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EVALUATION METHODOLOGIES FOR NINE FEDERAL MOTOR VEHICLE SAFETY STANDARDS: FMVSS 105, 108, 122, 202, 207, 213, 220, 221, 222,

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16. Abstract

This is the Final Report of two studies to develop methodologies for evaluating a total of nine Federal Motor Vehicle Safety Standards:

- FMVSS 105: Hydraulic Brake Systems in Passenger Cars
- FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)
- FMVSS 122: Motorcycle Brake Systems
- 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 provides a summary and overview of the sixteen preceding reports, and an integration of the individual approaches for evaluating each Standard as presented in the earlier reports. The Final Report includes conclusions and recommendations, and it briefly reviews the nine Standards, and the approaches to evaluating the Standards. It discusses the statistical analyses of accident data, field and mail surveys, and laboratory testing which comprise the methodologies for evaluating the effectiveness of each Standard, and presents Work Plans with clearly-defined decision points between various tasks in each evaluation program. The evaluation programs may require from three to six years to complete. The maximum cost of completing all nine evaluations is estimated to be about $5.2 million over a six year period.

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METRIC CONVERSION FACTORS

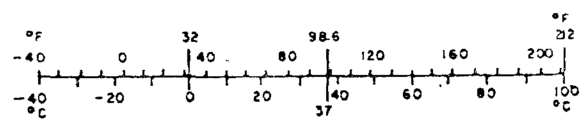
Approximate Conversions to Metric Measures

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

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

Approximate Conversions from Metric Measures

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



EXECUTIVE SUMMARY

This report summarizes the work performed by The Center for the Environment and Man, Inc. (CEM) to design comprehensive methodologies and implementation plans for evaluating the effectiveness of nine specified Federal Motor Vehicle Safety Standards (FMVSS). The nine Standards examined in this study are:

- FMVSS 105 - Hydraulic Brake Systems in Passenger Cars
- FMVSS 108 - Side Marker Lamps and High Intensity Headlamps (Only)*
- FMVSS 122 - Motorcycle Brake Systems
- FMVSS 202 - Head Restraints
- FMVSS 207 - Seating Systems
- FMVSS 213 - Child Seating Systems
- FMVSS 220 - School Bus Rollover Protection
- FMVSS 221 - School Bus Joint Strength
- FMVSS 222 - School Bus Seating and Crash Protection

This report includes conclusions and recommendations for evaluating the Standards, reviews of the Standards, approaches to their evaluation, discussion of the evaluation methodologies, and implementation plans for performing the evaluations.

Judgmentally, the following comments can be made concerning the feasibility of satisfactorily evaluating the effectiveness of each of the Standards. Presentation is ordered by greatest likelihood of success in establishing the effectiveness with which the Standard meets its objectives.

FMVSS 202: Head Restraints

- Previous analyses have shown that head restraints are effective in reducing neck injuries for left and right front seat passengers involved in rear end and other accidents.

- The evaluation program proposed herein will sharpen the results of previous studies and attempt to determine the relative effectiveness of built-in head restraints and adjustable head restraints--which are often not properly adjusted.

- It appears that each year of the order of 5 million front seat occupants in rear end accidents may benefit to some degree from the presence of head restraints. Thus, the population potentially impacted by FMVSS 202 is large.

- It is estimated that effectiveness is highly likely to be satisfactorily determined within the first year of a potential 6-year evaluation program (which can be integrated with the evaluation of the effectiveness of FMVSS 207: Seating Systems).

*The formal title of FMVSS 108 is *Lamps, Reflective Devices, and Associated Equipment*. The Standard covers 15 separate lighting elements, of which only two are considered in this study.

FMVSS 213: Child Seating Systems

- Child seating systems -- properly used -- would be expected to reduce injuries to children in automobile accidents. However, no definitive studies are known which estimate the degree of injury reduction. At present, the requirements specified in the Standard are directed toward proper seat use and static force capabilities.

- The evaluation program recommended herein begins with analysis of existing mass accident and detailed accident data. If necessary, this is followed by a NASS special data collection and analysis effort; pediatrician and emergency room surveys; on-site and mail surveys to determine usage patterns and attitudes; and laboratory dynamic tests.

- It is grossly estimated that about 300,000 or more children age 5 or less are in automobile crashes each year. Of these, about 500 are killed and possibly 5000 are seriously injured and 50,000 are less severly injured. There are 16 million children age 5 or less, and a total of about 8 million child seats have been sold over the past decade. Yet, usage of child seats appears to be much less than 10 per cent of children observed in cars.

- It is estimated there is a high probability that effectiveness may be determined in about 2.5 years following completion of the analysis of the pediatrician and emergency room surveys. If the surveys and dynamic tests are required, it is estimated that the evaluation program will require 4 years.

FMVSS 222: School Bus Seating and Crash Protection

- Padding, proper seat dimensions and strength, and proper seat spacing will reduce injuries to children resulting from bus accidents or violent maneuvers. However, there is presently no adequate amount of detailed accident data to provide a basis for comparison of Pre- and Post-Standard effectiveness, because the Standard became effect 1 April 1977,and school bus accidents are relatively rare events, in terms of passenger miles driven.

- The evaluation program recommended includes clinical analysis of bus accidents in the MDAI data file (less than 100); and annual analysis of mass accident and special NASS accident data bases over the next 3 to 5 years, as necessary. Additional information will stem from static and dynamic laboratory tests and data obtained from an instrumented bus program in NASS areas. (These latter tests are conducted primarily to evaluate FMVSS 220 and 221.)

- An estimated 22 million pupils are transported to and from schools each year, but there are only about 6,000 injuries and 10-20 students killed inside buses each year. An extensive special NASS data collection effort for 3 to 5 years might be able to obtain data on about 1000 of the injuries per year, which would be adequate to evaluate Pre- and Post-Standard effectiveness. New buses enter the inventory at the rate of about 30,000 per year, so it will be a few years before an adequate number of Post-Standard buses will be in enough accidents to provide sufficient cumulative data to satisfactorily determine the injury reduction effectiveness of the Standard.

- There appears to be a high likelihood of satisfactorily determining the effectiveness of this Standard. Because it will take considerable time to accumulate sufficient Post-Standard data, it is estimated that it will take at least three, and possibly five, years to completely evaluate the Standard.

FMVSS 105: Hydraulic Brake Systems in Passenger Cars

- When it first became effective in 1968, this Standard essentially formalized SAE Recommended Practices issued in 1964, and, among other things, required split brake systems and brake warning lights on all new cars. Between 1964 and 1968, about half the cars produced in the U.S. had split brake systems, so there are presently few Pre-Standard cars in operation today. As U.S. cars became heavier and faster, manufacturers turned to disc brakes. Fade and water recovery became of greater importance. In 1976, a revised version of the Standard (FMVSS 105-75) became effective.

- To compare Pre- and Post-Standard brake-related accidents, initial effort will be placed on analysis of existing mass accident data, which is expected to produce effectiveness information on brake system defect rates, characteristics of struck and striking cars in crashes, and ratios of brake-related crashes. If more information is needed to satisfactorily evaluate the Standard, laboratory tests to determine the impact of vehicle age on brake performance are proposed. This may be followed by additional laboratory tests of vehicles and drivers, and a survey of brake indicator outage rates. If needed, an instrumented vehicle program would provide additional information on driver characteristics and pre-crash/crash conditions.

- Previous analyses suggest that less than five percent of accidents are brake-related, but this implies a potential population of perhaps 0.5 to one million such crashes per year. It is likely that many brake-related accidents are influenced by the age of the car,as well as size and weight, etc. Because it is probable that the effectiveness of Post-Standard brakes will be only marginally better than Pre-Standard brakes, a significant amount of mass accident data will have to be analyzed to clearly define the degree of effectiveness. Due to the lack of detail in mass accident data, and other potentially confounding effects, it is only nominally probable (i.e., more than 0.5) that this Standard can be satisfactorily evaluated.

- Using only the analysis of mass accident data, it is possible that this Standard could be evaluated within about one year. If laboratory and other tests are required, a program of up to six years duration is envisaged.

FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)

- The real world effectiveness of side marker lamps and high intensity headlamps can only be measured during darkness or other conditions of reduced visibility. Use of forward and rear side marker lamps (required after January 1, 1970) should aid in identifying and judging distance of vehicles approaching each other at an angle, leading to accident avoidance. A previous study, however, has estimated the effects of these lamps in reducing side collisions at about one percent. High intensity headlamps are allowed, but are not required. They can increase sighting distance from 20 to 40 percent on high beam and much less on low beam. These headlamps are being provided on some new 1978 models; no accident data are available yet on their effect in reducing (or possibly increasing) nighttime accidents.

- The evaluation program recommended herein includes eight separate Tasks, three of which will provide results for both sidemarker lamps and high intensity headlamps. The analysis of side marker lamps will begin with the use of mass accident data to determine their effectiveness in accident reduction. If necessary, field and laboratory tests of sighting distance and conspicuity will be carried out and, finally, field surveys of lamp usage and outage have been recommended. The analysis of high intensity headlamps begins with laboratory and field tests, then continues with a real world study of night driving plus analysis of existing mass accident data for overdriving headlamps and glare complaints. If needed, the final Tasks involve surveys of headlamp usage, outage, and misaiming.

- There are approximately 10 million new cars manufactured yearly; since January 1, 1970, all of them have been required to have front and rear side marker lamps, but none of them has been required to have high intensity headlamps (they are allowed options). Night accidents accounted for 56 percent of all motor vehicle deaths and 36 percent of all accidents in 1975. Thus, the driving population affected by FMVSS 108 is large. It is only nominally probable that this Standard can be satisfactorily evaluated because (1) evaluating side marker lamps involves isolating a small effect in a large data base and (2) evaluating high intensity headlamps calls for dealing with a manufacturer-determined feature being introduced relatively slowly and whose potential effect is small.

- It is possible that this Standard could be evaluated in about four years, if all the proposed Tasks were carried out. Using only the analysis of side collisions in existing mass accident data, it is possible that the evaluation of side marker lamps could be completed in less than one year. The probability of a satisfactory evaluation of high intensity headlamps remains uncertain throughout the entire time period.

FMVSS 207: Seating Systems

- When it first became effective in 1968, this Standard basically formalized the SAE Recommended Practices issued in 1963; an extension of the Standard in 1972 incorporated additional requirements, including requiring a seat to remain in its adjusted track position during load application. Evidence suggests that the actual strength of seating systems after the effective date was little different from the strength of seating systems before the Standard. It would appear that the principal compliance has been directed toward including a self-locking restraining device on folding seat backs, and a control for releasing this restraining device. Although hinged seat back locks would appear to be effective in reducing deaths and injuries, definitive studies are not known.

- The evaluation program recommended herein can be integrated with the evaluation of the effectiveness of FMVSS 202 (Head Restraints) and includes several Tasks which serve to evaluate both Standards. The evaluation begins by using existing mass and detailed accident data to analyze seat failure, occupant fatality and injuries. If necessary, this will be followed by dynamic laboratory tests and, finally, by an instrumented vehicle data collection and analysis.

- The population affected by FMVSS 207 will be slightly larger than the five million front seat occupants discussed in the summary of FMVSS 202 (Head Restraints) since this Standard will affect not only those front seat occupants involved in rear end accidents but also those involved in other types of collisions, such as front impacts at low speeds. The population potentially impacted by FMVSS 207 is, then, quite large.

- It is estimated that there is a nominal probability that the effectiveness of this Standard can be evaluated in the proposed six-year program. However, it is expected that the effectiveness of seat back locks can be successfully ascertained within the first 16 months of the study. If it is judged necessary to demonstrate differences in overall seating strength as a result of FMVSS 207, it is anticipated that the bulk of the full evaluation program would have to be carried out.

FMVSS 220: School Bus Rollover Protection

- This Standard involves improvement in the structural quality of school buses. It institutionalized existing design recommendations of the School Bus Manufacturers Institute; virtually all school bus manufacturers were following these suggested practices before the April 1, 1977, implementation of the Standard. Assessment of the effectiveness of the Standard will be difficult because of: (1) an inadequate amount of detailed accident data due to the recent introduction of the Standard; (2) the relative rarity of school bus accidents; and (3) the prior compliance of most school bus manufacturers.

- The evaluation program recommended herein begins with a static diagonal roof loading laboratory test designed to evaluate the appropriateness of the present roof loading requirements of FMVSS 220 relative to actual forces encountered in a rollover crash. Additional data may be acquired from an instrumented bus program in NASS areas, from a NASS data analysis and, if necessary, from detailed laboratory tests based on the recommended earlier studies.

- An estimated 22 million pupils are transported to and from schools each year, but there are only about 6,000 injuries and 10-20 students killed inside buses each year. An extensive special NASS data collection effort might be able to obtain data on about 1,000 of the injuries per year, which would be adequate to evaluate Pre- and Post-Standard effectiveness. New buses enter the inventory at the rate of about 30,000 per year, so it will be a few years before an adequate number of Post-Standard buses will be in enough accidents to provide sufficient cumulative data to satisfactorily determine the injury reduction effectiveness of the Standard if, indeed, it can be determined at all.

- It appears unlikely (that is, there is less than a 50 percent probability) that the effectiveness of this Standard can be satisfactorily evaluated within the five-year evaluation effort proposed herein. Because most school buses met the roof strength requirements before the Standard became effective, determining whether or not there are significant differences between Pre- and Post-Standard buses becomes extremely difficult, primarily because of the extremely low rate of accidents in which school buses roll over.

FMVSS 221: School Bus Body Joint Strength

- This Standard complements FMVSS 220 (School Bus Rollover Protection) in that it specifies minimum strength requirements for school bus body joints. These requirements are designed, however, to avoid structural collapse of bus bodies during all crashes, rather than just rollover crashes. FMVSS 221 applies only to school buses with a Gross Vehicle Weight Rating of more than 10,000 lb, manufactured after April 1, 1977. It is likely that many school buses manufactured prior to that date were already in compliance with the Standard.

- The evaluation program recommended herein begins with a laboratory test--a dynamic angular shear test that will be used to measure not only roof strength but also the joint strength requirements of this Standard. Additional data may be acquired from an instrumented bus program in NASS areas, from a NASS data analysis and, if necessary, from detailed laboratory tests based on the earlier studies recommended.

- An estimated 22 million pupils are transported to and from schools each year, but there are only about 6,000 injuries and 10-20 students killed inside buses each year. An extensive special NASS data collection effort might be able to obtain data on about 1,000 of the injuries per year, which would be adequate to evaluate Pre- and Post-Standard effectiveness. New buses enter the inventory at the rate of about 30,000 per year, so it will be a few years before an adequate number of Post-Standard buses will be in enough accidents to provide sufficient cumulative data to satisfactorily determine the injury reduction effectiveness of the Standard if, indeed, it can be determined at all.

- It appears unlikely (i.e., there is less than a 50 percent probability) that the effectiveness of FMVSS 221 can be satisfactorily evaluated within the five-year evaluation effort proposed herein. Determining whether or not there are significant differences between Pre- and Post-Standard buses is particularly difficult because the lack of data and the fact that many school buses met the specifications before the Standard became effective.

FMVSS 122: Motorcycle Brake Systems

- Data on motorcycle accidents involving brake performance are either non-existent or inadequate. It is difficult to identify the role of brakes in causing or avoiding an accident in the little data that do exist. There appear to be several other more significant causal factors involved, such as motorcycle rider inexperience and failure of automobile drivers to perceive and react appropriately to motorcycles on the road.

- The evaluation program recommended herein is a three-year study with the first two Tasks beginning concurrently: an analysis of mass accident data and a mail survey to provide background information on potentially confounding effects that might influence other analyses. During the study, NASS data is analyzed at three different times, and both a laboratory dynamometer test and field tests of brake performance and rider behavior are recommended.

- There has been a significant increase in the use of motorcycles in the U.S. over the past several years. Between 1964 and 1975, the number of registered motorcycles increased 404 percent, for an average increase of 16 percent a year; there has been no other type of registered vehicle whose growth approaches that of motorcycles. Since 1969, there have been approximately one million motorcycles a year manufactured or imported in the U.S. There are about 3,000 motorcycle deaths in the U.S. annually.

- There appears to be, at the most, a 50 percent probability that FMVSS 122 can be satisfactorily evaluated by the end of the three-year study described herein. A further possible step might be to design an intense NASS special motorcycle accident data collection to acquire detailed data which might provide a better basis for analyzing brake system effectiveness in reducing accidents.

Cost Data Analysis

An additional objective of these studies is the determination of the out-of-pocket expenses incurred by the consumer, as a consequence of each Standard. The cost categories to be considered include:

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

Direct and indirect manufacturing, and capital investment (including testing) represent real resources used and can be estimated well. Markup is conceptually more difficult--it involves pricing strategies and the oligopolistic nature of the market--and would require a detailed study of detailed cost data and pricing practices. Dealer markup is somewhat confounded by market fluctuations and the nature of the used car trade-in market. Taxes include not only sales tax on the vehicle, but also taxes on materials throughout the entire manufacturing process.

In spite of the above difficulties, CEM has developed cost data sampling plans for analyzing the costs. The methodology has two parts: (1) determining what new components are required in order to comply with a Standard; and (2) selection of the vehicle makes, types, etc. (or child seats) to be sampled. In the first instance, it is sometimes difficult to determine the difference between the "cost of compliance" and the actual cost incurred by the manufacturer, who may have chosen to "overdesign" a component (e.g., side marker lamps) for aesthetic aspects.

For the second point, it is necessary to efficiently select representative vehicles from the full field of designs. Discriminating compliance factors must be determined, and the costs are estimated with a model which separates the manufacturing and market components of cost. Also, selected categories of vehicles are lumped together when makes and models are similar with regard to the Standard.

This general two part methodology applies to eight of the nine Standards considered herein. It does not apply to FMVSS 213: Child Seating Systems, because to a great degree child seats were not "modified" to meet the Standard. Instead, entirely new designs were introduced. However, since there are not many child seat manufacturers (i.e., about 14), it is feasible to include all of them in the determination of the incremental changes the Standard has produced.

Specific hardware costs will be collected for each Standard. The number of models for which costs will be collected depends on the differences in costs and implementations between models and manufacturers. In addition to manufacturer and model size (for most Standards), the principal factors that must be considered in the cost data acquisition plans are as follows:

- FMVSS 105: Type of brake--power, power assist, standard.
- FMVSS 108: Manufacturer/models offering high intensity headlamps.
- FMVSS 122: Motorcycle engine displacement: under 125 cc, 125-349 cc, 350-449 cc, 450-749 cc, 750 cc and over.
- FMVSS 202: Adjustable *vs.* fixed head restraints.
- FMVSS 207: Two-door *vs.* four-door cars.
- FMVSS 213: Fourteen major manufacturers of child seating systems tested by Consumers Union in 1977 will be sampled.
- FMVSS 220/221/222: Number of seats installed.

Confounding Effects of Interactions between Standards

The purpose of Federal Motor Vehicle Safety Standards is to avoid motor vehicle accidents and reduce death and severity of injuries in such accidents. Fifty FMVSS have been issued, beginning with 20 in 1968. Many of the original Standards largely made official existing standards, or Recommended Practices of the Society of Automotive Engineers. Often manufacturers had followed SAE recommendations prior to the effective date of Federal Standards. Thus, it is often difficult to definitively establish the difference between "Pre-Standard' and "Post-Standard" vehicles.

In summary, there are two major causes of confounding effects which make difficult the statistical analysis of at least some Federal Motor Vehicle Safety Standards. They are:

- The simultaneous implementation of Standards. It may be possible to show there is a reduction in accidents and deaths and injury severity. But it may be virtually (or totally) impossible to separate out the fractional part of the reduction that is specifically due to a single Standard. Furthermore, the overall effect may, in fact, be due in part to the synergistic effects of several Standards working together.

- Partial or full compliance with the Standard prior to its effective date. Split hydraulic brakes and brake failure indicator lights are an excellent example of this confounding effect. Split hydraulic brakes were standard production line equipment on some models of cars as early as 1964, and all U.S.-produced 1967 models had this system; so when FMVSS 105 became effective in 1968, it had essentially no impact on the type of brakes used on U.S. cars, and studies of the effectiveness of the Standard must take this into account.

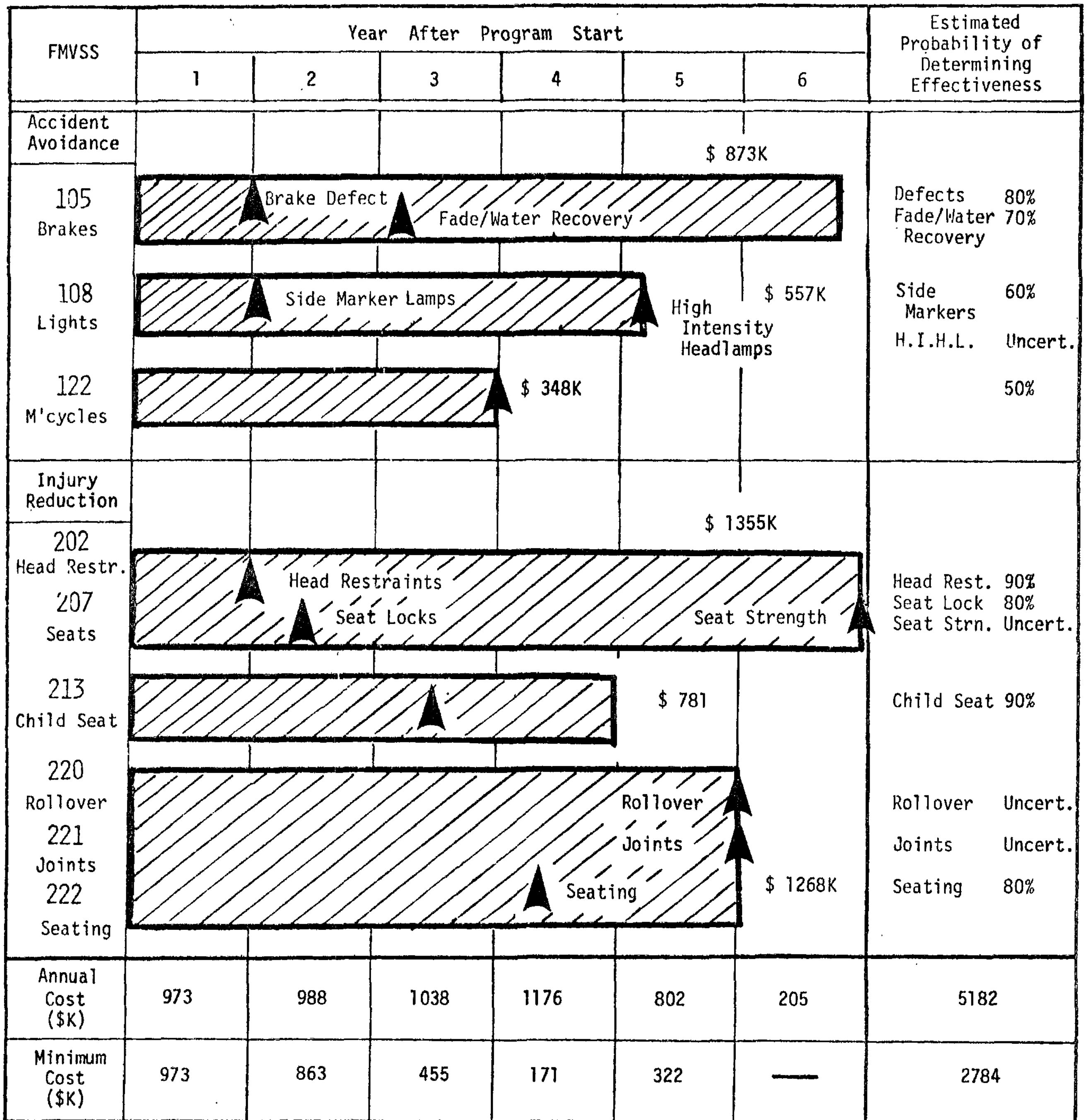
Overview and Summary of the Six Effectiveness Evaluation Programs

Figure 1 on the next page summarizes the comments above into a format which compares the full scope of each proposed effectiveness evaluation program. Also shown in the figure by the symbol ▲ are the earliest possible completion dates for certain aspects of the various programs. In general, such dates are speculative; that is, the proposed early analyses must be completed and the results must be reviewed before it will be possible to decide whether it is necessary or worthwhile to perform the next set of laboratory experiments and/or field surveys and/or additional data analyses.

In the case of brake defects (FMVSS 105), side marker lamps (FMVSS 108), head restraints (FMVSS 202) and folding seatback locks (FMVSS 207), it is estimated that the effectiveness evaluations may be satisfactorily completed within 1 to 1.5 years after program start. The effectiveness of the fade and water recovery aspects of passenger car brakes (FMVSS 105) and child seating systems (FMVSS 213) may be satisfactorily determined during the third year of the program. The motorcycle brake evaluation program (FMVSS 122) is scheduled for completion at the end of the third year, but there is the possibility that the difficulty of acquiring adequate detailed data, free of confounding effects, may preclude completely satisfactory evaluation of the effectiveness of the Standard, although a great deal of knowledge about motorcycle brakes will doubtless be obtained.

The satisfactory evaluation of the effectiveness of school bus seating and crash protection (FMVSS 222) may be possible in the fourth year, or no later than the end of the fifth year of the program. The long delay is necessary to acquire sufficient school bus accident data for the analyses, because the Standard is new (1977) and school bus accidents are relatively rare events.

Evaluation of the effectiveness of some aspects of hydraulic brake systems (FMVSS 105), high intensity headlamps (FMVSS 108), seat strength (FMVSS 207) and school bus rollover protection (FMVSS 220) and body strength (FMVSS 221) will be both difficult and time consuming. Results are not expected to be available



▲ = Earliest date for possible conclusion of effectiveness evaluation.

Figure 1. Effectiveness evaluation program summary for nine Federal Motor Vehicle Safety Standards.

until the fifth and sixth years of the program, and even then it is not possible at this time to state with high confidence that effectiveness will be determined with the desired high statistical confidence levels. There are a number of reasons for this uncertainty, including paucity of reliable detailed data and/or the inability to control for confounding effects, such as the role of motorcyclist inexperience in brake-involved accidents and/or the role of motor vehicle drivers in car-motorcycle accidents.

The full effectiveness evaluation program, as designed by CEM, is expected to take up to six years, and to cost about $5.2 million, as shown in Figure 1. This dollar figure is based on the assumption that certain early evaluations will not provide adequate results for satisfactory evaluation of the Standards, thus requiring additional expensive laboratory experiments, field surveys and data collection efforts, and special detailed accident data collection programs. If all the questionable early analyses are adequate, then under these "best of all worlds" conditions, it is estimated that the minimum cost of evaluating the effectiveness of the nine Standards would be only about $2.8 million. Annual cost breakdowns are shown at the bottom of Figure 1.

It is CEM's judgment that some early analyses may be adequate, and the evaluation of the Standards may require of the order of about $4.5 million, which would reflect lack of need for some laboratory or field tests, or one of the instrumented vehicle programs. Each of the evaluation programs has been structured with several "decision points," so full opportunity is given for consideration of whether the next phase of the program is needed, or whether results already obtained provide satisfactory evaluation of the effectiveness of a Standard.

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Mr. John Ball:	FMVSS 207:	Seating Systems
Ms. Kayla Costenoble:	FMVSS 122:	Motorcycle Brake Systems
	FMVSS 213:	Child Seating Systems
Mr. Joseph Reidy:	FMVSS 108:	Side Marker Lamps and High Intensity Headlamps
	FMVSS 202:	Head Restraints
Mr. Edward Sweeton:	FMVSS 105:	Hydraulic Brake Systems in Passenger Cars
	FMVSS 220:	School Bus Rollover Protection
	FMVSS 221:	School Bus Body Joint Strength
	FMVSS 222:	School Bus Seating & Crash Protection

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- Dr. Leonard Hafetz
- Dr. Uwe Koehn
- Dr. Michael Sutherland

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CEM also wishes to thank the many people in various automotive, motorcycle, school bus, and consumer and medical organizations and societies, and others, who so graciously responded to our many telephone and letter inquiries.

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ABBREVIATIONS USED

AIS	Abbreviated Injury Scale
ANACOVA	Analysis of Covariance
CALSPAN	Formerly Cornell Aueonautical Laboratory
CEM	The Center for the Environment and Man, Inc.
CU	Consumers Union
DOT	Department of Transportation
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GVWR	Gross Vehicle Weight Rating
HSRI	Highway Safety Research Institute
IPF	Iterative Proportional Fitting
MDAI	Multidisciplinary Accident Investigation
MPH	Miles per Hour
NASS	National Accident Sampling System
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
RSEP	Restraint System Evaluation Program
SAE	Society of Automotive Engineers

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Background

The first Federal Motor Vehicle Safety Standards were issued by the National Highway Traffic Safety Administration in 1967 and 1968 for 1968 and 1969 model year cars. An essential problem with these and subsequent Standards is to determine whether they are effective in achieving the purpose for which they were enacted.

This study was funded in two parts by NHTSA's Office of Program Evaluation, to develop methodologies to evaluate a total of nine Federal Motor Vehicle Safety Standards (DOT-HS-7-01674 and DOT-HS-7-01675). The Standards selected for study were:

- FMVSS 105 - Hydraulic Brake Systems in Passenger Cars
- FMVSS 108 - Side Marker Lamps and High Intensity Headlamps (only)*
- FMVSS 122 - Motorcycle Brake Systems
- FMVSS 202 - Head Restraints
- FMVSS 207 - Seating Systems
- FMVSS 213 - Child Seating Systems
- FMVSS 220 - School Bus Rollover Protection
- FMVSS 221 - School Bus Joint Strength
- FMVSS 222 - School Bus Seating Systems and Crash Protection.

This study was similar to a previous effort performed by The Center for the Environment and Man, Inc. (CEM) for NHTSA in 1977, which developed evaluation methodologies for four other FMVSS: FMVSS 214 (Side Door Strength), FMVSS 215 (Exterior Protection), FMVSS 301 (Fuel System Integrity), and FMVSS 208 (Occupant Crash Protection). That work was summarized in DOT-HS-802 346.

In developing effectiveness evaluation methodologies for the nine Standards, CEM has completed seventeen separate reports in seven months. Section 7 provides a list of the end products of the two studies summarized herein.

1.2 Objectives

The overall objectives of the study were to develop methodologies to evaluate the nine FMVSS. The specific objectives to achieve the overall goal were to:

- Review background material on the nine Standards.
- Study the feasibility of evaluating the effects of each of the nine Standards.
- Develop a study design which would provide estimates of effects of a Standard given certain confidence limits and sample sizes.
- Prepare a detailed work plan to implement the study design.
- Describe in detail the procedures for obtaining the data and performing the evaluations.

*The formal title of FMVSS 108 is "Lamps, Reflector Devices and Associated Equipment." The Standard covers 15 separate lighting elements of which only two are considered in this study.

1.3 Scope

The study was limited to seven months total (actually two six-month studies which overlapped). Each Standard was evaluated over a two and one-half month period in which the feasibility study and preliminary study design were first completed, then reviewed, and a final study design and detailed work plan prepared. The first month of the study was basically devoted to the review of all the Standards, while the last was primarily directed toward integrating all the Standard evaluations into an overall six-year program, contained in this report.

1.4 Approach

Our overall approach was to try to develop methods which would utilize existing data to provide some preliminary information on the effects of the Standard and to guide the laboratory experiments, field tests and surveys, and collection and analysis of new data. The approach taken by CEM in developing the preliminary study designs involved intensive interaction between Study Team members. Special meetings between project staff and consultants on the nature of existing and potential data evolved toward specific analytic tools. After the preliminary study designs were developed, CEM refined them for actual implementation. Finally, after the final design and implementation plans for the individual Standards were finished, an effort was made to integrate the separate plans.

1.5 Limitations

The task of developing a detailed plan for performing a complex exploratory analysis of both existing and to-be-collected data is quite difficult to do in the abstract. Many decisions are determined by the nature of the data. In some cases preliminary results were derived from exploratory analyses of existing data bases. However, in most cases, testing of our proposed methods was precluded.

Secondly, some material was generated during the study which does not directly serve to evaluate the effectiveness of a Standard, but was desirable from the point of view of background. These are such items as the general discussion of statistical methods, the discussion of cost estimating methodologies, etc. In addition, some items were outlined in detail for comprehensiveness, but they do not directly address the question of effectiveness. These are primarily concerned with usage surveys.

1.6 Outline of the Report

Section 2 presents conclusions and recommendations. Section 3 reviews the Standards. Section 4 discusses the approaches to evaluating the Standards. Section 5 deals with the specific methodologies which are suggested to analyze the Standards. Section 6 presents individual and integrated implementation plans. Section 7 lists the end products generated during this study.

The Appendix contains a discussion of statistical techniques which can be applied to the evaluation of the accident and other types of data collected. The latest versions of the Standards, as well as the original versions, can be found as Appendices to the companion CEM final report: *Review of Nine Federal Motor Vehicle Safety Standards* (CEM Report 4228/4229-601).

2.0 Conclusions and Recommendations

2.1 Conclusions

CEM concludes that it could take up to $5.2 million and from three to six years to completely evaluate the effectiveness of the nine Standards. Generally, CEM estimates that the likelihood of successfully estimating the effectiveness of each Standard is, beginning with the most likely:

- FMVSS 202: Head Restraints
  - Previous studies have shown that head restraints are effective in reducing neck injuries for left and right seat front passengers involved in rear-end and other crashes. The proposed evaluation program will extend previous research--particularly in determining the relative effectiveness of fixed and adjustable head restraints. Head restraints may benefit of the order of 5 million front seat occupants involved in rear-end collisions each year.

- FMVSS 213: Child Seating Systems
  - Child seating systems are probably quite effective in reducing death and injuries in automobile accidents. However, probably no more than about 10 percent of children 5 years old or less are put in child seats. Of the 16 million children 5 or less, about 70,000 children are injured in crashes annually, but only about 500 are killed. The proposed evaluation program calls for field usage surveys and dynamic testing, as well as analysis of existing mass accident data and detailed accident data.

- FMVSS 222: School Bus Seating and Crash Protection
  - Padding, proper seat dimensions and strength, and proper seat spacing will reduce injuries to children resulting from school bus accidents or violent maneuvers. New buses are added to the present inventory of about 300,000 at a rate of about 30,000 per year, primarily for replacement. The school bus Standards became effective April 1, 1977, and school bus accidents are relatively rare events--there are only about 51,000 annually (1976). There are only about 6,000 students injured and 10-20 killed inside buses each year, a very low rate, given that about 22 million students are bussed each school day. It will require 3 to 5 years to collect adequate bus accident data to satisfactorily evaluate the effectiveness of this Standard. Laboratory testing for FMVSS 221 and 222 will contribute some knowledge which will enhance the data analyses.

- <u>FMVSS 105: Hydraulic Brake Systems in Passenger Cars</u>
  - Previous analyses suggest that less than five percent of all accidents are brake related, but this implies that there are 0.5 to 1 million such crashes per year. Split brake systems and brake outage warning lights were installed on about half the cars produced between 1964 and 1968, when the Standard became effective. Many brake accidents may be affected by car age. Car weight and driver age and sex may also influence the severity of brake related accidents. It is likely that the change in brake effectiveness due to the Standard is small, and it may be difficult to establish the degree of effectiveness improvement at a high statistical confidence level. In addition to mass accident analysis, laboratory tests and field survey of brake outage indicator lamps are planned.

- <u>FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)</u>
  - A previous study has estimated the effects of <u>side marker lamps</u> at about one percent. <u>High intensity headlamps</u> have only recently been permitted on U.S. vehicles (November 1, 1976). Effectiveness of <u>side marker lamps</u> will first be evaluated by analyzing mass accident data. Since the effect is likely to be small, a large volume of data will be analyzed. If this is not adequate, a series of laboratory experiments and field surveys will be performed. <u>High intensity headlamps</u> are expected to improve sighting distance, but may cause glare in adverse weather and/or create glare blindness for oncoming motorists. The study will begin with some basic laboratory and field tests. This will be followed by analysis of mass accident data (after enough has been collected). If needed, three additional field surveys will be performed. Because of lack of definitive data and/or confounding effects, it may be difficult to satisfactorily evaluate these two features of FMVSS 108, which will be carried out in a joint program.

- <u>FMVSS 207: Seating Systems</u>
  - The principal effects of this Standard apply to folding seatback locks and seat holddown mechanisms. Mass and detailed accident data from the Fatal Accident Reporting System (FARS) will be analyzed first, and may be adequate to satisfactorily determine effectiveness. If not, there are plans for dynamic laboratory tests and instrumenting vehicles in the field, to collect data in actual crash situations. This study will be conducted in conjunction with the evaluation of FMVSS 202 (Head Restraints).

- <u>FMVSS 220: School Bus Rollover Protection</u>
  - School bus Standards are so recent (April 1, 1977), and accidents--especially rollovers--are so rare that several years will have to pass before enough detailed and/or mass accident data will be available. Therefore, the analysis will begin with basic laboratory static tests and clinical analysis of the few available Multidisciplinary Accident Investigation (MDAI) data. After a year or so, analysis of mass accident data will begin, and will be repeated annually for about five years. As it becomes available, special

NASS data will be analyzed, including results from buses instrumented with accelerometers in NASS Primary Sampling Unit Areas. Also, more detailed dynamic laboratory test data will be obtained, if needed. This will be a joint program also involving FMVSS 221 and FMVSS 222.

- FMVSS 221: School Bus Body Joint Strength
  - Accidents which result in the failure of school bus body joints are almost, but not quite, as rare as school bus rollovers. In general, the comments for evaluation of the effectiveness of FMVSS 220 also apply here, with the exception that some early dynamic laboratory tests will be performed. This Standard will be evaluated in conjunction with FMVSS 220 and FMVSS 222.

- FMVSS 122: Motorcycle Brake Systems
  - There are little or no data relating brakes and motorcycle accidents. Furthermore, rider experience (or, inexperience) appears to be of paramount importance in the majority of motorcycle accidents. Coupled with the apparent fact that many motorcycle accidents appear to be caused by the failure of automobile drivers to perceive and react appropriately to motorcycles on the road, this indicates that confounding effects will make difficult the evaluation of this Standard. The three-year program will begin with analysis of existing mass accident data and a mail survey to provide information on potentially confounding effects. NASS data will be analyzed periodically as they become available, and laboratory and field tests are recommended.

2.2 Tabular Summary of Conclusions and Recommendations

Tables 2-1, 2-2, 2-3, and 2-4, which follow, give a complete overview of various conclusions and our recommendations on how the Standards should be evaluated.

