DOT HS-802 345

FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMVSS 214: SIDE DOOR STRENGTH

Contract No. DOT-HS-6-01518

May 1977

Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
WASHINGTON, D.C. 20590

Prepared for the Department of Transportation, National Highway Traffic Safety Administration, under Contract No.: DOT-HS-6-01518. This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 802 345		

4. Title and Subtitle	5. Report Date
FINAL DESIGN AND IMPLEMENTATION PLAN FOR EVALUATING THE EFFECTIVENESS OF FMVSS 214: SIDE DOOR STRENGTH	May 1977
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No. CEM Report 4207-564
9. Performing Organization Name and Address The Center for the Environment and Man, Inc. 275 Windsor Street Hartford, Connecticut 06120	10. Work Unit No. 11. Contract or Grant No. DOT-HS-6-01518
12. Sponsoring Agency Name and Address U.S. Department of Transportation National Highway Traffic Safety Administration 400 Seventh Street, S.W. Washington, D.C. 20590	13. Type of Report and Period Covered Tasks #4 & #5 Report 10/76 - 3/77 14. Sponsoring Agency Code

15. Supplementory Notes

16. Abstract

This report covers the final design and implementation plan for evaluating the effectiveness of FMVSS 214 (Side Door Strength). The plan for the evaluation study considers measurability criteria, alternative statistical techniques, data availability/collectability, resource requirements, work schedule, and other factors. It is expected that the effects of side door beams are most discernable only in relatively low speed, angle collisions where the corner of the striking bumper impacts near the center of a door. The plan described herein is to use three sources of data: (1) historical data files (e.g., Texas and North Carolina) which contain information on accident type and injury; (2) data presently being collected by NCSS, which will have additional velocity, deformation, and injury estimates; and (3) possibly new field data required to supplement NCSS data. NHTSA will be able to use historical data to compare injury severity crash experience of matched sets of side beam and non-side beam vehicles. Using NCSS and supplementary data, side door beam evaluation can be focused on a more narrowly defined set of circumstances where the intrusion and injury severity crash effects are expected to be most discernable, and the effectiveness of FMVSS 214 can be established.

17. Key Words	18. Distribution Statement
Federal Motor Vehicle Safety Standards FMVSS 214 Side Door Strength Standard Evaluation Statistical Methods	Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

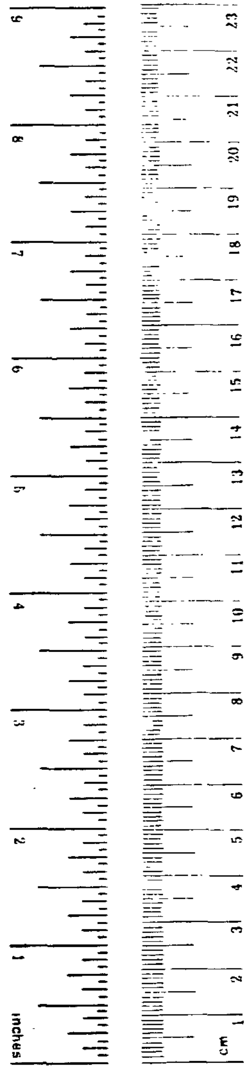
19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	90	

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

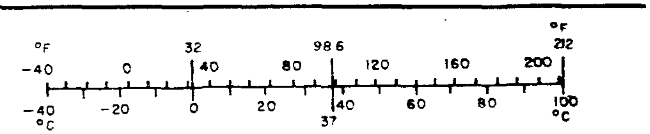


TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	1-1
1.1	Background	1-1
1.2	Summary of Evaluation, Cost Sampling and Work Plans	1-6
2.0	OVERVIEW OF THE EVALUATION	2-1
3.0	OVERALL APPROACH FOR EVALUATION OF FMVSS 214	3-1
3.1	Analysis of Mass Accident Data	3-1
3.2	Analysis of Detailed Accident Data	3-3
4.0	EVALUATION PLAN	4-1
4.1	Mass Accident Data	4-1
4.2	Detailed Accident Data	4-11
4.3	Other Data Bases	4-37
5.0	COST SAMPLING PLAN	5-1
5.1	Background	5-1
5.2	Relevant Cost Items	5-3
5.3	Frequency Sampling Plan	5-4
6.0	WORK PLAN	6-1

