and the less formal techniques and procedures that are useful for undesigned experiments or when simply "exploring" new data. Tukey christened the former "confirmatory data analysis" and the latter "exploratory data analysis." The original analogy used to contrast the two sets of attitudes was to point to the differences between formal court proceedings used to arrive at "the truth" *versus* the more intuitive and less formal inferential behavior that a good detective, such as Sherlock Holmes, would allow himself in the process of collecting evidence that might or might not be used in a formal court proceeding at some later data. While exploratory data analysis is never an answer in itself, experience with its techniques has shown that it has unique value to the researcher when faced with large, complex and perhaps faulty data bases. An introduction to the wealth of techniques in exploratory data analysis is available from Tukey's text and computer software for many of these techniques exists at a number of the larger university computer centers [2].

Recently the field of data analysis (as differentiated from formal mathematical statistics) has also been influenced by the development of useable "Bayesian" and pseudo-Bayesian techniques of inference. While these techniques are firmly rooted in a purely mathematical foundation of inference, their acceptance has been limited, due to the continuing controversy among statisticians as to their appropriateness in various situations. The nub of the problem is that Bayesian techniques make a point of allowing prior information (sometimes subjectively arrived at) to influence the results of estimation, model building and, indeed, the complete process of inference from data. Such honesty about the use of subjective information obviously is disturbing to those who feel that data analysis both can and should be a totally objective process. However, the benefits of Bayesian and pseudo-Bayesian techniques are quite attractive and their use by a researcher in dealing with a real analysis problem should not be seen as an endorsement of the full Bayesian philosophy of inference. Bayesian-like techniques of data smoothing and of simultaneously estimating many parameters are of real value when trying to reduce the complexity and dimensionality of multidimensional data sets. Similarly, such techniques allow a researcher to incorporate previous data bases into the analysis of his present data base in a logical, mathematically tractable and theoretically desirable way. Most classical statistical procedures are hard put to find a way to use such prior information when exploring a new data base.

When addressing the particular problems of measuring the effectiveness of various FMVSSs using the existing data bases, it would be unwise to become too attached to any one approach to the analysis. Given the variety of data bases and the variety of problems each data base presents, only a healthy electicism towards statistical method and philosophy will provide the "robustness" of inference and thoroughness of analysis necessary for adequate assessment of effectiveness. The following discussion of different statistical techniques is provided in the spirit of fostering such healthy electicism. Each technique is applicable to some of the existing data sets and, in fact, it would often be valuable to explore a particular data base using many such techniques jointly or sequentially. For example, many data bases provide the researcher with multidimensional tables of frequency counts in a number of categories. Such data are amenable to many of the exploratory data analytic techniques to look for potential structure; they are also amenable to a number of data reduction techniques such as principal component analysis and factor analysis in an effort to reduce its complexity and dimensionality; more formally, the data or some transformation of the data may be modeled, explored and smoothed using loglinear analysis. Similar analyses may be tried using classical linear models methods and "trusting" in the robustness of such methods [3]; finally, Bayesian-like techniques are applicable when such tables of counts are updated periodically and one wishes to use the structure of past tables to influence the analysis of the most recent table.

The point is that a thorough assessment of effectiveness demands a willingness to apply many techniques to each collection of data and to assess findings of each technique in light of the quirks of the data and in light of the findings of other techniques.

This appendix is intended to provide an introduction to the concepts, vocabulary and logic of some of the many statistical and data analytic techniques that are applicable to the evaluation of the effectiveness of Federal Motor Vehicle Safety Standards.

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3. Truett, J., J. Cornfield and W. Kannel. "A Multivariate Analysis of the Risk of Coronary Heart Disease in Framingham," *Journal of Chronic Disease*, vol. 20, 1967: 511-524.

ANALYSIS OF COVARIANCE

The analysis of covariance (ANACOVA) is a statistical procedure which provides a model for the behavior of a continuous dependent variable as a linear function of a set of independent variables, some of which are continuous and some of which are discrete. In this sense it combines the features of both a regression analysis (continuous independent variables) and an analysis of variance (discrete independent variables). The entire problem is handled conditionally on the values of the independent variables so that the only variation assumed is in the dependent variables.

The most natural application of ANACOVA occurs when modeling observations (Y's) which have been taken in the format of one of the usual analysis of variance designs, but other observable variables (X's) are available to the researcher and they are suspected to be contributing significant effects to the magnitudes of the Y's apart from any effects in the analysis of variance portion. Then one ought to add to the model a regression of the Y's on these X's to better explain the variability of the former. The X's are called covariates or concomitant variables. The approach is to adjust the Y's according to the associated X's and only then use the adjusted Y's for analysis and interpretation of the data according to the original analysis of variance design.

An example will clarify the discussion of the previous paragraphs. Suppose we wish to study the braking distance to full stop for different vehicles. We take a set to such observation (Y's). Among the explanatory variables we might consider are:

(a) Brake type - disc, drum, disc/drum (categorical/discrete).
(b) Vehicle speed at time brakes are applied (continuous).
(c) Road surface condition - wet, dry, etc. (categorical/discrete).
(d) Vehicle weight (continuous).
etc.

If, for example, we wish to compare brake types, it is clear that any effects on stopping distance due to differences in brake types will be totally masked by the effect of vehicle speed at the time the brakes are applied. Hence, to run a meaningful test of differences in performance of brake types requires removing the effects of differing vehicle speeds at the time the brakes are applied. In this setting a test of differences among brake types would be handled by an analysis of variance while the differing vehicle speeds would be viewed as values of an independent regression variable. The addition of further discrete variables to this discussion elaborates the analysis of variance portion of the model while the addition of further continuous variables results in additional independent regression variables. However, the basic idea is unaffected. Ultimately, hypothesis tests will be developed for the presence of effects for either type of variable.

The important assumption usually demanded for a valid analysis of covariance is that the concomitant variables are unaffected by (i.e., independent of) the analysis of variance variables. In the above example, for instance, it is reasonable to assume that the vehicle speed at the time the brakes are applied is independent of the type of brake system on the vehicle. Even when such independence may not quite hold, one can still apply an analysis of covariance. However, the interpretation of the results of such an analysis must be carefully considered due to the confounding of variable effects.

We now formally develop the analysis of covariance (ANACOVA). For convenience we assume one categorical (or discrete) variable and one continuous varable and then the model:

$$(1) \quad Y_{ij} = \mu + \alpha_i + \beta(X_{ij} - \bar{X}..) + \varepsilon_{ij}$$

$$j = 1, \ldots, n_i, \; i = 1, \ldots, k$$

with

$$\bar{X}.. = \sum_{i=1}^{k} \sum_{j=1}^{n_i} X_{ij}/n \quad \text{and} \quad n = \sum_{i=1}^{k} n_i$$

In this model we would interpret Y_{ij} as the observed stopping distance of the j^{th} vehicle (or j^{th} stop of one vehicle) having brake type i. X_{ij} is the associated vehicle speed at the time the brakes were applied and is centered about $\bar{X}..$; the overall mean of the X_{ij}'s and ε_{ij} is the model error for the observations. These errors are assumed normally distributed and independent (the latter being quite reasonable in our example). The parameter μ is the overall mean braking effect; α_i is the effect due to brake type i; and β is the regression coefficient for the independent variable, vehicle speed.

Two hypotheses are of interest to test

H_1: $\alpha_1 = \alpha_2 = \ldots \alpha_k = 0$, and

H_2: $\beta = 0$

H_1 tests for the brake effects, i.e., no differences in performance of the different brake types. H_2 tests whether the inclusion of the covariate actually explained a significant amount of the variation in the Y's. Presumably H_2 will be rejected or else we would not be considering the X's in the first place. In our example, certainly vehicle speed at the time the brakes are applied affects the vehicle's stopping distance.

From (1)

$$Y_{ij} - \beta\,(X_{ij} - \bar{X}..)$$

would be exactly the adjusted observation we would want for testing H_1. Unfortunately, since β is unknown, these adjusted Y_{ij} are not "observable." However, if b is an estimate of β we will define

$$Y_{ij} - b\,(X_{ij} - \bar{X}..)$$

as the adjusted value of Y_{ij} (usually said to be adjusted to $\bar{X}..$). This adjustment of the Y observations will change the entire picture of the experiment.