TABLE 2-1

SUMMARY OF RECOMMENDED APPROACHES

<table>
<tr><th>FMVSS 105: Hydraulic Brake Systems</th><th>FMVSS 122: Motorcycle Brake Systems</th></tr>
<tr><td>
• Analyze Mass Accident Data for:
  - Brake system defect rate
  - Improvement in Post-Standard brake performance
  - Ratio of brake-involved accidents (Pre- vs. Post-Standard)
• Decide if Further Analysis is Required
• Perform Laboratory Tests
  - Age effects
  - Fade
  - Water recovery
• Decide if Further Analysis is Required
• Perform Laboratory and Field Tests
  - Pedal pressure (driver capabilities)
  - Static pressure (failure modes)
  - Brake indicator light outage rates
• Instrumented Vehicles with Accelerometers
  - Collect real world crash acceleration data
  - Piggyback this on NHTSA Crash Recorder Program
• Evaluate Standard Effectiveness
  - Propose next steps, if needed.
</td><td>
• Analyze Mass Accident Data for:
  - Reduction in brake-related accidents/injuries, due to Standard
• Decide if Further Analysis is Required
• Mail Survey
  - Rider characteristics
  - Tire types used
  - Structural modifications
• Analyze Detailed Data
  - NASS
  - California Motorcycle Study
• Decide if Further Analysis is Required
• Laboratory Dynamometer Tests
• Reevaluate Available NASS Data
• Decide if Further Analysis is Required
• Field Tests with Volunteer and Professional Riders
  - Brake performance
  - Rider behavior
• Reevaluate Available NASS Data
• Evaluate Standard Effectiveness
  - Propose next steps, if needed.
</td></tr>
<tr><th>FMVSS 108: Side Marker Lamps</th><th>FMVSS 108: High Intensity Headlamps</th></tr>
<tr><td>
• Analyze Mass Accident Data for:
  - Reduction in side collisions at night and reduced visibility
• Decide if Further Analysis is Required
• Perform Laboratory and Field Tests
  - Lab: Conspicuity of side markers
  - Field: Sighting distance of side marker lamps
• Decide if Further Analysis is Required
• Perform Field Surveys and Analyses
  - Lamp usage
  - Lamp outage
• Evaluate Standard Effectiveness
  - Propose next steps, if needed.
</td><td>
• Perform Laboratory and Field Tests
  - Lab: Glare effects from adverse weather
  - Field: Sighting distance
• Decide if Further Analysis is Required
• Perform Field Test of Night Driving Behavior at Hazardous Locations
• Analyze Mass Accident Data for:
  - Accidents due to overdriving headlamps
  - Accidents due to oncoming glare
• Perform Field Surveys and Analyses
  - Use of high beams
  - Headlamp outage
  - Misaiming of headlamps
• Evaluate Standard Effectiveness
  - Propose next steps, if needed.
</td></tr>
<tr><td colspan="2">←(Joint Evaluation Program)→</td></tr>
</table>

TABLE 2-1

RECOMMENDED APPROACHES (Continued)

FMVSS 202: Head Restraint Systems	FMVSS 207: Seating Systems
● Analyze Insurance Claim Data for Neck Injuries Pre- and Post-Standard ● Analyze Detailed NCSS Data for Neck Injuries Pre- and Post-Standard ● Decide if Further Analysis is Required ● Perform Head Restraint Usage Field Survey ● Decide if Further Analysis is Required ● Perform Laboratory Dynamic Tests ● Decide if Further Analysis is Required ● Instrument Vehicles with Accelerometers - Collect real world crash data - Analyze Data ● Evaluate Standard Effectiveness - Propose next steps, if needed.	● Analyze Existing Data for: - FARS: Occupant fatalities in cars with seat back locks - MDAI and NCSS: Clinical and statistical analyses of injuries, Pre- and Post-Standard - Mass Accident Data: Injury rates in 2-door and 4-door cars, Pre- and Post-Standard ● Decide if Further Analysis is Required ● Perform Laboratory Dynamic Tests ● Decide if Further Analysis is Required ● Instrument Vehicles with Accelerometers - Collect real-world crash data - Analyze data ● Evaluate Standard Effectiveness - Propose next steps, if needed.
←(Joint Evaluation Program)→	
FMVSS 213: Child Seating Systems	**FMVSS 220/221/222: School Bus Standards**
● Analyze Mass Accident Data - Primarily N.Y. State - Deaths/Injuries for Children 5 or less ● Analyze Detailed Accident Data - NCSS, NASS data - Determine effect of different seat types ● Evaluate Results of Tennessee Child Seat Study ● Decide if Further Analysis is Required ● Perform NASS Special Study on Use/Nonuse of Child Seats in Accidents ● Perform Pediatrician and Emergency Room Surveys ● Decide if Further Analysis is Needed ● Perform Field Survey of Use/Misuse of Child Seats ● Perform Mail Survey of Parental Attitude on Use of Child Seats ● Perform Laboratory Dynamic Tests ● Evaluate Standard Effectiveness Propose next steps, if needed.	● Perform Preliminary Laboratory Tests - Roof Strength: static diagonal loads - Joint Strength: Dynamic angle shear impact ● Perform Clinical Analysis of MDAI Data ● Decide if Further Analysis for 220/221 is Required ● Instrumented Buses in NASS Data Collection Areas ● Perform NASS Special Study on School Bus Accidents ● Periodically Analyze All Available NASS Data (All NASS plus Special Study) ● Decide if Further Analysis is Required ● Perform Laboratory Dynamic Tests ● Continue Periodic Analysis of All Available NASS Data (All NASS plus Special Study) ● Evaluate Standard Effectiveness - Propose next steps, if needed. (Joint Evaluation Program for FMVSS 220/221/222)

TABLE 2-2

CONCLUSIONS CONCERNING MEASURES OF EFFECTIVENESS AND DATA AVAILABLE FOR ESTIMATING THEM

<table>
<tr><th>FMVSS 105: Hydraulic Brake Systems</th><th>FMVSS 122: Motorcycle Brake Systems</th></tr>
<tr><td>● Accidents Avoided
- Use mass accident data for analysis of brake-involved accidents (speculative)
● Accidents Which Could Have Been Avoided
- Use mass accident data to estimate Pre-Standard brake system defect accidents and effect of brake system improvement
● Measures of Performance Which Limit Effectiveness
- Use data from laboratory dynamometer tests
- Gather data from tests on:
-- Driver braking capabilities
-- Brake failure modes
-- Brake warning system failures
- Use data gathered from instrumented vehicles operating in the real world.</td><td>● Accidents Avoided
- No data available
● Accidents Which Could Have Been Avoided
- Use mass accident data, information on riders and vehicles, and detailed accident data
● Measures of Performance Which Limit Effectiveness
- Use data from laboratory dynamometer tests
- Use data from field tests of
-- Brake performance
-- Rider behavior.</td></tr>
<tr><th>FMVSS 108: Side Marker Lamps</th><th>FMVSS 108: High Intensity Headlamps</th></tr>
<tr><td>● Reduction of Side (or Angle) Collisions at Dusk/Dawn/Nighttime/Other Low Light Conditions
- Use mass accident data
● Increased Visibility of Cars
- Use data from field tests and laboratory tests
● Measures of Usage Which Limit Effectiveness
- Use field surveys.</td><td>● Reduction in Accidents (or Emergency Maneuvers) Resulting from Overdriving Headlamps
- Use mass accident data
- Use field survey data
● Increased Driver Sighting Distance
- Use field test data
● Decreased Driver Sighting Distance Due to Glare from High Intensity Headlamps
- Use field test data
● Increased Frequency of Glare/Blinding Complaints in Accidents
- Use future mass accident data
● Measures of Usage Which Limit Effectiveness
- Use field surveys of usage.</td></tr>
<tr><td colspan="2">←(Joint Evaluation Program)→</td></tr>
</table>

TABLE 2-2 (Continued)

FMVSS 202: Head Restraints	FMVSS 207: Seating Systems
● Reductions in Frequency and Severity of Neck Injury - Use insurance claim files - Use detailed accident data: NCSS ● Measures of Performance and Usage Which Limit Effectiveness - Usage survey - Dynamic laboratory tests - Instrumented vehicles.	● Reduction in Frequency of Seat System Failure - Use detailed accident data: NCSS, MDAI ● Reduction in Occupant Injury in Frontal Crashes - Use mass accident data ● Reduction in Frequency of Entrapment of Rear Seat Occupants - Use FARS ● Measures of Performance Which Limit Effectiveness - Dynamic laboratory tests - Instrumented vehicles.
←(Joint Evaluation Program)→	
FMVSS 213: Child Seating Systems	**FMVSS 220/221/222: School Bus Standards**
● Reductions in Frequency of Serious and Fatal Injuries to Children - Use mass accident data - Use detailed accident data: NCSS and NASS - Evaluate results of Tennessee child restraint study - Evaluate results of pediatrician survey, re child injuries in crashes - Evaluate results of emergency room survey, re child injuries in crashes ● Measures of Performance and Usage Which Limit Effectiveness - Usage survey - Mail survey of parental attitudes of use/misuse - Dynamic laboratory tests.	● Reductions in Deaths and Injuries in School Bus Accidents - Use mass accident data - Use detailed accident data: MDAI, NASS - Use detailed accident data from special instrumented vehicle program ● Measures of Performance Which Limit Effectiveness - Preliminary laboratory tests - Detailed laboratory tests.

TABLE 2-3

RECOMMENDED ANALYSIS METHODS

FMVSS 105: Hydraulic Brake Systems	FMVSS 122: Motorcycle Brake Systems
• Rate of Catastrophic Brake Malfunction - Loglinear analysis • Analysis of Struck vs. Striking Vehicle (Brake System Improvement) - Comparison of rates • Ratio Estimation of Accidents Avoided - Ratio analysis • Laboratory Dynamometer Tests - Comparison of rates and measures • Pedal Pressure Tests (Drivers) - Comparison of rates and measures • Static Brake Tests (Failure Modes) - Comparison of rates and measures • Brake Indicator Outage Rates - Comparison of rates and measures • Instrumented Vehicles - Comparison of rates and measures.	• Analysis of Front-Rear and Left Turning Collisions - Analysis of covariance or loglinear analysis • Motorcycle Brake Failure Analysis - Comparison of rates using loglinear model • Laboratory Dynamometer Tests - Comparison of rates and measures • Motorcycle Survey - Comparison of rates and measures • Field Tests of Braking Performance - Comparison of rates and measures • Field Tests of Riding Behavior - Comparison of rates and measures.
FMVSS 108: Side Marker Lamps	**FMVSS 108: High Intensity Headlamps**
• Analysis of Side Collisions - Loglinear analysis • Sighting Distance Field Test - Analysis of variance • Laboratory Test of Conspicuity - Comparison of rates and measures • Field Survey of Lamp Use - Comparison of rates • Field Survey of Lamp Outage - Comparison of rates.	• Sighting Distance Field Test - Analysis of variance • Laboratory Test of Effects of Glare Under Adverse Conditions - Comparison of measures • Night Driving Behavior at Hazardous Locations - Analysis of covariance • Analysis of Mass Accident Data - Comparison of rates • Field Surveys of Headlamp Usage, Outage, and Misaiming - Comparison of rates and measures.
←(Joint Evaluation Program)→	

TABLE 2-3 (Continued)

FMVSS 202: Head Restraints	FMVSS 207: Seating Systems
• Analysis of Insurance Claims - Comparison of rates • Injury Analysis Based on Accident Data - Contingency table analysis using a loglinear model • Head Restraint Usage Survey - Comparison of rates • Dynamic Laboratory Tests - Comparison of rates and measures • Analysis of Instrumented Vehicle Data - Comparison of rates and measures.	• Injury and Seat Failure Analysis Using Detailed Accident Data - Contingency table analysis using loglinear model • Occupant Fatality Analysis - Contingency table analysis • Injury Analysis Using Mass Accident Data - Loglinear analysis • Dynamic Laboratory Tests - Comparison of rates and measures • Analysis of Instrumented Vehicle Data - Comparison of rates and measures.

←(Joint Evaluation Program)→

FMVSS 213: Child Seating Systems	FMVSS 220/221/222: School Bus Standards
• Analysis of Mass Accident Data - Loglinear analysis • Analysis of Detailed Accident Data - Loglinear analysis • Pediatrician and Emergency Room Surveys - Comparison of rates • Field Survey of Child Seat Use/Misuse and Mail Survey of Parental Attitudes on Seat Use - Comparison of rates and measures • Dynamic Laboratory Tests - Comparison of measures.	• Preliminary Static and Dynamic Laboratory Tests - Comparison of measures • Clinical Analysis of Bus Accident Injuries (MDAI) - Case-by-case analysis • Analysis of NASS Bus Accidents - Contingency table analysis • Analysis of Instrumented Vehicle Accidents - Contingency table analysis - Case-by-case analysis • Detailed Laboratory Tests - Comparison of measures.

TABLE 2-4

SUMMARY OF COSTS OF RECOMMENDED PROGRAMS FOR FMVSS EFFECTIVENESS EVALUATION

($ Thousands)

Cost	Federal Motor Vehicle Safety Standard						Total
	105	108	122	202/207	213	220/221/222	
	Hydraulic Brake Systems	Side Marker Lamps and High Intensity Headlamps	Motorcycle Brakes	Head Restraints and Seating Systems	Child Seating Systems	School Buses	
1. Staff	495	407	237	613	533	375	2,660
2. Data Processing	41	18	20	25	16	8	128
3. Laboratory Tests	77	14	50	100	115	155	511
4. Equipment	260	43	41	567	14	730	1,655
5. Field Data Collection	-	75	-	50	103	-	228
Total	873	557	348	1,355	781	1,268	5,182

The costs indicated in Table 2-4 correspond to full effectiveness evaluation program costs as indicated in Figure 1 in the Executive Summary (also, Figure 6-8). It is emphasized that the full costs reflect a potentially pessimistic view concerning the success of the various statistical analyses of available or soon-to-be-available data bases. If the "best of all worlds" were to occur, CEM estimates that satisfactory evaluation of all Standards could be accomplished for about $2.8 million, or about half the total cost of $5.2 million, shown above. However, if some or all of the early analyses are unable to provide results with adequate statistical confidence levels, NHTSA may choose to undertake the more expensive and time-consuming field surveys, laboratory and field tests, and instrumented vehicle programs that have been recommended.

It is CEM's judgment that some early analyses may be adequate, and the evaluation of the Standards may require of the order of about $4.5 million, which would reflect lack of need for some laboratory or field tests, or one of the instrumented vehicle programs. Each of the evaluation programs has been structured with several "decision points," so full opportunity is given for consideration of whether the next phase of the program is needed, or whether results already obtained provide satisfactory evaluation of the effectiveness of a Standard.

3.0 Review of Standards

This section reviews and summarizes essential background information concerning the Standards which must be considered in developing a plan to evaluate their effectiveness. The nine Standards which have been examined are:

- FMVSS 105 - Hydraulic Brake Systems in Passenger Cars
- FMVSS 108 - Side Marker Lamps and High Intensity Headlamps (Only)
- FMVSS 122 - Motorcycle Brake Systems
- FMVSS 202 - Head Restraints
- FMVSS 207 - Seating Systems
- FMVSS 213 - Child Seating Systems
- FMVSS 220 - School Bus Rollover Protection
- FMVSS 221 - School Bus Joint Strength
- FMVSS 222 - School Bus Seating and Crash Protection.

Each Standard is reviewed in a separate subsection, except the School Bus Standards,which are treated together.

3.1 Review of FMVSS 105: Hydraulic Brake Systems in Passenger Cars

Background

This Standard evolved from a basic requirement, first published in 1967, to a highly specific regulation which became effective on January 1, 1976. There were many additions and changes in this nine-year period. FMVSS 105, the original Standard, became effective January 1, 1968. Extensive interactions between vehicle manufacturers and the Federal government produced a much more specific document, FMVSS 105a. FMVSS 105a was first published in September 1972, revised in May 1973, and had an effective date of September 1, 1975. FMVSS 105a was then published as FMVSS 105-75 in February 1974; it was further revised, and emerged in June 1975 with an effective date of January 1 , 1976. The technical differences between FMVSS 105a and 105-75 are minor. There were, however, a number of differences between FMVSS 105 and 105-75, most of which involve the specification of performance requirements. The original FMVSS 105, requiring a split braking system, essentially ratified several SAE Recommended Practices which had been in effect since 1966.* Table 3-1 describes the applicability by model year of Pre- and Post-Standard activities related to the Standard.

Purpose of FMVSS 105†

The purpose of FMVSS 105 is to specify requirements for hydraulic service brake systems, indicator lamps, and parking brake systems in passenger vehicles.

*Some U.S. automobile manufacturers began installing the split braking system on selected models in 1964. In 1966, about half the cars produced had the split brake system. By 1967, the split brake system was a standard item on all makes and models. Thus, this requirement of FMVSS 105 could add no additional effectiveness in preventing accidents, for all it did was to require manufacturers to continue doing what they had been doing for the past one to four years.

†In general, throughout this report we shall refer generically to the Standard as "FMVSS 105." Where a time distinction is important, we will refer to "FMVSS 105, 105a, or 105-75" as appropriate.

TABLE 3-1

APPLICABILITY OF FMVSS 105 BY MODEL YEAR

Model Year	Braking System Requirements
Pre-Standard:	
1964	• Split brake systems on production models of Cadillac, Rambler Classic and Ambassador, and Studebaker.
1966	• Split brake systems on entire Chevrolet line, plus above. • Publication in June 1966 of SAE Recommended Practice J937, *Service Brake Performance Requirements - Passenger Cars.*
1967	• Split brake systems on all U.S.-produced passenger vehicles. • First publication of tentative basic requirements for FMVSS 105.
Post-Standard:	
1968	• FMVSS 105 effective 1 January 1968. • Requirements for pedal pressure and deceleration from specified speeds; fade stops; brake temperature; wet brake stops.
1973	• Statement on FMVSS 105a published for review, at beginning of 1973 model year.
1974	• Revised statement on 105a published for review, prior to 1974 model year.
1975	• Statement on FMVSS 105-75 first published for review, prior to 1975 model year.
1976	• Revised statement on FMVSS 105-75 published for review, prior to 1976 model year. • FMVSS 105-75 effective 1 January 1976,mid-way through 1976 model year.

The general purpose is to insure safe braking performance under normal and emergency conditions.

General Requirements of FMVSS 105

Each passenger car vehicle must be equipped with a service brake system capable of meeting eight general requirements:

1. It must be capable of stopping the vehicle in four effectiveness tests within specified distances and from specified speeds.

2. In the event of a rupture or leakage type of failure, the service brake system must continue to operate and must be capable of stopping the vehicle from 60 miles per hour (mph) within specified distances.

3. Systems equipped with one or more brake power assist units or brake power units must be capable of stopping the vehicle from 60 mph within specified requirements with one such unit inoperative.

4. It must be capable of stopping the vehicle in two separate specified fade and recovery tests.

5. It must be capable of stopping the vehicle in a specific water recovery test.

6. The vehicle must be capable of making 10 spike stops from 30 mph, followed by 6 effectiveness stops from 60 mph, at least one of which must be within the specified stopping distance.

7. Vehicles must have a dash panel warning light that indicates a) gross loss of hydraulic supply pressure; b) a drop in fluid level in the hydraulic reservoir; and/or c) application of the parking brake.

8. The parking brake system must hold the vehicle for five minutes loaded to GVWR on a 30 percent grade in both forward and reverse orientation.

Measures of Effectiveness

The conceptual measure of effectiveness for this Standard should be the number of accidents that were avoided and did not happen as a result of compliance with the braking performance requirements. Unfortunately, these occurrences are known only to the drivers and occupants immediately involved and are almost never recorded. Records of their frequency would be available only as a result of special programs set up to collect this information, and even then the results would be biased by the subjective reporting by the drivers involved.

As an alternative, the corollary measurement of accidents that occurred but which could have been avoided by brake systems complying with the Standard might be used. Since almost all accidents involving significant injury and property damage are recorded to some degree, the information should be available. Perhaps the most difficult task in this approach is the determination, first, of whether the brake performance was a significant factor in the accident and, second, whether compliance of the brake system with the Standard requirements would have prevented the accident from happening. If mass accident data were used, this task might be addressed by determining which make/model year vehicles complied with various versions of the Standard and which did not. Then the relative frequency of accidents in which braking was probably involved could be the critical factor to be compared for each group.

The major weakness in using accident frequencies in mass accident data is the lack of a clear-cut distinction between vehicles meeting the Standard requirements and those not meeting them. The requirements of the Standard cover such a broad spectrum of performance characteristics that it is unlikely that any given vehicle can be classified as meeting or not meeting all the requirements. To be accurate, the analysis would have to distinguish which requirement(s) of the Standard were applicable to each accident and whether or not the vehicle involved complied with this (these) requirement(s) at the time it was manufactured. This information is not available in mass accident data; therefore, data from a more detailed type of accident reporting such as that of multidisciplinary accident investigation (MDAI) teams would be required.

Means of Complying with the Standard

There have been two major versions of the Standard, FMVSS 105 (effective on January 1, 1968) and FMVSS 105-75 (effective on January 1, 1976). The early version of the Standard codified to a significant degree Society of Automotive Engineers (SAE) Standards and Recommended Practices that had been in effect since June 1966. Three new requirements, however, were imposed by FMVSS 105 and were responded to as follows [1]:

- Split system for emergency braking. The requirement for a split system was met by constructing a dual master cylinder and a front/rear system division.* Table 3-2 indicates when split brake systems first appeared.

- Warning light to indicate brake failure. The requirement for a warning light was achieved by including a differential pressure valve which shuttled and turned on the failure light if the pressures in the front and the rear systems differed by more than a specified amount.†

- Parking brake to hold vehicle on 30 percent grade. Parking brake systems were modified and upsized to satisfy this requirement.

The revised and present version of the Standard, FMVSS 105-75 greatly expanded testing requirements, including testing for partial system failure, and made water recovery tests mandatory rather than optional. This new version of the Standard expresses requirements in terms of maximum stopping distance and number of stops for specified speeds in both effectiveness tests and tests for partial system failure.

To meet the new requirements of FMVSS 105-75, a variety of compliance approaches was needed. These include [1, 2]:

- Increased use of front disc brakes and, on some models, rear disc brakes to replace drum-type brakes.

- Various types of boosters and upsizing of hydraulic braking systems.

- Rebalancing of brake systems and in some instances introducing a brake bias, in which in some cases, up to 75 percent of the braking effort may be provided by the front brakes.

*Even though the split brake system was not specified by the 1966 SAE Standard, it was installed in about half the U.S.-produced cars in 1966 and virtually all model year 1967 cars.

†Most of the Pre-Standard cars which had split brake systems also had brake failure warning lights.

TABLE 3-2

MODEL YEAR IN WHICH SPLIT BRAKE SYSTEMS APPEARED

Make	Model Year in Which Split Brake Systems First Appeared
American Motors Rambler	1964
Buick	1967
Chevrolet	1966
Chrysler line	1967
Ford line	1967
Oldsmobile	1966
Pontiac	1966
Saab	1964

Source: *Motor's Repair Manual* [3]; *Consumer Reports* [4]

- Use of multistroke parking brake control.
- Inclusion of dash panel lights which warn of low fluid levels in the master cylinders.

The specific means of complying with the requirements of FMVSS 105a and 105-75 are very much dependent on the existing braking system characteristics and vehicle weight and performance characteristics which were present in 1975 model year cars, prior to the newer versions of the Standard. Decision alternatives could include, for example, a choice of either disc-type brakes in both front and rear *vs.* front disc brakes and upsized rear drum brakes with perhaps a re-balanced brake system. What is important to keep in mind is that a manufacturer's decision quite likely reflected both the need to comply with the Standard and a desire to follow a planned evolution in vehicle characteristics and performance in a given line and/or meet competition. The upsizing of brakes became particularly important to car manufacturers in the early 1970's, when vehicle weights climbed and posted interstate highway speeds increased. For example, in the 1975 model year--probably the peak year in automobile weights--Cadillacs ranged from 5105 to 6032 lb; the Chevrolet Impala weighed about 4800 lb; and a Chevrolet station wagon was almost 5000 lb [5]. Similarly,posted highway speeds were common at 70 and 75 mph, and 80 mph posted speeds occurred in some parts of the U.S.

Secondary Effects of Compliance

In providing a braking performance threshold to insure safe vehicle operation under normal conditions, there are two possible negative effects that are worthy of consideration. They are:

1. Loss of vehicle control while braking. In situations where pavement is wet or slippery due to ice or snow, sensitive brakes may cause the operator to lose steering control, preventing him from otherwise being able to avoid a collision.*

2. Rear end collisions. Should a newer vehicle that complies with the Standard stop suddenly in traffic and the vehicle directly behind is older and does not comply, or has a braking system which is worn and in need of service, then such a situation could contribute to an increase in the frequency of rear end collisions between old (striking) and new (struck) cars.

Real World Performance of the Standard

As mentioned in a previous section, the information required to accurately measure the performance of the Standard is not available in mass accident data and must be provided by accident investigations by skilled, multidisciplinary teams. For the amount of information obtained, this type of activity is relatively expensive and time consuming. Thus, little has been done on a widespread scale. As an example, the Institute for Research in Public Safety at the University of Indiana conducted a study of this sort for nearly two years in Monroe County, Indiana. A total of 219 accidents was investigated, which represented about 6 percent of all accidents, and of these, approximately 4 percent were found to have brake failure definitely involved [6]. Another study was conducted for one year in the Santa Clara and San Mateo Counties area of California by the Stanford Research Institute, whereby only those accidents that were investigated were the ones suspected of involving mechanical defects of any of the vehicles involved [7]. A total of 48 of the accidents investigated was considered to be caused by mechanical defects. Of these, twelve were caused by brake system failure. Neither of these two studies attempted to relate brake failure with requirements of the Standard.

Additional difficulties in the use of mass accident data include, but are not limited to:

- Virtually all 1967 models and about half the 1966 model U.S.-produced cars had split brake systems and probably could have at least approximately met the stopping distance requirements that went into effect on January 1, 1968.

- It is not apparent that much, if any, automated mass accident data are available for years prior to 1967, thus limiting the availability of data on crashes of new cars or pre-1967 cars that did not have the split brake system.

- Cars that are two or more years old may incur brake failures that are caused by lack of maintenance and/or age (i.e., worn brake linings, failure of seals in the wheel cylinder, deterioration of flexible lines, etc.). It is doubtful that mass accident data would shed much light on why a brake system failure occurred, and whether the failure could be referenced to a characteristic covered by the Standard.

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*Anti-skid brake systems have been available for various heavy luxury cars since 1969. They have not yet been applied to any large-volume vehicles.

3.2 Review of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)

Background

This Standard originally went into effect on January 1, 1968; however, at that time, the Standard applied only to vehicles 80 or more inches in width--primarily larger commercial vehicles.

Passenger vehicles manufactured in 1969 (January 1, 1969 - December 31,1969) could meet the requirements for side markers with any combination of lamps or reflectors mounted front and rear. After January 1, 1970, all passenger vehicles had to have an amber lamp positioned as far front and a red lamp as far to the rear as possible on the sides of the vehicle. (Some vehicles achieved this by combining the front and/or rear side marker lamps with front and/or rear lighting components.)

The original FMVSS 108 largely ratified the existing head lighting practices embodied in the Society of Automotive Engineers Standards and Recommended Practices. As of November 1, 1976, NHTSA allowed the manufacturers to provide either a high-intensity rectangular headlamp system or existing lower intensity systems, thus permitting an increase in maximum light output from 75,000 to 150,000 candela.

Purpose of FMVSS 108

The overall purpose of the Standard is to avoid accidents by improving the driver's visual information during darkness or other conditions of reduced visibility. Specifically,

- Side marker lamps are intended to help drivers notice the presence of and judge the distance to other vehicles when the vehicles are at an angle to one another, and
- High intensity headlamps are intended to increase the illumination of the path ahead.

General Requirements of FMVSS 108

Side Marker Lamps

Currently, all vehicles must be equipped with side marker lamps: an amber lamp positioned as far forward and a red lamp as far to the rear "as practicable." The side marker lamps have to meet the minimum candlepower requirements of SAE Standard J592e. The SAE Standard sets minimum and maximum candela measures which must be taken from a position 15 feet from the side of the vehicle half-way between the front and rear marker lamps.

From *January 1, 1969 to December 31, 1969*, the Standard could be satisfied with any combination of lamps or reflectors positioned front and rear as long as the colors were correct--amber forward and red rear. SAE Standard J544e applies to reflex reflectors and sets minimum candlepower reflectance for entrance angle of the light (20 degrees left and right and 10 degrees up and down from the axis of reflector and observation angle, 0.2 and 1.5 degrees from the entrance angle).

Before *January 1, 1969*, no side marker lamps were required.

High Intensity Headlamps

Since *November 1, 1976*, two high intensity rectangular headlamps have been allowed on passenger cars, replacing either two-unit or four-unit conventional headlamps. The high intensity headlamps can have a total maximum high beam output of 150,000 candela, which is double the output of conventional headlamps. (Low beam intensity is about 20 percent higher.) The dimensions and testing requirements of these new beams are given in SAE Recommended Practice J1123. That recommended practice references several other SAE Standards as to specific tests. The critical SAE Standard is J579c because that establishes the photometric design and beam pattern requirements. High intensity headlamps are larger than the regular rectangular headlamps--142 x 200 mm *vs.* 100 x 165 mm or 5.6 x 7.9 in *vs.* 4.5 x 6 in.

Two basic tests are required by the Standard. The first test consists of measuring the intensity of light falling on a test screen 25 feet (7.6 m) from the headlamp unit. The intensity of light is measured at certain points to assure separate vertical and horizontal balance and establish a maximum level of light intensity away from the "hot spot." The second test measures intensities at certain points arranged up to 12 degrees left and right and several degrees up and down. Candela are measured for both upper and lower beam, and must exceed proscribed minima and be within other maxima. The absolute maximum is 75,000 candela for one lamp, or 150,000 for both; however, lower maxima are given for critical angles, such as up and to the left.

Measures of Effectiveness

The overall effectiveness of the Standard is the degree to which it achieves its objective--accident avoidance. Specific measures of effectiveness are:

Side Marker Lamps

- Reduction of side (or angle) collisions at dusk/dawn/nighttime/other low light conditions.
- Increased visibility of cars as measured by an observer's sighting distance.

High Intensity Headlamps

- Reduction in accidents (or emergency maneuvers) resulting from over-driving headlamps.*
- Increased driver sighting distance with high intensity headlamps.
- Decreased driver sighting distance due to glare from high intensity headlamps.
- Increased frequency of glare/blinding complaints in accidents.

*"Driver ability to see" is a variable depending on many factors such as fog/rain/snow, windshield cleanliness, headlamp aiming, and headlamp cleanliness, as well as the driver's own visual abilities.

Means of Complying with the Standard

Side Marker Lamps

- Before *January 1, 1969,* regular passenger vehicles were not required to have any side markers. However, due to modeling considerations, some earlier models had various lights which were visible from the side.

- Between *January 2, 1969 and December 31, 1969,* vehicles could satisfy the Standard for side marker lamps in one of four ways:

  (1) Using one red and one amber reflex reflector.
  (2) Using one red and one amber side marker lamp.
  (3) Using a red side marker lamp and an amber reflex reflector.
  (4) Using a red reflex reflector and an amber side marker lamp.

The amber element should be as far front and the red element as far to the rear as practicable on each side of the vehicle.

- After *January 1, 1970,* cars had to have lamps for both forward and rear side markers. Some models achieved this by enlarging the front and/or rear lighting group so that it could be seen from the side; other models had totally separate side marker lamps.

High Intensity Headlamps

There is no requirement for the use of high intensity lighting systems. A restriction on candlepower output was removed for passenger vehicles manufactured after November 1, 1976, allowing high intensity rectangular two-headlamp systems. These headlamps can produce twice the high beam output of regular lights and about 20 percent more low beam output.

The Type 2B high intensity headlamps are of a larger size than regular rectangular headlamps. This change was desired by the manufacturers and is not a requirement of the Standard. The increased illumination could have simply been increased by a heavier filament or through the use of a quartz-halogen light source in existing headlamp designs.

Primary and Secondary Effects of Compliance

Both side marker lamps and high intensity headlamps will only have an effect when they are used during darkness or other conditions of reduced visibility.

The primary effects of side marker lamps will be in situations where vehicles are approaching one another at an angle. The side marker lamps should aid vehicle identification and distance judgment, thus leading to accident avoidance. There are no significant secondary effects of side marker lamps. One speculative effect is that drivers will depend on the side marker lamps for visual use while driving and thus reactions to and identification of Pre-Standard cars under poor visual conditions would be even further degraded.

The primary effect of the high intensity headlamps will be that the roadway will be better illuminated. However, this increased illumination may lead to increased glare for other drivers. The degree to which the increased illumination helps avoid accidents depends largely on driver characteristics, e.g., how far ahead the driver looks. Two potential secondary effects of the high intensity headlamps are (1) that the headlamps may make other drivers aware of the location of the Post-Standard vehicle; and (2) that the brighter lamps may cause greater numbers of animals to be "frozen" in the roadway leading to an increase in such potentially hazardous situations.

Real World Performance of the Standard

The estimated effect of side marker lamps in reducing side collisions at night has been of the order of 1 percent [8]. The effect of the lamps may be larger during periods of dusk/dawn/adverse weather where running lights (but not headlamps) are in use.

High intensity headlamps are currently being provided on some new 1978 models. Therefore, no accident data have as yet been analyzed to provide any estimate of the effects of these headlamps in reducing (or possibly increasing) certain types of nighttime accidents. Night accidents caused 56 percent of motor vehicle deaths and about 36 percent of all accidents in 1975 [9].* Overdriving of headlamps seems to be a prevalent behavior in nighttime driving. Observation of headlamp usage shows that the high beam usage--where the new high intensity lamps would provide the greatest improvement--is generally low, about 5 percent of nighttime driving [10].

The high intensity headlamps will increase candlepower output about 20 percent on low beam and up to 100 percent on high beams. However, this increased output does not increase visibility distance proportionately. Because illumination levels follow an inverse square law, sighting distance could be increased potentially between 20 and at most 40 percent on high beam and much less on low beam. However, the increased illumination for one driver can result in increased glare for other drivers. Headlamp glare has been cited as a factor in up to 4 percent of night accidents [11].

The final factors in the real world performance of the headlamps relate to the driver's behavior--how far down the road he looks, how he uses high lights, how he looks when there is opposing glare, whether he is sober, etc. Therefore, the effect of the headlamps cannot be realistically evaluated in laboratory experiments.

*California Highway Patrol data indicate alcohol involvement in about three-quarters of all fatal or injury accidents. Two-thirds of these drivers were legally drunk. Results of Alcohol Safety Action Project Studies indicate that the number of drunken drivers is significantly greater at night [12].

3.3 Review of FMVSS 122: Motorcycle Brake Systems

Background

FMVSS 122, effective January 1, 1974, specifies required equipment relating to motorcycle brake systems and establishes test procedures for these systems. FMVSS 122 basically codified existing SAE recommendations which were last revised on March 1, 1971, and were published by NHTSA in the *Federal Register* that same month. Most manufacturers had complied with the SAE recommendations relative to brake systems, and few design changes were directly attributable to FMVSS 122 [13]. This, and other issues, make the evaluation of the effectiveness of FMVSS 122 difficult.

The original effective date for FMVSS 122 was September 1, 1973; it was extended to January 1, 1974, to give the Japanese--who account for 85 to 90 percent of motorcycle sales in the U.S.--and other manufacturers sufficient model changeover time [14]. This Standard has not been significantly changed or modified since it first became applicable. Minor changes involving dynamic testing of the motorcycle brake systems have been made and are stated below:

- Effective October 14, 1974: Service brake systems for motorcycles with attainable speed in one mile of 30 mph or less were exempted from three tests: fade and recovery, reburnish, and final effectiveness.

- Effective June 14, 1976: Change in tire type and test procedure skid number.

This Standard applies both to two-wheeled and three-wheeled motorcycles.

Purpose of FMVSS 122

The overall purpose of the Standard is to avoid accidents by insuring safe motorcycle braking performance under both normal and emergency conditions. Safe motorcycle braking performance is to be achieved by specifying required equipment for motorcycle brake systems and establishing performance test procedures for these systems.

General Requirements of FMVSS 122

All motorcycles manufactured after January 1, 1974, are required to have either a split hydraulic service brake system or two independently actuated service brake systems. However, split hydraulic brake systems for motorcycles are still in the developmental, experimental stage; they are not available on commercially-manufactured motorcycles. According to the SAE motorcycle brake subcomittee chairman, split hydraulic brakes are covered by FMVSS 122 for the following reasons:

- The motorcycle brake Standard followed the passenger car brake Standard.
- When and if such systems become available, they will be covered by an existing Standard.
- These systems do exist on some three-wheeled motorcycles, such as those used by the Post Office [15].

Actuation of a service brake system may be either mechanical or hydraulic. If a braking system is hydraulically actuated, each master cylinder must have a separate reservoir for each brake circuit. In addition, the filler opening for each reservoir must have a cover, seal, and cover retention device. The minimum reservoir capacity must be equivalent to one and one-half times the total fluid displacement resulting when all wheel cylinders or caliper pistons services by the reservoir move from a new-lining-fully-retracted position to a fully-worn-fully-applied position.

In addition to the split or independent braking requirement, the Standard requires that one or more electrically operated service brake system failure indicator lamps be mounted in front of and in clear view of the rider.* Each indicator must have a red lens with the legend "Brake Failure" on or adjacent to it. The failure indicator lamp will be activated under the following conditions:

- When not more than 20 pounds of pedal force is applied to the service brake in the event of pressure failure in any part of the service brake system.

- When level of brake fluid in a master cylinder reservoir drops to less than the manufacturer's specified safe level or to less than one-half the fluid reservoir capacity (without application of pedal force).

- When ignition switch is turned from "Off" to "On" or "Start" position.

FMVSS 122 also requires visual inspectability of the brake lining thickness for both drum and disc brakes. Visual inspection of the drum brake shoe lining either directly or with a mirror must be possible without removing the drums. The disc brake friction lining must also be visually inspectable without removing the pads.

Finally, a parking brake is required equipment on all three-wheeled motorcycles. This brake must be engaged by mechanical means and operated by friction principles.

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*The use of the term motorcycle "rider" rather than "driver" throughout this study is quite deliberate. Not only is it the term used by motorcyclists themselves, but it also serves as a reminder of the many differences between the two types of operators. A car is far more "forgiving" than a motorcycle. There are many things a car driver can do--light a cigarette, drink a cup of coffee, turn his head to talk to a passenger--which might be disastrous if done by a motorcyclist. In addition, a sense of closeness develops between a cyclist and his cycle, the more he rides it and becomes familiar with it. This characteristic has been expressed well by writer R. M. Pirsig [16]:

> "On a cycle the frame is gone. You're completely in contact with it all. You're *in* the scene, not just watching it anymore...that concrete whizzing by five inches below your foot is the real thing, the same stuff you walk on...the whole experience is never removed from immediate consciousness."

Measures of Effectiveness

The overall effectiveness of this Standard is the degree to which it achieves its objective--accident avoidance. The primary conceptual measure of effectiveness would be the number of accidents that were avoided and did not happen as a result of compliance with the braking performance requirements of the Standard. However, since these occurrences are known only to the riders immediately involved and are almost never recorded, using the number of accidents that were avoided due to the Standard as a measure of effectiveness would be quite difficult. As an alternative, the corollary measurement of accidents that occurred but which could have been avoided had the brake systems complied with the Standard might be used. However, since data on motorcycle accidents are either non-existent or inadequate, using this alternative as a measure of effectiveness would also present problems. Any attempt to evaluate FMVSS 122 using motorcycle accident data would require detailed investigations of accidents. If enough data were available, it could be determined which make/model year motorcycles complied with the Standard and which did not. Then the relative frequency of accidents in which brake performance could be a causal factor could be compared for each group. Obtaining data for this type of analysis would necessitate sending a team of motorcycle accident investigation experts to the scene of an accident. From this it might be possible to determine whether or not the accident could have been avoided had the motorcycle brake system complied with the Standard.

A quantitative measure of effectiveness would be the reduction in the number of brake-related motorcycle accidents from Pre-Standard to Post-Standard vehicles. However, as mentioned before, motorcycle accident data are scarce, and, therefore, this type of analysis would be very difficult. Also, there is no clear distinction between Pre- and Post-Standard motorcycles since most manufacturers complied with the requirements of the Standard before it became effective January 1, 1974. According to a NHTSA specialist on FMVSS 122, this Standard basically codified existing SAE recommendations with which the industry had already complied.*

Another measure of effectiveness should be the number of accidents that were caused as a result of compliance with the Standard. Brakes in compliance with the Standard will decrease the stopping distance of the motorcycle and could cause a greater number of front-rear collisions where the automobile, if following too closely, collides with the rear of the motorcycle.

On the other hand, if the Standard has led to an increase in braking effectiveness [i.e., decreased stopping distances, ability to stop in a straight line, smooth control of stop (front and rear wheels), reduction in fade, etc,], then another measure of effectiveness might be a decrease in the number of rear end collisions involving motorcycles colliding with the rear of automobiles.