APPENDIX A: INTRODUCTION DATES OF SIDE DOOR REINFORCEMENT BEAMS

APPENDIX B: DISCUSSION OF STATISTICAL METHODS

APPENDIX C: ANTICIPATED DISTRIBUTION OF AIS LEVELS IN SAMPLED ACCIDENT DATA

APPENDIX D: ACCURACY OF RECONSTRUCTED ΔV

ABBREVIATIONS USED

AIS	Abbreviated Injury Scale
AMC	American Motors Corporation
ANACOVA	Analysis of Covariance
ANAVA	Associated Analysis of Variance
ANOVA	Analysis of Variance
BLS	Bureau of Labor Statistics
CDC	Collision Deformation Classification
CRASH	Calspan Reconstruction of Accident Speeds on the Highway
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GAO	General Accounting Office
GM	General Motors
HSRC	Highway Safety Research Center (University of North Carolina)
HSRI	Highway Safety Research Institute (University of Michigan)
KABCO	A Five-level Injury Severity Scale
MDAI	Multi-Disciplinary Accident Investigations
NAS	National Accident Summary
NASS	National Accident Sampling System
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
OIC	Occupany Injury Classification
OMB	Office of Management and Budget
RSEP	Restraint Systems Evaluation Program
SMAC	Simulation Model for Automobile Crashes
SWRI	Southwest Research Institute
TAD	Traffic Accident Data (TAD is a vehicle damage scale)
VSDSS	Vehicle Safety Design Surveillance System (N. Y. State)
VW	Volkswagen

1.0 INTRODUCTION

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

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

This report contains the final design and implementation plan for evaluating the effectiveness of FMVSS 214 - Side Door Strength.

1.1 Background

The rationale for issuing this Standard was the observation that occupant injury severity in side-door impact crashes increased with depth of intrusion. To reduce this intrusion, and thereby injury severity, strengthening side doors was suggested. Beginning with the 1969 model year, many car models were equipped with side door guard beams. The Standard became effective on January 1, 1973, and has not been amended since then.

Purpose of FMVSS 214

- Specific purpose is to set strength requirements for side doors.
- General purpose is to minimize the safety hazard caused by intrusion into the passenger compartment in a side impact accident.

General Requirements of FMVSS 214

Any passenger car side door that can be used for occupant egress must meet three crush resistance tests, using a specified test device:

- Initial Crush Resistance of not less than 2,250 lb.
- Intermediate Crush Resistance of not less than 3,500 lb.
- Peak Crush Resistance of not less than 7,000 lb, or two times the curb weight of the vehicle, whichever is less.

Relationship Between Standard Specifications and Conceptual Measures

The specifications of the Standard are given in terms of a static test. Conceptual measures of its real world performance are the intrusions occurring in actual crashes, resulting from the dynamic interaction of two vehicles, or a vehicle with an object. Conceptual measures of its ultimate effectiveness are the expected injury severity in a side door impact crash, or the probability of an injury's exceeding a certain level of severity. Both intrusion and injury severity are dependent on many pre-crash and crash phase factors.

Therefore, it appears conceptually impossible to directly evaluate the effect of reduced intrusion upon injury reduction.

Quantitative Measures of Effectiveness

The ultimate performance measure of FMVSS 214 is its effect on occupant injury. To do an adequate statistical analysis of this effect, a specific quantitative measure of injury must be available. Unless such a reliable measure is available, detecting shifts in injury severity resulting from the imposition of FMVSS 214 will be nearly impossible. The requirement for a reliable injury severity measure could be relaxed only if the primary effect of the Standard was a shift in injury severity at the highest end of the scale (e.g., from fatal to seriously injured or from seriously injured to minor). Since such a shift is not expected to occur, a comprehensive injury scale is necessary.

Most existing accident data bases rely on police accident reports for determination of injury severity. This usually consists of a five point scale of K, A, B, C, O, where:

- K = Killed
- A = Serious visible injury
- B = Minor visible injury
- C = No visible injury
- O = No injury.

Though these injury levels are defined more precisely than indicated, definitions may vary between jurisdictions, and have changed over time. The greatest practical drawback of this scale is that the assignment is made at the scene of an accident by a police officer, on the basis of only a few visible indications. The greatest conceptual problem is that the "A" category tends to cover a very wide range of injury severity; in effect, it covers the entire range of injuries which are of primary concern for evaluating FMVSS 214. A more satisfactory scale is the Abbreviated Injury Scale (AIS), which is available in some comprehensive data bases (NASS, NCSS)*. It is a seven point scale, 0 through 6, where:

- 0 = No injury
- 1 = Minor
- 2 = Moderate
- 3 = Severe (not life-threatening)
- 4 = Serious (life-threatening, survival probable)
- 5 = Critical (survival uncertain)
- 6 = Maximum (currently untreatable)

*NASS = National Accident Sampling System
NCSS = National Crash Severity Study

The AIS is precisely defined by a dictionary defining specific injuries for six body regions. In the case of multiple injuries, medical judgment is used to assign an overall AIS level. One drawback of the AIS scale is that it essentially expresses the threat to survival, but not other aspects of the injury, such as degree or kind of resulting disability.