Let us introduce convenient and somewhat "standard" notation for the various sums of squares to be considered.

$$S_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{..})^2$$

$$T_{yy} = \sum_{i=1}^{k} n_i (\bar{Y}_{i.} - \bar{Y}_{..})^2$$

$$E_{yy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_{i.})^2$$

$$S_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2$$

$$T_{xx} = \sum_{i=1}^{k} n_i (\bar{X}_{i.} - \bar{X}_{..})^2$$

$$E_{xx} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2$$

$$S_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})$$

$$T_{xy} = \sum_{i=1}^{k} n_i (X_{i.} - \bar{X}_{..})(\bar{Y}_{i.} - \bar{Y}_{..})$$

$$E_{xy} = \sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})$$

where

$$\bar{X}_{i.} = \sum_{j=1}^{n_i} X_{ij}/n_i \text{ and } \bar{X}_{..} \text{ as before}$$

$$\bar{Y}_{i.} = \sum_{j=1}^{n_i} Y_{ij}/n_i \text{ and } \bar{Y}_{..} = \frac{\sum_{i=1}^{k} n_i \bar{Y}_{i.}}{n} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} Y_{ij}}{n}$$

It is easy to verify that $S_{yy} = T_{yy} + E_{yy}$, $S_{xx} = T_{xx} + E_{xx}$ and $S_{xy} = T_{xy} + E_{xy}$. Computational formulas for these quantities may be easily developed by expansion.

First consider the hypothesis H_2. From (1) we may fit a regression line for each of the n_i observations at a fixed i. The resultant estimators would be

$$b_i = \frac{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i})^2} \qquad i = 1, \ldots . k$$

Pooling these estimations we obtain:

$$\bar{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})(Y_{ij} - \bar{Y}_{i.})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{i.})^2} = \frac{E_{xy}}{E_{xx}}$$

$\bar{b}^2 E_{xx}$ is the sum of squares associated with $\bar{b}$ while $E_{yy} - \bar{b}^2 E_{xx}$ is the appropriate error sum of squares. The former has one degree of freedom associated with it while the latter has $n - (k+1) = n-k-1$. Thus, we can test H_2 using:

(2) $$\frac{\bar{b}^2 E_{xx}}{(E_{yy} - \bar{b}^2 E_{xx}) / (n-k-1)}$$

The statistic (2) is distributed as F with 1 and n-k-1 degrees of freedom and we reject H_2 for large values.

While $\bar{b}$ seems to have arisen in a rather arbitrary manner, one can show that it is, in fact, the least squares estimator of β.

Returning to H_1, under this hypotheses (1) becomes

(3) $$Y_{ij} = \mu + \beta (X_{ij} - \bar{X}_{..}) + \varepsilon_{ij}$$

The model in (3) is just a simple linear regression for the entire set of n observations. The least squares estimate of β for such a model is

$$\hat{b} = \frac{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})(Y_{ij} - \bar{Y}_{..})}{\sum_{i=1}^{k} \sum_{j=1}^{n_i} (X_{ij} - \bar{X}_{..})^2} = \frac{S_{xy}}{S_{xx}}$$

$\hat{b}^2 S_{xx}$ is the sum of squares associated with $\hat{b}$ while $S_{yy} - \hat{b}^2 S_{xx}$ is the error sum of squares for fitting (3). The difference between the error sum of squares of the reduced model (3) and the error sum of squares of the full model (1) is the sum of squares associated with the α_i, i.e., with H_2 and equals

$$(S_{yy} - \hat{b}^2 S_{xx}) - E_{yy} - \bar{b}^2 E_{xx})$$

This sum of squares may be shown to have k-1 degrees of freedom associated with it while as before the error sum of squares for the full model has n-k-1. Thus, we can test H_1 using

$$(4) \qquad \frac{[(S_{yy} - \hat{b}^2 S_{xx}) - (E_{yy} - \bar{b}^2 E_{xx})]/(k-1)}{(E_{xx} - \bar{b}^2 E_{xx})/(n-k-1)}$$

The statistic (4) is distributed as F with k-1 and n-k-1 degrees of freedom and we reject H_1 for large values of F.

In addition to performing the F tests in (2) and (4) it is customary to present a table of adjusted $\bar{Y}_i$'s as an aid in interpretation. The adjusted $\bar{Y}_i$'s are defined as

$$\bar{Y}_i - \bar{b}\,(\bar{X}_{i.} - \bar{X}_{..})$$

In our example the adjusted $\bar{Y}_i$ would be the average stopping distance for vehicle(s) with brake type i adjusted for speed when brakes were applied. These adjusted average stopping distances can be compared directly to assess differences in average performance of the various brake systems.

The reader seeking further detail on the analysis of covariance may consult Bancroft or Snedecor and Cochran for elementary discussions [1,2].

To illustrate the Analysis of Covariance, consider the following fictitious data set.

Vehicle Number	Brake Configuration		Speed at Time Brakes Applied	Stopping Distance
1	Drum	Type 1	30	80 (4.38)*
2	Drum		40	105 (4.65)
3	Drum		50	170 (5.13)
4	Drum		60	240 (5.48)
5	Disc/Drum	Type 2	30	64 (4.16)
6	Disc/Drum		40	92 (4.52)
7	Disc/Drum		60	226 (5.42)
8	Disc	Type 3	30	60 (4.09)
9	Disc		50	140 (4.90)
10	Disc		60	210 (5.35)

*Values in parentheses are logarithms of stopping distances, which will be used in the alternative analysis. These values are plotted in Figure B-1.

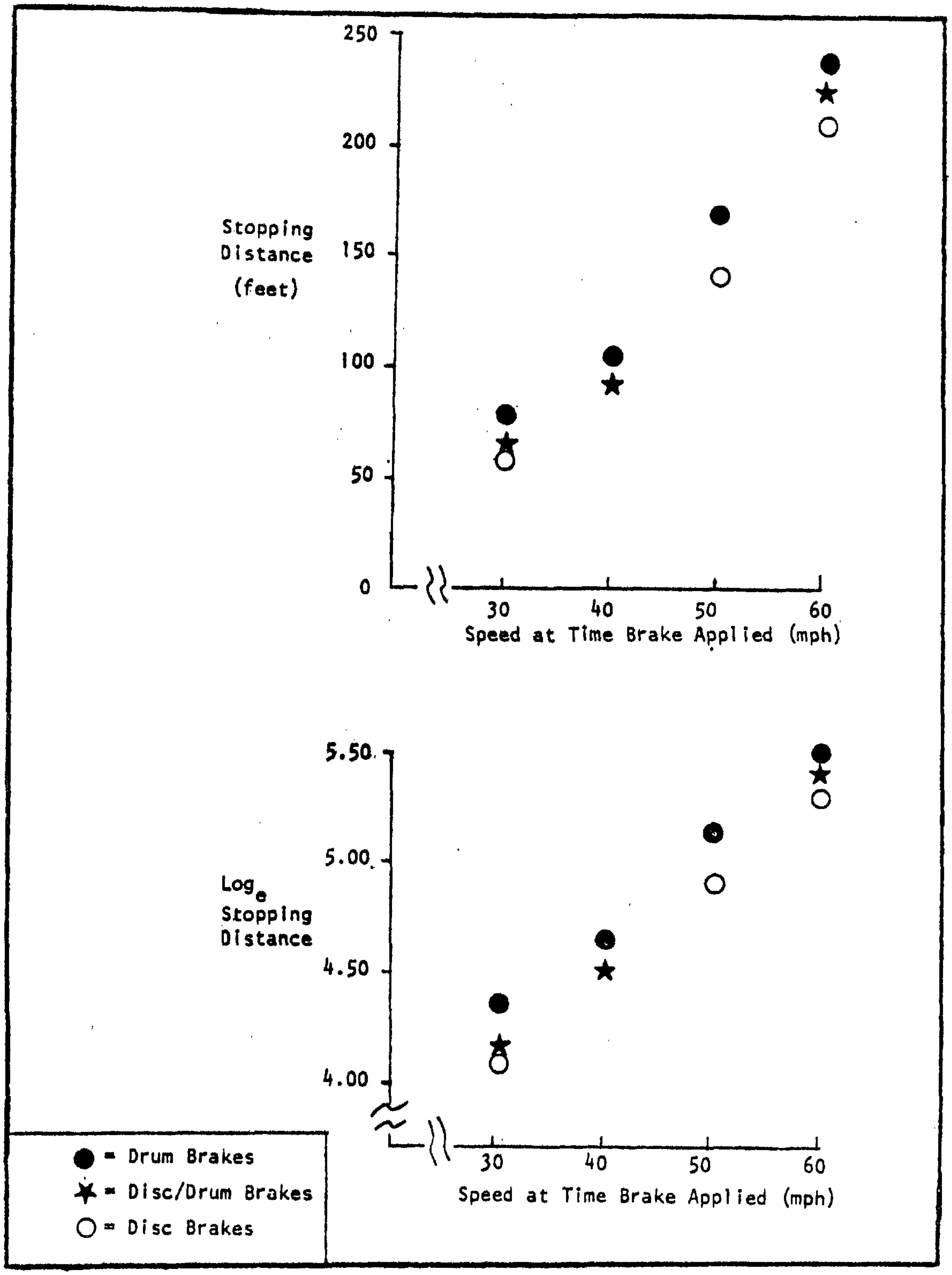

Figure B-1. Plots of fictitious stopping distances.