Finally, as another quantitative measure of effectiveness, Pre-Standard and Post-Standard motorcycles could be tested on a specially designed motorcycle dynamometer. Measurements could be made of the degree to which Pre-Standard brake systems compare with Post-Standard brake systems.

*The latest and most recent revisions to SAE Motorcycle Road Test Code J108a and Service Brake System Performance Requirements J109a were March 1971.

Means of Complying with the Standard

As mentioned before, most manufacturers were following SAE recommended practices for the design of safe braking systems before FMVSS 122 became effective on January 1, 1974. The most recent SAE recommendations and the first published notice of FMVSS 122 both occurred early in 1971. This gave motorcycle manufacturers three years to "comply" before the performance specifications officially became a Federal Standard. The SAE recommendations for independent or split brake systems were, in general, sufficient to comply with the Standard.

Motorcycle manufacturers are providing independent front wheel and rear wheel braking circuits which are either mechanically operated drums or hydraulically operated discs. The choice of system configuration is dependent on the size and weight of the cycle, the purpose or use for which it is intended, and consideration of the general ability of motorcycle operators. Although there are no set rules, some generalities in the use of braking systems can be observed. Large tour cycles and medium and large sport cycles tend to use hydraulic disc brakes on the front wheel. Medium displacement cycles generally use a double leading shoe drum system on the front wheel, but there appears to be a trend toward discs here also. The light, small displacement commuter motorcycles are usually equipped with a single leading shoe drum system on the front wheel. The rear braking circuit on most motorcycles is usually a single leading shoe drum with only a very few employing rear disc systems [17].

Primary and Secondary Effects of Compliance

The primary effect of compliance with the Standard should be improved braking performance during both normal and emergency situations. In general, braking performance is a function of stopping distance, ability to maintain desired direction of control (usually in a straight line), and the force required to lock the brakes (brakes which lock easily are undesirable). With proper operation of the brakes, stopping distances for Post-Standard motorcycles will be less than for Pre-Standard cycles. Brake failure rates should also be less frequent for motorcycles that are in compliance with the Standard. However, because the performance of motorcycle brake systems is so highly dependent upon the proper operation of the brakes by the rider, the primary effect of compliance (improved braking performance) will be obscured. Proper operation of the brakes involves correct coordination of the front and rear brakes. Many motorcycle riders rely primarily on the rear brakes either because of inexperience or the fear of locking the front wheel [18]. This severely reduces the effectiveness of the brake system.

In summary, the degree to which compliance with the Standard will result in improved braking performance depends not only on the capability and condition of the brakes, but also on at least the following: the rider's ability to correctly modulate front and rear brakes separately to avoid wheel lockup and subsequent loss of stability; the tire tread characteristics; the road surface; the wetness or dryness of the road; the lighting conditions; and, as much as anything else, the braking skill of the operator.

The 1971 SAE specifications for motorcycle braking systems were based,at that time, on what brakes should do, not on what they could do, according to R.A. Little, who was Chairman of the SAE Motorcycle Brake Subcommittee [19]. At that point, the requirements of the Standard went beyond the state-of-the-art. Compliance with the Standard has resulted in motorcycle brakes providing greatly reduced stopping distances and has had a substantial effect on performance [19].* Potential secondary effects of the Standard include the following:

- Loss of motorcycle control while braking. The newer motorcycle brake systems may be too effective, especially on wet or slippery road surfaces. Brakes respond and perform as well when road surfaces are wet or dry, but since there is less friction between the tires and road because of the wet or slippery road surface, the possibilities for brake lockup and subsequent skidding are increased. This, of course, may cause the operator to lose control and prevent him for otherwise being able to avoid a collision.†

- Rear End Collisions. Should newer motorcycles that comply with the Standard stop suddenly in traffic and the vehicle directly behind is unable to stop in time, this situation could very well contribute to an increase in the frequency of rear end collisions between cars (striking) and motorcycles (struck). This situation may be very difficult to define since there might be a tendency for car drivers to follow motorcycles more closely than other vehicles.

Real World Performance of the Standard

Data on motorcycle accidents involving brake performance are either nonexistent or inadequate. Therefore, estimating the real world performance of FMVSS 122 is presently a very difficult task. In order to gather the necessary amount of detailed data to evaluate the effectiveness of the Standard, teams of motorcycle accident investigation experts would have to be sent to the scene of motorcycle-involved accidents. Since this type of investigation is relatively expensive, little has been done on a widespread scale. In the existing data, it is difficult to find any significant causal link between motorcycle accidents and defective brakes.

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*For example, California highway patrolmen, on motorcycles with Pre-Standard braking systems, would shout, as they stopped speeders, "Wait, I'm coming back!" as they braked past. They would then turn around and ride back to the stopped vehicle. This no longer occurs with Post-Standard brakes [20].

†Antilock braking systems for motorcycles are now being developed, which could improve this situation.

3.4 Review of FMVSS 202: Head Restraints

Background

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 many vehicles until a mid-model year change. Two methods evolved for complying with the Standard. 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.

Purpose of FMVSS 202

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.

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

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* 217 lb and 28 in [21].

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 cylindrical 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 rearmost portion of the head form should not be displaced more than 4 in rearward of the displaced torso reference line. In addition, the head restraint must withstand a load of up to 200 lb 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 in above the seating reference point.
- The lateral width, when measured either 2.5 in below the top of the restraint or 25 in above the seating reference point, must be at least 10 in for bench type seats or 6.75 in for individual seats.

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.

*SAE Recommended Practice J963 describes an anthropomorphic test device for dynamic testing and Part 572 of Title 49 of the Code of Federal Regulations establishes the specifications for the anthropomorphic test dummy for FMVSS 208.

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).

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.

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 in wide for bench seats and 6.75 in wide for bucket seats. The top of the restraint must be 27.5 in above the seating reference point.

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

(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 a fixed high seat back.

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 rearview and sideview mirrors should provide drivers with adequate information, the facts are that there are many cases where drivers choose 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 possible secondary effect is rear seat occupants striking front seat head restraints.

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 [22, 23]. 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 not 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.

*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.

3.5 Review of FMVSS 207: Seating Systems

Background

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 3-3 describes the application by model year of Pre- and Post-Standard activities related to the Standard.

TABLE 3-3

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.

Purpose of FMVSS 207

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.

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 in-lb 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 conspicuously labeled to that effect.

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. In this report, 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 NCSS and Multidisciplinary Accident Investigation (MDAI) data file contain detailed data on seating system failure [24]. 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 AIS will also be available in National Accident Severity Study (NASS) data.

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.

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 [25]. 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 [26].

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 [27]. This automatic electromechanical releasing feature is not required by the Standard.

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 being 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* [25].

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 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 [28].

Severy, *et al*. 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 [25]. 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 3-4. 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 3-4

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

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.

Source: *Consumer Reports* [29].

3.6 Review of FMVSS 213: Child Seating Systems

Background

FMVSS 213 (Child Seating Systems) became effective April 1, 1971; it evolved from a basic set of requirements first published by NHTSA in the *Federal Register* in March 1970. Many of the changes and modifications requested by automobile manufacturers and by the Juvenile Product Manufacturers' Association were incorporated into the Standard. This includes those test requirements involving forward movement of the child during a crash, since child seating systems are fastened by existing vehicle seat belts, and NHTSA did not intend to force "unjustified compliance burdens on child-seat manufacturers caused by certain vehicle seat belt configurations over which they had no control" [30]. Dynamic testing of child restraints is not new, although such tests are not yet part of the requirements of the Standard. Dynamic tests have been conducted by organizations such as the Highway Safety Research Institute (HSRI), Calspan, General Motors and the DOT-NHTSA Safety Research Laboratory. At present, FMVSS 213 subjects child seating systems to a static load test, using the torso block outlined in FMVSS 209 (Seat Belt Assemblies). The test requires the child seating system to retain the torso block while subjected to a static load of 1000 pounds in a forward direction or 500 pounds in a rearward direction. This is intended to approximate a 30 mph frontal crash. Horizontal movement of the torso block is then measured.

Purpose of FMVSS 213

The purpose of FMVSS 213 is to establish requirements for labeling, installing, adjusting, and attaching child seating systems to vehicle seat belts, and to specify static tests of the seating system components. For the purpose of the Standard, a child seating system is defined as an item of motor vehicle equipment for seating and restraining a child being transported in a motor vehicle.* The general purpose of the Standard is to reduce fatalities and injuries to small children in crashes. Approximately 500 children aged 0 to 5 are motor vehicle occupant fatalities, and about 50,000 to 60,000 a year are injured. Available studies and accident data bases indicate a low usage of child seating systems.

General Requirements of FMVSS 213

Each child seating system manufactured after April 1, 1971, must conform to the general requirements listed below.

- It must have a label permanently attached to it, containing the following information: (1) manufacturer's or distributor's name, (2) model number or name; (3) month and year of manufacture; (4) place of manufacturer or distributor; (5) description of the types of motor vehicles and designated seating positions in those vehicles in which the system is either recommended or not recommended for use; (6) warning against use on hinged or folding

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*As originally defined in March 1970, a "child seating system is ...an item of motor vehicle equipment for seating and restraining a child being transported in a passenger car, multipurpose vehicle, truck, or bus." As amended September 23, 1970, the definition reads: "...an item of motor vehicle equipment for seating a child being transported in...," eliminating the work "restraining." The NHTSA rationale behind the definition change was that all devices designed to seat children in motor vehicles must conform to the Standard.

vehicle seats unless these seats have latches; (7) designation whether for use on rearward or forward-facing seats; and (8) recommendation of maximum height and minimum and maximum weight of children who can safely occupy the system.

- The original Standard allowed only the manufacturer's name on the label. The September 30, 1970,amendment allowed use of the manufacturer's or the distributor's name--whoever would accept complete responsibility for the safe performance of the system.
- The September 30, 1970,amendment also removed two previous labeling requirements: (1) minimum height; and (2) the phrase "capable of sitting upright by themselves."

- It must include an instruction sheet with a step-by-step installation procedure for installing, securing and adjusting the system, and for positioning a child in the system.

- It must be sufficiently adjustable to provide a snug fit for a child of any size for which the seat is recommended.

- It must be designed and constructed in relation to attachment, so that:
  - It is attached to the vehicle seat back only by a component inserted between the vehicle seat back and seat cushion.
  - It is attached to Type 1 (lap belt) or Type 2 (pelvic and upper torso restraints) seat belt assemblies.
  - It is restrained against forward movement in forward-facing seats and against rearward movement in rearward-facing seats.

- Restraint forces must be distributed so that they are on the pelvis or thorax of a child in a forward-facing system. For rearward-facing systems, the restraint forces must be:
  - On the back of child's torso and back of neck during forward movement of child.
  - On the pelvis and thorax during rearward movement of child.

  Restraint forces may also be distributed over other areas of the child's body as long as the above conditions are met.

- Each forward-facing seating system must have a head restraint that limits rearward angular displacement of the child's head relative to the child's torso line. Child weights relative to the height of the head restraint are specified.

- If webbing is used to distribute restraint forces, the webbing in direct contact with a child's body must be at least 1.5 in wide. The webbing that sustains restraint forces must meet the requirements of a Type 3 seat belt assembly.*

*A Type 3 seat belt assembly is a combination of pelvic and upper torso restraints for persons weighing up to 50 lbs and capable of sitting upright by themselves--that is, children approximately 8 months to 6 years old.

- Attachment hardware that sustains restraint forces, plus buckles, retractors and other metal parts must meet the corrosion resistance requirements of FMVSS 209 (Seat Belt Assemblies).

- The mechanism for releasing those components that directly restrain the child must release when a force of not more than 20 lb is applied.

- For impact protection, any rigid component that contacts the child's head or torso during an injury must have no corner or edge with a radius of less than 0.25 in and must be covered with deformable force-distributing material at least 0.5 in thick. Exceptions include:

  - Restraint buckle and belt attachment hardware attached only to webbing.

  - Rigid back or side of a system contractable only by child's torso, if contractable area of back or side is at least 24 sq in.

Measures of Effectiveness

The ideal measure of effectiveness of the Standard is injury reduction, i.e., the reduction in the frequency of serious and fatal injuries to children using child restraints. However, because of the low incidence of child restraint usage, it will be difficult to statistically model the effect of restraining children. However, one should be able to predict the injury severity of the unrestrained children. Thus, the effectiveness of the child restraint will be the difference between the observed injury severity of the restrained children and the expected severity if they were unrestrained.

A second basic measure is based on the proposed dynamic test of the child seating systems. The mechanical performance of the child restraint during a dynamic test will depend on the accelerations and excursions of the child dummies. These performance measures do not directly evaluate the effectiveness of the Standard, but they can be used to estimate the relative effectiveness of different types of restraint systems under controlled conditions.

Finally, because of the voluntary usage of the child seating systems, surveys of usage will provide relevant information on the (potential) performance of the Standard. In other words, the overall effectiveness of the Standard depends on the effectiveness of the child restraint in a collision, and the rate of (proper) usage of child seating systems. The potential overall effects may be very high even if the present effects are small, because of low usage rates. As part of understanding the usage questions, in addition to making direct observational surveys to estimate usage rates, CEM also suggests mail surveys to investigate other questions on usage and attitudes. These last items would not normally be considered part of evaluating the effectiveness of a Standard. However, because of the unique nature of this Standard with regard to usage, it seems that these investigations are relevant.

Means of Complying with the Standard

FMVSS 213 establishes minimum child seating system requirements and sets crash protection standards. All seating systems manufactured after April 1971, with the exception of Type 3 seat belt assemblies and systems for recumbent or semirecumbent children, must satisfy the minimum requirements of the Standard. The purchase or subsequent use of a child seating restraint, however, is left totally to the discretion of the consumer.

Child seating systems currently available and in compliance with FMVSS 213 vary widely relative to construction, method of installation, and in physical size, as determined by the size and weight limits for which the system is specified. In addition, many systems are substantially overdesigned relative to the minimum requirements established by the Standard. All systems must provide for proper labeling and readable installation instructions.

Consumers Union (CU) began testing child seating systems in 1972, a year after FMVSS 213 went into effect. In the four tests CU has conducted (1972, 1974, 1975 and 1977), each child restraint tested met the specifications of the Standard as attested by a compliance label to that effect, although many fell short of CU's own specifications [31,32,33,34]. According to an accounting firm which publishes yearly totals of child restraints sold, there are, at present, 13 major manufacturers of these systems [35]. The number of manufacturers' restraints tested by CU and the price ranges of their products are shown below.

- 1972: 15 manufacturers; restraints ranged from $8 to $50.
- 1974: 7 manufacturers; restraints ranged from $9 to $30.
- 1975: 16 manufacturers; restraints ranged from $10 to $41.
- 1977: 14 manufacturers; restraints ranged from $28 to $45.

Primary and Secondary Effects of Compliance

Manufacturers complying with the present requirements of FMVSS 213 produce child seating systems capable of meeting specified performance requirements. In addition, many systems now on the market surpass the minimum Federal static requirements; they have successfully undergone dynamic performance testing in private laboratories. (In 1974, NHTSA proposed extensive changes in FMVSS 213, replacing the static test requirements with dynamic tests. There has been no action on this amendment as yet.) The Standard does not address use of child seating systems.

The major secondary effect of compliance with the Standard involves the injury-causing capabilities of loose child seating systems--that is, those systems which are improperly attached and/or are being carried in the car unattached and not in use. These systems can become projectiles during crashes, adding to the injuries sustained.

There are other effects of FMVSS 213 which are not, in the strictest sense, secondary effects. These involve the use, non-use, and misuse of child seating systems.

An area considered particularly important by a NHTSA Standard specialist involves misuse of child seating systems [36]. This includes placing a child in a restraint not correct for the age and weight of the child, failing to use the tether strap when such an attachment is part of the system, and failing to use the vehicle seat belt to secure the child restraint.

Another "danger" connected to child seating systems involves the impact-resistant padding specified in the Standard. Over time, this padding may deteriorate, becoming hard and brittle. This deterioration lessens the restraint's protective characteristics (child seating systems generally have a long life span and are often used by many children).

Real World Performance of the Standard

Analyzing the real world performance of child seating systems presents a unique situation. Unlike most other FMVSSs, it applies to a device which is totally optional equipment, and which is purchased only by a relatively small percentage of the car-buying population.* Therefore, even if a child seating system meets the most rigid performance specifications (and dynamic laboratory crash tests indicate that most models on the market exceed the present requirements, its performance will be *ineffective unless it is used;* and the performance may be *reduced if it is used improperly*. At present, child restraints that have proved to be most effective in dynamic tests can also be the most cumbersome to use, requiring, for example, permanent installation of a tether strap [34]. As these systems become more sophisticated and more difficult both to install and to correctly position a child in, the danger is that their use will decrease. A major purpose of the surveys is to determine parent attitude towards child seating systems.

Although it is beyond the scope of this contract, a concerted, well-planned national "public relations" effort aimed at convincing parents to use child restraints is worthy of consideration. This might be an area of interest to NHTSA's Traffic Safety Programs Division. This division is presently involved in just such an effort working with the State of Tennessee, where a mandatory child restraint law became effective January 1, 1978. The Tennessee law requires the use of a child restraint for carrying any child under four when that child is traveling with a parent in the parent's own car.

Two other Safety Standards will affect the real world performance of this Standard: FMVSS 207 (Seating Systems) and FMVSS 209 (Seat Belt Assemblies). Any failure of the vehicle seat or of the vehicle seat belt system used to properly install a child restraint will affect that restraint's performance.

Other real world situations not specifically addressed in the Standard,which affect child seating system performance, are:

- Attachment. An improperly attached seating system may have an adverse effect on its performance.

*The 13 major manufacturers, in the last six years (1971-1976) have sold 6,927,522 child seating systems. During this period, sales have ranged from a maximum of 1,364,678 in 1972 to a minimum of 812,609 in 1974. Average yearly sales were 1,154,587 child restraints [35].

- Positioning of child. The performance of a child seating system may be adversely affected if a child is improperly positioned within it.

- Testing. Dynamic crash testing of child seating systems has relied primarily upon instrumented dummies, weighted dolls or, most recently, primates. None of these can exactly portray a human child's dynamic response.

3.7 Review of FMVSS 220/221/222: School Bus Rollover Protection/ Body Joint Strength/Seating and Crash Protection

Background

The School Bus Standards FMVSS 220 (Rollover Protection), FMVSS 221 (Body Joint Strength), and FMVSS 222 (Passenger Seating and Crash Protection) were developed by NHTSA and first published in the *Federal Register* from February through October 1975, in response to the Congressional mandate of the Motor Vehicle and School Bus Safety Amendments of 1974. The original date was October 26, 1976, but this was later revised to April 1, 1977. The Rollover Standard (220) resulted from a desire to improve structural quality of school buses, specifically the structural safety of the passenger compartment to protect occupants in the event a bus overturns. The Body Joint Strength Standard (221) complements FMVSS 220 in that it specifies minimum strength requirements to avoid structural collapse of bus bodies during all crashes, not just rollovers. The Passenger Seating and Crash Protection Standard (222) completes the injury and death reduction aspect among the three by specifying occupant protection for passengers which includes both the structural strength of the seating system, padding, and the provision of restraining barriers, and, in the case of small buses, restraints for each seat position.

Purpose of the Standards

The three Standards share a common purpose which is to reduce the number of deaths and the severity of injuries that occur in a bus crash. They only differ in the cause of the deaths and injuries which they address. These are as follows:

FMVSS	Cause of Death or Injury
220 - Rollover Protection	Collapse of school bus bodies caused by forces encountered in rollover crashes.
221 - Body Joint Strength	Separation of panel joints, which expose sharp edges and leave openings which allow occupant ejection during any type crash.
222 - Seating and Crash Protection	Impact of school bus occupants against components within the vehicle during crashes and sudden driving maneuvers.

General Requirements of the Standards

All school buses manufactured after April 1, 1977, must conform to the following general requirements.

- FMVSS 220 - Rollover Protection

  With the vehicle rigidly supported on its frame or sills and a force equal to 1½ times the unloaded vehicle weight applied to the roof by means of a specific flat plate, the downward vertical movement of any point on the plate must not exceed 5-1/8 in. Each emergency exit must be capable of opening both during and after full application of the force. The Standard applies to all school buses.

- <u>FMVSS 221 - Body Joint Strength</u>

  Test specimens taken from each body panel joint must be capable of holding the joint intact when subjected to a tensile force of 60 percent of the tensile strength of the weakest joined body panel. The Standard applies only to school buses with a Gross Vehicle Weight Rating (GVWR) of over 10,000 pounds.

- <u>FMVSS 222 - Passenger Seating and Crash Protection</u>

  - Passenger seats must face forward.
  - Seat back height must be 20 in and the seat back width must be at least 90 percent of the bench width.
  - Under a specified forward force, seat back forward deflection must not exceed 14 in or not deflect to within 4 in of another passenger or restraining barrier. The seat must not separate from the vehicle at any attachment point and the seat components must not separate from the seat at any attachment point.
  - Under a specified rearward force, the seat must not deflect to within 4 in of any part of another passenger seat, the seat must not separate from the vehicle at any attachment point and the seat components will not separate from the seat at any attachment point. (Effective April 1, 1978, the rearward seat back deflection must not exceed 8 in under a specified rearward force.)
  - If the rear surface of another seat is not within 20 in forward of any seating reference point, a restraining barrier within 20 in of the reference point must be provided. Performance of this barrier under a specified load in a forward direction must be the same as the seat requirements.
  - In a specified head protection zone, any contactable surface impacted by a head form at a specified velocity must not produce coaxial acceleration at the center of gravity of the head form greater than a specified maximum.
  - In a specified knee protection zone, the impact of a knee form at a specified velocity on a seat back or barrier must not produce a resulting force of the impacted material greater than a specified maximum.
  - Vehicles with GVWR greater than 10,000 lb must meet all of the above requirements. Vehicles with GVWR 10,000 lb or less must meet all except the 20 in maximum distance between the seating reference point and seat back or barrier in front of it. In addition, FMVSS 208, 209, and 210 must also be met by the lighter buses which are required to have restraint systems.

<u>Measures of Effectiveness</u>

Because the purpose of these Standards is to reduce deaths and injury severity among occupants involved in school bus accidents, it logically follows that the measure of effectiveness of the Standards is the degree of reduction in deaths and injury severity among occupants of Post-Standard buses involved in crashes as opposed to those in Pre-Standard buses. The actual assessment of effectiveness is not that simple. Many Pre-Standard buses probably conformed to many or all of the requirements of the Standards before this effectiveness date. It will be necessary to determine to what degree this is true for Pre-Standard buses involved in the crashes that are used for analysis.

Means of Complying with the Standards

FMVSS 220 - School Bus Rollover Protection

This Standard served to institutionalize existing design recommendations of the School Bus Manufacturers Institute. These suggested practices were being followed by virtually all school bus manufacturers before the implementation of this Standard on April 1, 1977. The general means of compliance would be to use heavier structural components and/or redesign the structural frame to resist crash deflections under the specified roof loadings.

FMVSS 221 - School Bus Body Joint Strength

This Standard applies only to school buses with GVWR of more than 10,000 lb, manufactured after April 1, 1977. It established tensile requirements for body joints to prevent body panels from separating from structural components and from each other during accidents.

It is likely that many school buses manufactured prior to April 1, 1977 were already in compliance with the Standard. Compliance can generally be achieved by:

- Varying the dimensions and material strength of school bus body panels.
- Increasing the number and strength of spot welds, continuous welds, or discrete fasteners or the glue used to join body panel members.
- Constructing the bus body in a unitary fashion that eliminates separate panels (i.e., fiberglass laminates, molded plastics, etc.).

FMVSS 222 - School Bus Passenger Seating and Crash Protection

This Standard specifies seating, restraining barrier, and impact zone requirements for school buses manufactured after April 1, 1977. The requirements imposed by the Standard and the associated means of compliance are different for buses over and under a GVWR of 10,000 lb. For school buses having a GVWR of 10,000 lb or less, compliance with the occupant restraint requirements of the Standard is accomplished with either a passive system or a seat belt system. If a seat belt system is used, either Type 1 or Type 2 belts may be used at the designated occupant seating positions other than the outboard positions in the front impact areas. The concomitant requirements of FMVSS 208, 209, and 210 as they apply to multipurpose passenger vehicles must also be met.*

There are four general means of compliance for school buses with a GVWR of over 10,000 lb.

*Standards 208, 209, and 210 essentially require either a passive protection or a seat belt system for each seating position, specify the seat belt design and operation, and the method of anchorage.

- Repositioning of seats so that the rear surface of another passenger seat is no more than 20 in from the seating reference point.
- Installation of a restraining barrier no more than 20 in from the seating reference point.
- Installation of additional seat padding.
- Redesign of seat support and seat structure to meet loading requirements.

Secondary Effects of Compliance

In providing stronger bus bodies and safer seating and crash protection, there are some negative effects which the Standards may produce and should be considered. They are as follows:

220 - Rollover Protection

- A substantial increase in number and size of structural members above the body floor line might raise the center of gravity of the vehicle to the point where it would seriously affect its handling and stability characteristics, particularly when unloaded.

221 - Body Joint Strength

- A lack of body openings, especially in catastrophic crashes, might necessitate more reliable and a greater number of emergency exits to permit occupant escape and access from outside the bus in the event of a crash.

222 - Seating and Crash Protection

- Higher seat backs may lead to an increase in disciplinary problems because of the impairment of driver rearview mirror visibility of the occupants.
- More crash padding in the bus interior will undoubtedly increase maintenance costs because of the increased damage and destruction of the padding by some students.
- With no more than 20 in seat spacing, some students, in particular the larger, older ones, will probably experience discomfort and try to correct it by sitting sideways in the seats. This may decrease seating space, increase discipline problems and contribute to driver harassment.*

Real World Performance of the Standards

Because the effective date of the Standards is so recent, there is no indication as yet of their performance. Since their purpose is to reduce death, injury severity and structural damage in the event of a crash, the measure of performance must be obtained from crash occurrences which, in the case of school buses manufactured after the effective date, will undoubtedly be comparatively rare events for some time.

*In March 1977 The School Bus Manufacturers Institute petitioned NHTSA to consider relaxed seat spacing requirements for school buses used on long field trips such as athletic events. The petition was granted and it was agreed that research and background review would begin on special requirements for "School Activity Buses."

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4.0 Approaches and Methodologies for Evaluating the Standards

4.1 Introduction

In general, there are seven approaches which may be used in evaluating the Federal Motor Vehicle Safety Standards. However, in many cases not all of the general approaches apply and in some cases no single approach could establish the effectiveness of the Standard, to the desired level of statistical significance. Essentially, the seven general approaches relate to the type of data that could be analyzed. The approaches are:

1. Analyzing mass accident data. Generally the data bases available are automated state motor vehicle department accident records. Some of the difficulties with using such data bases are: one cannot use results from a single state to project national estimates; they are not available for all states; they are not comparable from state to state; individual state records are not necessarily consistent from year to year, due to changes in reporting requirements or data collected; they collect only the more easily available accident information resulting in minimal detail; quality of data collection; etc. However, these data bases usually have large numbers of cases and are available for several consecutive years.

2. Detailed data. Generally, these data bases have been developed in response to contractual efforts to acquire more detailed information concerning motor vehicle accidents. In some cases, interdisciplinary teams of experts were used to collect data on the conditions of the accident vehicle, driver, scene, etc. The collection of this information is expensive and thus the size of the individual data bases is generally small. More recent detailed data collection efforts (NCSS and NASS in the future) are specified in a more statistically rigorous fashion so that the results of such relatively small data bases can be extrapolated.

3. Special data files. Insurance companies receive considerable numbers of claims, both property and medical liability, and, hence, provide a source of accident data other than that collected by police or other accident investigators. However, these data have minimal information on the accident. Since trade groups keep track of the rate of servicing and replacement of vehicle parts, this is a potential source. Another source on component outage are states which conduct periodic vehicle inspections.

4. Laboratory results. In cases where existing data bases are unavailable or inadequate, it may be necessary to evaluate the Standard based on results from some set of controlled laboratory tests. A major objection to such an approach is that these results may be very difficult to apply to the real world accident experience. Laboratory results which would be

analyzed can be generated by a variety of methods, from simple measurements of the status of a vehicle system in a sampled population of vehicles, to more elaborate simulations of actual traffic conditions.

5. "Survey" data. In many cases the overall effectiveness of the Standard depends on the usage or reliability of the components installed to meet the Standard. That is, if a Safety Standard has an effect only in certain situations, such as nighttime, or when the safety system is in use, then the overall effectiveness underestimates the specific effects of the Standards in reducing total accidents or injuries. For instance, the overall effectiveness of seat belts or headlamps depends on when and how they are used. Similarly, there is the problem caused if systems degrade or fail while in use; the driver may assume the safety system works while in actuality it may not, or not up to the Standard. Therefore, "surveys" of the vehicle and/or driver populations are sometimes necessary to develop a basis for evaluating the effectiveness of the Standard. These surveys would include both physical observation of vehicle behavior as well as questions about driver behavior.

6. "What if" approach. Some studies have used the detailed accounts of accidents to try to determine whether or not the accident could have been avoided (or made less severe) if the vehicle had been provided with certain special features. A determination is made, using the judgment of an "expert" panel. A variation of this approach, which reduces the subjective nature of the analysis somewhat, is to use computer simulation models to estimate the effect of changing certain factors. One problem is that the simulation approach applies more to the injury reduction Standards, while the judgmental approach applies more to accident avoidance cases.

7. Controlled real world experiment. From a statistical point of view, the most desirable situation is to have two groups of vehicles which differ in only one respect--only one group complies with the Standard. With regard to older vehicles, this is sometimes true in one model year. However, the number of situations where this applies is small. Hypothetically, one could imagine a case where certain large groups of vehicles were exempted from meeting certain Standards in order to provide a significant field test. (This was the thrust of former DOT Secretary Coleman's agreement with the manufacturers of air bags.) However, NHTSA's sanctioning of such an experiment may involve moral and ethical problems.

Using these seven approaches, one can address one of four basic questions:

- Overall Effectiveness. For this we need a representative data base for all accidents. The accuracy of the estimate of the effect of the Standard within the data base will be further reduced by the original data sampling variations, biases, and factors which cannot be controlled.

- Specific Effectiveness. Given a certain set of conditions, we can estimate the effectiveness of the Standard relative to these constraints, e.g., the effectiveness of side door guard beams in side collisions. Another specific estimate of effectiveness might relate to results of laboratory experiments which record the results of certain tests.

- Reliability or Usage Measures. For many Standards the equipment covered must be properly used or in proper working order to have an effect. Therefore, the question of outage of such things as warning devices is pertinent; another question would be usage of restraint systems, etc.

- Performance. Since the Standards set performance requirements, it is logical that evaluation of the Standard might address the mechanical performance characteristics of the components in the safety system. First, these performance measures would basically be results of laboratory tests. Expanded test procedures from those required by the Standard might also be used to ascertain mechanical performance.

The purpose of the individual approaches is to gather information which will reveal relevant measures of performance and effectiveness. The statistical approaches which are eventually applied to estimate the significance of the performance and effectiveness measures are influenced by the nature of the data and the skills and desires of the analyst. In many cases, more than one statistical approach could be applied, as summarized in Table 4-1.

TABLE 4-1

GENERAL APPROACHES USED IN EACH EVALUATION PROGRAM

Evaluation Program	General Approach						
	1	2	3	4	5	6	7
	Analyzing Mass Accident Data	Detailed Data	Special Data Files	Laboratory Results	Survey Data	"What if" Approach	Controlled Real World Experiment
FMVSS 105	x			x	x		
FMVSS 108	x			x	x		
FMVSS 122	x	x		x	x		
FMVSS 202 & FMVSS 207	x	x	x	x	x		x
FMVSS 213	x	x		x	x		
FMVSS 220, FMVSS 221, & FMVSS 222	x	x		x			x

As shown in Table 4-1, it is clear that the most frequently used approaches for evaluating the Standards are:

1. Analyzing mass accident data.
2. Detailed data.
3. Laboratory results.
4. Survey data.

Special data files are used only to evaluate FMVSS 202. The "what if" approach is not included in the evaluation program for any Standard. It is a possible approach for some Standards when the proposed effectiveness evaluation program has been unsuccessful in reaching a conclusive result. Finally, the real world approach is applicable to FMVSS 105, FMVSS 202/207 and FMVSS 220/221/222 through suggested instrumented vehicle programs.

4.2 Overall Approaches and Major Problems of Evaluating the Standards

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 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 set 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 at least a reasonable probability that, by the end of the program, the effectiveness of the Standards will have been satisfactorily evaluated. However, in the event the issue remains in doubt, a number of "Next Possible Steps" are outlined.

4.3 Evaluation of FMVSS 105: Hydraulic Brake Systems in Passenger Cars

Figure 4-1 indicates a flow diagram/decision tree for evaluating the effectiveness of FMVSS 105. A time-phased Gantt chart is found in Section 6, which describes the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

Task #1: Analysis of Mass Accident Data

There are three parts to the Analysis of Mass Accident Data. Using the same data bases, the first subtask would investigate the rate of brake system defects. This study primarily evaluates the effect of the introduction of split brake systems. The second subtask primarily evaluates the overall improvement in the braking performance of Post-Standard cars. The third subtask estimates the number of accidents avoided due to improved brake system performance.

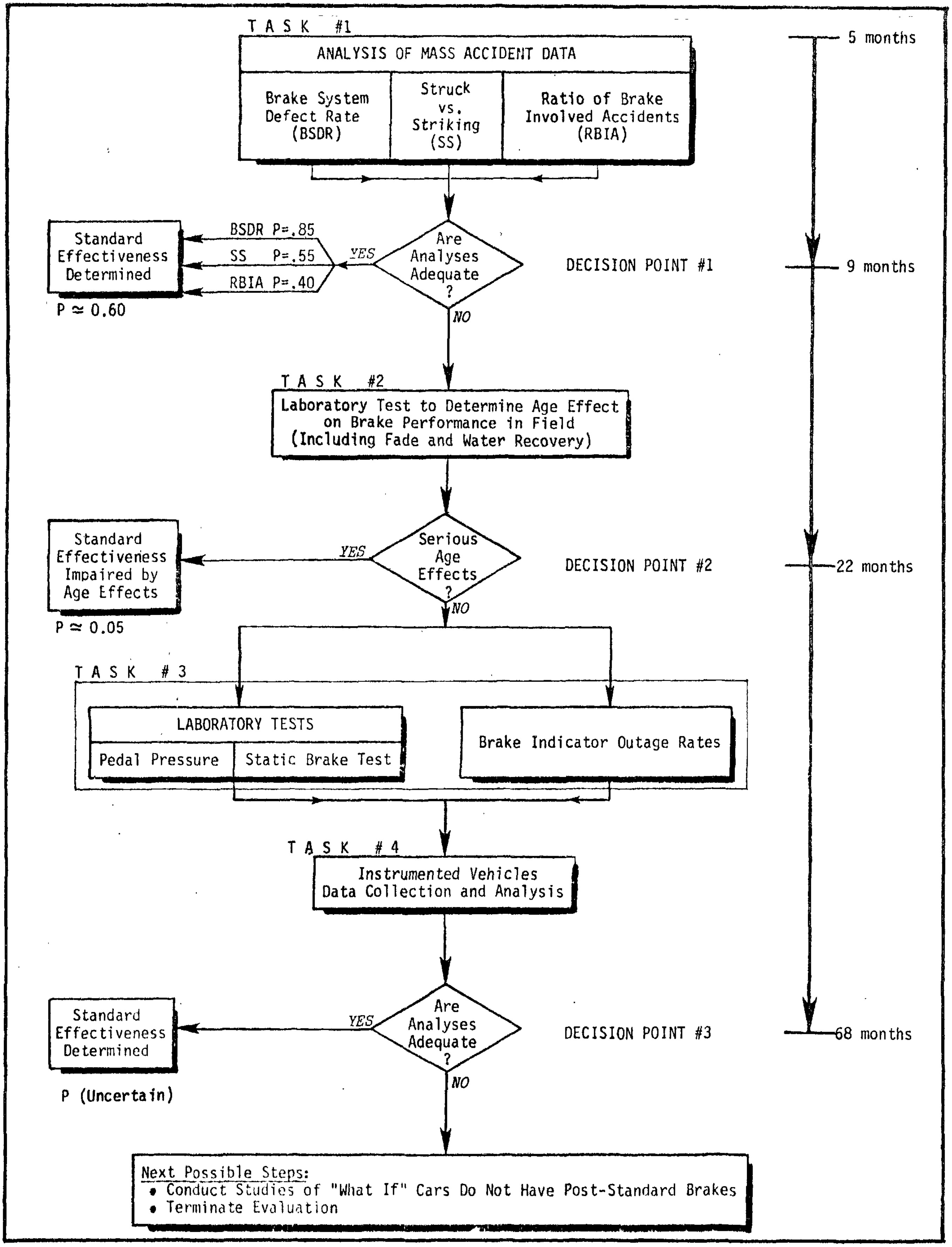

Figure 4-1. Flow chart for proposed evaluation of FMVSS 105: Hydraulic Brake Systems in Passenger Cars.

Decision Point #1

At the end of Month Nine, NHTSA would have to make a decision based on the results of Task #1. It is initially estimated that the probability of adequately evaluating FMVSS 105 with mass accident data is slightly better than half ($p = 0.6$). The individual subtasks have varying probabilities of success. The analysis of the rate of brake system defects has a high estimate of success because it focuses on a clear-cut change to split braking systems. The subtasks which focus on overall vehicle braking performance have lower estimates of probable success.

At this point, NHTSA must decide whether the analyses were adequate to evaluate FMVSS 105, based on available accident data. If they were not, then more knowledge is needed about brakes, and Task #2 should be undertaken.

Task #2: Laboratory Tests to Determine Age Effects on Brake Performance

This Task is a laboratory test which will establish whether there are any serious effects of age on Post-Standard brakes which could effectively erase benefits of the Standard in improving brake performance. By the end of Month 22, this Task will be essentially completed so that NHTSA can address the next decision point.

Decision Point #2

At the end of Month 22, NHTSA will have to decide whether the results of Task #2 indicate that there is a serious age effect for brakes. It is our initial estimate that this will not occur ($p = 0.05$). If such an event occurred, NHTSA would have to consider modifying the Standard to maintain the efficacy of brakes in use. The more likely outcome would be that braking performance is not seriously affected by age. At this point, NHTSA has not been able to adequately evaluate FMVSS 105 using mass accident data and knows that aging is not seriously affecting performance. Therefore, in order to adequately evaluate the Standard, one must gain more information about brakes and braking performance and Tasks #3 and #4 would be undertaken.

Task #3: Pedal Pressure/Static Pressure Laboratory Tests and Study of Brake Indicator Outage Rates

This Task contains three subtasks. The primary purpose of the first two subtasks (Laboratory Tests of Pedal Pressure and Static Brake Test) is to gain more understanding about the magnitude and distribution of braking force capabilities of drivers, and to understand the typical failure modes of the brake system. The Study of Brake Indicator Outage Rates is a survey of frequency of outage of brake system warning lights. This study specifically addresses that subparagraph of the Standard. There is also the possibility that the warning system fails a significant percentage of the time, misleading drivers about the effectiveness of their brakes. Information from Task #3 would be used to refine the relevant measuring points and amounts for Task #4.

Task #4: Instrumented Vehicles Data Collection and Analysis

Starting at the beginning of the fourth year (approximately Month 38) this Task would last for 30 months and would represent a program costing about $400,000. This Task depends on the availability and efficacy of the NHTSA Crash Recorder Program. Additional instrumentation would be added to the crash recorder instrumented vehicles to obtain specific information on braking performance, especially in relation to crashes. The data collected in this study would be carefully analyzed to determine effects of the Post-Standard brakes in real crash situations.

Decision Point #3

At the end of Month 68, NHTSA would review the results of the evaluation studies to determine whether the effectiveness of the Standard has been adequately determined. If the previous studies are not adequate, relatively few alternatives are left.