A more detailed description of injury severity is the Occupant Injury Classification (OIC). It is the best quantitative measure of injury severity available for evaluating FMVSS 214. It is available in a few existing data bases (RSEP, NCSS).* The OIC is a five character code, one of which is the AIS. The other four characters represent body region, aspect, lesion, and system/organ. The OIC would provide not only the most reliable measure for detecting shifts in injury severity, but it also would make it possible to distinguish between intrusion-related and non-intrusion-related injuries.

The quantitative measure of FMVSS 214 performance is passenger compartment intrusion. The collision code used by most existing data bases is the Traffic Accident Data Project Scale (TAD). It consists of an impact location code and a damage rating from 1 to 6. The TAD scale does not sufficiently define the location of passenger compartment impacts for the purpose of evaluating FMVSS 214. A more comprehensive collision scale is the Collision Deformation Classification (CDC) which is available in the RSEP and NCSS data bases. The location of the impact is quite precisely defined by the CDC, but the extent of deformation is not. The depth of intrusion is not directly defined by the CDC because of varying door widths and interior design. However, it may be derived by using the dimensions of the car.

Means of Complying with the Standard

FMVSS 214 was introduced in October 1970 with an effective date of January 1, 1973. The manufacturers had been working on side door guard rails since at least 1968.** Various proposals were made as to the structural means of complying with the Standard, including the use of beams, structural foam, and honeycombed members. A review of present vehicle door constructions shows that the method of compliance is primarily the use of formed or channel-shaped metal beams or stampings positioned near or against the inner side of the outer door

*RSEP = Restraint System Evaluation Program.

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

sheet metal surface,* thereby providing the greatest resistance to intrusion for the prescribed force application of FMVSS 214. Attachment of the reinforcing beams consists of spot or seam welds to the vertical door frame members on the hinge and latch sides of the doors. This method of reinforcing the doors is probably universal in the thin structured doors of small cars. Some of the larger vehicles, having a large door thickness between inner and outer panels, appear to accomplish the strength requirement by incorporating heavy metal frames within the door which are functional in supporting the window regulators and latch mechanisms, thereby reducing the cost of additional structure for the sole purpose of increasing door strength.

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

Primary and Secondary Effects of Compliance

Side door beams significantly reduce occupant compartment intrusion in low speed impacts. It appears that strengthened door construction has increased effectiveness of occupant protection in the case where vehicles strike a glancing blow into the center door span, due to the low velocity normal to the door surface at a given impact speed and the likelihood of deflecting the striking vehicle at relatively low impact speeds (below 15 mph). This could prevent vehicle entanglement and loss of driver control which might cause more serious secondary collisions. Primary factors in considering the overall protection afforded by improved side door strength are (1) the relative weights of the vehicles involved in a glancing collision; (2) the relative velocity of the striking vehicles; (3) the angle of impact and the front corner configuration of the striking vehicle; and (4) the vertical location of the door reinforcement in the struck vehicle.

The most important unintended secondary effect is that the stiffening of the side door increases the acceleration forces on occupants in lightweight vehicles struck at relatively low speeds. Other possible secondary effects are less certain. In sideswipes, the side door beam may deflect the

*The domestic manufacturers use channel beams with corrugated longitudinal reinforcing and sometimes center plate reinforcement. Volkswagen has used a simple channel beam on their newer models; however, in the VW Beetle the beam flanges narrow at the connection point, which may reduce their effectiveness in off-center or angle side door collisions.

striking vehicle rather than absorbing the kinetic energy and slowing the striking vehicle. In certain types of collisions, it is possible that the beam could come free and become an injury-producing object. Also, the addition of side beams should enhance the integrity of the compartment in higher speed frontal collisions.

Relation Between Specification and Real-World Performance of the Standard

The major factor affecting the relation between FMVSS 214 and real-world crashes is the static nature of the impact test. This limits the representativeness of the test to a narrowly defined set of crash configurations. There are many variables involved which influence occupant injury, but the assumption is that the test specifications delineate the critical ones. Thus, if the test specifications of the Standard are met, then a significant improvement in occupant crash protection is provided. The evaluation methodology must test this assumption.