For this set of data we compute:

$$S_{yy} = 49{,}372.1 \ , \ S_{xx} = 1450 \ , \ S_{xy} = 8095$$

$$E_{yy} = 47{,}830.1 \ , \ E_{xx} = 1433.31 \ , \ E_{xy} = 8048.3$$

$$T_{yy} = 1542.0 \ , \ T_{xx} = 16.7 \ , \ T_{xy} = 46.7$$

Our pooled estimate of β is

$$\hat{\beta} = \frac{E_{yy}}{E_{xx}} = 5.6$$

The associated F statistic for H_o: $\beta = 0$

is $$\frac{(E_{xy}^2/E_{xx})/1}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{45{,}192.4}{376.8} = 119.9$$

which is extremely significant,as would be expected.

To test H_o: $\alpha_1 = \alpha_2 = \alpha_3 = 0$, we compute the associated F statistic

$$\frac{[(S_{yy}-S_{xy}^2/S_{xx}) - (E_{yy}-E_{xy}^2/E_{xx})]/2}{(E_{yy}-E_{xy}^2/E_{xx})/7} = \frac{771.01}{376.80} = 2.05$$

which yields a description level of significance of approximately 0.2 under an F distribution with 2 and 7 d.f. respectively. While this is not terribly significant, it suggests that with more observations the hypothesis may be more decisively rejected.

The adjusted $\bar{Y}_{i.}$'s are

$$\text{adj } \bar{Y}_{1.} = \bar{Y}_{1.} - \hat{\beta}\ (\bar{X}_{1.} - \bar{X}_{..}) = 141.25 - 5.6\ (45-45) = 141.25$$

$$\text{adj } \bar{Y}_{2.} = \bar{Y}_{2.} - \hat{\beta}\ (\bar{X}_{2.} - \bar{X}_{..}) = 127.33 - 5.6\ (43.33-45) = 136.67$$

$$\text{adj } \bar{Y}_{3.} = \bar{Y}_{3.}\ \ \hat{\beta}\ (\bar{X}_{3.} - \bar{X}_{..}) = 136.67 - 5.6\ (46.67-45) = 127.33$$

Our variance estimate is $\hat{\sigma}^2 = 276.8$ with $\hat{\sigma} = 19.4$. Thus $\hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{adj } \bar{Y}_{2.}}$ $= \hat{\sigma}_{\text{adj } \bar{Y}_{1.} - \text{ adj } Y_{3.}} = 14.7$ and $\hat{\sigma}_{\text{adj } \bar{Y}_{2.} - \text{ adj } \bar{Y}_{3.}} = 15.8$ and we see that the difference in adjusted $\bar{Y}_{i.}$ is within the standard deviation, an insignificant finding.

However, a bit of study of the data indicates that speed at time brakes are applied (X) and stopping distance (Y) are not linearly related but are related approximately exponentially; (this is in fact suggested by numerous studies), i.e.,

$$Y = ae^{bx}$$

Hence, log Y and X would be approximately linearly related. Suppose we redo the analysis of covariance with log stopping distance as the dependent variable. The log stopping distances are given in parenthesis in the last column of the data table.

For this new ANACOVA we have

$S_{yy} = 2.47$	$S_{xx} = 1450$	$S_{xy} = 58.8$
$E_{yy} = 2.39$	$E_{xx} = 143.3$	$E_{xy} = 58.33$
$T_{yy} = 0.08$	$T_{xx} = 16.7$	$T_{xy} = 0.47$

This time $\hat{\beta} = 0.041$ and the associated F statistic for $H_o: \beta = 0$ is 1013.2. Again to test $H_o: \alpha_1 = \alpha_3 = 0$, we obtain

$$F = \frac{0.0666/2}{0.0164/7} = 14.2$$

That is, now F is significant at level 0.005. The transformation of the data has drastically improved the fit of the model and dramatically revealed the differences between the brake systems. The differences are also shown by the adjusted log $\bar{Y}_{i.}$ which are:

$$\text{adj log } \bar{Y}_{1.} = 4.91$$

$$\text{adj log } \bar{Y}_{2.} = 4.77$$

$$\text{adj log } \bar{Y}_{3.} = 4.74$$

Again, if we look at $\hat{\sigma}^2 = 0.0023$, we have $\hat{\sigma} = 0.048$. Thus, we have $\hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{2.}} = \hat{\sigma}_{\text{adj log } \bar{Y}_{1.} - \text{adj log } \bar{Y}_{3.}} = 0.036$ and $\hat{\sigma}_{\text{adj log } \bar{Y}_{2.} - \text{adj log } \bar{Y}_{3.}} = 0.039$. Now the difference in adjusted log $\bar{Y}_{i.}$ can exceed (between 1 and 3) $\underline{4}$ times the standard deviation, a highly significant finding.

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LOGLINEAR MODELS

Most of the classical statistical techniques such as regression analysis, correlation analysis, analysis of variance and their multivariate extensions concern themselves with the problems of finding, describing and assessing the significance of relationships between continuous variables. Analysis of variance (and related techniques) provide methods to assess the variability of a continuous variable on the basis of the presence or absence of discrete variables and so it provides a possible beginning point for the analysis of a discrete dependent variable behavior as a function of discrete independent design variables.

For many years the standard practice when faced with truly categorical or frequency count data was to use analysis of variance even though its use could not be generally supported by theory. However, through the tricks of transforming the original dependent variable, theoretical justification for analysis of variance of discrete data could be argued.

Recently the problem of correctly analyzing discrete data has been put on a solid theoretical footing with the development of loglinear models, which are described by Haberman, and Bishop, Fienberg and Holland [4,1]. Rather than continue to belabor the mathematics of the normal probability distribution that forms the backbone of the linear models involved in regression analysis and analysis of variance, a number of researchers have applied themselves to the development of a body of theory that is specifically designed for the analysis of frequency count data, especially frequency count data that take the form of cross-classified tables of counts.

The essential idea that allows development of such models is replacing most of the normal distribution by the Poisson distribution as a starting point for any theoretical discussion. The Poisson and the related multinomial distribution are the basic sampling distributions used in frequency count data. Just as the normal distribution enjoys the properties of being mathematically tractable, broadly applicable, and theoretically justifiable for continuous data,so too does the Poisson enjoy the same properties for discrete data. By modeling frequency counts as random variables generated by Poisson processes, the problem of analyzing such sets of counts can be couched in terms of the well developed theory of estimation for exponential families of frequency distribution [4,6].

In matrix notation the classical models can be expressed as follows: let $\underset{\sim}{Y}$ be a vector of observed values, let $\underset{\sim}{X}$ be a design matrix, let $\underset{\sim}{\beta}$ be a vector of model parameters, then any of the standard regression and analysis of variance models may be expressed as

$$E(\underset{\sim}{Y}) = \underset{\sim}{X}\underset{\sim}{\beta} \qquad (1)$$

where $E(\cdot)$ is the usual expectation operator. Loglinear models may be expressed similarly by letting $\underset{\sim}{f}$ be a vector of frequencies, $\underset{\sim}{T}$ a design matrix and $\underset{\sim}{c}$ a vector of model parameters, then the loglinear model is given as

$$\ell n\ E(\underset{\sim}{f}) = \underset{\sim}{T}\ \underset{\sim}{c} \qquad (2)$$

where ℓn is the logarithm function.