Next Possible Steps

There are two alternative actions which might be undertaken if the above analyses have failed to determine the effectiveness of FMVSS 105. If the above analyses have suggested that there might be a consistent effect of the Standard (although the level of statistical confidence in the estimate of effectiveness is low), then NHTSA could consider a retrospective "what if" type study of what might have happened in an accident if brakes had been better. However, if the above analyses have all been negative, one assumption is that the Standard has no discernable effect and its evaluation should be terminated.

4.4 Evaluation of FMVSS 108: Side Marker Lamps and High Intensity Headlamps(Only)

The flow diagram/decision tree for evaluating the effectiveness of FMVSS 108 is given in Figure 4-2 and Figure 4-3. A time-phased Gantt chart is found in Section 6 which describes the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

SIDE MARKER LAMPS

Task #1: Analysis of Side Collisions

Using existing mass accident data, this Task will attempt to determine the effectiveness of side marker lamps in reducing accidents during nighttime and other conditions of reduced visibility. This Task is the most direct assessment of the effectiveness of side marker lamps; however, based on a previous study, the expected effectiveness is small.

Decision Point #1

At the end of Month 11, NHTSA will have to decide whether the Analysis of Side Collisions adequately determines the effectiveness of the side marker lamps. CEM's initial estimate is that the probability of ending the evaluation at this point is one-half. The uncertainty is largely a product of determining a small effect in a large but nonetheless finite data base. If the results of the analysis are inadequate, NHTSA should proceed with the complementary studies included in Task #3 and Task #4.

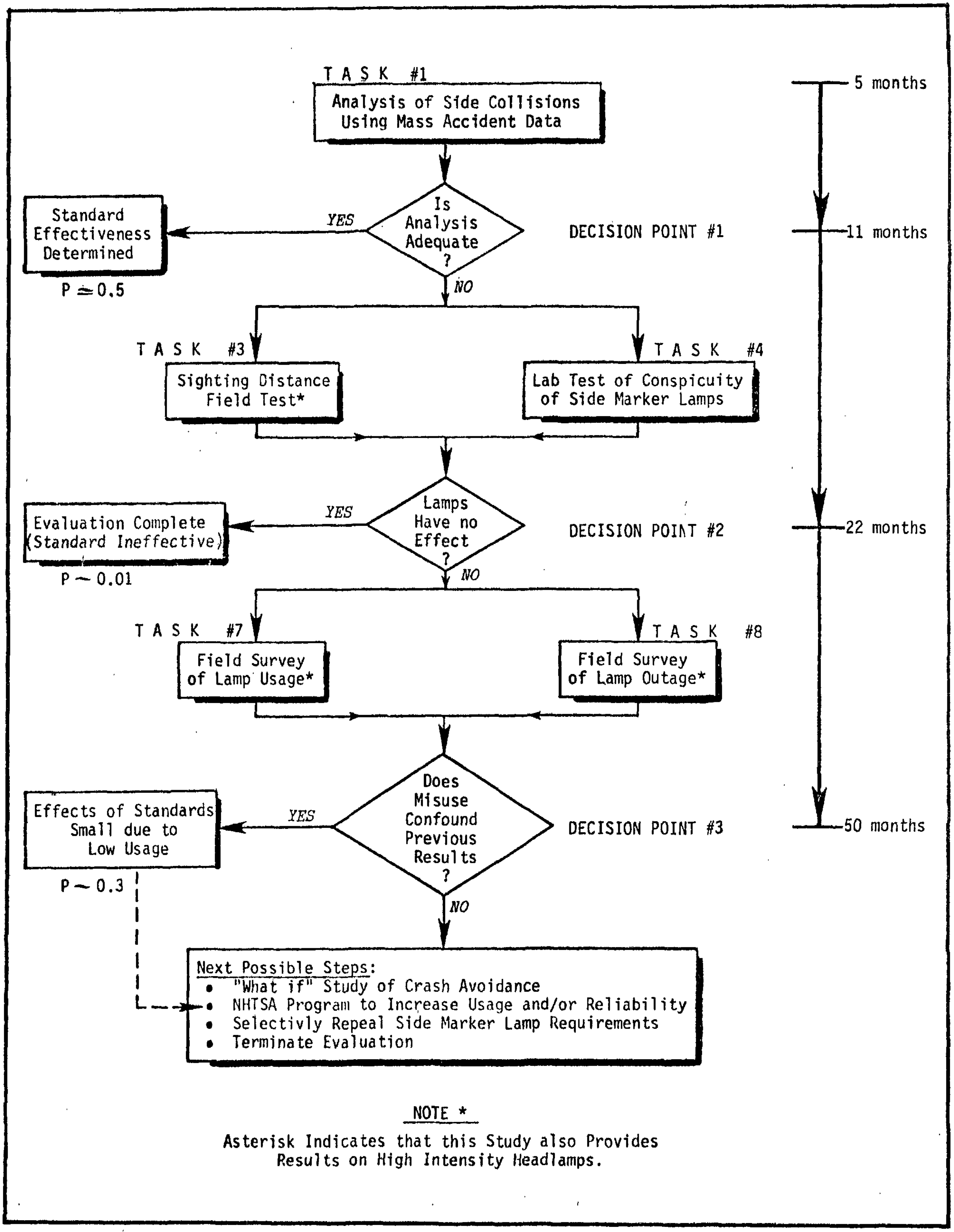

Figure 4-2. Flow chart for proposed evaluation of FMVSS 108: Side Marker Lamps.

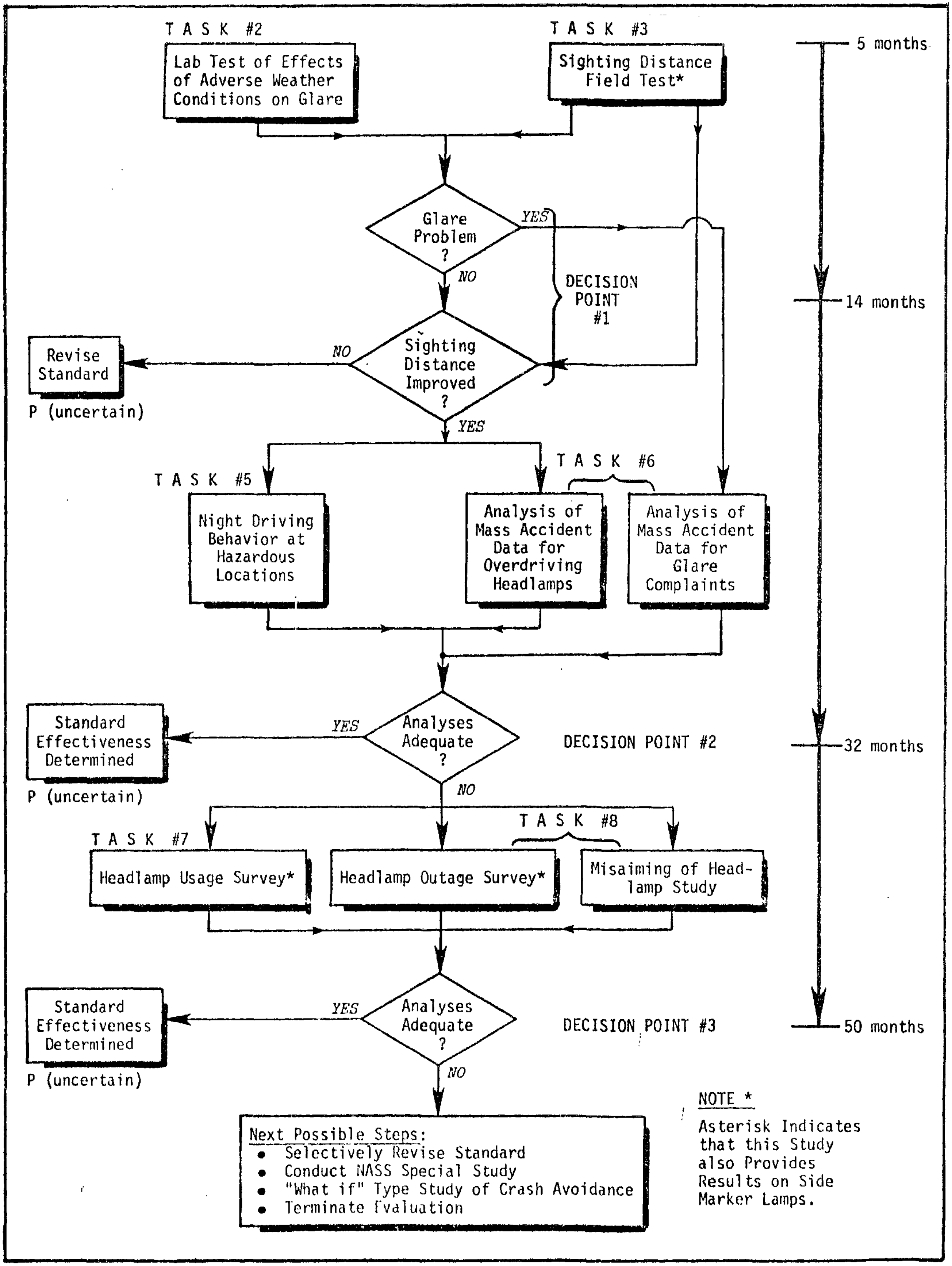

Figure 4-3. Flow chart for proposed evaluation of FMVSS 108: High Intensity Headlamps.

Task #3: Sighting Distance Field Test*

In the early part of this Task, the effect of side marker lamps on visibility of vehicles will be determined in field tests. Because of artificiality introduced by the testing procedure, this Task will establish the potential effect of side marker lamps in improving visibility rather than the actual effect in crash avoidance.

Task #4: Laboratory Test of Conspicuity of Side Marker Lamps

This Task complements Task #3 in that it will provide more detail on the effects of different types of side marker lamps (integral, separated, intensity of light, area of lamp, etc.). This test is under laboratory rather than field conditions; therefore, one could not make general inferences from this study alone. However, this study will establish if there are differences in conspicuousness between side marker lamps.

Decision Point #2

At the end of Month 22, NHTSA will know whether there are significant differences in sightability due to side marker lamps. It is CEM's estimate that it is highly likely that some effect will be found at least under certain conditions. At this point, NHTSA should also re-evaluate the initial study on side collisions. If the results of Tasks #3 and #4 contradict the results of Task #1 (i.e., side marker lamps have an effect in the laboratory tests but one cannot find an effect in accident reduction) then one must go on to Task #7 and Task #8 to learn more about the actual use of side marker lamps.

Task #7: Field Survey of Lamp Usage*

This Task concentrates on the question of whether and when side marker lamps are being used. If the lamps are not being used when they might be most effective, then one would understand the apparent contradiction encountered earlier.

Task #8: Field Survey of Lamp Outage*

This Task is complementary to Task #7, as it addresses another possible reason for the non-usage of side marker lamps. The source of this information is primarily from the examination of vehicle defect records in various states and observation of vehicles selected for the headlamp misaiming study (the other subtask in Task #8).

Decision Point #3

At the end of Month 50, NHTSA will have to decide whether the results of Task #7 and Task #8 show that usage factors confound the problem of estimating the effectiveness of the side marker lamps. CEM's estimate is that the probability is low (p = 0.3) that usage effects will confound the results of the evaluation.

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*This Task also helps evaluate high intensity headlamps.

Next Possible Steps

If none of the above analyses determine the effectiveness of side marker lamps, then there are several possible steps NHTSA might undertake. One is to do a retrospective study of accidents to see what would have happened if side marker lamps had been involved. The results of Task #7 and Task #8 might indicate that a program to increase usage and/or reliability of side marker lamps is desirable. If the analyses show no effect of side marker lamps, NHTSA might endeavor to selectively repeal certain requirements for side marker lamps. During any repeal program, accident trends should be monitored to warn of any adverse impacts. A final alternative is to terminate the evaluation.

HIGH INTENSITY HEADLAMPS

Task #2: Laboratory Test of Effects of Adverse Weather Conditions on Glare

This Task is a relatively straightforward experiment directed at concerns raised in the NHTSA Docket files with regard to dispersion of light from the surface of the headlamp. If light is widely scattered, there is the possibility that under certain environmental conditions there will be backscattering and glare.

Task #3: Sighting Distance Field Test*

This field test addresses the basic questions relating to high intensity headlamps: (a) How much do they increase visibility? (b) How much do they increase glare (and thereby reduce sighting distance)? These tests are done under controlled field conditions using volunteer drivers and specially prepared vehicles on a standard off-road track under closely monitored light conditions. This test will determine the potential differences between the regular and high intensity headlamps. This test cannot be directly translated into on-highway performance.

Decision Point #1

At the end of Month 14, NHTSA will have to consider several alternative decisions depending on the results of the initial studies. One possibility is that glare is a potential problem. In that case, NHTSA should initiate an analysis of mass accident data for glare complaints (Task #6). Another possible result is that sighting distance is significantly improved. In that case, NHTSA should initiate programs to evaluate that effect in actual circumstances, analyzing night driving behavior at hazardous locations by observation (Task #5) and also analyzing mass accident data for accidents where overdriving the headlamps may have been a significant factor (also Task #6). If the results of the first two studies have been negative, i.e., no significant difference in glare or sighting distance, NHTSA could decide to revise the Standard. CEM is uncertain of the likelihood of this negative result because of the degree of judgment involved in determining whether the effect is substantial or not. Calculations indicate that high intensity headlamps may only increase sighting distance 10 to 20 percent on high beam. And high beam usage is only a small fraction of total headlamp usage. Therefore, it is unclear whether NHTSA will consider a revision.

*This test also helps evaluate the effectiveness of side marker lamps.

Task #5: Night Driving Behavior at Hazardous Locations

Because of the small potential effect of the high intensity headlamps and their relatively slow rate of introduction (because they are a manufacturer-determined feature), the studies evaluating the effects of high intensity headlamps in real world situations are speculative. This Task outlines a study which will directly test the hypotheses that the high intensity headlamps are providing drivers with better information sooner by studying their behavior in selected highway areas where night driving is difficult.

Task #6: Analysis of Mass Accident Data for Overdriving Headlamps and Glare Complaints

Because the skills and data bases for these studies overlap, they have been combined into one Task. They are kept separate in the flow chart to reflect the fact that different potential effects of the high intensity headlamps are being examined. Although it is not shown within the flow chart (but is shown on the Gantt chart in Section 6), these analyses could be repeated at a later date if the evaluation is still continuing.

Decision Point #2

At the end of Month 32, NHTSA can review the results of the analyses which looked at real world performance and decide whether these analyses, combined with the results of the earlier tests, adequately determine the effectiveness of the high intensity headlamps. Because of the speculative nature of the analyses, CEM is uncertain of the likelihood of adequately determining high intensity headlamp effectiveness. If the analyses are not adequate, NHTSA should proceed with studies which expand the knowledge about actual headlamp performance in the field by surveying usage, outage, and misaiming (Tasks #7 and #8).

Task #7: Headlamp Usage Survey*

This Task would try to determine if the reason for failing to find any effect of high intensity headlamps is due to the fact that they are seldom used on high beams, or people who use them consistently drive faster, etc. These results might explain the results previously achieved.

Task #8: Misaiming of Headlamps and Light Outage Survey

This Task has two subtasks. The primary subtask is to conduct a study of headlamp misaiming through careful measurements of headlamps of vehicles selected from the current motor vehicle population. The second subtask is to determine the light outage rate of the current motor vehicle population based on those selected for the misaiming study and state motor vehicle inspection and other similar records. The purpose of this Task is to determine if there are some consistent differences between high intensity and regular headlamps which can explain and perhaps revise the results encountered so far in the evaluation program.

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*This Task would also help determine the patterns of side marker lamp usage.

Decision Point #3

At the end of Month 50, NHTSA will be able to review the results of all of the above Tasks to determine whether the analyses have adequately determined the effectiveness of high intensity headlamps. CEM is uncertain what the likelihood is of success, because of the great uncertainty about the number of vehicles which will have high intensity headlamps and the potentially minimal effect they will have on sighting distance.

Next Possible Steps

The reasons for the failure to adequately evaluate the effects of high intensity headlamps will affect the choice of the next steps. One option is to try to revise the Standard on a selective basis so that one knows the size of the potential effect and can look at the differences in accidents between selected car populations. Another option is to conduct a NASS Special Study of nighttime accidents. A third possibility would be to use detailed accident data to estimate "what would have happened if" cars had high intensity headlamps. A final possibility is to terminate the evaluation program.

4.5 Evaluation of FMVSS 122: Motorcycle Brake Systems

The flow diagram/decision tree for evaluating the effectiveness of FMVSS 122 is given in Figure 4-4. A time-phased Gantt chart is found in Section 6 which describes the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

Task #1: Analysis of Existing Mass Accident Data

Existing mass accident data from states will be analyzed to determine if there is a reduction in motorcycle brake-related accidents/injuries as a function of introduction of the Standard. The study will also provide information relevant to conditions associated with brake-related accidents. This information will be useful in subsequent analysis.

Decision Point #1

The mass accident data analysis will be reviewed to see if it is adequate to evaluate the Standard. It is not expected that it will be.

Task #2: Survey of Rider Characteristics/Tires/Structural Modifications

This Task will be initiated at the same time as Task #1. It is a mail survey which will provide background information on potentially confounding effects that may influence the mass accident data analysis, and/or subsequent analyses.

Task #3: Analysis of NASS and California Accident Data

In this Task, detailed motorcycle accident data from NASS and a California study (now in progress) will be analyzed to determine the effectiveness of Pre- and Post-Standard motorcycle brakes. In the event the evaluation requires performance of later Tasks, subsequent additions to the NASS data base will be evaluated at appropriate points.

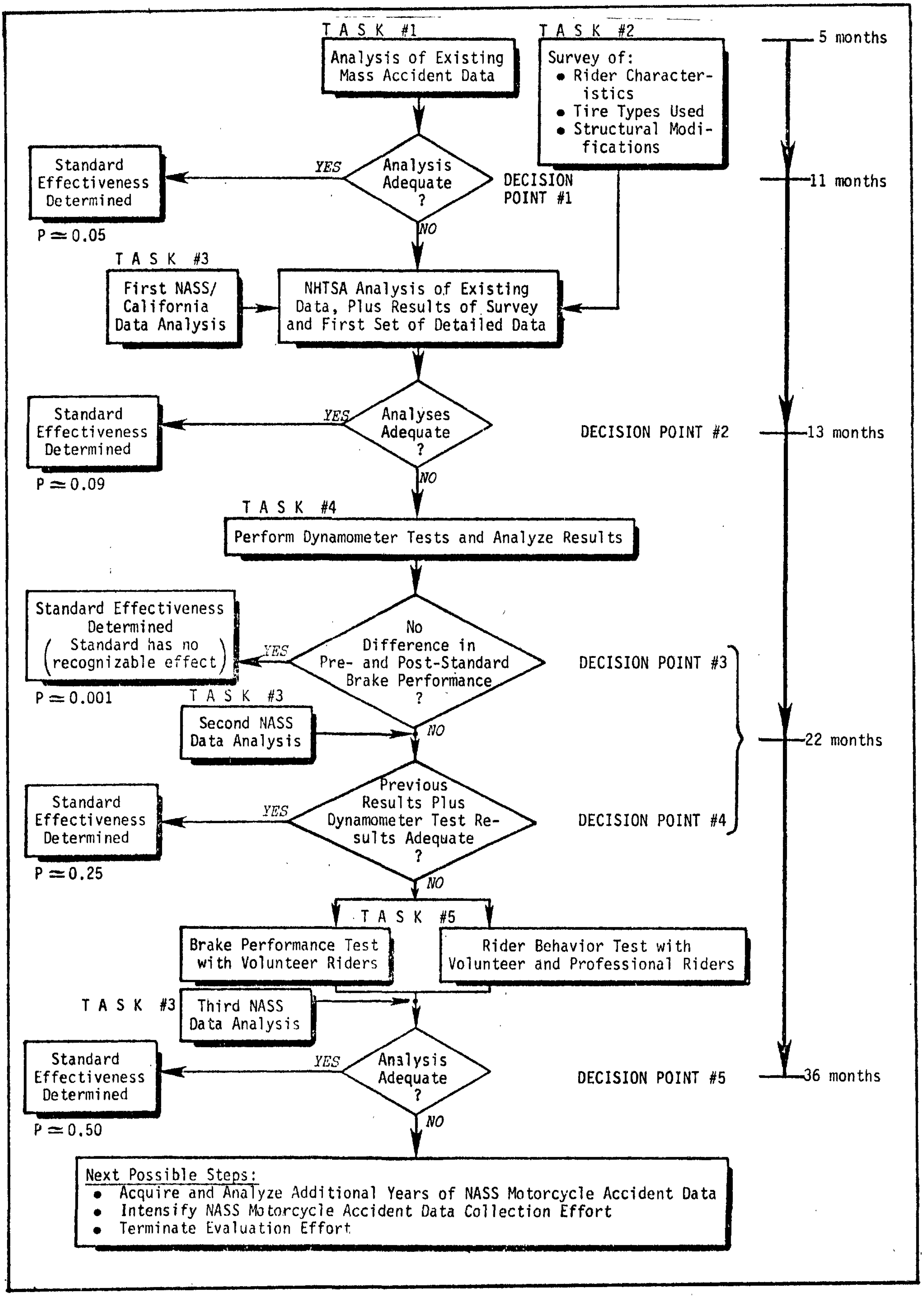

Figure 4-4. Flow chart for proposed evaluation of FMVSS 122: Motorcycle Brake Systems.

Decision Point #2

The combination of Task #1, #2, and #3 results will be reviewed by NHTSA and a decision made concerning the adequacy of the analyses. It is not anticipated they will be adequate. If this is the case, laboratory dynamometer tests of motorcycle brakes will be undertaken.

Task #4: Motorcycle Dynamometer Test

Pre- and Post-Standard motorcycles with essentially common tire types will be tested on dynamometers to determine braking differences.

Decision Point #3

If the dynamometer tests show no difference between Pre- and Post-Standard brake performance, it may be deduced that the Standard has produced no recognizable effect, and the evaluation may be terminated. (Revision of the Standard might be considered.) However, this outcome is considered highly unlikely.

Task #3 (Continued): Analysis of New NASS Data

Because an additional year of NASS data will be available, the previously-developed analysis programs will be rerun, and the NASS analysis updated.

Decision Point #4

If, as may be expected, the dynamometer tests clearly establish Pre- and Post-Standard brake characteristics, then this new information will be used to re-interpret the results from the previous tasks, including the updated NASS analysis. It is possible--though not highly likely--that this evaluation will be adequate. In the more probable event that the evaluation cannot yet be concluded, field tests will be made.

Task #5: Field Tests of Brake Performance and Rider Behavior

Professional and volunteer riders will be obtained to determine characteristics of Pre- and Post-Standard motorcycles, and the variations in rider performance. This additional information is expected to enhance the ability to interpret previously derived results.

Decision Point #5

After updating the NASS data analysis, all results will be reviewed. At this point, the probability of having adequate results is estimated to be about 50 percent. If it is concluded that the results are inadequate, there are at least three possible next steps.

Next Possible Steps

Several additional years of NASS data might be acquired and analyzed. As the data base grows,the analysis may become more adequate, although the inclusion of new Pre-Standard motorcycle accidents will diminish. It may be appropriate to fund an intense NASS motorcycle accident data collection and analysis effort, or it may be appropriate to terminate the evaluation.

4.6 Evaluation of FMVSS 202/207: Head Restraints/Seating Systems

The flow diagrams/decision trees for evaluating the effectiveness of FMVSS 202 and FMVSS 207 are given in Figures 4-5 and 4-6. A time-phased Gantt chart combining both Standards is found in Section 6, which describes the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

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 each other.

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 successfully 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, and #7) will have to be done, they are programmed sequentially to maximize the utilization of new information and provide for a 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 restraints--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

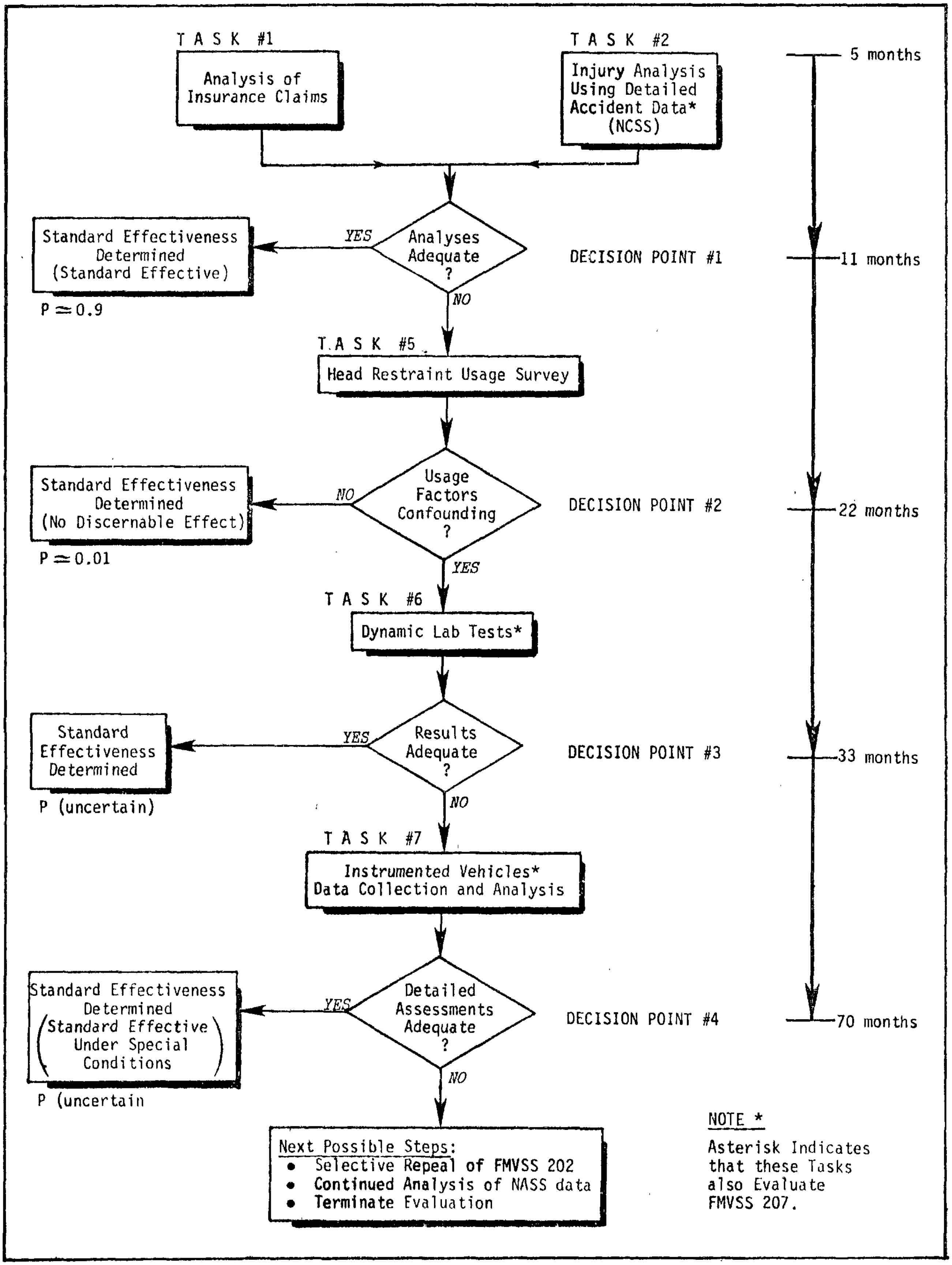

Figure 4-5. Flow chart for proposed evaluation of FMVSS 202: Head Restraints.

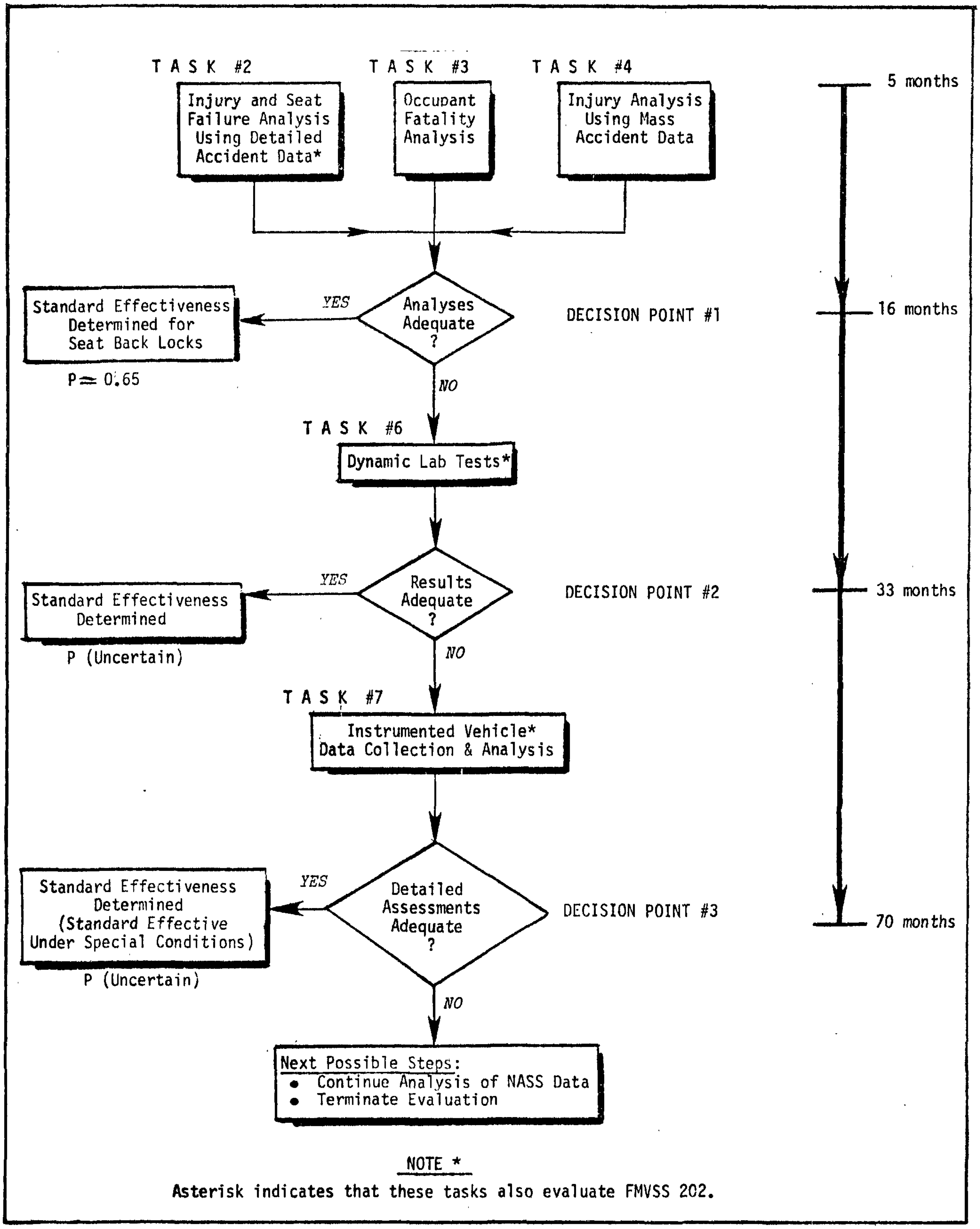

Figure 4-6. Flow chart for proposed evaluation of FMVSS 207: Seating Systems.

restraints. In order to gain more knowledge on the effectiveness, given different types of positioning of head restraints *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 FMVSS 207. Most of the tests will evaluate head restraint and seating systems simultaneously. If FMVSS 202 or 207 were 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 vaied.

Decision Point #3

At the end of Month 33, NHTSA will review the results of the Dynamic Laboratory 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 are 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 proceed with the expensive instrumented vehicle program (Task #7). Therefore, considerable time is put in the evaluation program Implementation Plan (see Section 6) for review and reevaluation.

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 are potentially very high. Such a study will also be very expensive and time-consuming; CEM estimates over $700,000 and two and one-half years would be required.

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 whether the later Tasks will be sufficient to evaluate the Standard given earlier analyses failure. To a great extent, the likelihood of success in the later analyses depends on the reasons for failure in the earlier analyses.

*Results of this Task also help evaluate seating systems.

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 selectively repeal (or modify) the head restraint Standard requirements. If no effect is shown, and no difference found between types of head restraints, the Standard might be dropped for some vehicles selectively. If some types of head restraint showed more promise than 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; it could also 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 using FARS data, mass accident data and detailed accident data is better than half ($p = 0.65$). 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 systems, 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 reevaluation or reanalysis 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 become available, or to terminate the evaluations.

4.7 Evaluation of FMVSS 213: Child Seating Systems

The flow diagram/decision tree for evaluating the effectiveness of FMVSS 213 is given in Figure 4-7. A time-phased Gantt chart is found in Section 6 which describes the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

Task #1: Analysis of Mass Accident Data

This Task is concerned with determining if the number of deaths and the severity of injuries to children under five years old have been reduced because of use of child seating systems. In the analysis--primarily of New York State data--child restraint system usage, including use, non-use, and misuse will be considered. While the initial analysis will be completed by Month 11, additional analyses will be performed during Year 3 and Year 4 as more data become available.

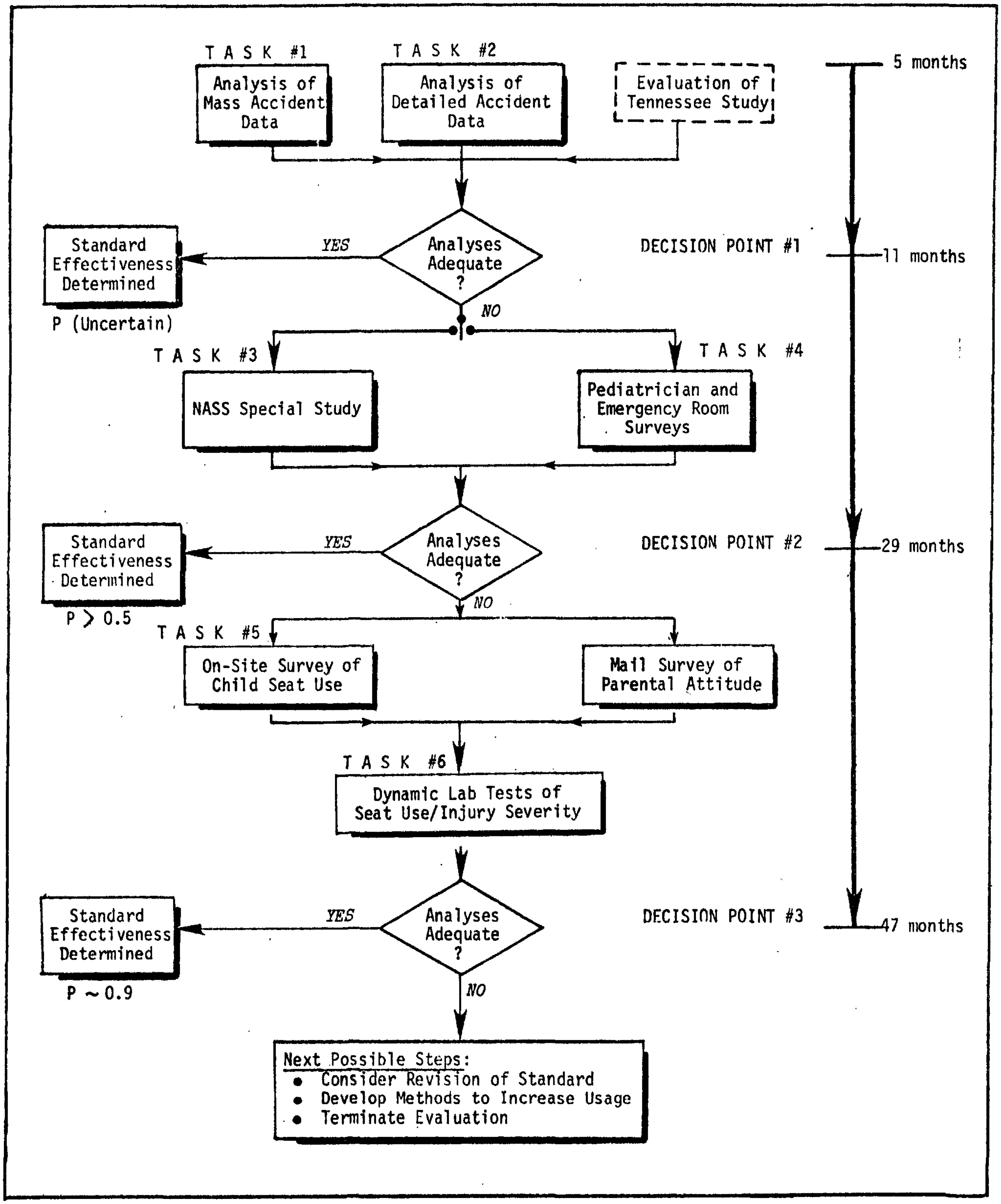

Figure 4-7. Flow chart for proposed evaluation of FMVSS 213: Child Seating Systems.

Task #2: Analysis of Detailed Accident Data

The purpose of this Task is to use detailed accident data to (1) estimate the effect of vehicle type, child weight and height, etc. on injury to children with and without seat restraints; and (2) investigate differences between different types of commercially-available child seating systems. The initial analysis which will be completed by Month 11 will use mainly NCSS data while subsequent reanalyses are scheduled as NASS data become routinely available.

Decision Point #1

At the end of Month 11, NHTSA can make a decision based on the results of Task #1 and Task #2 and the results obtained from a special study evaluated in Tennessee funded by other sources. At this Decision Point, and at each other point in the analysis, there is a great deal of uncertainty as to whether the effectiveness of the Standard can be determined. The reasons for this include the unique characteristics of the Standard, i.e., it covers optional equipment that is not an integral part of the motor vehicle, and the resulting low usage of child seating systems and misuse of these systems. Hence, at no place in the flow diagram in Figure 4-7 is there an indication of a numerical probability of determining the Standard effectiveness. If the effectiveness of the Standard is not determined at the first Decision Point, the next possible steps include a special NASS study and/or the Pediatrician and Emergency Room Surveys.

Task #3: NASS Special Data Collection and Analysis

This Task specifies a special data collection effort under NASS which would begin in Month 17 and continue for one year. This special effort may be required to collect a special sample of accidents involving child seating system use, non-use or misuse. Regular data collection under NASS may be inadequate to obtain a sufficient number of cases for evaluation of child seating systems.

Task #4: Pediatrician and Emergency Room Surveys

This Task is composed of two subtasks dealing with separate studies. A nationwide survey of pediatricians is planned, to collect data on the use of child restraints in relation to the number and severity of children's injuries in motor vehicle accidents. A followup analysis of selected accident cases may be performed. A second survey will obtain data from hospital emergency rooms on the number of children injured in car accidents, the severity of accidents, and, if possible, the seating system use.

Decision Point #2

At the end of Month 29, NHTSA will again reach a Decision Point based on the results of Tasks #3 and/or Task #4 as well as earlier work. For the purposes of costing the study in Section 6, it is assumed that both Task #3 and Task #4 are undertaken. If the NASS Special Study is not undertaken between the first and second Decision Point, it is highly probable that it would be performed following the second Decision Point, if the effectiveness of the Standard is not determined. If the effectiveness of FMVSS 213 is not determined at the second Decision Point, two more tasks are planned, the on-site and mail surveys and dynamic lab tests.

Task #5: On-Site and Mail Surveys

This Task includes two surveys to provide information on the use of child seating systems and parental attitudes. In the On-Site Survey, data will be collected with relation to the use, misuse and non-use of child seating systems. The mail survey would concentrate on parents' attitudes toward child restraints.