FMVSS 214 requirements are based on assumed relation between depth of intrusion and occupant injury. Injury may be caused by the vehicle door intruding upon the occupant as well as by the occupant's striking the door and/or other parts of the car, or other occupants. Intrusion of the door is dependent on the force of the impact, as is the force with which the occupant hits elements of the vehicle interior. It is not directly obvious to what extent the observed correlation between intrusion and injury reflects a causal effect of intrusion rather than their both being a result of the common force of impact. Therefore, it is not sufficient to restrict the evaluation to studying the depth of intrusion. It is also necessary to study injury reduction with respect to all relevant pre-crash and crash factors.

Some of the relevant factors which might be considered are: vehicle loading, road conditions, duration and degree of braking and/or rolling, and energy absorbed in vehicle rotation after impact. Injuries may be related to vehicle seating arrangements, occupant distance from the door, the shape of the interior surfaces, and the number of passengers seated adjacent to one another. The obvious factors of vehicle weights, relative velocities, body types, and occupant age, size/weight, and restraint-use must be considered. The Standard specifications cannot address all these real-world performance variables, but the evaluation methodology must identify, isolate and make use of the important ones. It will be necessary to perform a set of statistical analyses in a sequential, sometimes-iterative fashion to systematically determine answers to such questions as:

- Which are the key real-world variables?
- How adequate are existing data bases?
- What additional data (volume, parameters) should be collected?
- How effective is the Standard?
- How well correlated are the test specifications and the objectives of the Standard?

1.2 Summary of Evaluation, Cost Sampling and Work Plans

The plan to evaluate the effectiveness of FMVSS 214 must consider the characteristics of two generic types of vehicle accident data: (1) mass accident data and (2) detailed accident data. The mass accident data which can be considered is restricted to those states which have automated the data for several years. Mass data suffer from lack of standardization among states, inadequate definition of injury severity, and the lack of impact velocity data. For these reasons, old mass accident data are not adequate for evaluating the effectiveness of FMVSS 214. However, mass data can be used to investigate the effects which vehicle age and other characteristics might have on an analysis of side beam effects, using more detailed data.

The initial analysis of the effects of side beams will be carried out using the detailed NCSS data to be collected from October 1976 through March 1978. The analysis will be conducted within the framework of (1) an Analysis of Covariance Model which evaluates both continuous and discontinuous variables and (2) a Log Linear Model which accepts only categorical variables. The analytical techniques to be employed include (1) regression analysis, (2) contingency table analysis and (3) the indexing method. The evaluation plan anticipates the possibility that definitive and unambiguous results may not be obtained from the initial analysis of NCSS data, due primarily to inadequate sample size. If this circumstance occurs, a field collection of additional data is required. The data collection may include some additional parameters not in the NCSS data, if this is appropriate. A more definitive analysis of detailed accident data (both NCSS and new data) will then be carried out. This latter statistical analysis will be similar to, but not necessarily a replication of, the initial analysis with NCSS data alone.

A cost sampling plan has been developed to estimate costs as a function of the following cost categories: (1) direct manufacturing, (2) indirect manufacturing, (3) capital investment (including testing), (4) manufacturers' markup*, (5) dealers' markup*, and (6) taxes*. The costs are to be determined during the model year prior to the introduction of side beams, the model year

*CEM considers that reliable information on these items for specific models is not obtainable.

in which side beams were added, and the following model year. "Out-of-pocket" costs are only loosely related to the items listed above and lifetime operating and maintenance costs are explicitly excluded. A frequency sampling plan has been proposed which considers vehicle manufacturer, market class and body type. In consideration of data gathering costs, it is desirable to limit the number of models sampled to between 15 and 25. This necessitates making assumptions about the variance of cost data and the representativeness of the stratifications used.

The work plan for the evaluation study of FMVSS 214 is divided into three phases with a total of five tasks. Phase 1 includes the analysis of mass accident data (Task 1) and the analysis of direct out-of-pocket costs to the consumer for implementing FMVSS 214 (Task 2). It is estimated that the acquisition and analysis of data from North Carolina and Texas will require professional resources of one person-year and $5000 for computer processing. Task 1 is scheduled to be completed seven months after initiation of the study.* The collection and analysis of consumer cost data will also require one professional person-year and up to $1000 for computer processing. It is anticipated that the work under Task 2 will be completed nine months after the start of the study. This will conclude Phase 1.

Phase 2 is concerned with the NCSS data acquisition and analysis. Task 3 work in this phase concludes with a report on the work accomplished under Tasks 1, 2 and 3 and an assessment of the need (if any) for acquiring additional detailed accident data. It is estimated that two professional person-years are required for the Task 3 effort and about $8000 is needed for computer processing. The Phase 2 (i.e., Task 3) effort will begin in Month 7 of the study and conclude 15 months after the study begins.