Once the model, (2), is set up, the problem of estimating the vector of parameters $\underset{\sim}{c}$ must be considered. Concomitantly the problem of estimating the actual predicted values, $E(\underset{\sim}{f})$, must be faced. Fortunately, if one solves either problem, the other is automatically solved.

Various researchers have suggested various techniques to solve the estimation problem. The major schools of thought can be categorized as the maximum likelihood approach [1,4], the minimum discrimination information approach [5] and the weighted least squares approach [3]. All of these approaches are identical asymptotically and, more realistically, they all seem to agree on reasonable size data bases. However, there is no proof that for finite samples they would always "agree." The choice of technique is really a matter of specific application, complexity of analysis desired, and ease of computation. For most loglinear models as applied to cross-classified data, the maximum likelihood approach offers the user an easy algorithm to be employed to compute E(f) under the model and to, therefore, estimate the vector of parameters c. The algorithm is called iterative proportional fitting and dates back to 1940 when it was used to adjust tabled data so that the table's marginal distributions would "agree" with some desired standard distribution [2]. (See the Adjusting Rates section of this appendix for more discussion of the use of the iterative proportional fitting algorithm.) For situations in which more than just "model fitting" is desired, then a generalized Newton-Raphson technique must be used to solve the maximum likelihood equations or one must forego maximum likelihood and turn to one of the other techniques. Newton-Raphson maximum likelihood, weighted least squares and minimum discrimination information techniques all demand the ability to invert large matrices, but they all provide the user with the necessary parameter variance-covariance matrix needed for testing and setting confidence limits. Simply put, the detail of analysis desired is directly related to the computational power to which one must have access.

Regardless of the particular estimation techniques used to fit and test models for categorical data, it is now possible to explore such data from a sound theoretical footing with the use of loglinear analysis.

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CLUSTERING

A cluster is a group of similar objects. As such, clusters are very familiar; indeed, almost all words are cluster labels; car, house, physician, milkshake, green--all conjure in the mind generic objects or qualities. Clusters serve many purposes, of which three major ones are *summarizing, prediction,* and *theory development.*

Clusters summarize because objects are described by properties of the clusters to which they belong. All the details particular to the object and irrelevant to the present purpose are ignored. For example, in response to "What bit the mailman?" the reply, "a dog," or, "an Irish Setter," is better than "Sir Oliver Flaherty,..." where the pedigree has been omitted, even though all those responses describe the same animal.

Clusters predict because we expect objects in the same cluster to be similar, or to share similar properties. When the clusters being examined are sufficiently distinct (and particularly when this is unexpected), there is great incentive to uncover the reasons underlying the clustering. This may lead to new theory, and thus, the third major use of clustering.

The recent formal development of clustering techniques began in the 1950's spurred on by biologists interested in numerical taxonomy. Many of the techniques in use are eminently reasonable, but have as yet no sound statistical basis.* In the introduction to his book, *Exploratory Data Analysis,* Tukey says that it is well to know what you can do before you measure how well you have done it [6].

To the extent that methods of measuring "how well one has done" are still unavailable, clustering remains an art to be practiced with care. The ready availability of computer programs that cluster has probably led to an many unsound and incorrect analyses as the blind use of multiple regression.

Methods of Clustering

Clusters can be grouped as follows:

- Partitions
- Hierarchical clusters
- Clumps

In a partition, an object cannot belong to two clusters simultaneously, and every object is in a cluster. In hierarchical clusters there are different levels of clusters. At each level the objects are partitioned. At the highest level, all the objects are in a single cluster. Lower level clusters are either wholly within or wholly without higher level clusters--the classic example being the classification of animals: a lower cluster being "primates," which is part of "mammals," a subgroup of "vertebrates," etc. The hierarchy is often described by a tree or dendrogram,

*However, it is reassuring to note that many sturdy babies have parents totally ignorant of genetics and physiology.

with high level clusters as big branches, lower level ones as twigs. The objects clustered would be leaves. Clumps are clusters that can overlap. In later sections, unique assignment of objects to clusters is the main interest and clumping is not considered.

So far, the objects to be clustered have not been clearly defined. In most applications the data are arranged as an array, with cases as rows and variables as columns. Usually the objects to be clustered are cases and the variables are used to determine cluster assignment. After clustering, the average or modal value of a variable in a cluster is the typical value for a case in the cluster. The cases have been reduced to a lesser number of clusters. The variables can be reduced in a similar manner. If linear combinations of variables are considered, the first few principal components or some small number of factors from a factor analysis might be kept. The clusters then correspond to the principal components or factors. There are also techniques that simultaneously cluster both cases and variables.

Some Specific Clustering Techniques

For each method described, the kind of data for which it is appropriate, the nature of the clusters produced and an illustrative example are given. The description of the technique is pared to the motivating rationale; greater detail and complete algorithms can be found elsewhere in the references.

K-means

This technique uses Euclidean distances. The variables used in the distance calculation should be continuous and properly scaled. Given a specific number K of clusters, it allocates objects to clusters so as to minimize the within-cluster sum of squares. The allocation is achieved by iterative swapping of points between clusters, and a version of the algorithm is soon to be available in the BMDP set of statistical computer programs.

The clusters produced by the K-means technique tend to be convex--if the clusters are expected to be snakelike, then K-means is inappropriate, as the "snake" generally will be broken into more than one cluster. See Figure B-2.

When the number of clusters, K, is changed, the new clusters need have no nice relationship to the old ones. Indeed, the question of how many clusters to use is still open, despite recent theoretical developments.

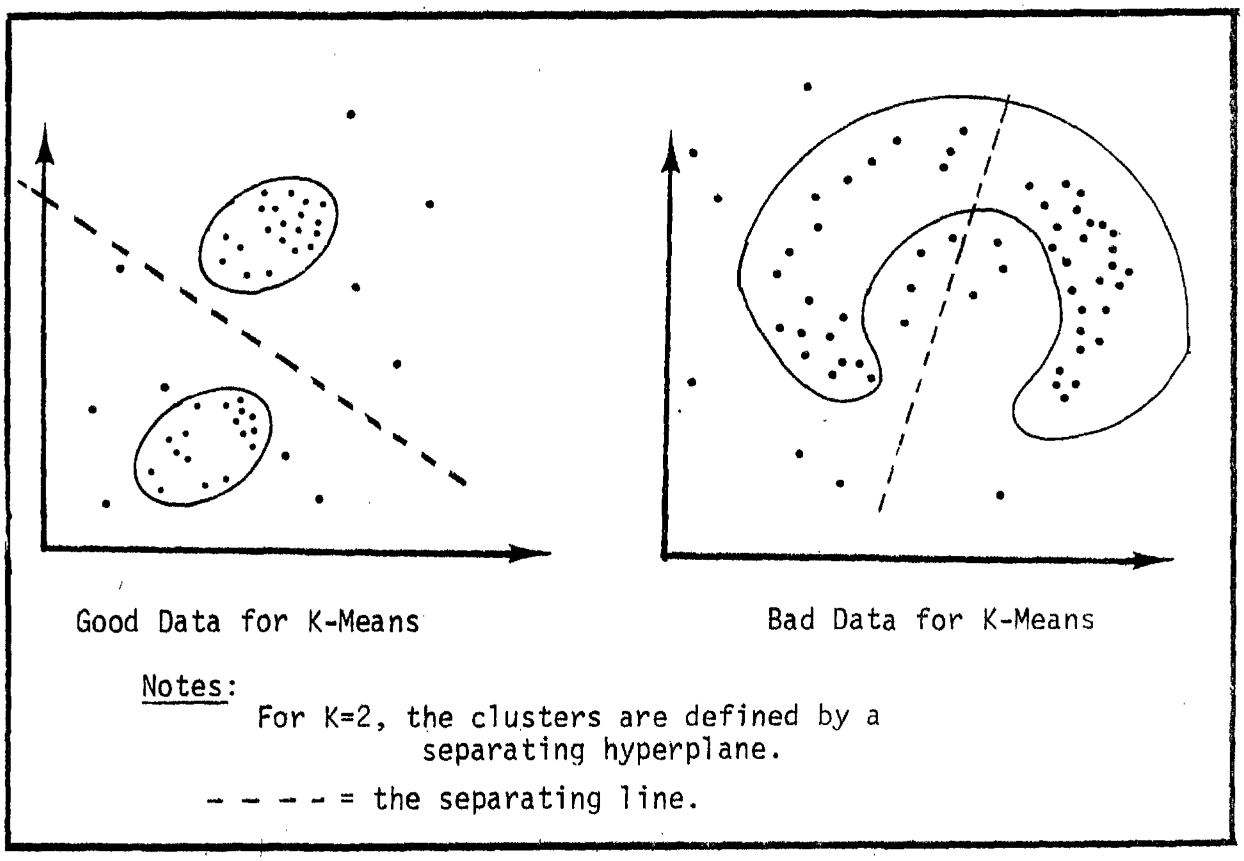

Figure B-2. K-means clustering.