Task #6: Dynamic Laboratory Tests

The objective of this Task is to determine if commercially-available child restraints can prevent serious injury to child occupants. The results of previous dynamic tests will be used in designing the new lab tests. Additionally, information on the use and misuse of child seating systems from Task #5 will be utilized.

Decision Point #3

At the end of Month 47, a third Decision Point will be reached. The dynamic testing may permit reinterpretation of previous studies and allow the effectiveness of the Standard to be determined. If this is not the case, three possible courses of action are envisioned.

Next Possible Steps

If the effectiveness of FMVSS 213 has not been determined, possible further steps include: (1) possible revisions to the Standard; (2) the development of methods to increase usage; and (3) the termination of the evaluation of the Standard.

4.8 Evaluation of FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/Seating and Crash Protection

The flow diagram/decision tree for evaluating the effectiveness of FMVSS 220, FMVSS 221 and FMVSS 222 is given in Figure 4-8. A time-phased Gantt chart is found in Section 6, describing the Implementation Plan. A brief description of the Tasks and Decision Points is given below.

Task #1: Laboratory Tests

There are two separate laboratory tests which should be made prior to any in-depth analysis of accident data. The first is the static diagonal roof loading test which evaluates the appropriateness of the present roof loading requirements of FMVSS 220 relative to actual forces encountered in a rollover crash. The second is the dynamic angular shear test used to measure not only roof strength but the joint strength requirements of FMVSS 221 and the relative injury severity associated with the seating and interior crash protection requirements of FMVSS 222.

Decision Point #1

It is estimated that the laboratory tests will require six months to complete after which NHTSA will be able to determine whether or not there are significant differences between Pre- and Post-Standard buses with regard to FMVSS 220 and FMVSS 221 strength requirements. If not, the decision may be made to revise the requirements of these Standards.

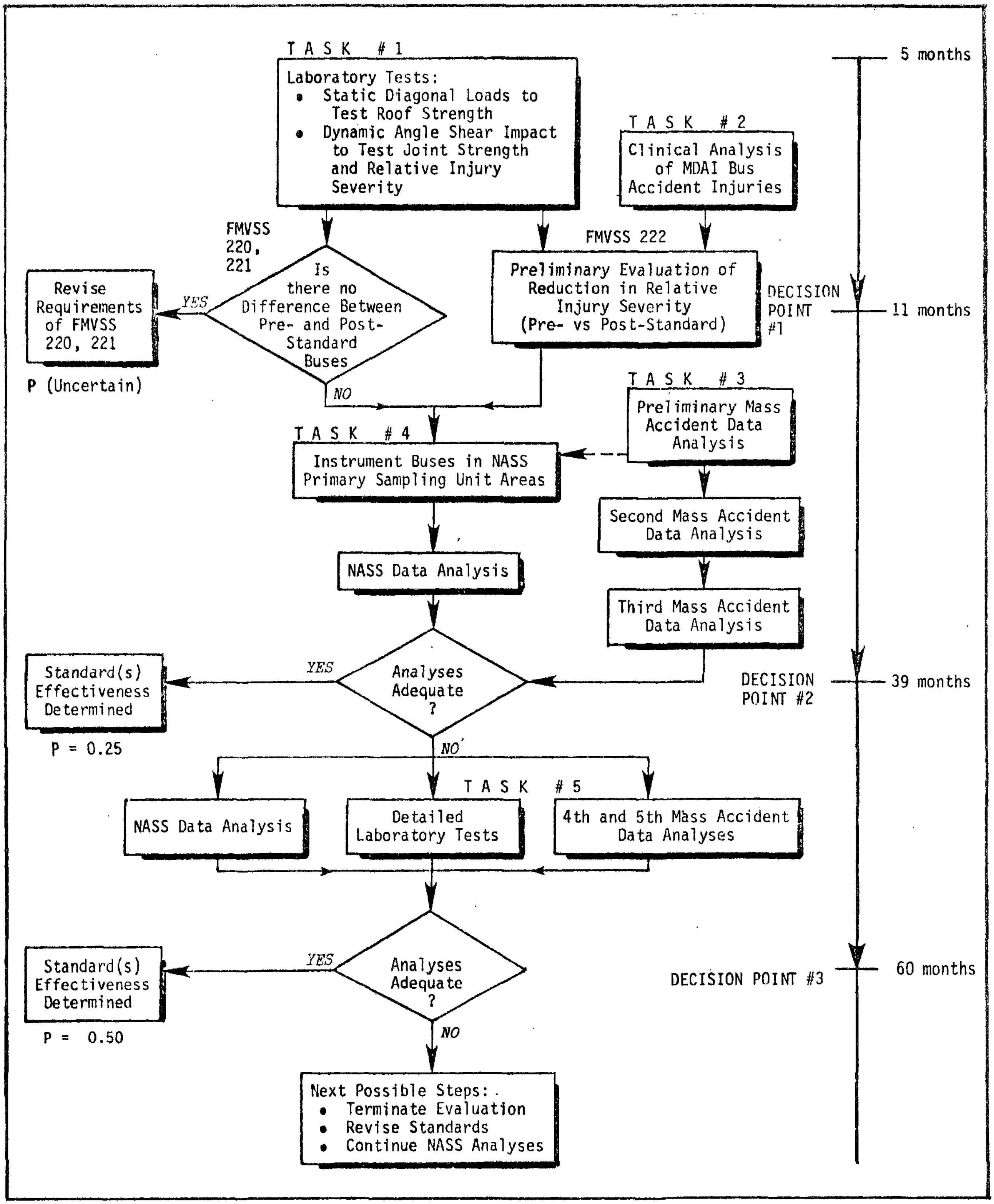

Figure 4-8. Flow chart for proposed evaluation of FMVSS 220: School Bus Rollover Protection; FMVSS 221: School Bus Body Joint Strength; FMVSS 222: School Bus Seating and Crash Protection.

Task #2: Clinical Analysis of MDAI Data

Conducted concurrently with Task #1 would be an in-depth analysis of available MDAI school bus accident data, in order to determine if there is any reduction in relative injury severity between Pre- and Post-Standard buses with regard to seating and interior crash protection requirements of FMVSS 222. Expectations are that the results of this analysis, together with the test results of Task #1, will not be able to clearly indicate any reduction, so that no decisive action will be necessary. However, the results of this Task may be extremely useful in Task #4 to help in establishing instrumentation and data collection requirements.

Task #3: Mass Accident Data Analysis

Although no decisive results are expected from the initial analysis of mass accident data from such states as New York, Texas and North Carolina, the possibility increases with time that significant reductions in injury severity will appear in Post-Standard vehicles. Also, there may emerge from this initial analysis valuable insight into the requirements of vehicle instrumentation and data collection of Task #4. Once the methodology for evaluating mass accident data has been developed, this activity will be carried out every six months on a continuing basis throughout the remainder of the evaluation study.

Task #4: NASS Vehicle Instrumentation and Accident Data Analysis

Should the results of Tasks #1 and #2 indicate continuation of the evaluation on the NASS data collection level, the information gained in these Tasks will be used to instrument all school buses in the NASS Primary Sampling Units and initiate data collection of all school bus accidents in these areas. This total effort is expected to require two years to complete before enough data have been collected on Post-Standard school buses involved in accidents. In the meantime, the analysis of mass accident data will continue at regular intervals.

Decision Point #2

At the end of Month 39, after the two-year collection and analysis of the NASS school bus accident and vehicle instrumentation data have been completed, it may be possible to reach a decision as to the effectiveness of the Standards. This would be the first point in the study where the probability of reaching this decision is relatively significant.

Task #5: Detailed Laboratory Tests

If no decision is reached in Task #4 on the effectiveness of the Standards, a further effort of detailed laboratory tests would be required, based on the knowledge gained from the accident data and associated vehicle instrumentation data accumulated by NASS at this point. These tests would be primarily concerned with the accelerations and occupant impacts experienced in actual crashes as recorded by instrumentation. In many cases, impact sled tests will be used with instrumented anthropomorphic dummies instead of actual buses in order to minimize costs. Due to the cost and magnitude of this effort, it is anticipated that three months will be required for NHTSA review and six months will be necessary before contract award. The Task itself will require a year to complete.

Decision Point #3

At the end of Month 60, Task #5 is completed, and a period of 21 months will have elapsed since the last Decision Point. During this time, NASS data collection will continue and the mass accident data analysis will have been continued. It is expected that the final analyses of these two data bases, along with laboratory test results, may produce enough evidence to make a decision on the effectiveness of the Standards, especially FMVSS 222.

Next Possible Steps

Should no decison be reached on the effectiveness of the Standards after Task #5, the possible alternative actions are limited. They are (1) revise the Standards' requirements; (2) continue collection and analyses of NASS and mass accident data; (3) modify and/or accelerate NASS data collection; or (4) terminate the study.

4.9 Integrating the Evaluation Approaches

There are a number of reasons for attempting to integrate the evaluation approaches. The evaluation of different Standards requires common data bases. Many of the analyses use similar analytical and statistical techniques. The evaluation of many of the Standards necessitates various types of static and dynamic laboratory testing. The evaluation of some of the Standards may require programs to instrument thousands of vehicles in the field. Many of the proposed approaches and generic studies are scheduled to occur at approximately the same time, assuming that the six evaluation studies (evaluating the effectiveness of the nine Standards) all begin at about the same time. Naturally, similar skills and qualifications of personnel are required for generic studies or approaches. This affords the opportunity for one group to perform similar-type studies for several Standards, with a potential for cost savings. A few of the more obvious opportunities for integrating or combining various studies to consider multiple Standards in the evaluation are summarized below.

- Mass accident data are used, without exception, in all six programs to evaluate the Standards. The data are scheduled to be analyzed, at least in a preliminary manner, during the first year for the following Standards: FMVSS 105, FMVSS 108, FMVSS 122, FMVSS 202, FMVSS 207, and FMVSS 213. It is recognized that not all evaluations use exactly the same mass accident data base, but there is a large commonality both as regards the data used and the statistical techniques. Clearly, especially during the first year, there are opportunities for cost savings by having a single group of researchers use common data bases and analytical techniques to evaluate multiple Standards. The cost saving potential is much smaller after the first year, but would still be appreciable in Year 3 when reanalyses occur for four Standards, and the three Standards dealing with buses (FMVSS 220, FMVSS 221 and FMVSS 222) are being evaluated.

- Many of the comments made above relative to evaluation approaches using mass accident data also apply to the use of detailed accident data. Detailed accident data bases are used both for statistical analyses and clinical analyses. The case-by-case clinical approach is used in evaluating both FMVSS 202/207 and FMVSS 220/221/222 during the first year. Detailed accident data (NASS) are also used to evaluate FMVSS 122 and FMVSS 213 during the first two years and later in the program.

- During the fourth year through the sixth year of the study, an instrumented vehicles data collection and analysis program is scheduled to evaluate FMVSS 105, FMVSS 202 and FMVSS 207. This program for each Standard is, of course, contingent on the result that the Standard could not be evaluated by means of earlier, less expensive approaches. Obviously, if the instrumented vehicle program must be carried out for all three Standards, opportunities for cost savings exist by instrumenting a common set of vehicles and establishing a single data collection effort.

- All evaluation programs may require dynamic and/or static laboratory testing to evaluate the Standards. The tests are scheduled throughout the first five years of the program, depending on the logical sequences of information needs as presented in Section 4.2. The lack of concentration of the tests to a particular year or two may limit the opportunity for cost savings through an integrated effort. However, the planned repetitive use of facilities and personnel over a period of years for at least subsets of the laboratory tests may permit modest cost savings.

- While not an evaluation Task, it should be noted here that the cost data analysis efforts to evaluate the direct costs of implementing the Standards have many aspects in common. Most Standards require a frequency sampling plan and analogous statistical analyses and all cost data analyses are scheduled to occur during the first year. An integrated effort could reduce required resources.

Although the above suggested integration of approaches offers a distinct potential for efficiency and cost savings, there will be some added burden in terms of planning and coordination. Secondly, the combined analysis will be, perforce, less focused on any individual Standard. And, finally, it may be judged that cost effectiveness is not an important criterion and that comprehensiveness is, resulting in integration by Standard, rather than task similarity. If this viewpoint is taken, the individual Standard evaluation programs could be carried out as outlined in Section 4.2, with only secondary consideration given to taking advantage of commonality of Tasks (i.e., evaluation Tasks that use a common data base, similar analytical techniques, or have similar data collection efforts).

4.10 Confounding Effects of Interactions Between Standards

The purpose of the National Traffic and Motor Vehicle Safety Act of 1966 was to reduce motor vehicle accidents and the deaths and injuries resulting from such accidents. The Act specifies that appropriate Federal Motor Vehicle Safety Standards should be established to achieve that purpose. Three criteria for each Standard are that they be practical, needed for motor vehicle safety, and be objectively stated. Through 1977, the National Highway Traffic Safety Administration had issued 50 Standards; 20 of which went into effect in 1968. There are 38 Standards which refer to passenger cars (and, sometimes, other vehicles); 4 Standards which refer primarily to trucks; 3 to motorcycles; 4 to school buses only; and 1 to child seating systems.* Of these, 26 Standards are primarily designed to help motorists avoid accidents (the 100 series); 22 Standards are primarily designed to reduce the frequency and severity of injury in accidents (the 200 series); and there are 2 post-crash Standards

*Passenger cars (primarily):	FMVSS 101-118, 124, 125, 201-212, 214-216, 219, 301, 302.
Trucks (primarily):	FMVSS 119, 120, 121, 126.
Motorcycles:	FMVSS 122, 123, 218
School Buses:	FMVSS 217, 220, 221, 222
Child Seating Systems:	FMVSS 213

basically dealing with fires (the 300 series). One can infer from the above that a great deal of official activity has taken place covering a wide variety of motor vehicles and their attributes.*

A special problem in evaluating the effect of a Standard (and of the possible confounding effect of other Standards) is the fact that a good number of the original FMVSS were largely recognitions of existing Society of Automotive Engineers Standards or Recommended Practices. An example of this is FMVSS 105 (Hydraulic Brake Systems for Passenger Cars). SAE recommended split brakes in 1964; manufacturers had generally adopted this system by 1966. FMVSS 105 went into effect in 1968, generally ratifying the SAE standard while adding some additional requirements for parking brakes and warning lights. However, in evaluating FMVSS 105, one must consider the effectiveness of the split brake system in cars in general, even those produced before the Standard became effective. This advanced compliance with a Standard also occurs in Standards issued more recently, because in these cases, the manufacturers have had considerable advance notice of the proposed Standards.

In summary, therefore, the problems of confounding effects due to interactions between Standards are:

- Simultaneous implementation, and
- Advanced compliance.

In any analysis, one must examine what has actually occurred, because the interactions can have a serious effect on the results and on their credibility.

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*In addition to the Federal Motor Vehicle Safety Standards, there have been a large number of other changes in motor vehicles and in the accident environment in the last decade. Dramatic changes in the size of vehicles; changes in the highway environment and speeds, etc. are included. In some cases, it is possible to control for these other changes;oftentimes, it is necessary to accept them as random factors in any analysis. The primary purpose of this section is to warn of the effects induced by Federal Motor Vehicle Safety Standards which might confound an analysis. The discussions of analyses in Section 5 describe how some of these and other factors are controlled for in specific cases.

4.11 Cost Data

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, 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 estimated well: 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, it may be 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.

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*Personal communication from Warren G. LaHeist, 18 January 1977.

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

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

Generally, specific hardware costs will be collected for each Standard. The number of models for which costs will be collected depends on the differences in costs and implementations between models and manufacturers. In addition to manufacturer and model size (for most Standards) the principal factors that must be considered in the cost data acquisition plans are as follows:

- FMVSS 105: Type of brake - power, power assist, standard.
- FMVSS 108: Manufacturer/models offering high intensity headlamps.
- FMVSS 122: Motorcycle engine displacement - under 125cc, 125-349cc, 350-449cc, 450-749cc, 750cc and over.
- FMVSS 202: Adjustable *vs.* fixed head restraints.
- FMVSS 207: Two-door *vs.* four-door cars.
- FMVSS 213: Fourteen (14) major manufacturers of child seating systems tested by Consumers Union in 1977 will be sampled.
- FMVSS 220/221/222: Number of seats installed.

5.0 ANALYSES FOR EVALUATING THE STANDARDS

5.1 Introduction

5.1.1 General Introduction

This section contains descriptions of the approaches suggested for evaluating the nine selected Standards. The approaches include analyses of mass accident data, of detailed accident data, of surveys and of laboratory tests. Each approach is described in more detail in the Task 4&5 Final Design and Implementation Report prepared for the individual (or group) of Standards (see Section 7). In this section material is organized according to commonality of approach (i.e, all mass accident data analyses) in order to allow comparison between the evaluation of Standards. The last subsection (5.5) deals with the analysis of costs of complying with the Standard. If the reader wishes more detail, or is interested only in certain Standards, then the Task 4&5 reports should be reviewed. In summary, this section is meant to be an overview of the detail presented in the earlier task reports. It provides the reader/decision-maker with overall, synthesized information.

A general caveat applies to the subsections which follow: there is no absolute certainty that the methodologies suggested to evaluate the Standards will yield definitive results. In some cases it is doubtful that the effectiveness of a Standard can be established with satisfactory confidence--although one might be able to establish that the effectiveness can be no greater than a certain amount. However, even in cases where current information suggests positive results are achievable, one can never be absolutely certain that unforeseen problems will not arise. For this reason, one must always recognize the basic conditional nature of the suggested approaches.

5.1.2 Introduction to the Data Bases

There are several ways to describe the data bases which are suggested for use in the evaluation of individual Standards. One difference is that some data already exist, others are collected in order to be analyzed, and a third type is data which will be collected for other purposes and can be utilized in the evaluation program. Another way of categorizating the data sources is by content: some have information on accidents; some have results from personal, mail or observational surveys; and others have measurements from laboratory tests. Almost no single data base is expected to be able to provide adequate information to satisfactorily determine the effectiveness of a Standard. Mass accident data bases have large size but generally lack detail on the accident; conversely the detailed accident data bases are limited in size. Laboratory tests are by definition controlled and somewhat artificial and thus cannot directly represent the real world effect of the Standard in reducing accident occurrence or injury severity. Survey data will largely be used to check previous analyses and refine the following specific data bases.

- Mass Accident Data Bases

In the analyses of mass accident data, three primary sources have been suggested: Texas, New York and North Carolina. These have been selected for reasons of size, and consistency and duration of computerized files. The files contain complete samples of all accidents occurring in a state in a single year (for Texas this amounts to about 600,000 cases/year). These large data bases are filtered to select those accidents where an effect of a Standard is expected to be observable.

Another mass accident data base which is suggested for use is FARS (Fatal Accident Reporting System). This file is a compendium of nearly all fatal motor vehicle accidents occcurring in the U.S. each year. FARS, however, is based on information collected by state agencies and thus there are differences in reporting the level of detail about accidents. Finally, there are a few additional mass accident state data files suggested for specific analysis: Virginia and Florida for glare complaints (FMVSS 108: High Intensity Headlamps) and Tennessee for child restraints.

- Detailed Accident Data Bases

The primary sources of detailed accident data are: the Multidisciplinary Accident Investigation (MDAI) file at the University of Michigan, the Restraint System Effectiveness Program (RSEP), the National Crash Severity Study (NCSS, ongoing), and the National Accident Sampling System (NASS, just starting). There are different problems associated with these files. The first two (MDAI and RSEP) are not representative probability samples of accidents, and even NCSS has some problems of representativeness. The MDAI file was accumulated over a considerable period of time by a large number of organizations. RSEP focused primarily on seat belt related factors and only front seat passengers. NCSS is collecting considerable data on accidents and injuries; however, the rate of involvement of some Pre-Standard cars is small and likely insufficient for the evaluation of some Standards, e.g., vehicles manufactured before 1968. NASS is supposed to have the flexibility to focus on certain special situations. However, that Special Studies Subsystem (SSS) has not yet been demonstrated. In some cases, because of the smallness of the sample of appropriate accident cases, these files will be used for clinical rather than statistical analyses.

- Special Data Files

Four special data files are suggested for use: the first is an auto insurance injury claim file. This file would be constructed from hardcopy records and used to evaluate the effectiveness of head restraints (FMVSS 202). The second file that is suggested is the R.L. Polk registration file. This file is suggested in many cases where a rate of accidents per registered vehicle is used in the analysis. The third and fourth data files would be constructed from information derived from surveys of pediatricians and emergency rooms, concerning children in auto accidents.

- <u>Surveys</u>

  The major purpose of the surveys is to "observe" and record "behavior." This occurs in the purest sense in those surveys which are directly observational, such as the head restraint usage survey or child restraint usage survey. Somewhat more technical are surveys which record "behavior" through instrumentation, rather than human observation. The major examples of this type of survey are the instrumented vehicles studies for FMVSS 105, 202/207 and 220/221/222. Another type of survey suggested is field tests. These are not controlled laboratory tests; however, they are more controlled than the observation of behavior in the real world. Examples of this type of study are the sighting distance field test for FMVSS 108 and the field tests of motorcycle riding behavior for FMVSS 122. Finally, there are two mail surveys which are designed to determine behavior and attitudes of, in one case, motorcycle riders and, in the other case, parents of small children , re child seats.

- <u>Laboratory Tests</u>

  The laboratory tests are more strictly controlled and reproducible than the surveys. There are three types of laboratory tests suggested. The most common (and familiar) are dynamic crash tests with appropriate body parts mounted on sleds and instrumented dummies. In the case of buses (FMVSS 220/221/222) this type of test extends to full-scale vehicle crashes. Another type of laboratory test is one of vehicle mechanical performance. The most elaborate of these are dynamometer tests for motorcycles and passenger cars. Others are simpler, just checking the characteristics of lights or brakes. The last type of lab test is a controlled experiment to test how conspicuous different types of side marker lamps are to individuals.

In summary, there is a diverse set of data bases or data sources which could be utilized to help evaluate the effectiveness of Standards. The following sections note what data will be required for each approach.

5.2 Mass Accident Data

5.2.1 FMVSS 105: Hydraulic Brake Systems in Passenger Cars

5.2.1.1 Rate of Catastrophic Brake Malfunction

Effect. The use of split braking systems instead of single braking systems should reduce the rate of catastrophic brake malfunction. This reduction should appear as a decrease in the proportion of accidents in which brake malfunctions are involved.

Technique. If there is no effect, the proportion of accidents involving brake malfunctions is (stochastically) independent of whether the braking system is single or split. The degree of dependence shown by the data is assessed in a *loglinear analysis* of the contingency table shown in Figure 5-1 . Many such tables will be examined (for example,tables for accidents involving only vehicles of a certain weight range, or a given age, etc.).

		Braking System	
		Single	Split
Accident Involved a Brake Malfunction	No	n_{11}	n_{12}
	Yes	n_{21}	n_{22}

Figure 5-1 . Breakdown of accident counts for Catastrophic Brake Malfunction Analysis.

Assuming the rate of occurrence of accidents that do not involve brake malfunctions is not affected by the brake system type (single/split), the odds ratio

$$\frac{n_{11}n_{22}}{n_{21}n_{12}} = \left(\frac{n_{22}}{n_{12}}\right) / \left(\frac{n_{21}}{n_{11}}\right)$$

estimates the relative risk of split as opposed to single braking systems. When this odds ratio is close to 1, the brake system has little effect on brake malfunction accident involvement. The loglinear analysis (see Appendix A) produces estimates and confidence intervals for the logarithm of the odds ratio. The details of the analysis given in the effectiveness evaluation report for this Standard take into account the low expected proportion of accidents involving brake malfunctions [1].

Sample Size. The proportion of accidents involving brake malfunctions is expected to be of the order of one or two percent. The power considerations sketched in the evaluation methodology report suggest that in order to detect a decrease of 35 percent in brake malfunctions with a reasonable certainty, at least 5,000 accidents are required for each of conforming and non-conforming vehicles; this is for each table considered.

Data Sources. The two principal data sources proposed are North Carolina State accident files (with approximately 250,000 accident-involved vehicles/year) and Texas State accident files (with over 600,000 accident-involved vehicles/year). The 5 percent sample of the Texas file maintained by the Highway Safety Research Institute could be used for preliminary investigations.

5.2.1.2 Analysis of Struck *vs.* Striking Vehicle

Effect. Since the majority of Pre-Standard automobiles will not have the braking capability of Post-Standard vehicles, in rear-end collisions involving one car with Pre-Standard and one with Post-Standard brakes, the Pre-Standard vehicle will be more frequently the striking car. Clearly, age effects must be taken into account.

Technique. The probability of the older car striking the newer car, in rear-end collisions involving two cars of fixed age, is calculated for three situations; both cars have Pre-Standard brakes; both have Post-Standard brakes, and only one car (the newer one) has Post-Standard brakes. In this last mixed situation, the probability that the older car strikes the newer one is expected to be larger than for the equality of two proportions. The proportions themselves should vary smoothly with the specified vehicle ages, and be consistent when consideration is restricted to vehicles of specified weight classes. Complete details are given in the evaluation methodology report.

Sample Size. The proportion of older cars hitting newer cars in the rear is anticipated to lie between one-half and three-quarters. To detect a shift of one percentage point, say from 50 percent to 51 percent or from 70 percent to 71 percent, the closer the initial percentage is to 50 percent the larger the sample size required. To find a shift of one percentage point with a test of level 0.05 and power 0.90 then requires, conservatively, 43,000 accidents for each of the three brake status classes. Because less than 30 percent of all accidents are rear-end collisions, only very large accident files will provide this number of cases in any given year.

Data Sources. Substantial numbers of accidents are needed for this analysis. Three State mass accident files are suggested: Texas, North Carolina and New York State. If the results for these files show large effects, the analysis can be confirmed using some of the smaller State mass accident data files, such as Washington State.

5.2.1.3 Ratio Estimation of Accidents Avoided

Effect. Vehicles with brakes conforming to FMVSS 105 should have better braking performance than vehicles whose brakes do not conform. For accidents in which braking ability is a major factor, the number that were avoided through imposition of the Standard is estimated.

Technique. Two kinds of accidents are considered. In one, braking capability is important; for example, side collisions or rear-end collisions. In the other, imposition of the brake Standard does not affect the probability of the accident occurring (sideswipes, accidents in parking lots for example). This second type of accident is used to control for exposure when extrapolating what the number of accidents (in which braking ability is important) would have been had the brake Standard not been implemented. The details of this ratio type extrapolation technique, including bias and precision considerations, are given in the evaluation methodology report. The estimates of the number of accidents avoided is to be produced for a variety of subsets of the accidents, defined according to vehicle characteristics--age, type of brake (power assisted, drum,etc.) --and perhaps driver characteristics.

Sample Size. The size of the anticipated effect is not known. Exploratory analysis will provide preliminary estimates of the effect, and this will allow assessment of required sample sizes.

Data Sources. The proposed data sources for this analysis are the State accident files for Texas, New York and North Carolina.

5.2.2 FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)

5.2.2.1 Analysis of Side Collisions

Effect. Increased conspicuity of vehicles with side marker lamps will result in their being less often struck in the side at times of reduced visibility (night, dawn, dusk; rain, snow, fog).

Technique. The frequency with which vehicles with and without side marker lamps are struck in the side, for various light conditions, weather conditions and times of day are calculated. Comparison of these frequencies with frequencies of some other accident, such as rear-end collisions, as in the loglinear analysis used in 5.2.1.1, Rate of Catastrophic Brake Malfunction, will allow estimation of changes due to side marker lamps. Other methods of controlling for exposure, such as using registration figures, could also be tried, but do not have much promise. Since vehicle use is a function of vehicle age, vehicle age must be controlled for. The details of the analysis are given in the effectiveness evaluation report for this Standard [2].

Sample Size. The changes in accident rates are expected to be small. For right angle collisions, the change is from 13 to 14 percent occurring at night for Pre-Standard vehicles to one percentage point less than that for Post-Standard vehicles. So for this simple Pre-Post comparison, comparing night side collisions *vs.* all other side collisions, approximately 22,000 accidents for each of the Pre- and Post- vehicles are required to obtain a one-sided test of level 0.05 and power 0.9. When the side collisions are analyzed in greater detail, more precise isolation of the effect of the side marker lamps may offset the larger samples needed to produce reasonable numbers of accidents in specific situations, such as rural side collisions at dusk in fog.

Data Sources. The principal files of mass accident data used in these analyses will be the State accident files from Texas, North Carolina and New York; the years will be 1968 through 1974.

5.2.2.2 Overdriving Headlamps

Effect. The more powerful the headlamps, the further ahead a driver can see. At night on unilluminated roads, a driver in a vehicle with high intensity headlamps will be able to see more, and so avoid more, than if he were using a vehicle with regular headlamps. The effect sought is, therefore, a reduction in nighttime accidents avoidable with increased sighting distance, for vehicles with high intensity headlamps relative to vehicles with regular headlamps.

Technique. Several types of accidents are considered. These include but need not be limited to, an object (a pedestrian or animal perhaps) on the road being struck and vehicles running off the road at a curve. The counts of these accidents are found for vehicles with and without high intensity headlamps. These counts are then standardized by comparison with registration figures or counts of involvement in some other type of accident. The resulting rates are then analyzed for differences attributable to the use of high intensity headlamps. When involvement in other accidents is used to control for exposure, a loglinear analysis, as used for catastrophic brake malfunctions (Section 5.2.1.1) is appropriate.

When registration figures are used, the proportion of accidents involving vehicles with high intensity headlamps can be compared with the corresponding proportion for registrations, in a simple binomial test. The standardized counts must be examined for age trends, since vehicle usage patterns depend strongly on age. A more detailed discussion is given in the detailed effectiveness evaluation report for this Standard.

Sample Size. The effect sought is likely to be small. The number of vehicles with high intensity headlamps will also be small, initially, since they were first introduced in model year 1978. Analysis of accidents for 1978 and 1979 will suggest suitable sample sizes for later years.

Data Sources. The accident files proposed for this analysis are the mass accident files for the States of Texas, New York, and North Carolina. Initially, accidents occurring in the years 1978 and 1979 will be used. Accidents occurring in later years may need to be studied.

5.2.2.3 Analysis of Glare Complaints

Effect. One potential effect of high intensity headlamps is that they could blind other drivers. The effect sought in this anlaysis is an increase in accidents due to glare blinding.

Technique. For nighttime accidents, the proportion indicating glare involvement is recorded. This proportion is analyzed to determine its relationship with the corresponding proportion of vehicles with high intensity headlamps. This last proportion can come from registration figures or, more directly, from induced measures such as the proportion of vehicles with high intensity headlamps hit in some other nighttime accident, such as a rear or side collision. The expected relationship is that there will be a linear trend, and this can be explored using regression methods. As a check on the analyses, they will be repeated for subsets of the accidents involving glare complaints. These subsets should be selected according to highway and driver characteristics. Details are given in the effectiveness evaluation report for this Standard.

Sample Size. While with normal headlamps glare is involved in between 0.5 and 4 percent of nighttime accidents, the corresponding proportion for high intensity headlamps is not known. Exploratory analyses of accidents occurring in the years 1975-1979 will suggest the probable size of the effect and so lead to suitable sample size estimates.

Data Sources. Any mass accident file used must record galre complaints in some form. The sources proposed are the State files for Texas and New York, initially for accident years 1975-1979. Other possible sources are Virginia and Florida State files.

5.2.3 FMVSS 122: Motorcycle Brake Systems

5.2.3.1 Analysis of Front-Rear and Left Turning Collisions

Effect. If the requirements of FMVSS 122 have led to an increase in brake effectiveness, then motorcycles whose brakes comply with the Standard will be able to stop faster and in shorter distances than motorcycles whose brakes do not comply. This improved braking ability should result in a reduction in accidents in which motorcycle braking is a major avoidance maneuver. Two such types of accidents are motorcycles running into the rear of another vehicle, and motorcycles colliding with an oncoming vehicle turning left. In accidents that do occur, greater energy absorbtion by the brakes should result in decreased levels of injury.

Technique. To determine accident reduction, the approach used in 5.2.1.3, Ratio Estimation of Accidents Avoided,is appropriate. Exposure is controlled for using an accident in which the motorcycle's braking capability is not use, such as a collision between a vehicle and a left turning motorcycle. To examine reductions in injury severity, *analysis of covariance* or *loglinear analysis* (see Appendix A) is proposed. Further details and a discussion of nuisance factors that tend to confound the analyses are given in the effectiveness evaluation report for this Standard [3].

Sample Size. The size of the effects sought are not known at present. Exploratory analysis will therefore be necessary before appropriate sample sizes can be suggested.

Data Sources. The proposed sources of mass accident data for the injury severity and accident avoidance analyses are the state files for North Carolina (2,905 motorcycle accidents in 1973), Texas, New York and Washington. Accidents occurring in 1969 and later are to be used. For accident avoidance, analysis of data from the Fatal Accident Reporting System (FARS) is suggested, for the same years.

5.2.4 FMVSS 202/207: Head Restraints/Seating Systems

5.2.4.1 Injury Analysis for Seating Systems

Effect. If the self-locking restraining device for folding seat backs is an important deterrent to injury, then front seat occupant injury rates for Pre- and Post-Standard 2-door cars will be different in frontal accidents.

Technique. The effect sought will not be present in 4-door cars, so these can be used to control for exposure. Since the effect is likely to be influenced by many other factors, vehicle model years are compared in selected groups for specific years. Within these groups, the relative risks of injury for Pre- and Post-Standard 2-door and 4-door cars are compared in a loglinear type of analysis (see Appendix A). Restraint usage can be accounted for in this analysis, and further details are given in the effectiveness evaluation report for this Standard [4].

Sample Size. The size of the effect is not known. However, power considerations suggest that 5,000 to 10,000 cases for each of 2 and 4-door Pre- and Post-Standard vehicles, for each grouping of vehicle/model year, will allow detection of moderate changes with reasonable certainty. Since approximately seven percent of all accidents involve a frontal collision, these sample sizes are realizable with the suggested data sources.

Data Sources. The proposed data sources for this analysis are the mass accident data files for the states of North Carolina, New York and Texas, for the years 1968 to 1971.

5.2.4.2 Analysis of Insurance Claims

Effect. The purpose of this study is to estimate the reduction in the frequency of neck injuries by head restraints through analysis of neck injuury insurance claims. This study is based largely on an earlier study by O'Neill, *et al.* in 1971 [7]. 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 than settlements were used because of the length of time necessary to settle many claims. In this proposed study, settled claims from about the same period (1969-1971) will be used in order to give some measure of severity of neck injury and its reduction.

Technique. 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 (In the early 70's, the Travelers Insurance Company closed approximately 150,000 accident claims per year.) The rate of driver neck injury 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 years should be examined.

Sample Size. The sampling rate will determine the number of accident claims that must be processed. It can be relatively low, given that approximately 3000 to 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.

Data Sources. The neck injury insurance claims are to be extracted from the insurance files of one or more large insurance companies.

5.2.4.3 Occupant Fatality Analysis

Effect. One potential adverse effect of FMVSS 207 is that in 2-door vehicles the seat back locks may trap rear seat occupants in severe crashes. This evaluation approach looks, then, for a change in the risk of death for rear seat occupants in 2-door cars.

Technique. The number of rear seat fatalities are compared between 2-door and 4-door cars for Pre- and Post-Standard vehicles, using conditional binomial tests or a loglinear model. The wrinkle in the analysis is that the proportion of 2-door cars among all cars was rising rapidly at the time the Standard was introduced, so that the vehicle mix must be taken into account. How to do this and other details of the analysis, together with a preliminary examination of some FARS data, can be found in the detailed evaluation methodology report.

Sample Size. In order to detect a moderate effect with reasonable certainty, approximately 500 rear seat fatalities are needed for each of 2-door Pre-Standard, 2-door Post-Standard, 4-door Pre-Standard, and 4-door Post-Standard vehicles. The difficulty is in obtaining sufficient Pre-Standard data. The small number of Pre-Standard cases can be offset to some extent with additional cases from Post-Standard vehicles, and three years of FARS data may be adequate for the anslysis.

Data Sources. The Fatal Accident Reporting System (FARS) has data on almost all fatal accidents. Data for 1975 through 1977 will be analyzed. Accident involvement counts (a surrogate measure of exposure) can be culled from mass accident data files for the states of New York, North Carolina and Texas.

5.2.5 FMVSS 213: Child Seating Systems

5.2.5.1 Analysis of Child Deaths and Serious Injuries

Effect. Use of child seating systems should result in fewer deaths and reduced injury severity. A caveat here is that reliable information on correct usage of the child seating system is not available. The interpretation of any effect shown will be tentative.

Technique. The major comparison is between restrained and unrestrained children not more than five years old. Conditional on the child being in an accident, the probability of injury of a given severity or greater (death included) is analyzed in a loglinear model, controlling for a variety of factors that include at least the child's seating position, his age and a measure of the crash severity. Further details and some preliminary analyses are given in the effectiveness evaluation report for this Standard [5].

Sample Size. To detect a change of 10 percentage points with reasonable power at the least detailed level of analysis requires approximately 500 restrained children and 500 unrestrained children. Small numbers of restrained children can be offset by very large numbers of additional unrestrained children; for example 300 restrained and 3,000 unrestrained children provide the same degree of discrimination. To obtain these numbers of cases, data will need to be pooled from more than one source.

Data Sources. The major data source is the mass accident file for the State of New York, which records about 900 cases a year of children 0-4 years old using child restraints. In addition, screening of variables and independent verification of substantial effects could use the FARS files: for the two years 1975 and 1976, a total of 4753 children 0-5 years are reported, of whom 46 (or one percent) were using child seating systems. The potential problem with the FARS data is the lack of uniformity in the data reported by the various states.

5.2.6 FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/ Seating and Crash Protection

5.2.6.1 Analysis of Deaths and Injuries in School Bus Accidents

Effect. This group of FMVSSs aims to reduce injury severity in accidents. With mass accident data, it may be possible to detect gross changes in the distribution of injury severity (including death as the most severe injury). Any such effect will be primarily the result of FMVSS 222, Seating and Crash Protection.

Technique. The distributions of injuries for accidents in which the bus did and did not comply with the Standards are displayed as a contingency table. These distributions are then compared using a chi-square technique specifically tailored for detecting shifts. An alternative approach could use a loglinear model for this analysis. The stability of the results of this analysis will be examined by controlling a variety of factors. These should include but need not be limited to the type of accident, whether or not the bus rolled over, the weight and make of the bus. One measure that is important for evaluating FMVSS 220 (Rollover Protection) is the number of people ejected from the bus. Further discussion is in the detailed effectiveness evaluation report [6].

Sample Size. In order to detect a substantial effect (say a shift of 20 percentage points) with reasonable certainty, data on at least 500 children injured in school buses conforming to the Standards are required. There will be larger numbers of children injured in non-conforming buses initially, since new buses replace about 10 percent of the fleet each year. Four years of data, starting in 1977 when the Standards were implemented, will consist, then, of accidents for a fleet with 25 percent of its buses dating from after the Standard went into effect.

Data Sources. The mass accident files from the states of New York, North Carolina and Texas will be used. Data from the years 1974 on will pertain to Pre-Standard buses, while data from 1977 on will inform on Post-Standard buses. These three states jointly should produce about 500 children injured in Post-Standard buses by 1980.

5.3 Detailed Accident Data

5.3.1 Scope

Analyses using detailed accident data will be performed for FMVSS 122, Motorcycle Brake Systems, FMVSS 202/207, Head Restraints/Seating Systems, FMVSS 213, Child Seating Systems and FMVSS 220/221/222, School Bus Rollover Protection/Body Joint Strength/Seating and Crash Protection.

5.3.2 FMVSS 122: Motorcycle Brake Systems

5.3.2.1 Motorcycle Brake Failure Analysis

Effect. The Standard should lead to a reduction in the proportion of accidents with motorcycles in which brake malfunctions and failures are involved.