Phase 3 deals with the collection of new detailed accident data and the analysis of these data combined with NCSS data (Task 4). A final report will be written in Task 5 documenting all analyses and results of the effectiveness evaluation for FMVSS 214. The bulk of professional resources required for Task 4 will be needed to collect, edit, and automate the field accident data. This will vary greatly with the number of additional detailed accident cases required. It is anticipated that between two and seven professional person-years may be required for data collection and automation. A total of 3.7-8.7 professional years are needed for the entire Phase 3 effort, which includes data analysis and report preparation, as well as data collection. Computer processing will require

*It is assumed that the study will not begin prior to July 1977.

an additional $5000.* The third phase begins in Month 16 of the study and concludes in Month 36. Total study duration is dependent on the amount of field data to be acquired and the number of locations used for acquisition. Under the most optimistic, accelerated data collection efforts, it will probably not be possible to perform a thorough, comprehensive evaluation in less than 24 months, unless analysis of NCSS data indicates that no new data are needed--a situation presently judged unlikely.

In summary, it is expected that the entire study will require approximately:

- 7.7 to 12.7 person-years of effort.
- $18K to $20K for computer data processing.
- At least 24 and possibly 36 months for accomplishment, if additional new data are required.

If it is decided not to analyze existing mass data, and if initial analysis of NCSS data indicates sufficient data for evaluation (a situation judged unlikely), then it is estimated that this reduced evaluation effort will require approximately:

- 3 person-years of effort.
- $9K for computer data processing.
- 9 months for accomplishment.

The minimal level effort is not recommended.

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*Most of the statistical analysis "set-up" effort will have been accomplished in Phase 2.

2.0 OVERVIEW OF THE EVALUATION OF THE EFFECTIVENESS OF FMVSS 214

2.1 General

The requirement for strengthened side doors is based on the experience that injury severity increases with depth of door intrusion in side impact crashes. Therefore, the performance requirement of the Standard is to limit the door intrusion in a crash. The ultimate purpose, however, is to reduce injury severity. If the Standard is successful, injury frequency will also be reduced, because minor injuries will be reduced to no injury.

The injury generating mechanism is complicated. If a car is hit by another car, the door is deformed until the reaction forces are strong enough to move the car. Calculations suggest that initially the door structure is moving toward the occupant. Later, when the vehicle is moving sideways, the occupant moves relative to the vehicle and will finally hit the vehicle structure somewhere, and possibly eject. The situation is similar when a car skids into a fixed object sideways. Since the side beam affects only one aspect of the injury mechanism, its effect may not be very obvious. Also, it may be limited to only certain types of injuries.

2.2 Factors Influencing the Evaluation

The objective of the evaluation of the effectiveness of the Standard is two-fold: (1) to evaluate the performance reduction in intrusion, and (2) to evaluate the reduction in injuries. In both cases, it is clear that many factors other than side door strength influence the depth of intrusion and the forces on the occupant, and thereby the resulting injury. The most important other factors are probably the speeds of the colliding vehicles, the angle between the directions of vehicle movement at the time of impact, and the exact point of door contact. Other factors are details of the construction of the vehicles, and the characteristics of the occupants such as height and weight. To make a valid comparison between cars with and without side beams, the effects of such factors have to be controlled in the analysis, or otherwise eliminated.

The effects of the extraneous factors influencing intrusion and injuries are not sufficiently well known to eliminate them by analytical methods. Therefore, statistical methods have to be applied to empirically determine the influence of these factors and to eliminate them. There are several difficulties in applying existing statistical techniques. One is that most of the factors influencing intrusion and injury are continuous, but some are categorical. However, in practice, some continuous variables are given only by categories. The combined use of categorical and continuous variables in a model poses a number of operational problems. A more serious problem in studying injury reduction is that injury is a categorical variable. Statistical analysis techniques which deal with categorical dependent variables can detect shifts from one category to another, but they cannot discern small but consistent shifts among several categories. An analysis limited to only two categories (e.g., "injury" and "no injury") may not be sensitive enough to detect small shifts over a wide range.

2.3 Potential Alternative Approaches

If exactly one type of level of injury would result from any given combination of precrash factors, it would be relatively easy to determine the influence of these factors. In reality, however, the type and severity of injury resulting from a specific crash is not precisely predictable. The best one can expect is to predict the probabilities with which the various levels or types of injuries occur. If the categories of "no injuries" and "injuries of low severity" are not completely reported, the estimates of these probabilities can be seriously distorted, and it might become impossible to detect a real effect of a Standard. The practical question is: how complete are "no injury" and "low injury" crashes reported? The success of any analysis that uses "frequency of a certain injury level" hinges on the answer.