Single Linkage

This method uses Euclidean distances, and it produces hierarchical clusters. Typical objects for which single linkage is a good technique are stars in the sky, and the corresponding clusters are constellations. With this example in mind (see Figure B-3) a clustering is determined by a threshold distance. If, by moving from star to star with jumps less than this threshold, it is possible to move from one star to some other star, then these stars are in the same cluster or constellation. When the threshold distance is increased, early clusters join to form larger ones. Single Linkage clusters are usually long and straggly, and are most unlikely to be convex. As such, they do not correspond to one's intuitive idea of a cluster being a distinct ball in multidimensional space. The fault, if any, lies with intuition, which is but the unusual and incomprehensible tamed by familiarity.

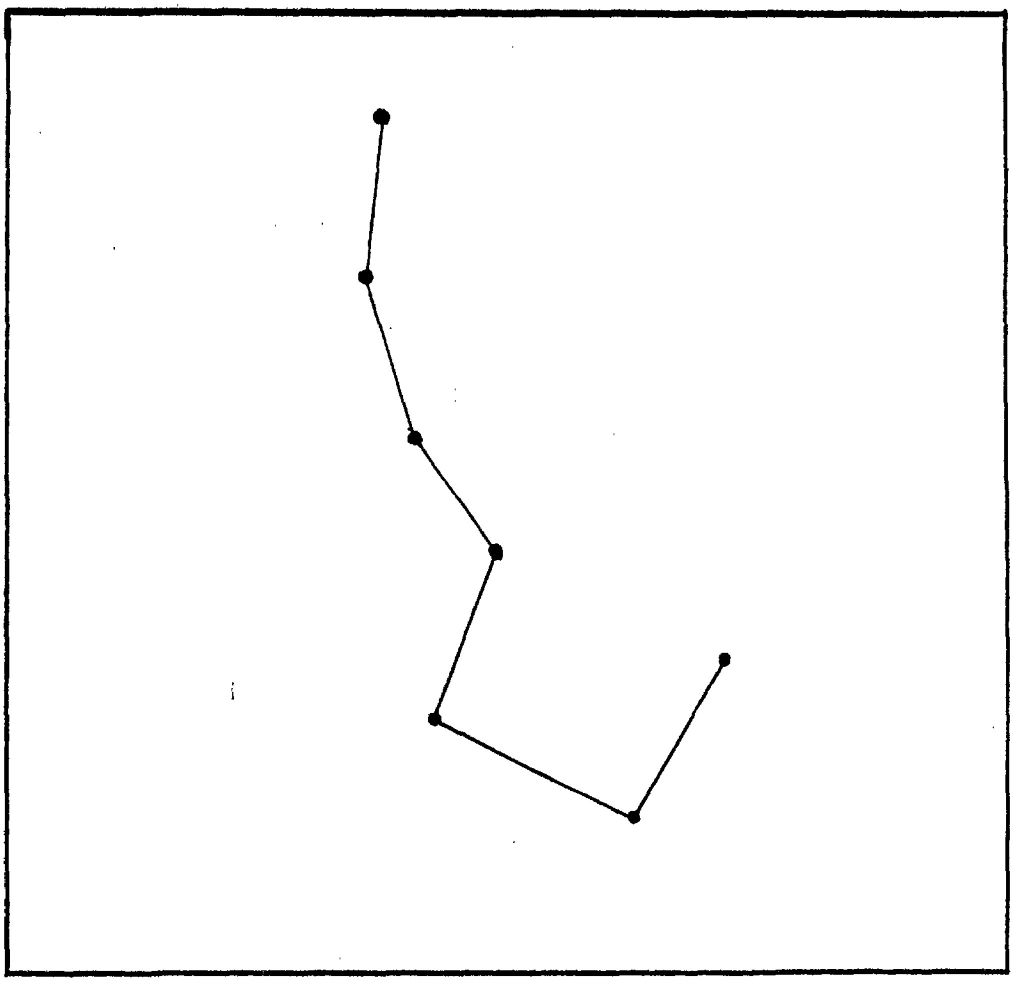

Figure B-3. The constellation Ursa Minor, with its single linkage cluster indicated.

Some Difficulties with Clustering

Almost all clustering algorithms work with distances. Once the clusters have been found, and compelling reasons for their existence unearthed, then good variables that separate the clusters can be defined. However, it is exactly these variables that we need to produce the clusters. This is not the "chicken or the egg" problem exactly, but it does show that the activity of clustering should be iterative: one clusters, then scrutinizes the results, and clusters again.

If variables are measured in different units--say speed in kilometers per hour, lengths in millimeters and distances in meters--they are not immediately comparable. They should be scaled before being used in calculating distances. The usual scaling standardizes using an inverse covariance matrix, to produce Mahalahobis-like distances. When doing this, it is most important to use the within cluster covariance matrices; even if the clusters are real, their positioning may lead to an overall covariance matrix that cannot show the individual clusters distinctly, as shown in Figure B-4.

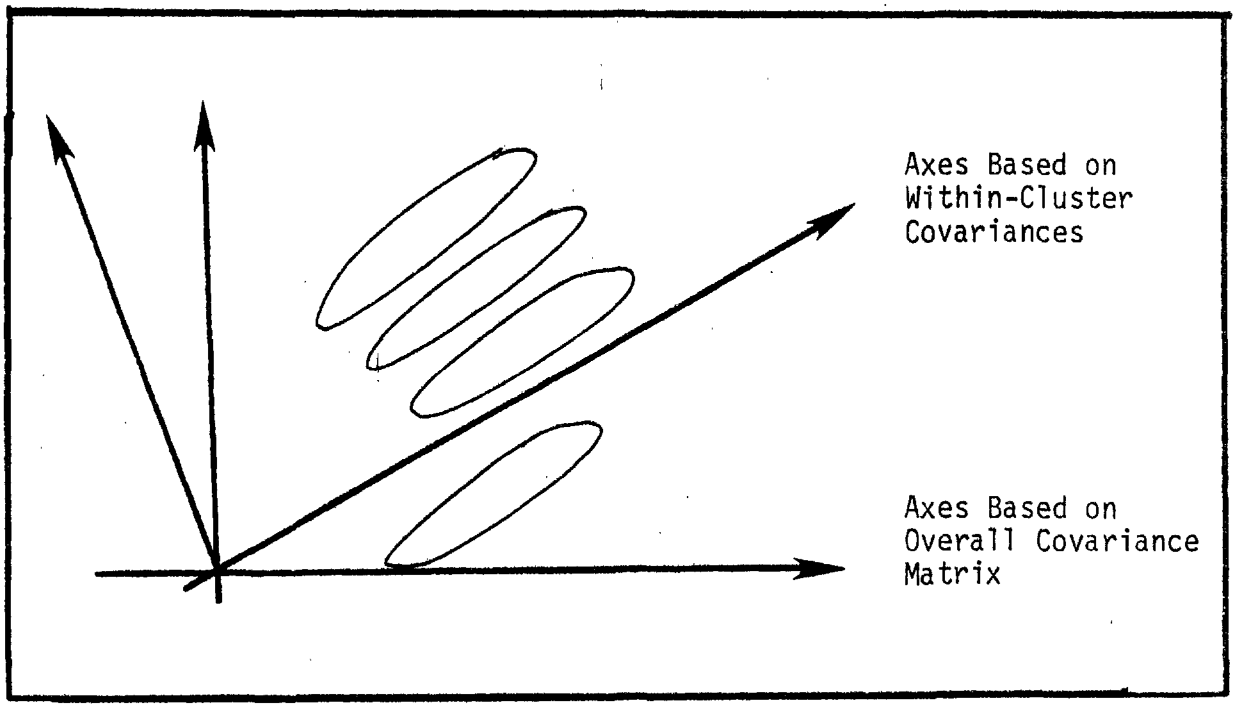

Figure B-4. Scaling with different covariance matrices.