Technique. The ratio of the Pre- and Post-Standard rates of occurrence of brake failures or malfunctions leading to accidents is a parameter in a loglinear model. Exposure is controlled for by considering accidents that do not involve braking, such as left turning motorcycles struck by oncoming traffic, or by using registration figures. This technique is used for FMVSS 105, Hydraulic Brake Systems for Passenger Cars, with mass accident data (Section 5.2.1.1). For motorcycles, however, mass accident data, tailored more to passenger cars, do not give enough information. Confounding factors that obscure the effect sought and lead to uncertainty in interpreting the results of the analysis include motorcycle operator errors and conspicuity. Further discussion and greater detail can be found in the effectiveness evaluation report for this Standard [3].

Sample Size. To detect (with reasonable certainty) a reduction by 30 percent of the rate of brake malfunctions in accidents, 200 brake malfunction accidents for each of Pre- and Post-Standard motorcycles are needed, assuming seven times as many control accidents. A reduction by 50 percent needs 55 brake malfunction accidents. Further data collection will be necessary to reach this number of investigated accidents, but initial analysis of existing data will supply preliminary information on the potential effectiveness of the Standard.

Data Sources. Existing data to be analyzed come from two sources. The California Highway Patrol (CHP) has detailed records of accidents involving CHP vehicles only. The University of Southern California has detailed multidisciplinary investigations of at least 900 motorcycle accidents in the Los Angeles area.

This second set of data is expected to become part of NASS. Further data could be acquired in a NASS special study.

5.3.3 FMVSS 202/207: Head Restraints/Seating Systems

5.3.3.1 Injury and Seat Failure Analysis

Effect. The objective of the analysis is to see what changes in the probability of injury and the injury mechanism result from imposing the Standards. Three aspects are considered: reduction in neck injuries due to head restraints, injuries to rear seat passengers caused by head restraints, and injuries due to seat failures.

Techniques.

a.) Reduction in neck injuries due to head restraints.

Two classes of accidents are considered: rear-end collisions and accidents in which a neck injury occurred. For rear-end collisions, the frequency of neck injury for front seat occupants is calculated for different seat types, head restraint types, seating positions and restraint use patterns. Other factors to be controlled are occupant characteristics (such as age, sex and height or weight, etc.) and vehicle characteristics (such as model year, type, weight, etc.). Whether the head restraint was correctly adjusted will be hard to determine, but crude effects may well be detectable using simple contingency table techniques. For neck injuries, the type of collision is also of interest.

b.) Injuries to rear seat passengers caused by head restraints.

Some early head restraints, when adjusted, expose metal bars and knobs with sharp edges. These could conceivably lead to serious injury when a rear seat passenger hits them as he continues forward while the car containing him is slowed by a frontal impact. A clinical case analysis will show whether this adverse effect occurs, and if it does, whether the resulting injuries are less serious than those that would have occurred in the absence of head restraints.

c.) Injuries due to seat failure.

The accidents considered are frontal collisions. The probability of injury at least as severe as some cutpoint (AIS 3 or AIS 4 for example) for front seat occupants is calculated for different seat types, seating positions, seat lock presence or absence and restraint usage. Other factors to be controlled for include at least the presence or absence of people or objects in the rear seat, the car age, occupant characteristics and crash severity. The different injury rates are compared using contingency table techniques such as chi-square or, more sophisticated, loglinear modeling. The analysis is repeated for various cutpoints of injury severity.

Further details on all of these approaches are given in the effectiveness evaluation report for these Standards [4].

Sample Size. These are given in the same sequence as for the effects and techniques.

a.) Reduction in neck injuries due to head restraints.

It is known that there is a reduction in severity of neck injuries. The major constraint in the detailed accident data is the number of relevant Pre-Standard cases. To demonstrate the reduction in neck injury risk with a satisfactory degree of confidence, at least 500 rear-end collisions involving Pre-Standard vehicles are necessary for a gross analysis. As the stratification becomes more complex and more variables are controlled, the sample sizes required could increase by an order of magnitude.

b.) Injuries to rear seat passengers caused by head restraints.

The clinical analysis should investigate 300 injured rear seat occupants, of which 100 are in Pre-Standard vehicles, and the remaining 200 in Post-Standard vehicles (split evenly between vehicles with bench and vehicles with bucket front seats).

Data Sources. Initial analyses can be performed on existing MDAI, RSEP and NCSS data files. In particular, the NCSS has a special collection effort pertaining to head restraints. These initial analyses may suggest a continued collection effort within NASS.

5.3.4 FMVSS 213: Child Seating Systems

5.3.4.1 Analysis of Child Deaths and Serious Injuries

This analysis is the same as that described in Section 5.2.5.1, but it uses detailed instead of mass accident data.

Effect. The use of child seating systems should reduce the probability of severe injury or death in accidents.

Technique. Children not more than 5 years old are considered. The ratio of the injury probabilities for restrained and unrestrained children becomes a parameter in a loglinear model designed to control for a variety of factors that include at least the child's seating position, his age and a measure of crash severity or ΔV. The effect of the child restraint may be obscured, if it is not known whether it was correctly adjusted. With detailed data it may be possible to examine the relative performance of different models and types of restraints.

Sample Size. To detect a change of 10 percentage points with reasonable power at the least detailed level of analysis requires approximately 500 restrained children and 500 unrestrained children. Small numbers of restrained children can be offset by very large numbers of additional unrestrained children; for example, 300 restrained and 3,000 unrestrained children provide the same degree of discrimination. To obtain these numbers of cases, data will need to be pooled from more than one source.

Data Sources. The main sources of data for this evaluation approach will be NCSS and NASS. Existing detailed accident files (RSEP, MDAI) do not supply enough cases. To speed up data collection, a special study within NASS is recommended.

5.3.5 FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/ Seating and Crash Protection

5.3.5.1 Analysis of Deaths and Injuries in School Bus Accidents

This analysis is similar to the corresponding analysis using mass accident data, described in Section 5.2.6.1. With detailed data,a more searching analysis becomes feasible.

Effect. This group of FMVSS should reduce the probability of severe injury or death for children in school bus accidents. Any major shifts in the distribution of injuries will primarily be attributable to FMVSS 222, Seating and Crash Protection.

Technique. The distributions of injuries for accidents in which the bus did and did not comply with the Standards are displayed as a contingency table. These distributions are then compared using a chi-square technique specifically tailored for detecting shifts. An alternative approach could use a loglinear model for this analysis. The stability of the results of this analysis will be examined by controlling a variety of factors. These should include but need not be limited to the type of accident, whether or not the bus rolled over, the weight and make of the bus. One measure that is important for evaluating FMVSS 220 (Rollover Protection) is the number of people ejected from the bus. Further discussion is in the detailed effectiveness evaluation report [6].

Sample Size. In order to detect a substantial effect (say a shift of 20 percentage points) with reasonable certainty, data on at least 500 children injured in school buses conforming to the Standards are required. There will be larger numbers of children injured in non-conforming buses initially, since new buses replace about 10 percent of the fleet each year. Four years of data, starting in 1977 when the Standards were implemented, will consist then of accidents for a fleet with 25 percent of its buses dating from after the Standard went into effect.

Data Sources. The data for this analysis will come from NASS. CEM assumes that all school bus accidents in NASS PSUs will be investigated. It is anticipated that four years of data collection will contain approximately 600 children injured in Post-Standard buses.

5.4 Surveys and Other Data Analyses

5.4.1 FMVSS 105: Hydraulic Brake Systems in Passenger Cars

5.4.1.1 Survey of Brake Indicator Outage Rates

Effect. The purpose of this analysis is to evaluate the effectiveness of the brake warning system itself. It is of interest to examine what effect age and other factors causing component degradation have on the effectiveness of the brake warning system. Certainly, if the analysis demonstrates high failure rates with age, then the usefulness of these systems is in doubt. In this case, it would be recommended that a Standard regarding brake warning systems be developed. This information is also important for evaluating FMVSS 105. Obviously, if the indicator outage rate increases with age, then the frequency of a driver not knowing that his brake system is impaired will increase with the age of the brake system.

Technique. For this analysis it will be necessary to obtain vehicle registrations which provide information on vehicle make, model year, and in some instances, mileage.* State vehicle registrations will be used to determine the composition (with respect to vehicle age, model, and/or mileage) of the general vehicle population. From this, it can be determined whether or not the vehicle sample (as obtained from inspection stations, etc.) is representative of the entire vehicle population. If not, sample adjustments (using appropriate weighting values) can be made. For each vehicle make and model year the analysis is performed in the following steps:

Step 1: Using the available data, outage rates for indicator lamps, or line pressure imbalance sensors, or both are estimated. The test of the indicator lamp would be whether it worked or not when the ignition was in the "on" position before the engine is started. The rates will be calculated by dividing the number of vehicles with outages by the total number of vehicles tested.

$$\text{Outage Rate} = \frac{\text{No. outages}}{\text{Total no. of vehicles tested}}$$

However, since the total number of vehicles having defective brake warning systems will probably be very small, this value is unlikely to be useful.

Step 2: Using weights proportional to the proportion of the population in each category (vehicle model,year, mileage), the counts found in Step 1 are aggregated over all categories. Outage rates will be estimated by age and also by age and manufacturer.

Step 3: Step 2 will be repeated using mileage instead of vehicle age. Mileage may be a better indicator of vehicle degradation than age since it describes to some extent vehicle usage. A frequently used vehicle will experience greater wear and degradation than an unused vehicle.

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*Mileage data might be available in states where vehicle inspection is mandatory.

Step 4: Look for differences. Comparisons of outage rates should be made between vehicles of different ages, models, and mileage to see if certain portions of the vehicle population experience higher rates than others. Graphs of the results should be examined.

Sample Size. It is estimated that about 3,000 vehicles will be required to estimate outage rates as a function of vehicle ages, vehicle models and vehicle mileage.

Data Sources. Test vehicles could be obtained in a variety of ways:

- Using states with required periodic vehicle inspection for locating motor vehicles to be tested. In states with mandatory vehicle inspection, the brake warning system can be tested (if this is not already part of the inspection).
- Soliciting car owners in an area through ads or mailings offering free brake diagnostic information in exchange for participation. One would probably want to perform many tests on the car in return for the reward.*
- Making agreements with used car dealers to allow testing of selected vehicles before they are refurbished for resale.

It is anticipated that most of the vehicles obtained for the static brake test evaluation under FMVSS 105 will also be included in the brake indicator outage survey.

5.4.1.2 Instrumented Vehicles Data Collection

Effect. The characteristics of "emergency" braking usage will be measured and related to vehicle characteristics, owner/driver characteristics and ambient conditions.

Technique. A fleet of vehicles would be instrumented and enrolled in a test program over a period of at least two years. Desirable information to be recorded would be:

1. Brake deceleration (and impact severity in the case of collision).
2. Wheel speed to check for locking.
3. Brake line pressure.
4. Brake pedal force.
5. Vehicle speed.
6. Time of day.
7. Vehicle mileage.
8. Vehicle start/stop time for trip duration.

*It should be noted that the type of people who respond to ads may not be typical of the general population. This may result in a vehicle sample (as obtained by this method) that is not representative of the general vehicle population.

The analysis of the data which would be performed is largely heuristic in nature. The simpler tabulations that would be examined are frequency of severe braking by trip time and duration, and plots of brake pressure and pedal force *vs* speed and deceleration, given characteristics like brake type, vehicle weight, driver age and sex, etc. These initial multivariate tabulations do not directly address the question of the effectiveness of the Standard but rather describe the performance of brakes under actual traffic conditions. Some of the questions that this analysis might address include:

- The frequency during trips that brakes are applied and the degree of actual degradation of performance that is observed (fade). This question relates to the compliance test requirements in the Standard.
- What is the actual braking behavior of individuals, especially with regard to pumping the brakes *vs* jamming them on.
- The frequency of locking of one or more wheels during severe braking.
- Pre-crash braking conditions, in those few cases where instrumented vehicles were involved in crashes.

The analyst should be using only the simplest statistical methods to examine differences in distributions. The critical factor in this analysis is to examine the data for differences which have a functional explanation--for instance, differences due to age, sex, brake type, vehicle weight, speed, repeated braking, etc.

Sample Size. The number of vehicles required for the in-motion data collection program is estimated to be about 1,000.

Data Sources. The selection of vehicles used in the study could be company or government car fleets, rental fleets or possible privately owned automobiles. The group tested would presumably have different trip purposes, trip lengths, ambient settings, mixture of occupant loading, etc. in order to show differing "emergency" braking usage.

5.4.2 FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)

5.4.2.1 Sighting Distance Field Test

Effect. The purpose of this approach is to collect data under controlled conditions that will allow an assessment of the effects of headlamp system, target type and glare on drivers' nighttime sighting distance.

Because this approach is a controlled experiment, the results cannot be directly applied to real traffic situations. Nonetheless, the results of these trials will establish the effects of headlamp system and headlamp aim for different targets under moving vehicle conditions and will therefore more realistically reflect such effects than static absolute sighting distance tests could possible provide. A secondary aspect of the study will be to assess the effect of side marker lamps on the sightability of those vehicles.

Techniques. The most important design conditions are headlamp system (high intensity versus regular intensity), target characteristics and presence or absence of glare. It would be relatively straightforward to also include environmental conditions and various driver characteristics; however, experimental costs in both time and personnel needed would grow very quickly. For initial experimentation therefore, considering only the three design variables of headlamp type, target type and glare type is recommended.

The data will be collected under controlled field trial conditions. The experiments should be conducted at a test facility. Experiments should be run in phases; initial results are to be used to establish the range of estimated effects and interactions so that later phases may be modified to take advantage of this new information. For example, initial indications of large differences in sighting distance for high intensity and regular intensity headlamp systems would allow for a reduction in the total number of trials needed to assert that there is a significant difference between high intensity and regular intensity systems.

For each of the experiments the test driver will be accompanied by a technician who will instruct and observe the driver. The driver will press a button on the steering wheel which will transmit a signal which indicates he sights the target so that the vehicle's position may be recorded. In addition, other technicians will record some aspects of the trial, for example, ambient light, road condition, environmental variables, etc.

The appropriate form of analysis of the data is a straightforward application of analysis of variance. Certainly this will be the primary data analytic technique for each data set as described, but if variables such as ambient light, speed, road conditions, etc., are left "uncontrolled" they may be incorporated into the analysis through the auxiliary technique of analysis of covariance.

The sidemarker lamp data would be explored for effects using analysis of variance and the ambient light variable would be introduced as a covariate so the effectiveness for dusk to complete dark conditions could be summarized, since it has been suggested that the greatest effect occurs during the evening hours with little effect during night hours or during other periods of total darkness.

The headlamp system experiments are all designed for straightforward analysis by analysis of variance. Such analysis would provide not only assessment of significant effects, but would also provide actual estimates of the various effect sizes.

Sample Size. It is estimated that between 32 and 64 subjects would be required to participate in the sighting distance field experiments.

Data Source. A test facility is required such as a large test track or abandoned airbase that affords a long straightway (at least 1,500 feet), no undesirable light source and is not demanding of driving skills when driven at a comfortable rate of speed (35 - 45 mph).

5.4.2.2 Field Data Collection at Hazardous Locations

Effect. The purpose of this study is to evaluate whether high intensity headlamps have any effect on evasive or emergency maneuvers (and accidents) at hazardous locations at night. This study is of considerable relevance because it addresses the real world effects of the high intensity headlamps. The question is whether the vehicles equipped with these lamps react to the hazardous situation sooner (farther away).

Technique. The data acquisition and preparation will have three major steps:

1. Identification of locations for data collection.
2. Data collection procedure development and execution.
3. Data extraction for analysis.

This study is a considerable departure from typical accident analyses or controlled experimentation. The approach is basically to record via videotape the maneuvers of vehicles approaching a predetermined hazardous location at night. The hazardous locations will be determined primarily from highway department spot maps of accidents. The videotape records will be reviewed and the maneuvers of vehicles will be related to the type of headlamp. In more detail, the data obtained are:

- Driver

  (No data is directly available).

- Vehicle
  - Headlamp type
  - Beam usage (high/low)
  - Speed (entering the hazardous location).

- Social Context
  - Time
  - Date (weekday/ weekend or holiday).

- Ambient Environment
  - Weather conditions
  - Ambient light

- Highway Environment
  - Type of hazardous location:
    - -- Sharp curve
    - -- Lane drop
    - -- Exit
    - -- Construction site
    - -- Other highway discontinuity
  - Type of highway
  - Maximum straightline distance hazard invisible
  - Markings/warnings.

- Traffic
  - Density of traffic (in the same direction and in the opposing direction)
  - Gap between the case vehicle and the preceding and succeeding vehicles.

The method of analysis is analysis of covariance. The dependent variable is, for one analysis, how far the driver was from the hazard when he reacted. Headlamp type, beam usage, presence of other vehicles are the categorical factors, and initial speed is the covariate. Since many computer programs require a balanced design for the analysis of variance, another way of performing the analysis would be to set up the equivalent regression problem.

Sample Size. The suggested data collection procedure would sample 50 to 100 high intensity headlamp vehicles a week at each site; sampling at a minimum of 10 sites for one week, 500 to 1,000 vehicles is a reasonable number to expect. This will be enough to decide how much more data to collect, if it does not already give definitive results. A sample of about 3,000 vehicles may be required.

Data Sources. The identification of hazardous locations will be done primarily through examination of highway spot maps which show where accidents have occurred. Given a high density of accidents in a certain area these accidents should have a high proportion of nighttime accidents. The main criterion for selection of a site for data collection is that the site have a relatively identifiable problem which might be helped by increased driver visibility.

5.4.2.3 Survey of Lighting System Usage

Effect. The purpose of this study is to provide data on the patterns of usage of headlamps and running lights. The question of running light usage is important in order to estimate the potential effect of the side marker lamps. For instance, if the side collision analysis reveals that side marker lamps reduce side collisions by 10 percent in the early evening hours, but the usage survey finds that only 25 percent of drivers have their lights on during these hours, then the potential effect of side marker lamps is much higher. Also, if the side collision analysis finds no significant reduction in side collisions in the early evening hours despite the fact that the sighting distance experiment shows that those are the hours side marker lamps are most conspicuous, then this study will reveal whether the reason for the results of the side collision analysis is lack of usage.

The information on headlamp usage is important because the increased potential sighting distance provided by the high intensity lamps is most significant when the high beams are used. This potential improvement may not be much benefit if most driving is done on low beam, which is increasingly the case as areas become more densely populated and highways better lighted. In summary, this study will provide information on whether the potential effects of FMVSS 108 safety improvements are limited by their under-utilization.

Technique. The analysis of the data will be in two parts. One will seek to update and compare with earlier studies to see if there have been significant differences in headlamp beam usage, for example, less high beam usage, more dimming earlier when two vehicles are meeting, etc. However, in general, the analysis will follow earlier studies. The second aspect will be lighting system usage in relationship to ambient lighting conditions. Presumably, the use of the lighting system will follow a progression from running lights to low beams to a mix of high and low beam usage as it becomes darker and traffic less dense. While running light (and thus side marker) usage should be sensitive to ambient lighting conditions, the mix of high and low beam usage might also be affected. The use of running lights may be very sensitive to regional differences, including state laws which require lights to be turned on at certain times. The analysis of lighting system usage should be related to ambient lighting conditions and those ambient lighting conditions should be related to times and locations for different seasons. This last information will be generated in the side collision analysis.

Sample Size. It is estimated that lighting system usage data would be collected at about 10 sites to obtain an adequate sampling of highway environment, traffic conditions, regional differences, local topography and climate.

Data Sources. The 10 selected sites should include the following areas:

- Northeast
- Mid-Atlantic
- Southeast
- Midwest
- Gulf Coast
- Rocky Mountains
- Northwest
- Southwest

5.4.2.4 Misaiming of Headlamps

Effects. The purpose of this approach is to examine the character and degree of misaiming of headlamps in the vehicle population. The main thrust of this study is to determine if there are any consistent or adverse circumstances which lead to the misaiming of headlamps, first with regard to the new high intensity headlamps which are larger than the regular rectangular headlamps and second with regard to headlamps in general. Information about the degree of misaiming will be used with the results of other studies to infer the amount of unnecessary glaring taking place and the amount of reduced visibility this causes.

Technique. The acquisition of the headlamp performance data requires the development of a testing facility and instrumentation. (1) Following the lead of earlier defect investigation programs the tests would be conducted at state vehicle inspection stations (possibly state licensed inspection stations), local diagnostic centers, or field "laboratories" set up locally. (2) The test facility would need a space where lighting could be relatively controlled, the vehicle could be accurately positioned on tracks, and an aiming screen could be placed about 25 feet in front of the headlamps. (3) Photometers will be needed to measure the intensity of the headlamp beam at different points. There are two potential methods of arranging the photometers: (a) arranging many photometers in a grid pattern on the aiming screen and taking only one recording per instrument*, or (b) mounting one or more photometers on a track which runs in front of the headlamps and recording the intensity and position periodically. This latter method is recommended because of greater accuracy and flexibility. (4) When the test vehicle is brought in and positioned on the tracks a technician sits in the driver's seat, puts on the low beams, places the engine in neutral (or park) and runs the engine at about 2000 rpm because low idling speed may affect voltage to the lights. (5) The ambient light, the intensity of the low beams and the gradient of the light beams would be measured. At the same time other technicians could check for outage of other lights. The position of the high intensity spot could be derived from the intensity gradients. (6) Next the high beams would be tested. (7) The last test would be to load three technicians in the back seat of the vehicle to determine the vertical shift of the beam. Prior to undergoing the testing procedure, vehicle owners would fill out a brief questionaire and release form. The questionaire would indicate make, model, model year and information on headlamp replacement and aiming.

The analysis will be primarily an interpretation of the results of tests of the vehicles. The misaiming rates will be compared for different aged vehicles, for different make/market class vehicles, for different areas, for different types of headlamps, and for different aiming methods after replacement.

While the rates as collected stand alone, since each cell has few cases sampled, it is worthwhile to consider ways of increasing the accuracy of each rate estimate. The proposed method for doing this is to consider the rates as functions of headlamp type, vehicle age, etc. The rates then become dependent variables in a loglinear model with the other variables mentioned above as the independent variables. Those higher order interactions deemed insignificant indicate where collapsing is feasible, so that many different cells lend strength to the rate estimate in any one cell. Both the precision of the estimates, and their stability are increased.

Sample Size. If one were to test ten cars in each cell, assuming 30 car types, four lamp types, and four model years, one would need 4800 vehicles.

Data Sources. A test facility can be set up at state vehicle inspection stations, possibly state licensed inspection stations, local diagnostic centers or field "laboratories" set up locally.

5.4.2.5 Light Outage Rates

Effects. The purpose of this study is to estimate how often vehicle lighting systems (headlamps and/or side marker lamps) are totally or partially failed. This study does not directly evaluate the effectiveness of the side marker lamps and high intensity headlamps in reducing accidents. It is designed to investigate how often light components are failed and whether these failures are

*If the aiming screen is 8 feet tall and 20 feet wide and the photometers concentrated primarily on these areas where the light intensity is assumed to be greatest (every 1 foot there), then the 50 or more photometers might be needed.

related to make/model lamp design, etc. Frequent outage reduces the potential effectiveness of the safety device, and, in the case of the headlamp being out, it can lead to an accident.

Technique. This study is divided into two phases. The first phase will evaluate data from independent sources: state vehicle inspection data, NHTSA-sponsored defect identification programs and data collected in the headlamp misaiming study and lighting system usage study. Depending on the results of the first phase, a second phase may be desired to clarify ambiguous results.

If the initial analysis of the data suggests consistent patterns of outage (aside from age-related) then further data collection would be desirable to establish whether some other factor has a significant relationship to outage, e.g., certain types of vehicles (subcompacts) or certain makes of vehicles, or certain types of lamps (Type 2B) or some other factor, such as stringency of inspection program, etc. Any new inspection program should utilize existing state vehicle inspection programs. The existing state procedures would be refined, increasing level of detail on the particular factors where a significant influence is suspected. However, the structure and scope of any additional data collection is dependent on the results obtained from the analysis of existing, independent data sources.

Sample Size. The sample size desired for the second phase of the analyses is dependent on the detailed design of the additional data collection on outage.

Data Sources. The required data on outage would be obtained basically from existing state vehicle inspection programs.

5.4.3 FMVSS 122: Motorcycle Brake Systems

5.4.3.1 Motorcycle Surveys (Riders/Tires/Structural Modifications)

Effect. The purpose of this survey is to gather presently scarce data which will be useful in developing evaluation methodologies, and in interpreting the results of other analyses. This three-part survey is meant to provide information that will aid in evaluating FMVSS 122. The information it will develop is needed to understand the potential effect of the Standard for the typical rider.

The purpose of the survey of motorcycle riders is to estimate the characteristics of the general population of these riders. Motorcycle brakes are probably the most effective of any vehicle on our highways when operated by an experienced rider. However, because a high level of skill is required to properly operate the braking system, improper operation is common. Unfortunately, many aspects of motorcycle riding can only be mastered through experience. Therefore, this section of the survey, which is devoted to motorcycle riders, seeks answers to both demographic data and the experience of motorcycle riders so that these effects can be considered.

The purpose of the survey of motorcycle tire use is to determine which and how many motorcycles are using the various types of tires available. Because tire characteristics play a role in accident avoidance, it is of interest to know which and how many motorcycles are using the various types of available tires. Tire usage will obviously have an effect on the evaluation of the effectiveness of FMVSS 122.

The purpose of the survey of structural modifications to motorcycles is to gather data on the frequency and degree of motorcycle modication, with the emphasis on brake modifications. In this section, motorcycle dealers and repair shops will be included, in addition to motorcycle owners.

Technique. The following steps will take place in conducting the survey:

1. Design the three-part survey.
2. Develop data collection methodology.
3. Select sets of recipients for each part of the survey:
   - Motorcycle owners.
   - Motorcycle dealers.
   - Motorcycle repair and maintenance shops.
4. Mail out surveys.
5. Process and analyze data.

Sample Size. A 1974 Gallup survey had 4,187 respondents. Since the proposed survey will be analyzed in greater detail, a total of 7,500 respondents is suggested. A pilot survey of, say, 500 individuals will show how many individuals should receive the mailed questionnaire, given the response rate to both the mailing and telephone followup. As for motorcycle sales and repair shops, a sample of between 500 and 1,000 should be adequate.

Data Source. Data will be acquired by means of surveys mailed to motorcycle owners and motorcycle sales and repair shops, with telephone followup of nonrespondents. It may be most effective to send an overall survey--containing questions for demographic purposes--to the entire motorcycle population chosen, but send the tire and modification sections to selected sets of the whole population.

5.4.3.2 Field Test of Braking Performance

Effect. The purpose of this task is to design an experiment to test the performance capabilities of Pre- and Post-Standard motorcycle braking systems. A "laboratory" field-type test is being suggested in which professional and volunteer non-professional riders test-ride motorcycles equipped with Pre-Standard brakes (also referred to as "old brakes" in this discussion) and Post-Standard brakes ("new brakes") so that differences in braking performance can be measured. The non-professional riders have been suggested so that the differences determined are those which occur among the typical riders in reacting to everyday motorcycle riding experiences. The professional riders will provide control group data.

Technique. Measurements will be taken on the length of time it takes to stop on receiving a signal after having passed through a water puddle. Other such measurements will also be taken. Some of these will include:

a) Minimum straight line stopping distances in narrow lanes defined by pavement markings or rubber cones.

b) Minimum stopping distances in curves of decreasing ratio, defined as above.*

*The stopping distances are useful since they indicate how controllable the motorcycle is when performing a typical avoidance manuever.

c) Same as b) with reverse camber road surfaces.

d) a) through c) with different and intermittently uneven coefficients of friction road surfaces, and rough road surfaces (vertical curves).

Brake line pressure recorders are suggested to establish the relative work done by the front and rear brakes during the events outlined above.

To conduct the proposed analysis of braking performance, the following steps will be necessary:

1. Obtain motorcycles with Pre- and Post-Standard braking systems. It may be necessary to modify current motorcycles in order to have brakes similar to those considered Pre-Standard.
2. Obtain enough professional and "typical" (non-professional) motorcycle riders to perform the tests (volunteer, or perhaps there will be a small reward, in addition to the opportunity to ride motorcycles under test conditions).
3. Prepare test facility for various measures being tested (wet surface, curves, etc.)
4. Have a sufficient number of riders complete prescribed braking tests.
5. Compare performance of Pre- and Post-Standard braking systems.

A Latin Square experimental design will allow (1) each driver to ride each motorcycle and (2) each motorcycle to be ridden in each time period, i.e., each experience period.

Sample Size. It is estimated that about 10 motorcycles and 100 professional and non-professional riders will be required to conduct the testing.

Data Sources. Motorcycle policemen with at least 10 years of experience may provide a pool from which "professional" riders can be obtained. Some areas of the country (such as Southern California) have skilled precision-riding organizations, composed largely of law officers, who may be quite willing to participate.

5.4.3.3 Field Test of Rider Behavior

Effect. The purpose of this laboratory-type experiment is to obtain data on the riding behavior of motorcycle riders. This would include, but would not be limited to the rider's braking performance. The inherent instability of motorcycles is closely linked to braking performance. Stressing motorcycle brakes without inducing wheel lock-up requires a high level of skill. Antilock braking devices are now being developed which will allow the motorcycle operator to apply both front and rear brakes fully in emergency situations without skid-controlling modulation, resulting in maximum stress on the braking system. Until these antilock braking devices are fully developed, motorcycle braking systems are likely to be under-utilized except by operators of professional levels of proficiency. The rider behavior experiment is proposed to determine the ability of typical motorcycle operators to exploit the capabilities of the machine (and, specifically, the braking system).

Technique. The experiment might be conducted as follows. Volunteer riders arrive at the test track. They have previously authorized instrumenttation of motorcycles, signed any appropriate waivers, and filled out a questtionnaire detailing age, sex, length of time with current motorcycle, prior on and off road riding experience, past accidents, and other personal information as deemed relevant. Information about the motorcycle has been recorded also: make, model, repairs, modifications, tires, brake type, etc. The motorcycle is instrumented; the condition of the test track and the weather noted; and the volunteer rider and the professional rider ride around the track. Each will need to make several runs to familiarize himself with what will be unfamiliar to him (the professional with the motorcycle, the non-professional with the track) before the test recordings are made. The instrumentation of the motorcycle is designed to measure acceleration and deceleration levels and brake pressures.

The overall approach requires the following steps:

1. Obtain "typical" (non-professional) riders through advertising media (volunteer or otherwise is to be determined). These riders must own motorcycles with Post-Standard braking systems (1972 and later) and must be willing to use their motorcycles on a test track.
2. Hire professional motorcycle riders.
3. Prepare test track for various conditions.
4. Instrument motorcycles.
5. Send "typical" and professional riders through the test track, with the professional rider riding each volunteer rider's machine (after a familiarization period).
6. Analyze the effect of rider characteristics/habits/experience in relation to control of the motorcycle, stopping distances, etc. demonstrated by the volunteer rider controlled for by the same variables for the professional rider.

Sample Size. The sample of motorcycle riders and motorcycles might be a subset of the sample discussed in Section 5.4.3.2.

Data Sources. The "typical" riders needed could be solicited through newspaper advertisements and other means. The professional riders used here as controls might be motorcycle patrol policemen or professional racers.

5.4.4 FMVSS 202/207: Head Restraints/Seating Systems

5.4.4.1 Head Restraint Usage Survey

Effect. 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 [7]. 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.

Technique. The observations of head restraint usage 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. 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.

Sample Size. In the O'Neill study, 5,000 observations were collected. This number should provide a sufficiently small error.

Data Source. The data will be acquired in the NASS data collection areas from very short observations of traffic. 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.

5.4.4.2 Instrumented Vehicles Data Collection and Analysis

Effect. 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.

*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.

Technique. NHTSA is currently funding the development of a vehicle instrumentation program which involves the installation of crash recorders in a fleet of 50,000 vehicles. These devices will measure and record crash accelerations as a function of time. Two companies have been awarded contracts to develop the vehicle instrumentation program. Their tasks include the development of an acceleration/time recorder and implementation plan for the instrumentation program.

For the evaluation of head restraints and seating systems, additional vehicle instrumentation will be required to obtain the maximum force that is applied to both the head restraint (including high seat backs) and seat back by a front seat occupant during a crash. To record these forces,displacement devices (collapsible tubes giving a direct force measurement) will be inserted into the head restraints (or high seat backs) and seat backs. These devices will be placed horizontally and vertically at 2-3 inch intervals on both the head restraint and upper portion of the seat back. Also, strain gauges will be placed on the seat anchors, seat tracks, seat latches, and head restraint support bars (for adjustable only) to measure the rotation (twisting) that may occur during a crash situation. These readings can be fed into the crash recording device and stored.

In any analysis of neck injuries, various factors must be controlled for. Sex is one such variable, since women report more injuries than men. Neck injury will be examined as a function of head displacement. This displacement must be adjusted for both occupant height and head restraint height, since the displacement is expected to be larger for inadequate matching between seat and occupant. The displacement itself is a function of the accelerations and velocity changes during the crash. Approximate values of ΔV can be related to the strains measured in the seat, and an analytical model for head displacement can be developed.

Combining this with the probability of injury gives a means of examining the effect of different restraint adjustment heights in crashes of varying severity and, in particular, when the head restraint is at its lowest position, the effect of that restraint condition can be inferred. 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.

In the analyses of seating system failure, 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.

Sample Size. The basic sample will consist of accidents reported from 50,000 instrumented vehicles during a two-year collection period.

Data Source. The data source is the NHTSA-sponsored vehicle instrumentation program that involves instrumenting approximately 50,000 vehicles with a crash recorder [8].

5.4.5 FMVSS 213: Child Seating Systems

5.4.5.1 Pediatrician Survey

Effect. A nationwide survey of a sample of pediatricians is recommended to obtain data on children injured in motor vehicle accidents. The emphasis would be on the number of children killed and the severity of the children injured in and out of child seating systems. As with all "voluntary" safety equipment, the potential effectiveness of the device is limited by the rate of usage. Available data indicates a low rate of usage of child restraints. Available data, however, is very limited, and it is hoped that a survey such as this will increase the available data base.

Technique. The data will be acquired through the mail survey of pediatricians willing to provide information on the numbers of young children they see, the type and severity of motor vehicle accidents in which they have been involved, and any information they might have as to the use of child seating systems in these accidents. The survey questionnaire should be prepared so that information can be directly keypunched on cards for subsequent analysis.

For the data collected from the survey of cooperating pediatricians, an analysis similar to that described for the mass accident data is foreseen. However, because it is doubtful that accurate information about the accident itself can be obtained from the pediatrician, follow-up reports may be necessary. Restraints in terms of time and/or money might well lead to a decision to only follow-up on a certain percentage of the accidents reported. The balance between the accuracy achieved from the more detailed reports, and the loss of accuracy due to a smaller sample is not clear. If a selective follow-up is used, one should investigate a larger percentage (perhaps all) of the cases where restraints were used, since, if the total number of such reports is fixed, an attempt should be made to split them evenly between restraint use and nonuse cases. There are, clearly more of the latter.

Sample Size. The level of detail obtained in this survey will require, for adequate analysis, about 2,000 children using restraints when involved in an automobile accident, and at least that many non-restrainted children. Assuming that one child in twelve in an accident is restrained, a total sample of about 25,000 children in crashes is needed. Preliminary information suggests that a pediatrician is apt to examine 50 to 100 children a year who have been in accidents. If one can assume 50 reports from each pediatrician, 500 pediatricians would need to be involved over a one-year or shorter period. If 25 percent of the pediatricians contacted decide to participate, 2,000 should be contacted.

Data Source. The data source is pediatricians willing to cooperate in a study of children involved in motor vehicle accidents.

5.4.5.2 Emergency Room Survey

Effect. This survey is proposed to obtain data from hospital emergency rooms on the number of children injured in automobile accidents, the nature and severity of these accidents and, if possible, information on whether or not child seating systems were in use when the accident occurred. It should be noted at the outset that this survey is proposed as a speculative venture; there are many difficulties involved in trying to enlist the participation of a facility such as a hospital emergency room, with its frequently overtaxed and rotating staff.

Technique. The data will be acquired through the mail survey of cooperating hospital emergency rooms willing to provide information on the number of children involved and/or injured who are brought to the emergency room, the type and severity of the accidents in which they were involved and any information available as to whether or not child restraints were in use when the accident occurred. The survey questionnaire should be coded so that information on it can be put directly on cards for subsequent computer analysis. Accident data on children involved in motor vehicle accidents will be analyzed similarly to the analysis described for the mass accident data.

Sample Size. It is estimated that at least 5,000 accidents involving children are required.

Data Sources. The most useful data sources may involve the following:

- Some emergency rooms have begun computerizing their records, so data may become more readily accessible and available.
- There may be a chance of finding some "specialized" emergency rooms willing to cooperate because of their special concern for the subject or because of their approach to emergency medical treatment (for example, four physicians in a Washinton, D.C., suburb gave up their private practices to run a 24-hour hospital emergency room).
- Some hospitals have instituted special emergency rooms only for children involved in accidents.

5.4.5.3 On-Site Survey of Children in Automobiles

Effect. This survey is designed to collect real world data on the use, mis-use or non-use of child seating systems, through on-site observations. In addition, it is designed to obtain information on drivers' attitudes toward these systems, through short interviews with the drivers of cars in which child seating systems are observed.

Technique. The data will be acquired by trained persons through observations and interviews. Of particular importance would be the recording, through observations, of information on:

1. Child restraints being improperly used.
2. Child restraints present in cars but not being used.
3. Cars containing young children but no child restraints.

For ease in subsequent analysis, both the observation and the interview forms should be prepared so that the information on them can be coded directly onto cards for computer analysis. The real world survey will be used to determine usage and attitudes. It is not expected to give much information on the efficacy of child seating systems, since the reporting will probably be biased and inaccurate. However, since usage is low, if the restraint systems are reasonably effective, any increase in usage should lead to large decreases in injury and injury severity.

Since most ideas about non-usage now fall into the realm of conjecture, hard data is needed. The survey should help meet this need. It will also provide more detailed information on the problems of restraint usage. This information should be of value in any changes in the Standard that would be made relating to increasing usage. It may be necessary to allow a slight decrease in individual efficacy of child seating systems to significantly increase usage. The survey data should, at least, allow such questions to be addressed. Substantial statistical analysis of the data is not foreseen, since efficacy testing can best be done on accident data. The survey should be viewed as a preliminary data collection effort to help create subsequent ideas and directions of study.

Sample Size. During a one-month period in 1974, the Insurance Institute for Highway Safety (IIHS) conducted a limited study of the type outlined here [9]. Visual observations were made on restraint use of occupants of 5,050 autobiles containing at least one passenger under ten years old, and short interviews were conducted with the drivers. Because of greater detail, it is anticipated that a larger sample size, perhaps 10,000 automobiles with children, will be required for this study.

Data Source. Observations and interviews would take place at variety of areas, such as:

- Diverse parking lots, including those serving large supermarkets.
- Rural roads.
- Single lane entrances and exits of freeways and/or freeway exits with stop signs.
- Highway toll plazas.
- Mid-town parking garages associated with commercial outlets such as department stores and civic centers.
- Drive-in banks.

5.4.5.4 Mail Survey of Attitudes and Use

Effect. This survey is designed to sample, by mail, parents of children under five to determine their use/non-use of child seating systems and their attitudes towards these devices. In the literature on child seating systems, there are constant appeals to parents to use child restraints; the most protective restraint produced is of no value unless it is used, and is of reduced value if it is being used incorrectly. Current estimates put the use of child seating systems at less than ten percent, even though the actual number of child seats produced (about seven million thus far) is approximately 40 percent of the 0-5 year child population (about 16 million).

Technique. A survey form would be designed to mail to a selected sample of parents with children under five. Both demographic and attitude questions would be included, in an effort to determine the parents' knowledge of and use of child seating systems. Information will be sought on:

- Child seating systems used most.
- Whether cost was a deciding factor.
- Numbers of parents who use restraints.
- Where children sit in cars.
- Types of trips taken with children in car.
- Numbers of accidents in which these children have been involved.
- Whether child restraints were involved in these accidents.
- Types of cars driven.
- Age, occupation, income bracket of parents.
- Where information on child restraints obtained.
- Feelings toward child restraint (would they buy it again?).
- Child contentment in relation to safety system.
- Parents' use of seat belts.
- Ease of use of child seating system.
- Ease of moving restraint from car to car.