One way to overcome this problem is to restrict the analysis to towaway crashes. Need for towaway appears to be a fairly objective criterion for the severity of damage to a car. There exists, however, the possibility that side beams might reduce intrusion, and thereby reduce the need to tow a car, even though side beams may not reduce injury severity. In this case, reduction of the number of towaway crashes, and no change in injury severity in cars which are towed, may result in an apparent spurious increase in injury severity in side beam cars.

Another way to approach this problem is to study the risk of occupant injury per crash, or risk of occupant injury per exposure measure. Although this is conceptually possible, it encounters insurmountable practical difficulties. The only exposure measure which can currently be estimated--with low accuracy--is vehicle-miles-of-travel. Vehicle-miles-of-travel, however, does not necessarily reflect the frequency of exposure to side impacts, and much less an exposure to side impacts at specific angles, velocities, etc. Much more refined exposure measures would be needed to overcome this problem.

Another approach is applicable to collisions between two cars. If one restricts the study to collisions where injury to at least one vehicle occupant is equal to or greater than a certain level, then one can assume that reporting biases are largely eliminated, and by comparing the models and model years of cars in which injuries occur more frequently, one can draw conclusions on the effectiveness of side beams in reducing injuries. This approach has been developed, and is currently being tested for fatal injuries under Contract NHTSA-7-3261. However, results will not be available until the Fall of 1977.

Other approaches to eliminate or reduce the reporting bias are possible. For example, one might conduct a household survey to learn about the occurrence of unreported--and unreportable--side impacts. Such a survey would have to be very extensive; the responses might not be fully reliable; and to tie them together with the results of analyzing reported accidents could be difficult and not very reliable. Similarly, one might survey body shops for cars with side damage, or engage the cooperation of insurance companies. One difficulty with such an idea is that cars with little damage to the door may not be repaired, and older cars may not be insured.

We conclude that currently it appears most reliable to use towaway crashes as a basis for the analysis.

2.4 Data Collection

In addition to obtaining a consistent sample of crashes, one has to obtain sufficient information about the crashes. Certain information is readily available, such as make and model/year of the involved vehicles, and all associated characteristics. Age and sex of the occupants are also easily available as are impact areas on the vehicles. The velocities of the vehicles and the angle of impact, however, have to be reconstructed by fairly complex processes, which require various assumptions about the characteristics of the vehicles volved. While not totally accurate, such results are still far superior to anything that could be derived from analysis of available mass accident data.

The collection of new data should be biased towards low to medium severity side impacts, to help assure that the effects of side beams will be adequately sampled. Such accidents are most likely to be found at intersections in urban areas. In many studies, the question of whether the data are "nationally representative" is extensively discussed. For evaluation of side beam effectiveness, representativeness is not a problem; the effects of the Standard in specific crash situations can be estimated from a biased sample of crashes. Representativeness becomes a problem only if one wants to estimate the effects of the Standard relative to all crashes. To evaluate side beam effectiveness, it is better to obtain a biased sample from urban crashes, where most of the side impacts will be relatively minor, and side beams may be most effective. It is then possible to correct for the bias* and generalize the results to rural areas, where there are more high speed crashes in which side beams are apt to have little impact on intrusion and injury reduction because of the extreme severity of the crash effects.

*We recommend the use of State accident data to determine representative frequencies of types of accidents. This will form the basis for correcting the bias in the sample-accident data.

3.0 OVERALL APPROACH

A credible evaluation of the effects of FMVSS 214 requires the analysis of very detailed accident data, such as the NCSS data or data with a similar level of detail. Such data bases, however, have a serious disadvantage--they are based on accidents which occurred over a relatively short period of time; therefore, vehicle model year and vehicle age are closely correlated. Since the applicability of a Standard is determined by the model year, vehicles satisfying and not satisfying the Standard are of different ages. Thus, if there is any uncontrolled factor which is related to vehicle age, it may influence the results obtained from short-time period data bases. The only way to overcome this problem is to extend the collection of detailed data over several years. A second best approach is to use existing data bases which extend over longer time periods, such as state mass accident data bases. However, these suffer from many problems of completeness and reliability. An analysis of such data bases might suggest the existence of certain problems which might affect the analysis of limited time period data bases, though it may not necessarily rule out the existence of such factors.

The analysis of mass accident data is relatively simple, owing to the limited amount of detail. Therefore, as a first step the analysis of mass accident data is recommended.