Another question that has to be decided by the practitioner stems from the following: when many highly correlated measurements have been made on each object, the particular attribute measured is given importance corresponding to the number of measurements taken. Taken to extremes, only that attribute will be used in producing clusters. If Euclidean distance is used, this effect can be satisfactorily dealt with by using the principal components, each standarized to have unit variance, since the many essentially repeated measurements will tend to produce one principal component. However, by standardizing to unit variance, those principal components associated with the smallest latent roots, and which therefore correspond to random error in the data matrix, are given the same weight as the components with most of the information. Knowledge of both the clustering technique and the field in which it is applied is important if one is to guard against such possibilities.

The focus of much current research in clustering is how can the reality of clusters be assessed. For most clustering algorithms there is at best very limited theory leading to testable hypotheses. Most cluster validation is performed by running the algorithm on the data several times, omitting cases and/or variables at random. Those clusters that survive best are judged more likely to be actually present in the data. While the statistical theory can be circumvented by such devices, precise understanding of the relative merits of different clustering algorithms will develop only in conjunction with the theory.

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Describes most of the common methods of clustering, and gives the then-known statistical theory,much of it for the first time.

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MATCHING

Matching elements from two (or more) populations prior to making inferences about the differences between the populations has a long history in statistical studies. This is primarily due to the fact that matching is such an intuitively reasonable procedure.

Comparing similar elements to assess "treatment effects" rather than comparing, say, the two sampled population means seems like a reasonable procedure to use to reduce extraneous sources of variation that could possibly "mask" the treatment effect itself. Historically, it is this intuitively appealing notion that matching is, in effect, a "self blocking" technique useful for variance reduction that has made matching such a popular technique. Recently, matching has received added status as a straightforward method to reduce sampling costs in expensive experimental situations, e.g., experimental medical trials, surgical techniques or cancer treatment programs. Another recent application has been to apply matching in a *post hoc* fashion so as to "increase one's powers of inference" in non-experimental situations such as survey data.

It is especially the latter application of matching that is germane to the evaluation of FMVSSs using existing data bases, because we are often attempting to compare Pre- *versus* Post-Standard vehicles "free" of extraneous sources of variation. Matching is then very appealing as an easily understood method of variance reduction in observational evaluation studies such as the evaluation of Standards. However, there are definite methodological and even purely practical problems associated with matching. Over the last few years a number of researchers have strongly argued that matching is:

(1) Over-rated as a variance reduction technique.

(2) Expensive to implement, because even reasonably large data bases lose both in creating a large enough potential matching pool and then in searching for matches.

(3) Capable of producing extremely non-representative samples of "matched-pairs" neither member of which adequately reflects its parent population.

(4) Capable of actually masking certain effects related to the matching variables.

(5) Easily replaced by well-understood techniques of analysis of covariance and straightforward blocking, which is the most damaging observation.

Entry to this literature is afforded by the review articles of Cochran and Rubin, and McKinlay [1,2]. A less technical overview that sounds a cautionary note is the more recent article by McKinlay [3].

In conclusion, we do not recommend matching as one of the essential approaches to the analysis of the existing or proposed accident data bases. Our recommendation is based on the simple fact that for such large data bases it is methodologically sounder and more cost effective to use analysis of covariance and/or blocking as the basic approach to "controlled" comparisons of different groups. This is not to say that matching should not be used in the exploratory stages or even when asking specific questions--it should. Like aspirin, matching is not dangerous when used for specific small scale problems and when used in moderation. But is foolhardy when used to the exclusion of other more robust techniques or when used in situations, such as comparisons of large data bases, where it is expensive to implement, wasteful of potential data (the "unmatchables"), and potentially faulty in its implications.

<u>References and Further Reading</u>

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ADJUSTING TABLES OF COUNTS OR RATES

There are many reasons why a data analyst must sometimes analyze and summarize "adjusted" data rather than original data. Most of the reasons are directly related to the fact that the raw data have certain undesirable properties due to difficulties that have occurred in the data generation and data collection processes.

Some frequently encountered situations and their related reasons for adjustment are:

The Direct and Indirect Methods of Adjusting Rates

These methods address the fact that rates of occurrence in various strata of different populations are not directly comparable if the populations have differing strata structures. This is true since the rates would reflect both differing strata structure and (possibly) population differences of interest to the analyst. It is necessary, therefore, to "hold" structure constant in some sense and only then proceed to make inferences about possible differences between populations. The direct adjustment method approaches the problem by creating a standard population structure and then applying each particular population's rates to this standard population. The result of such a process is a set of expected rates for each population that are comparable in the sense that they are all computed from an agreed-upon standard population structure but reflect individual population rates. The indirect adjustment method approaches the problem by creating a standard set of rates and then applying these standard rates to the number of exposed cases in each cell of the individual population's strata structure. The result is again a set of comparable expected rates for each of the populations. The classic technique used for creating a standard population structure is simply to use the sum of the individual populations; similarly, the classic technique to derive a standard set of rates is simply to sum the occurrences and exposures across population for each strata group. When the standard population or rates are chosen from some outside source, the decision is, of course, highly dependent on the analyst's understanding of the implications that various choices have for his adjustment procedure; in other words, the choice is a matter of subjectively choosing a standard that is appropriate to the particular analytic purpose at hand. A wealth of literature exists which discusses the usefulness and the dangers of such techniques. Entry to it would be provided by the following references: Fleiss (1973), Yerushalmy (1951), Kitagawa (1964), Kalton (1968), Goldman (1971) and Bishop, Fienberg and Holland (1975).

The Adjustment of a Table's Margins to Show "Structure" in the Table and the Adjustment of Different Tables' Margins to Allow Comparisons between Tables.

Often tables of counts are collected so as to allow assessment of association between the variables that define the table structure, e.g., a table of counts of accidents by age and sex of driver would be useful to explore the age-sex association. Of course, we must first define a meaningful and manageable measure of association. A useful reference to the rich field of measures of association is Chapter 11 of Bishop, Fienberg and Holland (1975); however, for our purposes we will focus on the cross-product ratio (for a 2 x 2 table) and on sets of such ratios for multidimensional tables. The essential characteristic of the cross-product ratio that makes it an ideal index of association is that it remains invariant under row and column multiplications by positive constants. Translated into real tables, this means that tables such as below exhibit identical association between factor A and factor B.

$(\frac{2.4}{3.1} = \frac{4.40}{2.30} = \frac{12.20}{90.10} = \text{cross-product ratio}).$

	B	
A	4	3
	1	4

	B	
A	4	30
	2	40

	B	
A	12	90
	1	20

They are simply row and/or column multiples of one another (double the first column and multiply the second by 10 to go from the first to the second table; halve the second row and multiply the first row by 3 to go from the second to the third table). In fact, any table of the form

	B	
A	$2\ r_1c_1$	$3\ r_1c_2$
	$1\ r_2c_1$	$4\ r_2c_2$

exhibits equivalent association between factor A and factor B. With the equivalence of tables under row and column multiplications in hand, we may now approach the problem of displaying association in a table "free of marginal disturbance." A useful approach to the problem of presenting the association in a table to an audience would be to find an equivalent table that has simple margins, such as all marginal totals being 100 or 1, and then use this table to discuss the association structure exhibited by the data. The same idea of "standardizing" the margins is extremely helpful when attempting to look for differences between the structures of two or more tables. By standardizing, the individual cells are directly comparable and similarities and differences stand out free of "masking" caused by marginal differences between the tables. References for the cross-product ratio that are recommended would include Bishop, Fienberg and Holland (1975), especially Chapter 2; Goodman (1964); Mosteller (1968); and Plackett (1973).