Sample Size. A detailed analysis of the returns will require approximately 10,000 responding parents. At best, 20 percent of the sampled parents can be expected to respond immediately. This suggests an initial mailing of 50,000 questionnaires. However, it is usually the case that those people who do not respond are different in major respects from those who do. This will likely bias the survey results. To mail out follow-up questionnaires, one must be able to link each return with the respondent's address. This means that questions of confidentiality must be resolved, and legal aspects of the information given should be clearly explained in the cover letter mailed out with the questionnaire. Through a follow-up questionnaire and an intensive effort to interview a small subsample of those who have not responded to a second mailing, some estimates of the magnitudes and directions of the bias can be made. If follow-up is used, a smaller sample of, say, 35,000 parents could be used (this assumes a 20 percent response to the first mailing and a 10 percent response to the second, with intensive follow-up of 500 non-respondents).

Data Source. The child seating system use and attitude data will come from a selected sample of parents with children under five.

5.4.6 FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/Seating and Crash Protection

5.4.6.1 Vehicle Instrumentation and NASS Data Analysis

Effect. The purpose of this effort is to use simple three-axis accelerometers installed in a large number of buses to provide a set of actual peak accelerations imposed on buses during real crashes. These accelerations are at present unknown and figure importantly in both assessing the effectiveness of present Standards and in assessing possible modifications in buses and Standards.

Technique. It is crucial that a thorough monitoring system be available to investigate each crash and collect both the acceleration data and detailed accident/injury/injury causation data. Only by having detailed data on the accident and its outcomes will the relationships between accelerations and injuries (both severity and type) be amendable to analysis. It is assumed that the data will be collected by NASS investigation teams.

The analysis of this data would be similar to that proposed for the detailed accident analysis. This study has only added 3-dimensional accelerations during the accident as a new variable. Such accelerations would obviously be prime variables to "condition" on to determine if injury type or injury severity or both are strongly related to accelerations. In such an analysis the question of Pre *versus* Post is no longer pertinent but the logic of analysis is similar,for now one would ask about low accelerations *versus* high accelerations, etc. and look for differences in the dependent variables across such categories.

Besides relating accelerations during accidents to injuries it would also be necessary to relate such accelerations and their effects (on both the passengers and the bus itself) to the three Standards. The effectiveness of FMVSS 220 and 221 are directly related to bus deformation as a function of the accelerations, whereas the effectiveness of FMVSS 222 is most closely related to injury type and severity. Measures of effectiveness of FMVSS 220 and 221 that would be used to evaluate levels of acceleration would be penetration of body components into the passenger compartment and degree of body joint failure leaving openings and sharp metal edges exposed. FMVSS 222 would require measurement of levels of injury in each seat position, related to the cause of injury and whether or not it was caused by interior crash protection of body structural failure. The analysis of severe body penetration and joint failure will in all likelihood require photographs as a means of subjective measurement.

Sample Size. Based on NASS Primary Sampling Unit (PSU) population ratios, the number of buses to be instrumented in all PSUs is expected to be approximately between 22,000 and 40,000.

Data Sources. All the school buses (both Pre- and Post-Standard) in the area of each NASS PSU would be instrumented with simple, mechanically operated triaxial accelerometers.

5.5 Laboratory Data Analysis

5.5.1 FMVSS 105: Hydraulic Brake Systems in Passenger Cars

5.5.1.1 Distribution of Brake Pedal Pressures

Effect. It is evident that there are certain portions of the driver population (both male and female) that could not achieve certain levels of foot pressure which might be necessary in an emergency situation. The purpose of the laboratory tests, then, is to determine the percentage of drivers of given characteristics (age, sex, height, weight) who cannot achieve maximum force levels set by the Standard. In obtaining the distributions, consideration must be given to seat type and pedal adjustment. The vehicle braking performance may be inferior for that portion of the driving population that cannot achieve specified pedal pressures, even though the brake system is in compliance with FMVSS 105.

Technique. The test procedures would be to measure sustainable pedal pressures for five seconds. A series of six pedal applications would be averaged. Tests would be conducted for bench and bucket seat configurations, and with the brake pedal in a normal and low position. In analyzing the results, driver population will be categorized into 54 cells. These cells will be a function of two sexes, three age groups, three height groups, and three body types. For each sex, seat type and pedal adjustment combination, the analysis is performed in the following steps:

Step 1: In each cell the frequencies of maximum pedal pressure are tabulated.

Step 2: The distribution of maximum pedal pressure in the appropriate population is estimated. Using weights proportional to the proportion of the overall driver population in each cell, the frequencies obtained in Step 1 are aggregated over all the cells. The weighting affects the precision of the estimated distribution, but if the tails of the population distribution are generated by only a small segment of the population that lies in only a few of the cells*, then the tails of the estimated distribution are much more accurately pinned down than if the experiment had just been run on random samples of the same size for each sex.

Step 3: The estimated population distribution is smoothed. A member of a flexible class of frequency curves is fit to the estimated distribution. One such class is the Pearson curve system [10]. Which particular type of curve to fit from this family is decided on the basis of the skewness and Kurtosis of the estimated distribution, and once the type is determined, it may be possible to estimate parameters via maximum likelihood. Various methods make the estimation possible with a non-linear least square program [11, 12].

Step 4: The smoothed distribution is used to estimate what proportion of the population cannot achieve (for this seat type and pedal adjustment) the level of brake pedal pressure required by the Standard.

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*The test data will provide evidence as to the truth of this plausible assertion.

Once these steps have been performed, the effects of various combinations of sex, seat type and pedal adjustment can be examined.

Sample Size. It is estimated that only a small number (between four and ten) of subjects will be required for each cell to obtain an acceptable level of precision in the statistical analyses. Thus, it is anticipated that about 2,000 subjects will be sufficient (2 seat types x 2 pedal adjustments x 54 cells x 10 subjects per cell = 2160).

Data Sources. The subjects for these tests might be obtained in conjunction with obtaining vehicles for the static brake laboratory tests. Potential sources for drivers and vehicles include:

- Contracting with dealers of used cars.
- Advertising in local papers.
- Combining tests with state motor vehicle inspections for resold cars or new state registrations.
- Including brake tests as part of annual motor vehicle inspection for some sample of vehicles.

5.5.1.2 Static Brake Laboratory Tests

Effect. The laboratory tests are designed to evaluate the effect of age on the resistance of brakes, hoses and gaskets to pressure. Combined with results from other studies on the pressure which individuals can generate, the actual mode of applying the brakes, and the frequency with which they are applied, this study may reveal an expected number of partial brake system failures due to heavy brake pressure and age.

Technique. In the static brake test, failure rates (for brakes, hoses and gaskets) will be measured for different vehicle models, model years, brake system types, and mileage values at various pressure levels. The data obtained from this test will be analyzed to determine the effect of age on brake components' resistance to pressure. For this analysis, state vehicle registrations will be required in order to obtain information on vehicle models and model years for the vehicle population from which the test vehicles are obtained. Vehicle mileage data can only be obtained from vehicle inspection records in states that require mandatory vehicle inspection. Vehicle registrations and/or inspection records will be used to determine the composition (with respect to vehicle age, model, and/or mileage) of the overall vehicle population. A breakdown of the vehicle population by brake type is available and can be found in sources such as *Ward's Automotive Yearbook* and other automotive handbooks.* Using appropriate weighting factors derived from state vehicle registrations, adjustments in the test vehicle sample can be made so that each segment (as divided by vehicle model, brake type, model year, and mileage) of the sample is representative of each segment in the entire population.

The analysis is performed in the following steps:

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*However, these are national values and may not be representative of the brake type populations existing in each state.

Step 1: Using the static brake test data, failure rates will be estimated. Test data will be the number of brake systems which developed leaks in hoses or gaskets at different brake pedal pressures by brake system type, vehicle age, vehicle model, and mileage.

Step 2: Using weights proportional to the proportion of the population in each category (vehicle model, brake type, model year, and mileage), the frequencies of failure found in Step 1 are aggregated over all categories. Failure rates will then be estimated by vehicle age, by age and brake system type, and also by age and manufacturer. Rate adjustments can be made according to the method described in the Adjustment of Rates section in Appendix A.

Step 3: Step 2 will be repeated using mileage instead of vehicle age.

Step 4: Comparison of failure rates will be made between various models, brake system types, model years, and mileage values to ascertain if there are any segments of the vehicle population experiencing higher failure rates than other.

Sample Size. It is estimated that a sample population of about 3,000 cars will allow an adequate sampling of different vehicle models, model years, brake system types, and mileage values.

Data Sources: The vehicles for these tests might be obtained in conjunction with obtaining drivers for the laboratory tests on the distribution of brake pedal pressure. Potential sources for vehicles and drivers include:

- Contracting with dealers of used cars.
- Advertising in local papers.
- Combining tests with state motor vehicle inspections for resold cars or new state registrations.
- Including brake tests as part of annual motor vehicle inspection for some sample of vehicles.

5.5.1.3 Laboratory Dynamic Brake Testing of Used Vehicles

Effect. It can be safely assumed that vehicles manufactured after the effective date of the Standard qualitatively comply with the requirements when new. However, little is known about the actual quantitative measures of performance of the brake systems in vehicles, especially after they are put into use in the field and begin to accumulate mileage. The same is true for the entire vehicle population in the field. It is important to investigate differences in brake deterioration with age between Pre- and Post-Standard vehicles. For example, if Post-Standard vehicles rapidly deteriorate and fail to meet requirements after they are put into use, then the Standard is not truly effective.

Technique. Pre- and Post-Standard cars can be tested on a dynamometer-type dynamic brake tester in a laboratory setting by measuring the brake system parameters that are relevant to the Standard. The performance measures of interest include pedal force, stopping ability at various speeds, fade and recovery characteristics, water recovery, partial failure, and lining temperature. Additional information needed includes vehicle make/model year, brake type, mileage, brake service record and owner/driver history. The general procedure and technique is as follows.

Step 1: Select Standard requirement (e.g., speed, stopping distance, fade characteristics, etc.

Step 2: Select control variable (e.g., make/model year, age since last overhaul, etc.)

Step 3: Produce frequency plots and bivariate tabulations.

Step 4: Compare with Standard requirements.

Step 5: Prepare results for Fact Book.

Sample Size. It is estimated that about 2000 cars will be a sufficient sample to evaluate age effects in Pre- and Post-Standard vehicles with sufficient consideration given to vehicle make/model year, brake type, mileage and servicing characteristics.

Data Sources. Vehicles tested might best be obtained through a used car dealer or as trade-ins in a new car dealership. With this procedure, liability difficulties with private owners related to possible brake damage caused by testing would be avoided.

5.5.2 FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)

5.5.2.1 Laboratory Tests of Adverse Weather Effects on Glare

Effect. The purpose of the laboratory tests is to determine the relative performance of headlamps under adverse environmental conditions. This study has a relatively narrow focus and is concerned with the performance of headlamps in adverse, less typical circumstances. This study is important because of the problem of light scattering observed with the smaller regular intensity rectangular headlamps. There is more backscattering when there is rain or snow or fog and the light beam is scattered, rather than focused. This backscattering reduces the visibility of the drivers. If significant differences betwen headlamp designs are detected, this information would affect the selection of accident situations where one would expect to find, through analysis, a real world effect of the Standard.

Technique. For the different headlamp configurations tested*, one would measure the degree of penetration and degree of backscatter given a standard set

*Two and four lamps, round and rectangular, regular and high intensity on high and low beam.

of environmental conditions (fog/rain/snow).* In addition to different types of headlamps, the relative position of headlamps to the driver/observer might also have an effect.

The laboratory tests will require the use of a relatively large climate control chamber--large enough for a test frame with headlamps, and photometers 10 to 20 ft in front of and 5 to 8 ft behind the vehicle. The front wall needs to be non-reflective. The tests should be run as a full factorial design as only two measurements are required and the types of lamps are limited.

Sample Size. Measurements of light penetration and backscattering should be obtained under conditions of light, moderate and heavy rain, snow and fog (9 atmospheric conditions) configurations of two and four lamps, round and rectangular, regular and high intensity on high and low beams.

Data Sources. Representative high intensity and regular headlamps can be selected newly-manufactured for use at the laboratory facility.

5.5.2.2 Laboratory Test of Conspicuity of Side Marker Lamps

Effect. A laboratory-controlled visual experiment is suggested to determine if certain side marker lamp designs are more noticeable than other designs. If no difference is found between lamp designs and no effect of side marker lamps is found in the side collision analysis with mass accident data, then a plan to phase out the side marker lamp requirements may be reasonable. If certain designs appear more effective, however, then NHTSA might require those designs be followed.

Technique. In order to measure how noticeable different side marker lamp designs are, one first will need pictures of the different designs on vehicles taken under identical circumstances. The vehicles should all be of the same color, and a neutral background--a dark color and dark background would be the worst circumstance. The lighting of the vehicle should be from the direction of the viewer as if illuminated by headlamps. The picture should be taken under darkened circumstances with headlamps on low beam (and side marker lamps lighted) from a position about 20 ft from the side of the car and in line with the front of the vehicle (since this is the more typical position for viewing). These pictures should be taken for the most popular models for each market class and manufacturer and side marker lamp type (basically integrated or separate lighting units). Also, it is desirable to get pictures of special designs which might have more visibility.†

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*It might also be desirable to run one set of these experiments with headlamps obscured with a coating of salt/sand/mud spray typical of adverse weather driving conditions in many states. Such headlamp coatings often occur when there is snow, rain, or fog.

†Dirt and film may reduce the noticeability of side marker lamps considerably. The pictures should be taken of only clean, well-operating side marker lamps; however, in the analysis of results, this problem of dirt should be addressed. For example, Mercedes has designed front and rear lamp components so that they do not become fouled.

After a collection of slides are available, the test facilities need to be prepared. One will need a room with projection facilities and where the ambient light conditions can be controlled. There will be a standard glare source reducing the visual capability of the subject and simulating a "worst" condition. The intensity of the image being projected must be controllable and accurate. This could be done by using a rheostat connected to the projector.

The tests would be conducted as follows. Each subject would first be put in a darkened room for 10 - 15 minutes so that his or her eyes might become adjusted to the dark. The test would begin with the glare source light being turned on. With this light on, the subject would be asked to indicate when he noticed the image of a vehicle as it appeared on a screen in front of him. The intensity of the projected image would be gradually increased. The subject would press a button when he recognized the image and would speak into a microphone to indicate what led to recognition, e.g., side marker lamp or other light source. The pressed button would stop increasing the illumination of the image. Pressing that button, or perhaps some other, the illumination would be reduced and a new slide injected and the illumination being increased gradually again. The instensity of the projected image and the length of time to notice the image will be recorded. Each subject will view a relatively large set of pictures, though possibly not all possible make/model/lamp design combinations, during a test which lasts not more than one hour. If the test is much longer,the subject's eyes may become too tired. During that test not all images will be of sighted vehicles--in some cases there should be unlit vehicles and in other cases, no vehicle at all. This should be done to reduce guessing on the part of the subject. Data will be recorded on the subject vehicle to be identified, ambient environment being simulated and recognition measured.

Sample Size. The test subjects will be relatively few in number (40 should suffice). They should be evenly divided between men and women and in two age groups, under 40 and 40 and over, since at this age visual abilities begin to deteriorate. This gives ten individuals in each group. One might also require that half of each group wear glasses to determine if glasses have a consistent effect. The number of slides required for an adequate sampling of different types of side marker lights, different vehicle sizes varying light conditions, etc., might be of the order of 100.

Data Sources. Volunteers for participating in the laboratory tests might be obtained from drivers going through State motor vehicle inspections programs. Modest financial incentives could be offered to obtain the small sample group required.

5.5.3 FMVSS 122: Motorcycle Brake Systems

5.5.3.1 Motorcycle Dynamometer Brake Tests

Effects. A controlled motorcycle dynamometer brake test is proposed in order to estimate the effects of various factors on braking performance without the involvement of a rider. Tests will be made on three different classes of vehicles: used Post-Standard motorcycles, new Post-Standard motorcycles, and refurbished Pre-Standard motorcycles (these last two groups will have their brakes properly broken in prior to testing). The points of interest include what effect the Standard had, and how brake performance alters with use.

Technique. The motorcycles to be tested will be mounted on a dynamometer test setup. No rider will be involved. Instrumentation will be used on the motorcycle brake system to measure line pressures, lining temperatures, brake pedal force, etc. The dynamometer will be capable of measuring rotational speed, energy expended in braking, simulated vehicle velocity, and other parameters associated with the vehicle output. Brake line pressure or force recorders may be used to establish the relative work done by front and rear brakes during the testing. Tests to be performed could include measuring and recording:

- Brake fade at various speeds and stopping distances, during fixed numbers of successive stops.
- Sensitivity (force vs. grab) under various speeds and stopping distances.
- Lining temperatures.
- Brake line pressures, forces, torques, or tensions to all wheels during testing.
- Variations in all wheels.
- Any failures or malfunctions of the system.

In conducting a laboratory dynamometer test of motorcycle braking systems, the following steps would take place:

1. Review results of previous braking system tests which have used testing methods other than those specified in the Standard (i.e., HSRI, Calspan).

2. Prepare test facility and obtain selected number of motorcycles in various size and weight ranges.

3. Establish test procedures.

4. Instrument test motorcycles and mount on dynamometer.

5. Conduct braking performance tests for front and rear brakes separately, under various simulated conditions (weather, road surface, force of application, etc.)

6. Analyze and evaluate results of tests.

Sample Size. It is estimated that about 100 motorcycles will be required for testing. The four basic test groups are: used Post-Standard motorcycles (5-10,000 miles), used Post-Standard motorcycles (15-20,000 miles), new Post-Standard motorcycles and refurbished Pre-Standard motorcycles. Models must also be classified by manufacturer (Honda, Yamaha, Kawasaki, Suzuki, Harley Davidson, other) and engine displacement (125-349 cc, 350-449 cc, 450-749 cc, 750 cc and over). The four motorcycle classes, six manufacturer groups and four engine displacements yield a total of 96 cells. If three motorcycles were tested in each cell, 288 vehicles would be required. The estimate of 100 is made in recognition that not all manufacturers make motorcycles of all sizes and that similarities exist in braking systems between manufacturers and motorcycle sizes.

Data Sources. The new, used and refurbished motorcycles can be obtained from motorcycle dealers. Care must be exercised that all motorcycles tested have similar, new standard tires and brakes properly broken in prior to testing.

5.5.4 FMVSS 202/207: Head Restraints/Seating Systems

5.5.4.1 Dynamic Laboratory Tests

Effect. The dynamic laboratory tests are designed to establish the effects of different head restraint devices and seating system types during various impact situations including off-center and angular impacts. 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.

Technique. The dynamic tests will be performed using a test platform (sled) which will be designed to allow for adjustment of deceleration rates and impact angles. The four crash modes that will be used for testing 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 pruposes only).
- Rear Collision; without dummy (for test calibration purposes only).

The types of data that must be included in the analyses are (1) seating system characteristics and measurements, (2) head restraint characteristics and measurements, (3) dummy characteristics and measurements, and (4) test platform characteristics, (impact angles and deceleration rates). Parameters in these four classes of information that represent test conditions will be varied as appropriate for each of the four collision types listed above.

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 guages.

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*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.

Sample Size. It is estimated that about 100 seating systems and 20 vehicle bodies will be required for the dynamic testing of head restraints and seating systems. This will allow a sufficient sampling of Pre- and Post-Standard vehicles, seating system characteristics (seat type, track, anchoring, hinges and latches, etc), and head restraint characteristics (adjustable, non adjustable and see-through type).

Data Source. Various crash simulation facilities exist that are capable of simulating different deceleration levels that occur in crash situations. One such facility is 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 m.p.h. We are interested in testing four rates of deceleration (5, 10, 15, 20 g's).

5.5.5 FMVSS 213: Child Seating Systems

5.5.5.1 Dynamic Laboratory Tests of Child Seating Systems

Effect. The purpose of laboratory testing of child seating systems is to determine if commercially-available child restraints can prevent or reduce the likelihood of serious injury to children restrained in them under conditions which test, as best as possible, real world crash situations.

Technique. 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.

All of the crash modes to be used in the testing include use of a child dummy. The first three listed below, and the accelerations, are those required by NHTSA's proposed amendment to FMVSS 213. The fourth--front angle collisions--is a suggested addition.

- Front collision, acceleration simulating a 30 mph crash.
- Rear collision, acceleration simulating a 20 mph crash.
- Side collision, acceleration simulating a 20 mph crash.
- Front angle collision, acceleration simulating a 30 mph crash.
- Rollover tests.

Instrumentation design and location have been recommended to determine impact severity as well as resultant stress on the child dummy in the simulated crash situations. It is recommended that the dummy be instrumented in predetermined maximum stress locations based on previous crash data information. Readouts will be directly in stress (pressure) *vs.* time. The child dummy's head will, in addition, be instrumented to allow direct readout of acceleration/deceleration, which will be used to determine impact severity if and when it occurs.

High speed film will enable determination of positions of the dummy during the crash within the necessary accuracy of one millisecond. Reconstruction of the crash with stop frame accuracy of every millisecond, used in conjunction with analog information from the instrumented dummy, will provide enough data to determine dummy impact locations and severity, area and severity of dummy stress as it occurs, constraint failures or inadequacies (with some subjective analysis), and the dynamic response of the entire child dummy-child restraint system needed to evaluate the child restraint system's effectiveness.

Sample Size. It is estimated that approximately 200 tests will be acquired to assess the effects of (1) different type of child seating systems, (2) different types of crashes, (deceleration rates, impact angles, etc) (3) rollover conditions and (4) mispositioning of the child seating system.

Data Source. Dynamic testing of child seating systems can be undertaken at a large number of facilities such as those located at the Maryland Safety Research Laboratory, HSRI, Calspan and General Motors. About 15 different types of child seating systems must be obtained for testing.

5.5.6 FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/ Seating and Crash Protection

5.5.6.1 Dynamic Laboratory Tests of School Buses

Effect. The purpose of this study is to conduct dynamic laboratory tests of school buses to evaluate the Standard's effects on structural strength and rollover protection and seating and interior protection. Three sets of tests are envisaged - the first two related to evaluating FMVSS 220 and 221, while the last focuses on assessing FMVSS 222. The third test calls for the use of anthropomorphic dummies as test passengers.

Technique. In order to assess the structural integrity of the bus body under rollover conditions, the body should be loaded in an inverted position and rolled onto its corner roof edge(s) so that forces are applied diagonally across the rectangular section of the body as they are in a real rollover accident. Loading could be uniformally applied by the simple expedient of using sand bags held in place by a box type container. The loaded bus body should be tilted on its roof surface to an angle of 45° (approximately). The tilting should extend to both sides since there are some structural differences in bus body sides that must be taken into account (doors and potential non-symmetry due to other special features).

Testing the body for resistance to the diagonal sheer stresses on the side that the bus rolls over onto can be accomplished by driving the bus into an angled fixed barrier that clears the fender and hood so as to strike the front corner of the body.*

*This test is similar to SAE Recommended Practice J374a which is designed to evaluate the strength characteristics of passenger car roof systems under loading conditions simulating vehicle rollover. The test, as it stands, would not be applicable to school buses because of the extreme differences in roof profile and resulting strength characteristics.

Similarly, straightforward test crashes with fixed barriers will allow assessment of body joint strength, body to chassis integrity, and the tendency of panels to peel or tear under stress.

In all such crash tests, the choice of loads and speeds is of utmost importance. The most reasonable load and speed choices would be those that somehow exemplify the "typical" accidents whose severity the Standards are meant to diminish. These are experimental design questions that can draw upon the results of the three previous studies. The main purposes of the triaxial accelerometer instrumentation is to provide invaluable help in establishing force levels in typical crash situations.

The criteria used for evaluation would include at least the following:

- Extent of body collapse under fore and aft shear load.
- Extent of body collapse under diagonal load.
- Degree of penetration of the body parts into the passenger area.
- Ability of body panel joints to remain intact, thus distributing the stresses and not exposing sharp edges.
- Proper functioning of emergency doors.
- Inches of panel separation, possibly allowing passenger ejection.

The analysis of the above characteristics would be somewhat subjective in nature and would be conducted by comparative observation and photo analysis. An effort would be made to determine the interaction between these results along with the death and injury distributions and instrumented accelerometer results in the detailed NASS accident investigation of actual crashes in the field.

Dynamic tests to measure effects of seating and crash protection requirements of FMVSS 222 will be conducted primarily after crash force accelerations are known from instrumented buses involved in actual crashes in the field. Preliminary information will be gained by including instrumented dummies in the angular barrier crash test used to evaluate roof and joint strength but until actual crash forces are known, it will not be possible to relate levels of injury with actual field crashes. Once these crash accelerations and directions are measured, it may not be necessary to always use full size bus bodies to evaluate passenger impact forces with the dummies. Impact sleds would minimize costs while at the same time measure forces encountered by seat backs, side walls, etc. However, measuring injury levels due to impact with body parts penetrating the passenger compartment or joint separations will more likely require crashing of actual bus bodies containing instrumented dummies. Location and direction of impact will be determined by the use of high speed movies.

Sample Size. It is estimated that approximately 18 complete buses and 8 bus bodies would be required for the (1) static diagonal roof loading test, (2) the dynamic angular shear test and (3) the simulation of real world crash conditions employing anthropomorphic dummies.

Data Sources. School buses can be selected according to major school bus manufacturers and number of seats installed.

5.6 Cost Data Analysis

5.6.1 Introduction

This section does not address the evaluation of the effectiveness of the Standards. Instead, it outlines the methodology to be used to estimate the costs of complying with a Standard. There are two major aspects to the methodology. The first is to determine the additional components (and manufacturing operations) needed to estimate the added costs of complying with a Standard. The second component of the methodology is the selection of vehicles (or child seats) to be sampled for the most efficient and comprehensive estimation of the costs of compliance.

The first aspect of determining additional aspects required to comply with the Standard varies with the Standard of concern. For instance, FMVSS 108 required lamps of certain colors with a specific level of visibility from the side. On some vehicles this aspect of the Standard is satisfied by designing the front and/or rear parking light/turn signals so they are also visible from the side. This would seem to infer that there would no no cost of compliance. However, on other vehicles made by the same manufacturers, separate lighting fixtures are installed on the sides of the vehicle, obviously involving additional costs for components and installation. Even these costs are not necessarily the "costs of compliance" because the manufacturer might have overdesigned the fixture and thus, one can argue that the cost of compliance may be considered only the minimum needed to meet the Standard, with everything above that cost being an expense related to the Standard but not due to it. The above example is meant to indicate some of the diverse problems associated with the selection of items to be costed.

The following section discusses the second component of the cost estimating methodology which is the sampling of vehicles. Following that section will be sections which discuss the individual Standards with regard to the components and vehicles to be selected in the cost estimation and also special problems associated with each.

5.6.2 Sampling Plans

The problems associated with the second part of the methodology are basically statistical. How can one efficiently select representative vehicles for costs to be estimated which also represent the breadth of vehicle designs? The basic approach is to determine the discriminating factors between vehicles with regard to complying with the Standard. Given the categories determined, one would also select according to the prevalence of different vehicle types. However, rather than having to collect a sample of all vehicles in all categories to estimate costs, the costs are estimated with a model which separates the manufacturer component of cost and the market class component. The use of this model of costs allows one to sample fewer vehicles. A second fact which allows less than full factorial design is that some categories of vehicles can be lumped together when makes and models are similar *vis-a-vis* the Standard.

In general this two part methodology applies to eight of the nine Standards which are included in their study. This methodology does not apply to estimating the costs of compliance with FMVSS 213: Child Seating Systems. This is because, to a great degree, child seats were not simply modified to meet the standard but entirely new designs were introduced. However, given the relatively small number of child seat types, it is feasible to investigate all of them to determine the incremental changes which might have taken place.

5.6.3 Cost Data Analysis for FMVSS 105: Hydraulic Brake Systems

Components for Costing

There are four major components to brake systems:

- Actuating assembly
- Fluid connecting line network
- Conversion components
- Warning light system.*

The manufacturing costs of these items are considered to be 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.

Sample Stratifiers

To estimate costs three critical categorizations must be made:

- Manufacturer: GM, Ford, Chrysler, AMC, VW, etc.
- Size of vehicle: Subcompact, Compact, Intermediate, Full Size
- Brake type: Power, Power assist, Regular for disc and drum.

Special Problems

This Standard has several aspects some of which were complied with before the Standard went into effect (such as split brake system). In order to meet requirements for fade and water recovery, components were sometimes upgraded rather than new components added.

*Additional detail on the cost data and sampling plans in the specific Task 4 & 5 report for this Standard. See Section 7.0 for a complete list of available reports.

5.6.4 Cost Data Analysis for FMVSS 108: Side Marker Lamps and High Intensity Headlamps (only)

Components for Costing

For side marker lamps the basic components include:

- Reflector shields
- Bulbs
- Circuit fuses
- Wiring.

For high intensity headlamps the changes are:

- Sealed beam unit
- Voltage regulator
- Wiring.

Sample Stratifiers

For side marker lamps the stratifiers will be:

- Manufacturer
- Market class.

for a total of 15 categories. For high intensity headlamps the costs should be independent of car manufacturers and market class so that only lamp manufacturers and other electrical equipment manufacturers need be polled.

Special Problems

As mentioned in the introduction, depending on the make and model, the side marker lamps can be part of the front and/or rear lighting fixtures or they can be seperate entities. With regard to high intensity headlamps, NHTSA does not require these headlamps but rather has removed a previous restriction. The fact is though that the higher intensity rectangular headlamps do cost more. However, this cost is not due to the Standard *per se*.

5.6.5 Cost Data Analysis for FMVSS 122: Motorcycle Brakes

Components for Costing

The basic brake system components affected are:

- Drum brake circuit } motorcycles have one or both types of brakes
- Disc brake circuit }
- Brake system failure indicator lamp.

Sample Stratifiers

The stratifiers will be:

- Manufacturer (Honda, Yamaha, Kawasaki, Suzuki, Harley-Davidson)
- Engine displacement (under 125cc, 125-349cc, 350-499cc, 450-749cc, 750cc and over).

Special Problems

Changes to motorcycle brakes to bring them up to the level of the Standard started several years before the Standard became effective.

5.6.6 Cost Data Analysis for FMVSS 202/207: Seating Systems and Head Restraints

Components for Costing

In the interest of economy and from the viewpoint of practicality these two Standards have been combined. The components of the seating system include:

- Seat adjusters
- Seat frames
- Seat spring assemblies, padding, and covering material and trim
- Self locking device and control
- Seat system anchorage.

The components for the head restraint devices are basically the same as for the seating system if the head restraint device is built into the seat back. If it is an adjustable head restraint the specific components include:

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

Sample Stratifiers

The stratifiers will be:

- Manufacturer
- Market class
- Two door / four door (for seating systems)
- Seat type (for head restraints).

Special Problems

Aside from the seat back lock, determining the changes in seating systems due to requirements in the Standard will be difficult.

5.6.7 Cost Data Analysis for FMVSS 213: Child Seating Systems

Because the child seating systems are generally designed *in toto* rather than modified to meet the Standard as motor vehicles are, the costs of seating systems for all manufacturers would be collected and analyzed to estimate the marginal change in cost due to the Standard. A special problem will be to estimate the marginal costs for those manufacturers who have always produced child seats which met the Standard.

5.6.8 Cost Data Analysis for FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/Seating and Crash Protection

Components for Costing

For FMVSS 220:

- Heavier structural components
- Additional support components.

For FMVSS 221:

- Different sized body panels
- Heavier/stronger body panels
- Additional welds
- Additional rivets
- Additional adhesives
- Unitary body components.

For FMVSS 222:

- Additional seat padding
- Heavier/stronger seat structure supports
- Restraining barrier
- Seat belt systems (buses $\leq$ 10,000 lb)
- New seat attachments to floor
- Higher seat back.

Obviously FMVSS 222 is the Standard with the highest number of discrete additional and identifiable atoms.

Sample Stratifiers

The stratifiers will be:

- Manufacturer (there are 8 major manufacturers)
- Vehicle size (FMVSS 220,221).

In the case of FMVSS 222 costs will be estimated on a per seat basis.

Special Problems

No special problems are expected.

5.7 References for Section 5

1. Sweeton, E.R. and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 105: Hydraulic Brake Systems in Passenger Cars* (CEM 4228-588), Hartford, Connecticut, CEM, November 1977 (DOT-HS-7-01674)

2. Reidy, J.C. and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)* (CEM 4228-589), Hartford, Connecticut, CEM, December 1977. (DOT-HS-7-01674)

3. Costenoble, K.C. and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 122: Motorcycle Brake Systems* (CEM 4228-590), Hartford, Connecticut, CEM, December 1977. (DOT-HS-7-01674)

4. Ball, J.T., J.C. Reidy and G.M.Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 202: Head Restraints, and FMVSS 207: Seating Systems* (CEM 4229-596), Hartford, Connecticut, CEM, December 1977. (DOT-HS-7-01675)

5. Costenoble, K.C. and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 213: Child Seating Systems* (CEM 4229-597), Hartford, Connecticut, CEM, December 1977. (DOT-HS-7-01675)

6. Sweeton, E.R. and G.M. Northrop. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 220: School Bus Rollover Protection, FMVSS 221: School Bus Body Joint Strength; FMVSS 222: School Bus Seating and Crash Protection* (CEM 4229-599), Hartford, Connecticut, CEM, February 1978. (DOT-HS-7-01675)

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11. Mickey, M.R. and P.M. Britt. "Obtaining linear scores from preference pairs," *Communications in Statistics*, v. 3, no. 6, 1974: 501-511

12. Fleiss, J.L. *Statistical Methods for Rates and Propostions*, Wiley, 1973.

6.0 Implementation Plan

6.1 Implementation Plan for Each Standard

Individual implementation plans have been prepared to evaluate the following Standards and combinations of Standards.

- FMVSS 105: Hydraulic Brake Systems in Passenger Cars
- FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)
- FMVSS 122: Motorcycle Brakes
- FMVSS 202/207: Head Restraints/Seating Systems
- FMVSS 213: Child Seating Systems
- FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/Seating and Crash Protection.

Each of the six implementation plans is a logical sequence of approaches to evaluating the Standards. These approaches are expressed as explicit evaluation Tasks that are time-phased. As discussed in Section 4.2, 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.

In the same section, the rationale for each Task was discussed, together with the logical sequence of Decision Points that would occur for assessing whether the Standard effectiveness had been determined. At some Decision Points, it is possible that the program could terminate or that subsequent scheduled Task efforts could be reduced.

Some general remarks can be made before considering individual evaluation programs. The initial Tasks requiring statistical analyses of existing data or supporting tests usually occupy approximately the first year of the evaluation program. 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.

The Gantt charts for the six implementation plans shown in this section considered administrative time constraints as well as the time required to accomplish work under each Task. That is, it is recognized that time must be allotted for preparation of Requests for Proposals, proposal review and contracting. The period allotted for these processes varied somewhat, according to the magnitude of the Task. Some of the Tasks are carried out intermittently over a period of several years. This occurs especially if new or additional data must be collected over a period of time before an analysis or reanalysis can be realistically attempted. It occurs in the case of NASS, for example, and even with mass accident data in the situation of recently implemented Standards such as FMVSS 220/221/222.

The time-phased Gantt charts for the implementation plan for each evaluation program are given in Figures 6-1 through 6-6. The charts show the period of work under each Task, the cost of each Task, the implementation plan cost by year, and the times for major Decision Points relative to evaluating the Standard. In each plan, the cost data analysis is the highest numbered Task, but is completed in the first year. The schedule and costs shown assume that the entire implementation plan must be carried out. That is, in no instance will the Standard be completely evaluated prior to the final Decision Point shown at the end of the last scheduled Task. Alternatives to this situation are discussed in Section 6.2. The basis for the estimation of costs in each Task is given in the Tasks #4 & #5 Reports, discussed and referenced in Section 5.

The full implementation plan shown in Figure 6-1, to evaluate FMVSS 105, would require over five and one-half years to accomplish at an estimated cost of $873,000. The first two Decision Points occur in the first and second years after analyzing mass accident data (Task 1) and conducting dynamic brake testing in the laboratory. The highest spending levels are in the third and fourth years when in excess of $200,000 per year is required to conduct pedal pressure/static brake lab tests and determine brake indicator outage rates (Task 3) and get the instrumented vehicle program underway (Task 4). The total cost of Task 4, which goes into the sixth year, is estimated to be $400,000. Instrumentation of the vehicles accounts for over half of this cost.

The full implementation plan to evaluate FMVSS 108 is given in Figure 6-2. The entire program would require slightly over four years to complete at an estimated cost of $557,000. Separate sets of two Decision Points each are planned for side marker lamps and high intensity headlamps during the first three years. A large number of individual Tasks, totaling nine, are scheduled with many of the Tasks dealing with both aspects of the Standard. Only Task 3, the sighting distance field study, is costed in excess of $100,000. The highest yearly spending levels are in the first and fourth year, with annual expenditure rates close to $150,000.

The complete implementation plan to evaluate FMVSS 122 is given in Figure 6-3. The entire program would require three years to complete at an estimated cost of $348,000. This evaluation plan is both the shortest and the least expensive of the six plans presented in this section. The first two Tasks, analysis of mass accident data and special motorcycle surveys are completed during the first year, as is much of the Task 3 initial analysis of NASS and California accident data. Note, however, that additional analyses are scheduled in Task 3 at the end of the second and third year, as more data become available. The more expensive Tasks, motorcycle dynamometer brake tests (Task 4) and field tests (Task 5) are scheduled during the second and third year, respectively. The annual spending levels are estimated to range from $136,000 in the first year to $102,000 in the third year.

Task	Description	Time After Contract Go-Ahead (Years)						Task Cost ($K)
		1	2	3	4	5	6	
1	Analysis of Mass Accident Data							82
2	Laboratory Dynamic Brake Testing							147
3	Pedal Pressure/Static Brake Lab Tests and Brake Indicator Outage Rates							203
4	Instrumented Vehicles Data Collection and Analysis							400
	DECISION POINTS	1	2				3	
5	Cost Data Analysis							41
	COST BY YEAR ($K)	123	123	227	225	100	75	873

Figure 6-1. Schedule and costs for evaluation of FMVSS 105: Hydraulic Brake Systems in Passenger Cars.

Task	Description		Time After Contract Go-Ahead (Years) 1	2	3	4	5	6	Task Cost ($K)
1	Analysis of Mass Accident Data: Side Collisions								29
2	Laboratory Tests of Adverse Weather Effects on Glare (Headlamps)								46
3	Sighting Distance Field Study (Side Marker Lamps and Headlamps)								112
4	Laboratory Test of Conspicuity of Side Marker Lamps								46
5	Field Data Collection at Hazardous Locations (Headlamps)								70
6	Analysis of Mass Accident Data - Overdriving and Glare (Headlamps)								51
7	Survey of Lighting System Usage (Side Marker Lamps and Headlamps)								76
8	Misaiming of Headlamps and Light Outage Rates								86
	DECISION POINTS	Side Marker Lamps							
		Headlamps							
9	Cost Data Analysis								41
	COST BY YEAR ($K)		164	139	92	149	13		557

Figure 6-2. Schedule and costs for evaluation of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (only).

Task	Description	Time After Contract Go-Ahead (Years)						Task Cost ($K)
		1	2	3	4	5	6	
1	Analysis of Mass Accident Data							30
2	Motorcycle Surveys (Riders/Tires/Struc. Modification)							50
3	Analysis of NASS and California Accident Data							30
4	Motorcycle Dynamometer Brake Tests							100
5	Braking Performance & Rider Behavior Field Tests							97
	DECISION POINTS							
6	Cost Data Analysis							41
	COST BY YEAR ($K)	136	110	102				348

Figure 6-3. Schedule and costs for evaluation of FMVSS 122: Motorcycle Brake Systems.