3.1 Analysis of Mass Accident Data

The analysis of old mass accident data can have only very narrow objectives due to limitations inherent in the data. Information on key variables is not available or is not dependably reported and there is a lack of standardization in reporting among those states that do have automated data bases. For example, injury severity data for vehicle occupants are generally available in terms of the KABCO scale.* This has been shown to be unreliable at the low injury scale, a fact which greatly restricts its usefulness in evaluating the effectiveness of FMVSS 214. The utility of mass accident data is further restricted by the fact that impact velocity data are not available. It is, therefore, very strongly expected that mass accident data are not suitable for evaluating directly the effects on occupant injury experience which may accrue from the addition of side beams.

The above comments, however, do not rule out the possibility that mass accident data could provide useful information. It is obvious that most current

*KABCO is a five-category injury scale. See page 2.

and future accident data bases will contain an ever smaller percentage of non-side beam vehicles. Furthermore, since these vehicles are all from model year 1972 and earlier, they are only representative of older vehicles, while most side beam vehicles are still comparatively new. An analysis of NCSS data or data collected in the future must be conducted in light of the significant difference in average age of side beam and non-side beam vehicles. In addition to this, side beams were selectively introduced in model years 1969-1972, with a general preference for more costly, heavier models, at least during the first few model years. During this period, the characteristics of side beam and non-side beam vehicles of the same age may differ not only with regard to such easily controllable factors as vehicle weight, but also in more subtle aspects such as solidity of construction, special design factors, and other potentially injury-related factors.

The usefulness of mass accident, then, is mainly for its potential to evaluate the importance of the above discussed effects. Specifically, mass accident data can be analyzed to estimate the significance of vehicle age effects--possibly such minor effects as weakening by rust--and the significance, if any, of differences in the side beam and non-side beam vehicle populations* during the model years from 1969 through 1972. Secondary questions such as the effect of the tendency of younger, more injury-resistant drivers to drive older vehicles can be included in the analysis. The primary analytical approach would be to compare the injury experience in vehicles classified according to the common model year in which side beams were introduced. The significance of vehicle age and vehicle category effects would be evaluated by means of contingency table analysis. This analysis is not designed to provide information on the effects of side beams, but could result in useful guidance for conducting other statistical analyses with NCSS and new data.

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*These vehicle populations would be divided into different age and weight categories. The vehicle weight categories would roughly compare with market classes, such as subcompact, compact, etc.

3.2 Analysis of Detailed Accident Data

3.2.1 Availability of Detailed Data

The term "detailed data" is used to describe accident data which were obtained by extensive accident investigations in sufficient volume for the data to be useful in evaluating FMVSS 214. Although several "detailed data" bases exist (MDAI, RSEP), only the National Crash Severity Study (NCSS) may contain an adequate number of accidents in sufficient detail to evaluate the Standard. This is because there are certain critical variables whose values are needed within a reasonable degree of accuracy, and which are missing or unreliable in most existing files. An example of such a variable is the change in velocity (ΔV) of the struck car in a two-vehicle accident. That ΔV has an effect on intrusion and injury severity in a side impact is obvious and it must be considered in the analysis. Other necessary variables which are often missing in less detailed data sources are: occupant characteristics (other than the driver), AIS or OIC injury scales, striking vehicle information, accurate restraint usage information, and measures of intrusion.

The other important characteristic of detailed data sources is the available sample size of accidents that is needed for the analysis. In the case of FMVSS 214, the required accident types are car-to-car or single car towaway accidents with a vehicle struck in the left or right passenger compartment. The sample size necessary is a function of the magnitude of the expected difference (in injury severity or intrusion) between side beam and non-side beam cars, the number of stratifications used, the number of variables analyzed, and the desired significance level of the results. As a consequence of the initial analysis performed with the NCSS data, the status of the above factors may be such that the desired significance level cannot be attained solely with the sample size available in NCSS. A new data collection effort might then be necessary to supplement the NCSS data and give statistical results that provide satisfactory levels of significance.

3.2.2 Acquisition of New Data

This acquisition of new data on front-side collisions* will generally parallel the NCSS data collection effort as much as possible. The same eight

*The initial analysis of NCSS data will determine if single vehicle side accidents should be included. It is expected that the condition of these crashes will be too dissimilar and the number of cars too few to include them with the car-to-car accidents.

geographic regions are suggested, although the focus will be on particular types of accidents (front-side) occurring at low speeds, which probably will lead to concentration on urban and suburban intersection accidents.

The items of information to be collected will be nearly identical to the NCSS data items, except for certain unnecessary variables that have no relevance to this study (days of restricted activity, fuel leakage, etc.)* The recommended variables and definitions are suggested in order to maintain the comparability of new data with the existing NCSS data and also so that processing of the data will be the same, especially the reconstruction of ΔV.