The Smoothing of Data to Provide More Precise Estimates of Cell Probabilities

Another problem facing the data analyst interested in the analysis of multidimensional tables is that he often has very small cell counts in a large proportion of his full table. Only by collapsing across variables do reasonable cell counts become available. In these situations (since the faith one can put in any particular estimated cell probability is essentially a direct function of the observed cell count), there are many cell estimates that the analyst feels unsure of. A solution to this problem is to use the lower dimensional "faces" of the multidimensional table to model the full table and thereby provide smoothed estimated cell probabilities with characteristically smaller variances than the raw cell proportions. This technique is the heart of the approach to loglinear model building that Bishop, Fienberg and Holland (1975) present. Their whole approach to loglinear models and, therefore, to adjustment by providing smoothed cell estimates, depends upon the process of marginal standardization just presented in the last section. Namely, lower dimensional observed marginal tables are used as the "standards" while the initial cell entries in the full table are all set to one so that no association (i.e., interaction term) will be preserved other than what exists in the "standard" marginal faces. Of course, other techniques of loglinear model building also provide smoothed estimates with smaller variances too, but they are not so intimately related to the process of marginal standardization. For example, for the mathematically inclined, Haberman (1974), especially pages 376-385, is recommended.

Thus, the reasons for adjustment are: (1) to allow for meaningful interpretation of data and meaningful comparison of separate sets of data; and/or (2) to provide cell estimates in contingency tables that enjoy greater precision than the original data's cell proportions.

Other than the techniques of rate adjustment already mentioned, there is but one underlying technique that must be mastered to accomplish the various "standardization" adjustments and most of the loglinear model building forms of adjustment: namely, iterative proportional fitting (IPF). This iterative technique was suggested by Deming and Stephan (1940) for the adjustment of tables to make margins fit properly; they orginally had no thought of "preserving association under marginal multiplications" but rather suggested IPF as an approximation to a least squares procedure they were proposing.

IPF is easy to remember if one can just focus beyond the acronym to the process of "iteratively proportioning the desired margins among the table's cells until all margins converge on the desired margins." In three dimensions we would begin with some margin, arbitrarily that of variable 1, and adjust every cell in a given layer of the margin by the same multiplicative factor, so that the adjusted layer adds up to the desired marginal total. Next, add up the adjusted marginal totals for variable 2 and adjust each level by multiplying by a factor that makes them add up to the desired variable 2 margin. This, of course, messes up the margin for variable 1, but proceed on to variable 3. Having completed the adjustment so that margin 3 adds up correctly, both margin 1 and margin 2 will be out of kilter. Now simply start the cycle over again with variable 1. The process of iteratively proportioning the margins converges rapidly to a table of all counts with the property that they add to the desired margins.

A simple example using a 2 x 2 table might be valuable:

	2	3	5	1
	1	4	5	1
Actual margin	3	7		
Desired margins	1	1		

→

.4	.6	1.	1
.2	.8	1.	1
.6	1.4		
1	1		

↙

.667	.429	1.096	1
.333	.471	.904	1
1	1		
1	1		

→

.609	.391	1	1
.368	.632	1	1
.977	1.023		
1	1		

→

.623	.382	1.005	1
.377	.618	.995	1
1	1		
1	1		

→

.620	.380	1.	1
.379	.621	1.	1
.999	1.001		
1	1		

STOP

Notice that the process of IPF has in fact left the cross-product ratio unchanged

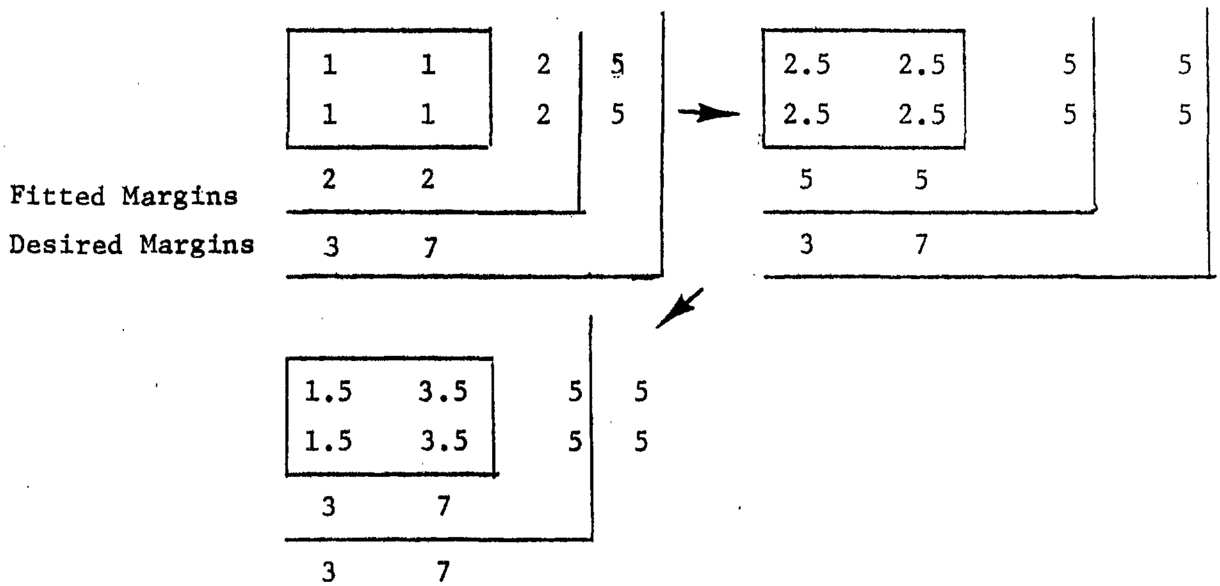
$$\left(\frac{.620 \times .621}{.379 \times .380} \approx \frac{8}{3}\right).$$

IPF is the algorithm that one would use:

(i) To adjust table entries to fit more up-to-date margins such as when margins reflect recent low dimensional data but the table entries are drawn from an older detailed sample. In modeling terms, this situation is using the detailed sample for higher order terms and the low dimensional data for lower order terms.

(ii) To adjust table entries to fit hypothetical margins or some selected set of marginal totals such as all ones (1) or all 100's. This standardization of margins makes it easy to discuss table structure without being bothered by different sample sizes and marginal totals in various layers of the table and, of course, it provides a neat way to allow for immediate comparison of structure between similar tables unencumbered by marginal variation between tables.

Besides these classical uses of IPF to adjust tables, the algorithm can be used to create most loglinear models of interest in the analysis of multidimensional contingency tables. The only new trick involved is to pretend that all one has are the margins and then iteratively proportion them throughout the full table that is initially filled with a constant value in each cell. [It is convenient to pick one (1) as the constant for each cell.] This process yields cell estimates that are identical with those of the loglinear model which has terms corresponding to each of the marginal faces used in the IPF. Actually, there is a technical quibble here in that the use of, say, a two-dimensional margin in IPF is equivalent to having both the corresponding two-factor interaction and both single factor terms in the loglinear model. For detailed information, the reader is urged to refer to Bishop, Fienberg and Holland (1975), and Fienberg (1977) but a simple example would show the basics.



Note that the cross-product ratio is one (1) indicating complete independence or lack of association between factor A and factor B which corresponds to the loglinear model with no two factor interaction term.

The IPF algorithm is also valuable because (a) it provides non-zero cell estimates for cells with sampling zeros (providing that the whole layer is not empty) and (b) it is easily amended to fit very complicated models where certain cells have to have some particular value. The ability to provide non-zero cell estimates is a simple function of the fact that the initial table of ones (1) is used to spread the observed marginal totals through the table. Therefore, empty cells are "proportioned" a share of the marginal information for their row, column, layer, etc. Similarly, the characteristic of being able to fit tables (equivalently, models) with fixed zeroes, fixed diagonals, etc. is accomplished by simply leaving a zero in the initial table for those cells and adjusting the initial margins to "leave room" for whatever fixed value one wishes to have.