The entire implementation plan to evaluate both FMVSS 202 and FMVSS 207 is given in Figure 6-4. The relationship between many aspects of evaluating head restraints and evaluating seating systems dictated that an integrated implementation plan be given for the two Standards. The Tasks shown in the Gantt chart are grouped from top to bottom as (1) those Tasks that evaluate only FMVSS 202; (2) those Tasks that evaluate both FMVSS 202 and FMVSS 207; and (3) those Tasks that evaluate only FMVSS 207. The entire program would require almost six years to complete at an estimated cost of $1,355,000. This is both the longest and most costly of the six proposed evaluation programs. Over $1,000,000 of this total cost is consumed by two Tasks, dynamic laboratory tests (Task 6) during the third year and the instrumented vehicle data collection and analysis (Task 7), during the fourth and later years. A number of smaller, less costly Tasks are scheduled for the first two years, with appropriate Decision Points separately dealing with FMVSS 202 and FMVSS 207. This will allow the possibility of not undertaking Task 6 and Task 7 or of reducing the scope of work under these Tasks. Assuming all work is performed, the highest annual costs are in the third and fourth years, with annual expenditure rates of $300,000 and $500,000, respectively.

The complete implementation plan to evaluate FMVSS 213 is given in Figure 6-5. The entire program would require four years to complete at an estimated cost of $781,000. The first two Tasks, involving analyses of mass accident data and detailed accident data,will be initially undertaken during the first year and repeated during the third and fourth years. The results of a usage/accident study carried out in Tennessee under separate funding will be reviewed each time the mass and detailed accident data results are studied. The Tennessee study is included as a line item in the Gantt chart, even though it is *not* a funded Task in the implementation plan. Note that Tasks 3 and 4 during the second and third year are presented in tandem in the Gantt chart. That is, either one or the other or both might be undertaken between the first and second Decision Points. For the purposes of costing,it is assumed that both Tasks are undertaken. If the NASS Special Study (Task 3) is not carried out here, it is highly probable that it would be performed following the second Decision Point, if the effectiveness of the Standard is not determined at that time. The annual spending rate ranges between $207,000 and $265,000 during the second through fourth years, with much lower spending during the first year.

The entire implementation plan to evaluate FMVSS 220/221/222 is given in Figure 6-6. The entire program would require five years to complete at an estimated cost of $1,268,000. This implementation plan is the second most expensive of the six evaluation studies. The bulk of the costs are under Task 4 where buses are instrumented in NASS Primary Sampling Units, beginning in the second half of the second year,and under Task 5 where detailed static and dynamic laboratory testing of school buses is accomplished during the fifth year. Tasks 4 and 5 are estimated to jointly cost almost one million dollars. During the first year and one-half of the program, initial laboratory tests (Task 1), clinical analyses (Task 2) and preliminary analysis of mass accident data (Task 3) are accomplished. Further analyses of mass accident data are scheduled under Task 3 throughout the five-year program. The annual rates of expenditure are quite unevenly distributed in the program, with very low expenditures during the third and fourth years and annual rates of expenditures ranging from $254,000 to $580,000 in the first two years and the fifth year.

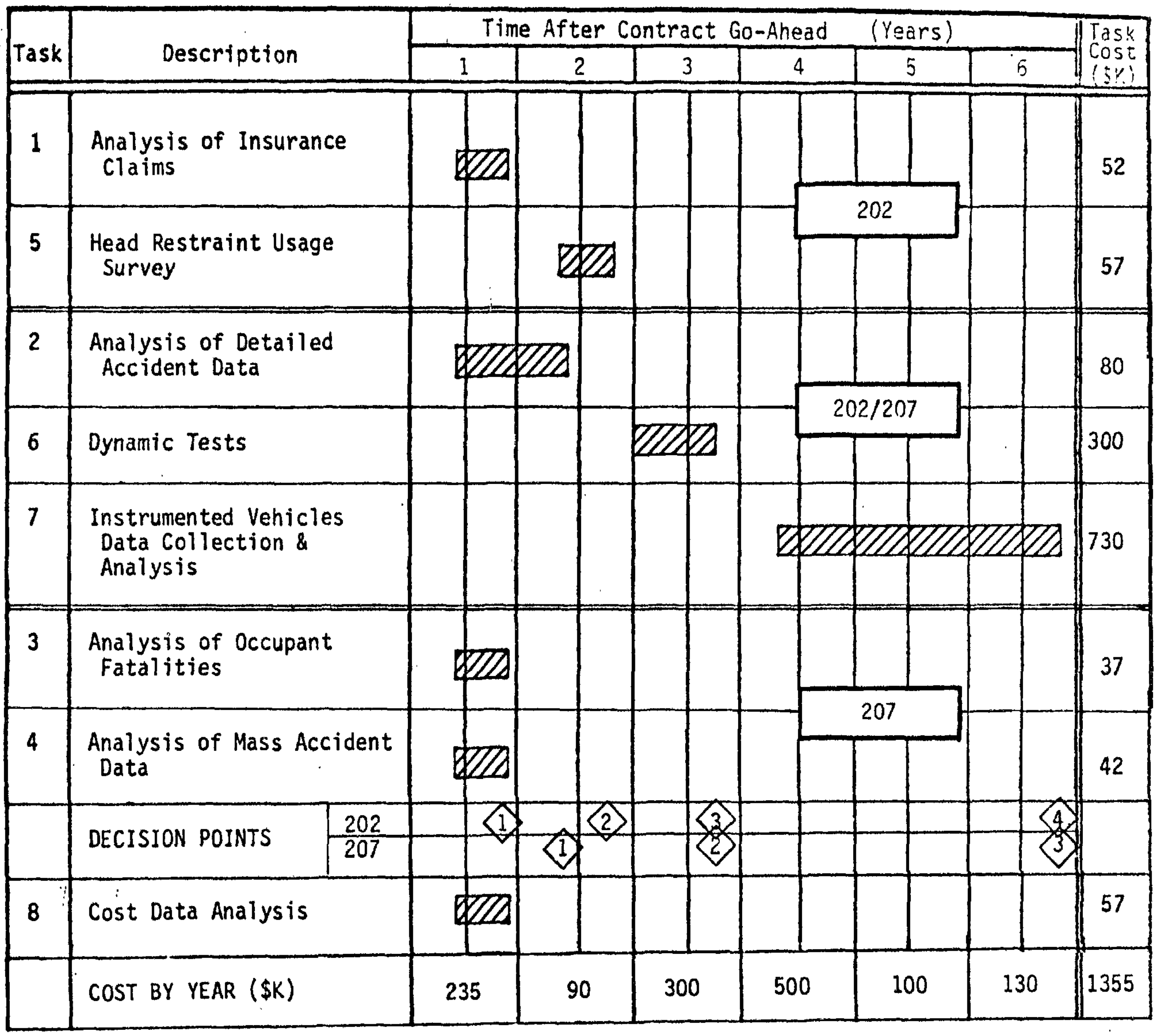


Figure 6-4. Schedule and costs for evaluation of FMVSS 202/207: Head Restraints/Seating Systems.

Task	Description	Time After Contract Go-Ahead (Years)						Task Cost ($K)
		1	2	3	4	5	6	
1	Analysis of Mass Accident Data							29
2	Analysis of Detailed Accident Data							27
	REVIEW OF TENNESSEE USAGE/ACCIDENT STUDY							
3	NASS Special Data Collection & Analysis				Either or Both			230
4	Pediatrician & Emergency Room Surveys							155
5	On-Site & Mail Surveys							120
6	Dynamic Lab Tests							200
	DECISION POINTS	1		2	3			
7	Analysis of Cost Data							20
	COST BY YEAR ($K)	61	207	265	248			781

Figure 6-5. Schedule and costs for evaluation of FMVSS 213: Child Seating Systems.

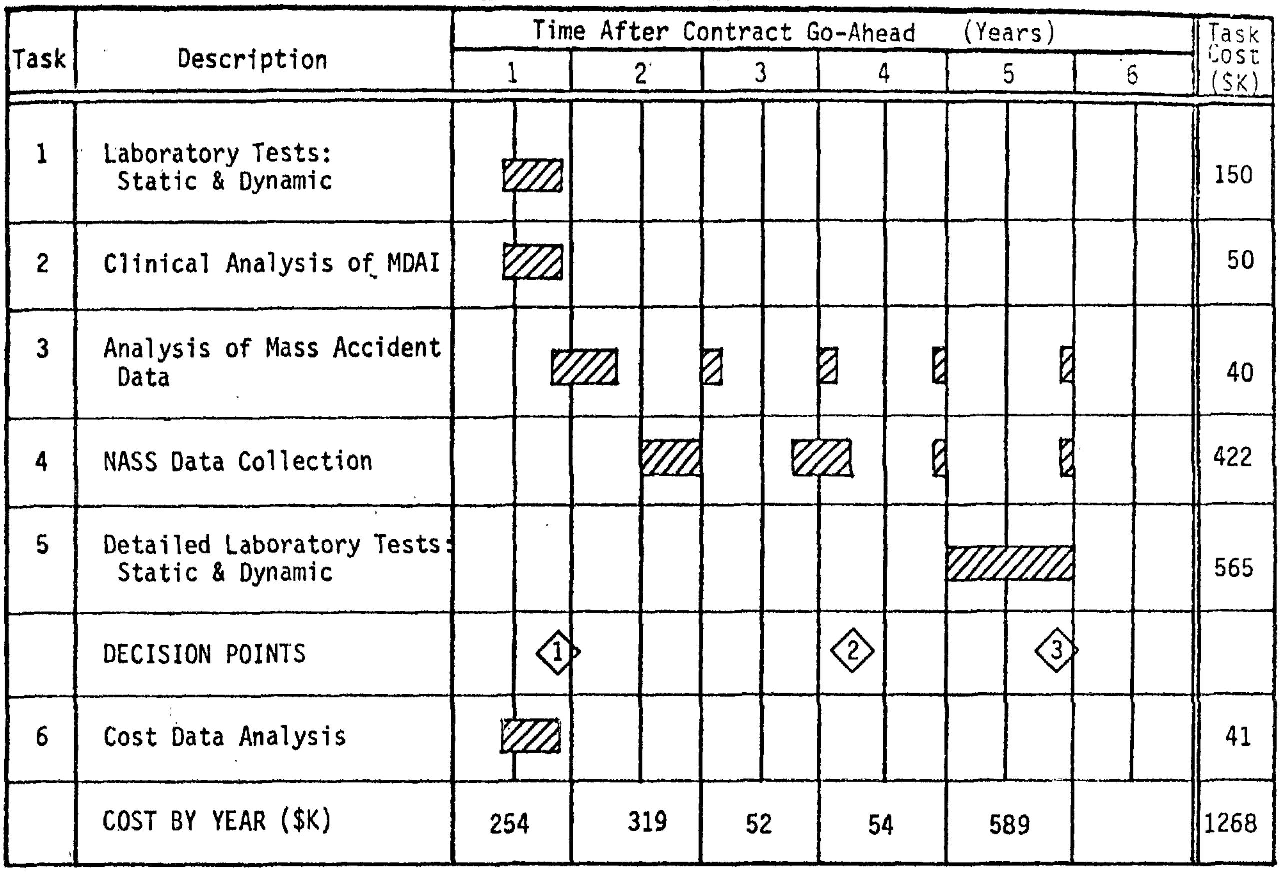


Figure 6-6. Schedule and costs for evaluation of FMVSS 220/221/222: School Bus Rollover Protection/Body Joint Strength/ Seating and Crash Protection.

6.2 Overview of Implementation Plans and Costs

The six evaluation programs outlined in Section 6.1 have maximum time periods ranging from three years for FMVSS 122 to almost six years for FMVSS 202/207. With the possible exceptions of FMVSS 108 and FMVSS 220/221, 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.

The cost of each evaluation program and the total costs are given by year in Figure 6-7. The costing displayed in the figure is arrived at based on the assumption that all Tasks in all programs are completely carried out. It is thus an estimate of maximum resources required. The "bottom line" shows that total annual expenditures for all programs vary little over the first five years, with a gradual increase from $973,000 in the first year to $1,176,000 in the fourth year and a decline to $802,000 in the fifth year. Expenditures are drastically reduced in the sixth and final year of the program with the evaluation plan for most Standards completed. The cost of all six evaluation programs with all individual Tasks undertaken is estimated to be $5,182,000.

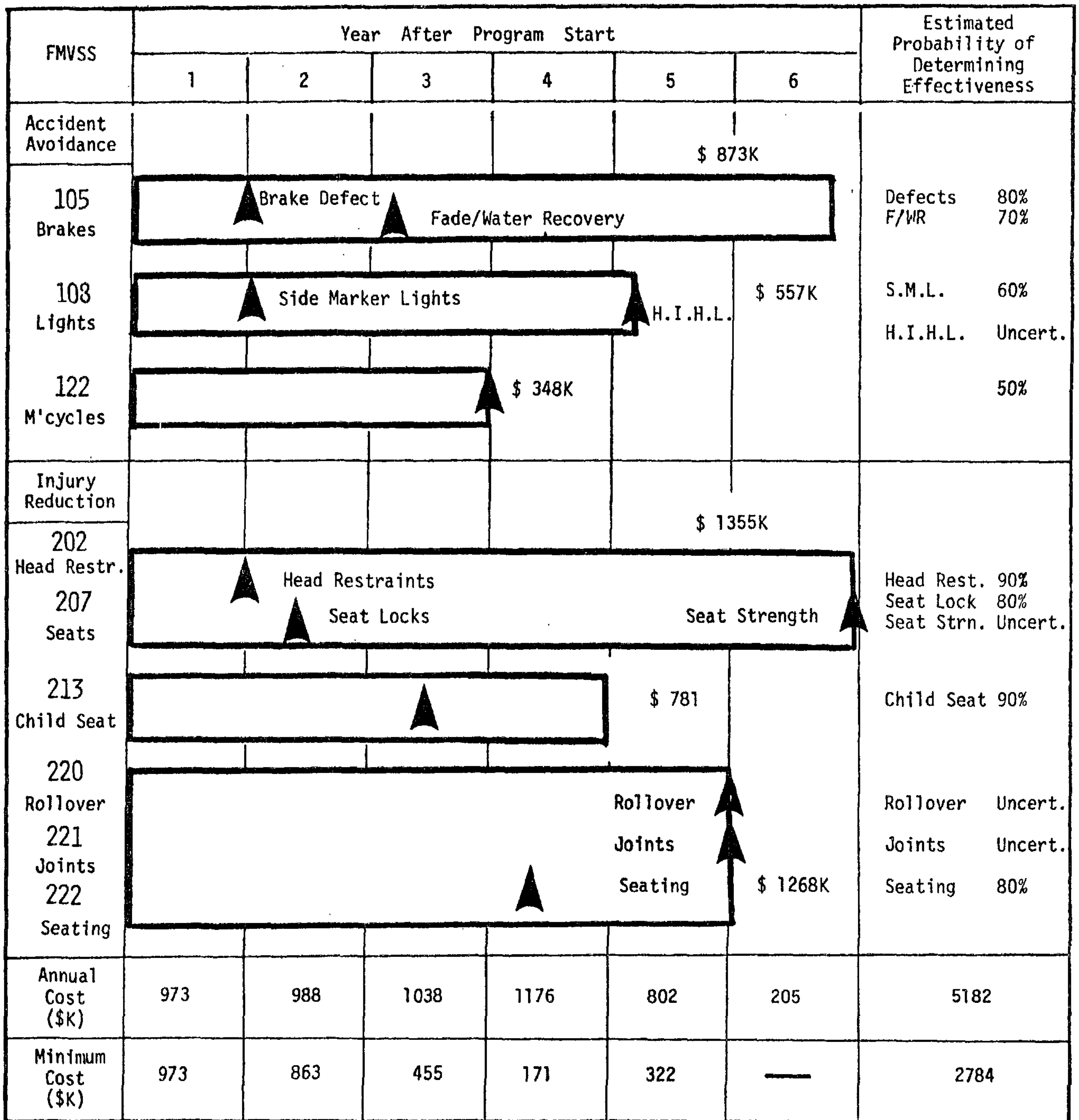
The estimates of minimum possible expenditures for each evaluation program are given in Table 6-1. The costing presented in the table is obtained from the assumption that the effectiveness of the Standard or an aspect of the Standard is indeed demonstrated at all those Decision Points where it is estimated that the probability of a successful evaluation exceeds 0.5. When this "scenario" is followed, the total cost of all six evaluation programs is reduced to an estimate of $2,784,000, or little more than half of the estimated maximum cost. The largest reductions are found in the FMVSS 105 and FMVSS 202/207 evaluation programs. It is important to point out that the large estimated reduction in cost of evaluation of FMVSS 202/207 is given on the expectation that the effectiveness of head restraints and seat back locks can be ascertained from the Tasks scheduled early in the program. If it is judged necessary to demonstrate differences in overall seating strength as a result of FMVSS 207, it is anticipated that the bulk of the complete evaluation would have to be carried out and close to maximum resources expended. Note also that in the case of FMVSS 108, it is anticipated that the entire evaluation program will have to be carried out. It is expected that the evaluation of the Standard effectiveness regarding motorcycle brake systems will require undertaking all scheduled Tasks.

A more detailed picture of the differences which are encountered in carrying out the full evaluation programs compared to what might occur due to an early conclusion of Standard evaluation is shown in Figure 6-8, and Table 6-2. The estimated earliest date for possible conclusion of the effectiveness of individual Standards or aspects of individual Standards is shown in the figure. The Standards or aspects in which it is judged that an early conclusion of the effectiveness evaluation is unlikely are the following:

- FMVSS 108: High Intensity Headlamp portion.
- FMVSS 122: Motorcycle Brake Systems.
- FMVSS 207: Overall strength of seating systems aspect.
- FMVSS 220: School Bus Rollover Protection.
- FMVSS 221: School Bus Body Joint Strength.

Federal Motor Vehicle Safety Standard	Year After Program Start						Program Cost ($K)
	1	2	3	4	5	6	
105 Hydraulic Brakes	123	123	227	225	100	75	873
108 Side Markers & High Intens. Headlamps	164	139	92	149	13		557
122 Motorcycle Brakes	136	110	102				348
202/207 Head Restraints & Seats	235	90	300	500	100	130	1355
213 Child Seating Syst.	61	207	265	248			781
220/221/222 School Bus Rollover, Joints, Seating	254	319	52	54	589		1268
Annual Cost ($K)	973	988	1038	1176	802	205	5182

Figure 6-7. Maximum cost of six implementation plans.



▲ = Earliest date for possible conclusion of effectiveness evaluation.

Figure 6-8. Overview of Standards evaluation programs.

TABLE 6-1

MINIMUM EXPENDITURES FOR IMPLEMENTATION PLANS

Federal Motor Vehicle Safety Standard	Year After Program Start						Total Minimum Cost ($K)	Resources Not Expended ($K)
	1	2	3	4	5	6		
105 Hydraulic Brakes	123	123	24	-	-	-	270	603
108 Side Markers and High Intensity Headlamps	164	71	92	117	13	-	457	100
122 Motorcycle Brakes	136	110	102	-	-	-	348	-
202/207 Head Restraints & Seating Systems	235	33	-	-	-	-	268	1087
213 Child Seating Systems	61	207	185	-	-	-	453	328
220/221/222 School Bus Roll-over, Joints, Seating	254	319	52	54	309	-	988	280
Total Minimum Cost ($K)	973	863	455	171	322	-	2,784	2,398

Because of the above assessment, the difference between estimated maximum and minimum resources required is least for the evaluation programs of the following Standards: FMVSS 108, FMVSS 122 and FMVSS 220/221/222.

In some contrast to the above, it is estimated that an early conclusion of the effectiveness evaluation within the first two years is quite possible for the following:

- FMVSS 105: Hydraulic Brake Systems
- FMVSS 108: Side Marker Lamps portion
- FMVSS 202: Head Restraints
- FMVSS 207: Seat Back Lock portion.

Note also that the evaluation of FMVSS 213, Child Seating Systems, could be completed within the first half of the third year. Because of the above assessment, the differences between estimated maximum and minimum resources required is greatest for the evaluation programs of the following Standards: FMVSS 105, FMVSS 202/207, and FMVSS 213.

TABLE 6-2

COMPARISON OF PROGRAM LENGTHS AND EXPENDITURES FOR MAXIMUM AND MINIMUM EVALUATION PROGRAMS

Federal Motor Vehicle Safety Standard	Time Required To Determine Effectiveness		Resources Expended to Determine Effectiveness	
	Maximum (Months)	Minimum (Months)	Maximum ($K)	Minimum ($K)
105	68	22	873	270
108-Side Markers High Intensity	50 50	11 50	557	457
122	36	36	348	348
202 207	70 70	11 16	1355	268
213	47	29	781	453
220 221 222	60 60 60	60 60 39	1268	988

7.0 End Products of This Study

During the two studies, *Evaluation Methodology for Three Federal Motor Vehicle Safety Standards* (Contract DOT-HS-7-01674) and *Evaluation Methodology for Six Federal Motor Vehicle Safety Standards* (Contract DOT-HS-01675), 17 reports (including this Final Report),and one briefing were prepared between August 1977 and March 1978. In addition to those materials (listed below), many special appendices were assembled.

<u>Tasks 2&3 PRELIMINARY REPORTS</u>

- CEM Report 4228-584. *Review of Three Federal Motor Vehicle Safety Standards: FMVSS 105: Hydraulic Brake Systems; FMVSS 108: Side Marker Lamp and High Intensity Headlamps (Only); FMVSS 122: Motorcycle Brake Systems*, August 1977.
- CEM Report 4229-592. *Review of Six Federal Motor Vehicle Safety Standards: FMVSS 202, 207, 213, 220, 221, 222*, September 1977.
- CEM Report 4228-585. *Preliminary Design of an Evaluation Procedure for FMVSS 105: Hydraulic Brake Systems in Passenger Cars*, September 1977.
- CEM Report 4228-586. *Preliminary Design of An Evaluation Procedure for FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)*, October 1977.
- CEM Report 4228-587. *Preliminary Design of an Evaluation Procedure for FMVSS 122: Motorcycle Brake Systems*, November 1977.
- CEM Report 4229-593. *Preliminary Design of an Evaluation Procedure for FMVSS 202: Head Restraints*, October 1977.
- CEM Report 4229-594. *Preliminary Design of an Evaluation Procedure for FMVSS 207: Seating Systems*, October 1977.
- CEM Report 4229-595. *Preliminary Design of an Evaluation Procedure for FMVSS 213: Child Seating Systems*, October 1977.
- CEM Report 4229-598. *Preliminary Design of an Evaluation Procedure for FMVSS 220: School Bus Rollover Protection; FMVSS 221: School Bus Body Joint Strength; FMVSS 222: School Bus Seating and Crash Protection*, December 1977.

The above nine reports are all preliminary. The first two reports form the basis for a single Task 1 Final Report (CEM Report 4228/4229-601). The last seven reports satisfy the requirements of Tasks 2 & 3 of the studies and provide inputs into the Tasks 4 & 5 reports listed below. The Tasks 2 & 3 reports contain appendices describing the Standards and preliminary versions of statistical techniques.

Tasks 4&5 FINAL DESIGNS AND IMPLEMENTATION PLANS

- CEM Report 4228-588. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 105: Hydraulic Brake Systems in Passenger Cars*, November 1977.

- CEM Report 4228-589. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 108: Side Marker Lamps and High Intensity Headlamps (Only)*, December 1977.

- CEM Report 4228-590. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 122: Motorcycle Brake Systems*, December 1977.

- CEM Report 4229-596. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 202: Head Restraints, and FMVSS 207: Seating Systems*, December 1977.

- CEM Report 4229-597. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 213: Child Seating Systems*, December 1977.

- CEM Report 4229-599. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 220: School Bus Rollover Protection, FMVSS 221: School Bus Body Joint Strength, and FMVSS 222: School Bus Seating & Crash Protection*, February 1978.

These detailed Tasks 4 & 5 reports contain appendices that give the Standards, present statistical techniques, and discuss proposed implementation cost categories. The reports have been reviewed and revised and are considered a final product of the study, as are the Final Reports and briefing, below.

FINAL REPORTS AND BRIEFING

- CEM Report 4228/4229-600. *Evaluation Methodologies for Nine Federal Motor Vehicle Safety Standards: FMVSS 105, FMVSS 108, FMVSS 122, FMVSS 202, FMVSS 207, FMVSS 213, FMVSS 220, FMVSS 221 and FMVSS 222, Final Report*, March 1978.

- CEM Report 4228/4229-601. *Review of Nine Federal Motor Vehicle Safety Standards: FMVSS 105, FMVSS 108, FMVSS 122, FMVSS 202, FMVSS 207, FMVSS 213, FMVSS 220, FMVSS 221 and FMVSS 222, TASK 1, Final Report*, March 1978.

- CEM DWN 985. *Presentation to the NHTSA of the Final Report of the Study Development of Evaluation Methodologies for Nine Federal Motor Vehicle Safety Standards*, 24 February 1978.

APPENDIX A

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.

References

1. Huber, P.J. "The 1972 Wald Lecture Robust Statistics: A Review," *Annals of Mathematical Statistics*, vol. 43, no. 4, August 1972, pp. 1041-1067.

2. Tukey, J.W. *Exploratory Data Analysis*, Addison-Wesley, Menlo Park, California, 1977.

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:

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

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

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

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

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

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

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 A-1.

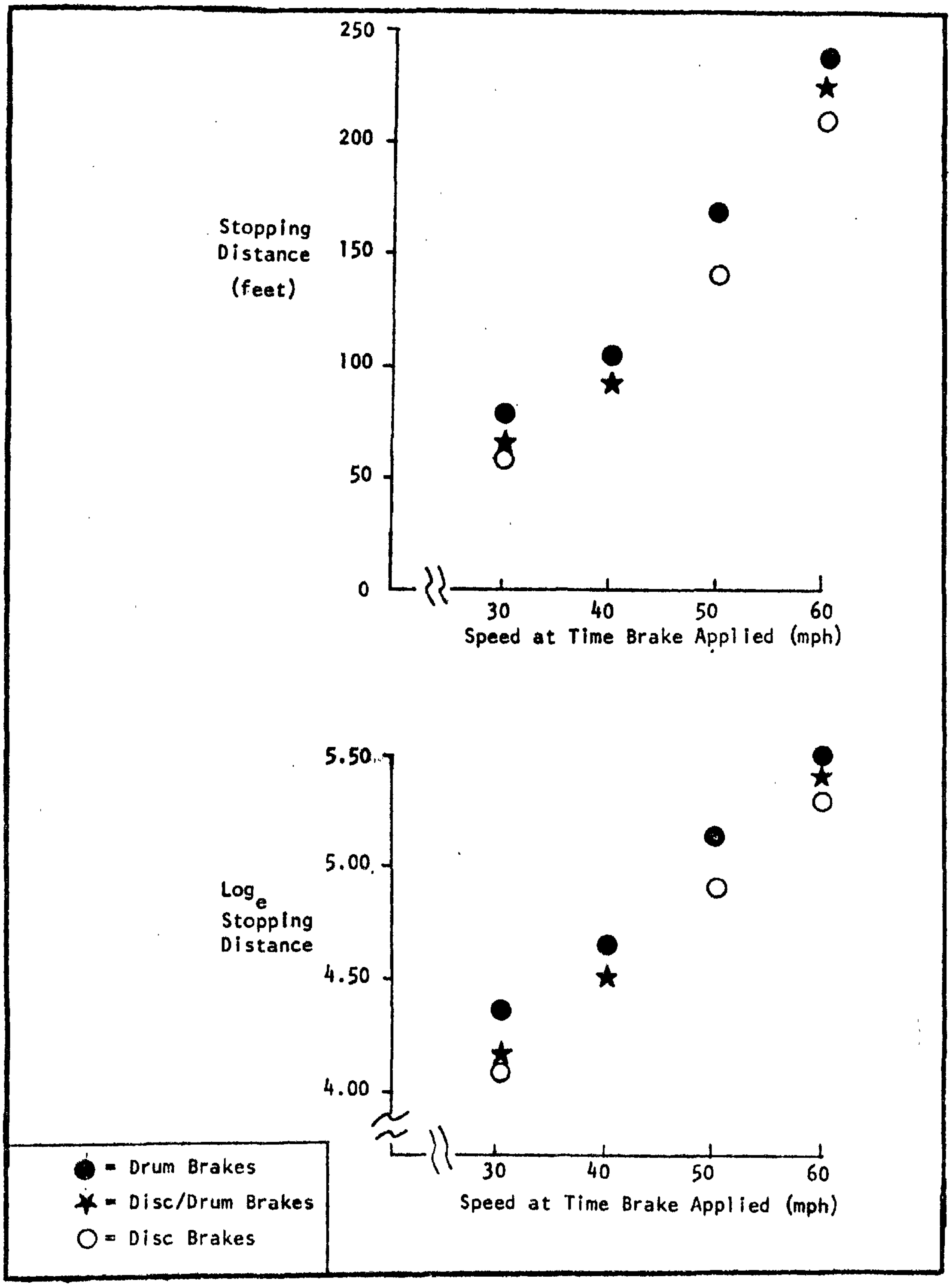


Figure A-1. Plots of fictitious stopping distances.

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) 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

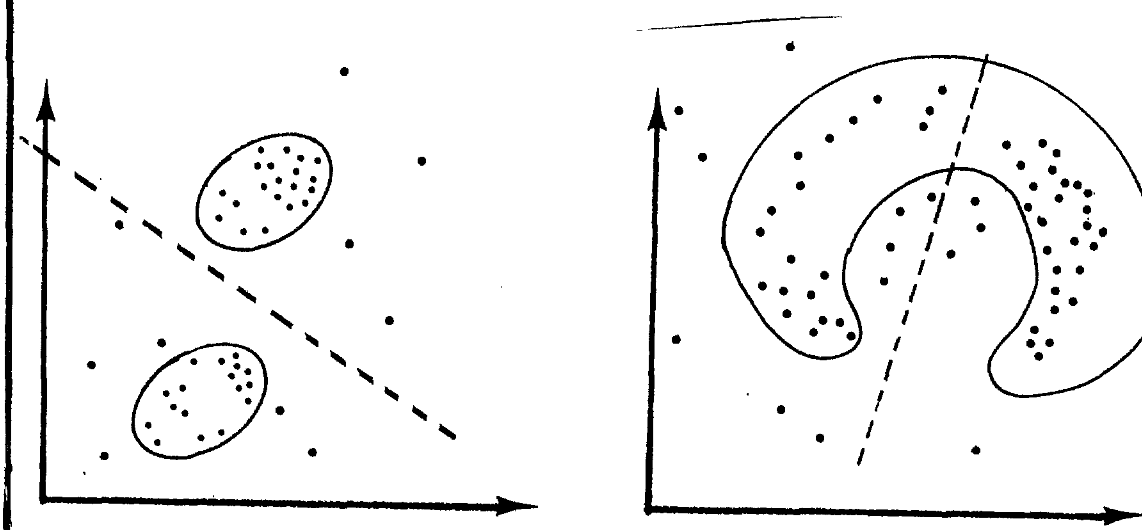
For each method described, the kind of data for which it is appropriate, the nature of the clusters produced and an illustrative example are given. The description of the technique is pared to the motivating rationale; greater detail and complete algorithms can be found elsewhere in the references.

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 A-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.



Good Data for K-Means　　　　Bad Data for K-Means

Notes:
For K=2, the clusters are defined by a separating hyperplane.
- - - - = the separating line.

Figure A-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 A-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.

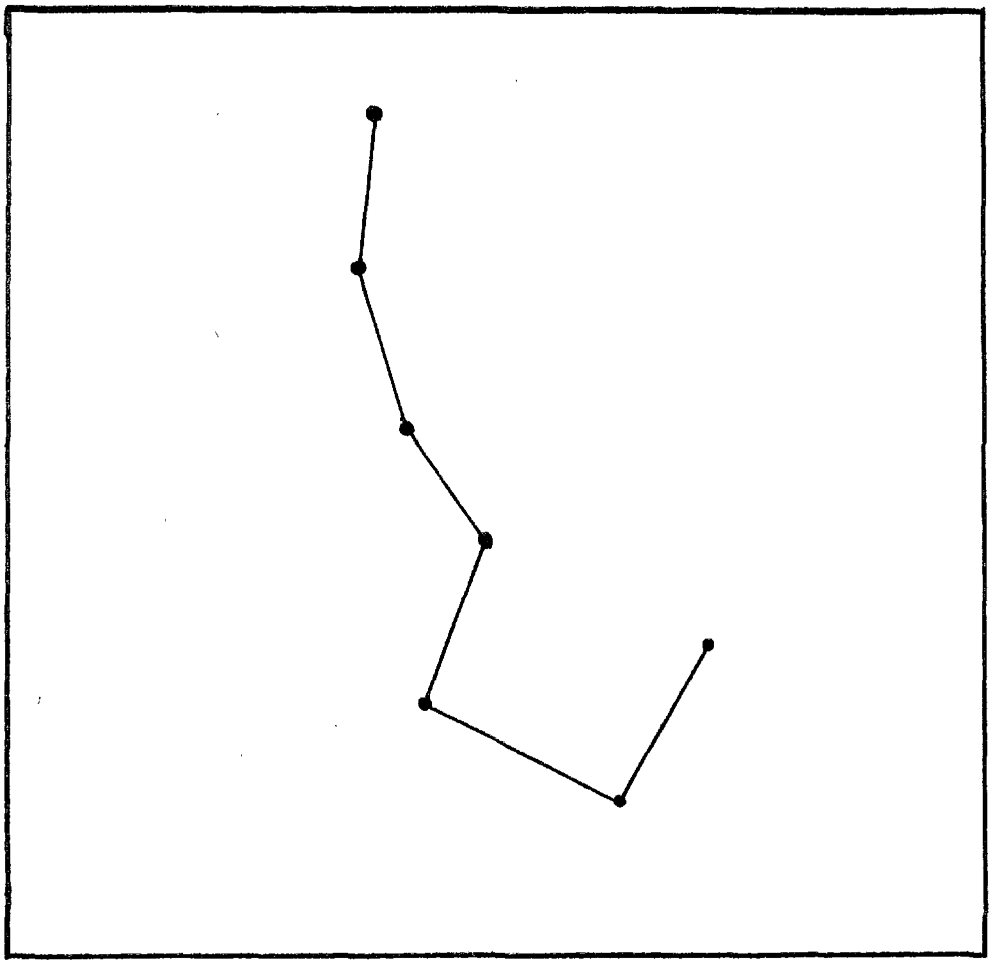


Figure A-3. The constellation Ursa Minor, with its single linkage cluster indicated.

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 A-4.

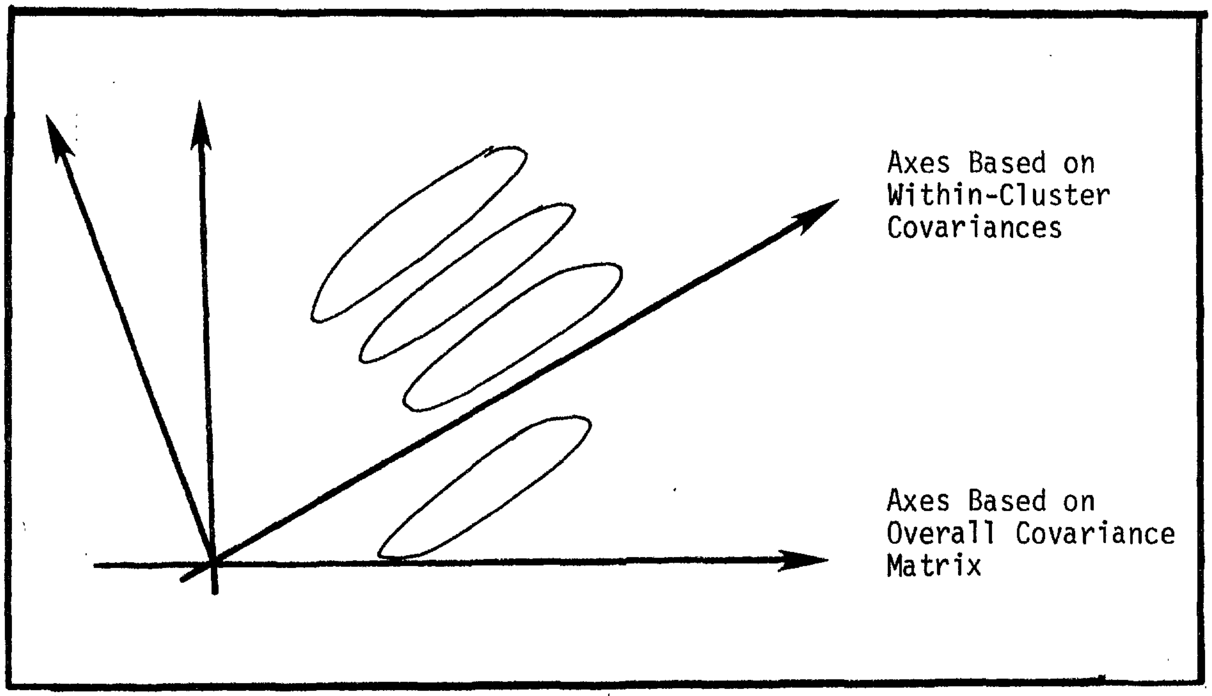


Figure A-4. Scaling with different covariance matrices.

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 standardized 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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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.

References and Further Reading

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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

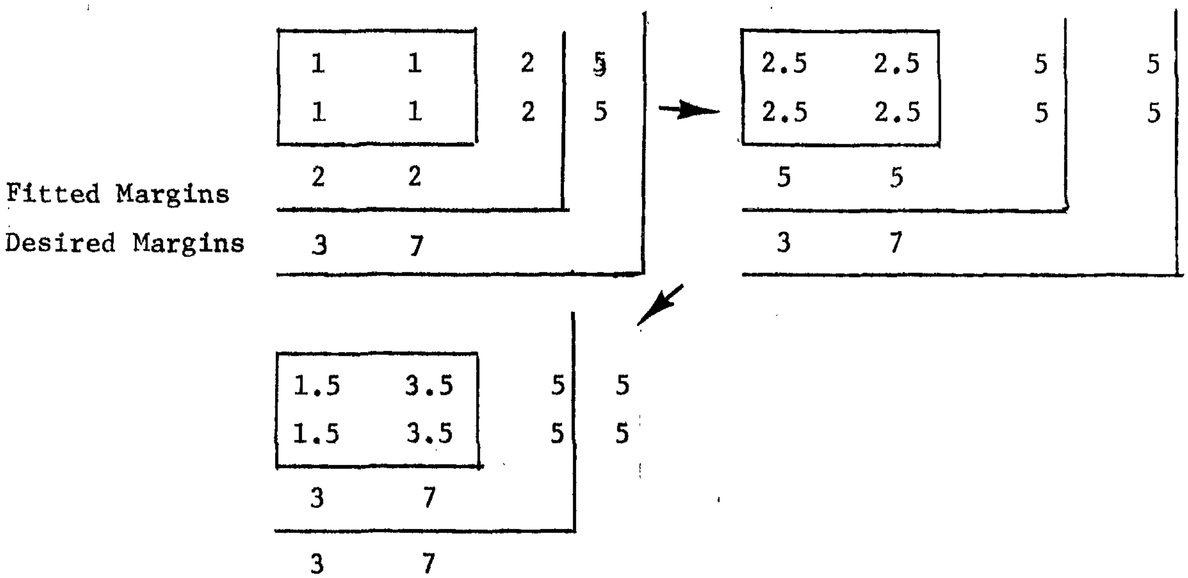
$$\left(\frac{.620 \times .621}{.379 \times .380} \approx \frac{8}{3}\right).$$

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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