In summary, IPF is an easy-to-program algorithm with broad applicability to the various types of adjustment problems we have discussed. It is also the basis for computing the expected cell counts under a wide class of loglinear models and so it ties together the problems of adjustment and the related problems of data smoothing by model building and prediction for multidimensional contingency tables. One should not,however, believe IPF is necessarily the only or even the best answer to loglinear model building and the concomitant process of data smoothing. As an adjustment technique, IPF is a marvelous tool but as a model building and testing device it lacks certain traits. It can not, for example, provide the user with a parameter covariance matrix, so certain hypothesis tests and confidence level statements are precluded. The only solution to this problem is to turn to other techniques for model building and testing. Good references for such techniques would be: Bishop, Fienberg and Holland (1975) - Chapter 10 provides an overview of such techniques; Haberman (1974) - difficult but elegant presentation of the maximum likelihood approach; Grizzle, Starmer and Koch (1969) - the linear models (GENCAT) approach; and Kullback (1971) - the information theoretic approach to loglinear model building.

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APPENDIX C

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 FMVSSs 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; 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 date *versus* 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.

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*Personal communication from Warren G. LaHeist, January 1977.

**CEM Report 4194-574, *Program Priority and Limitation Analysis*, December 1976, Contract DOT-HS-5-01225.

APPENDIX D

SEATING SYSTEM FAILURE MODES

Robert Cromwell

APPENDIX D

SEATING SYSTEM FAILURE MODES

The primary ways in which seating systems may fail are discussed for principal seat types in Sections D-1 through D-6.

D-1. FULL BENCH SEATS WITH FIXED SEAT BACK

This type of seat is typical of those used in four-door, four and six passenger vehicles. Experience in examining many hundreds of post-accident vehicles show two primary failure modes for this type of seat. First, the entire seat assembly, including the seat track, breaks away from its floor attachment at one or both sides. Full bench seats are commonly held to the floor sheet metal of the vehicle by two bolts at each side of the seat which secure the seat track. This type of seat separation occurs as a result of the bolt heads or nuts pulling through the floor sheet metal as a result of high localized forces in the bolt fastening area. Large washers are sometimes used on the attaching bolts beneath the flooring and provide some additional strength by providing greater force distribution area. In general, however, moderate rear end collisions with two or three occupants on the front seat create extremely high localized tensile forces on the two front seat track hold-down bolts and failures at this location by "floor pull-through" of the bolts are not uncommon. In frontal collisions of sufficient magnitude, all four bolts have been observed to pull through the flooring allowing the entire seat to separate from the vehicle. The second predominant failure mode is the forward deformation of the seat lock toward the steering wheel and dashboard. In practically all cases, this is caused by frontal vehicle collision with one or more unrestrained occupants in the rear seat. The rear seat occupants strike hard against the back of the front seat at a high location, usually at the top edge of the seat, creating a high forward bending moment on the seat back. Forward deformation of the front seat back usually occurs in the attachment area to the lower, horizontal bench seat and the forward angular motion of the seat back may reach the steering wheel area with a devastating effect on the front seat occupants. Another failure mode for full bench seats is the separation of the seat from the seat track. Experience has shown that this type of failure is not as common in full bench seats as in the separate or bucket type front seats. In practically all cases of forward displaced seat backs of the full width type caused by rear seat occupants, the seat back structure is deformed in a convex forward manner in the vehicle transverse direction. The maximum transverse seat back deformation occurs at the locations struck by the rear seat occupants.

D-2. FULL BENCH SEATS WITH SEPARATED FORWARD-SWING SEAT BACKS

This type of seat is typical of those used in two-door, four and six passenger vehicles where access to the rear seat is provided by swinging the seat back forward allowing a greater area for entrance through the single side door opening to the rear seat. Experience has shown that this type of seat usually fails by separation from the seat track in rear-end collisions. Frontal collisions throw rear seat occupants forward, resulting in forward displacement of the seat back due to deformation of the seat structure in the seat back hinge or pivot area. Forward impacting rear seat occupants often cause one side of the seat back to separate at the seat pivot. Typically, the side structural member of the seat back has a transverse hole near its bottom end which fits over an axle stub in the lower seat frame. Any significant sideward force on the seat back dislodges this pivot connection and that particular side of the seat back displaces forward, resulting in an angular seat back failure. The seat back latch mechanism seldom fails completely. The seat back latch mechanism often allows one inch or so of play (i.e., "free motion") at the top of seat even when in proper working order prior to collisions. Frontal collisions often result in some deformation of the latch system such that the latched free play motion at the top of the seat increases to perhaps three to six inches. Although complete failure of the latch system has been observed, this type of failure is usually associated with a very severe frontal collision where other parts of the seat assembly have been separated or distorted severely. Seat track separation from the floor sheet metal structure is not common with this type of seat, particularly in frontal collisions. This may be explained by the energy absorbing and breakaway characteristics of the less substantial seat back attachments and pivots compared to the more rigid full width, fixed bench seat back discussed in Section D-1 above. Seat bench separation from the seat track is not common for fixed back bench seats.

D-3. BUCKET SEAT WITH FIXED SEAT BACK

This type of seat is typical of two-door, two passenger sport cars and four-door, four or five passenger sedans, including subcompact cars, which are often equipped with a console separating the two front bucket seats. Experience has shown that the predominant failure of this type of seat is separation from the seat track during rear-end collisions. This type of failure directs the front seat occupant toward the back seat and often into the rear window area. Although seat back deformation has been noted in frontal collisions, the magnitude of the deformation is relatively small in all but the most severe collisions. Oblique or sideward collisions have been observed to twist the bucket seat back to one side as the "wrap-around" effect of the bucket shaped seat back better contains the occupant, and the seat back experiences a greater sideward inertial load.

D-4. BUCKET SEATS WITH SWING-FORWARD SEAT BACKS

This type of seat is typically used in two-door, two, four and five passenger vehicles where the forward swinging seat back is required for access to a storage area in two passenger cars and to the rear seat in four and five passenger cars. The predominant failure modes include seat track separation during rear-end collisions, allowing rearward displacement of the seat occupant as described in Section D-3 above. Fracture of the seat back connection at its attachment point to the lower seat also occurs (but with less frequency) during rear-end collisions, again allowing rearward motion of the seat occupant to the rear seat area. Frontal collisions result in seat track failures and moderate deformation of the seat back only when rear seat occupants strike the back of the seat back.* The seat back latch system rarely fails completely unless the impacting forces are oblique or sideward. In this case, the seat back pivots may separate at one side due to lateral seat back displacement and deformation. Loss of the locating pivot on one side of the seat often defeats the seat back latch and even though a latch mechanism may be located at each side of the seat, the failure of one of the latches greatly reduces the integrity and strength of the remaining latch due to off-center loading.

D-5. INDIVIDUAL LOUNGE TYPE SEATS

This type of seat is usually categorized as an optional, luxury class seat and is often equipped with fold down arm rests at the car center area. The seat backs are broad in width and although they have individual seat track adjustments for each of the front seats, a third center occupancy position is provided. This type of seat is not considered the "bucket" variety and lateral

*In small cars, the upper torso and head of even restrained rear seat passengers can strike the seat back with sufficient force to cause some seat back deformation, or if the rear seat passenger protectively uses his hands against the front seat back, near the top, the dynamic forces can be large enough to cause deforming bending moments.

motion of occupants is not restrained by the concave seat back shape associated with "bucket" type seats. Experience has shown that these seats are strongly constructed compared to the standard individual or bucket seats and failure of the seats in separation and deformation is less frequent than other types of seats. Severe frontal impacts, however, with rear seat passengers result in forward seat back deformation similar to that occurring in full bench seats where encroachment against the front seat occupancy contributes to injuries. Seat track and floor attachment separation has been noted to be infrequent on this type of seat in spite of their relatively heavy construction and associated greater weight.

D-6. SUMMARY

In summarizing the strength abilities of the various front seat configurations, it is clear that a deforming front seat back caused by rear occupant impacts is detrimental to the front seat occupant with regard to injury potential in frontal collisions. However, the deforming seat back is advantageous to the rear seat occupancy as the collapsing front seat back is an effective energy absorbing barrier and the rear seat occupants' injuries are most likely reduced. The rearward failure of a front seat back resulting from a rear-end collision is detrimental to both front and rear seat occupants suggesting that a seat back should be designed to withstand higher levels of rearward applied forces. At least one front seat occupant (the driver) is always present during vehicle operation and because rear seat passengers or other loose heavy objects in the rear seat area are present a relatively small percentage of the time, the forces existing to deform or separate the front seat in forward collisions are predominantly due to the deceleration forces acting on the relatively light seat back.