As has been discussed before, the volume of new data needed will depend on the size of the Standard's estimated effect and the desired level of confidence one wants in the final estimate. In Section 4.2.2 this relationship is described in greater detail. However, this example is based on the expected ratio of side beam and no-side beam cars in the NCSS data (2:1), with 3,000 total cases. We expect that if the frequency of an event of interest (injury type, injury level, etc.) is 0.10 in the larger sample (side beam cars) and the frequency of this event is 0.15 in the no-side beam cars, then the probability of detecting this difference is 97 percent. At low frequencies of occurrence and small differences, the probability of detecting the difference is very low, *viz.*, if the actual frequencies are 0.10 and 0.11 the probability of detecting that difference is only 48 percent even with 15,000 cases (10,000 and 5,000). The current best estimate of the level of effort for new data collection is about 3,000 new accident reports, which would give a relatively high probability of finding an effect if a difference of "reasonable proportions" exists.

The reliability of the newly collected data is a crucial element.. The accident investigation teams required to gather this NCSS-type data need not be as highly specialized as the multi-disciplinary accident investigation teams (MDAI); however, they must follow data gathering procedures carefully, especially with respect to the vehicle and environment. These latter data are subsequently used to reconstruct the accident and estimate ΔV. The suggested type of on-site perconnel are former traffic officers or other technically oriented individuals. There is also the need for a strong office staff to perform medical followups, coding of data, and quality control. An important managerial point to consider is that if too geeat a pressure exists for completed data forms, "manufactured" data begin to occur.

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*Such specific items are discussed in Section 4.2.2.

It is suggested that the new data be prepared in the same computer format as the NCSS data in order to facilitate the use of existing programs for pre-processing--which includes reconstructing ΔV and then preparing the data for the detailed analysis described below.

3.2.3 Analysis of Detailed Data

The objective of the analysis of detailed data is to determine if any discernable differences exist between cars with and without improved side door strength with respect to passenger compartment intrusion and occupant injury severity. The analysis will only be concerned with car-to-car and single car towaway accidents where the struck vehicle was hit in a side door. Car-to-truck accidents have been eliminated because the larger mass and different bumper configurations of trucks make them incompatible with the car-to-car analysis. Significant differences exist in the crash dynamics between car-to-car and single car accidents, so they will be analyzed separately. Complexities in the crash dynamics of other multi-vehicle (more than two) accidents make them incompatible also,but they occur infrequently enough to safely ignore.

The real-world performance of FMVSS 214 will be analyzed by using "extent of intrusion" as a continuous dependent variable. A mathematical model will be constructed which attempts to estimate a functional relationship between the probability of various levels of intrusion and a series of relevant independent variables. The primary independent variables to be considered are the change in velocity, the speed of the impacting vehicle, and the angle of impact. Secondary variables might include the bumper strength and/or width of the striking vehicle, the type of frame (unibody, x-frame, etc.) of the struck vehicle, and the weight of the struck vehicle (heavier vehicles might have inherently stronger structures). In addition to stratifying side beam and non-side beam vehicles, three further stratifications are needed to separate 4-door front, 4-door rear, and 2-door front points of impact.

The effect of increased side door strength on injury severity will be analyzed by using AIS level as a categorical dependent variable. As for the intrusion analysis, a predictive model will be fitted to relevant independent variables. Additional primary variables for the injury analysis should include seat belt usage, occupant age, the presence of an adjacent occupant, and whether other safety improvements were present in the vehicle (steering column, head restraints, glazing materials, etc.). Since improved door strength might create a shift in injuries from the torso to the head,* separate analyses will be performed for overall AIS level, head injury AIS, and torso injury AIS. Further stratifications will be needed to control for asymmetries with respect to left and right side and driver and passenger configurations. Six possible categories would be: driver-left impact, driver-right impact, left passenger-left impact, left passenger-right impact, rear passenger-same side impact, rear passenger-opposite side impact.

The statistical methodology recommended for the intrusion analysis differs from that recommended for the injury severity analysis. This is because "extent of intrusion" may be assumed to be a continuous depedent variable whereas AIS level must be a categorical dependent variable. The details of both approaches are described in Section 4.2.4.

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*This hypothesis is based on a simplified engineering analysis of the vehicle and occupant dynamics in the case of stiffer doors. In some cases of heavier cars striking lighter cars with stiffer doors, the preliminary analysis predicted higher occupant accelerations, though less intrusion. This result leads to the hypothesis about a shift in injuries from torso to head.

4.0 IMPLEMENTATION OF EVALUATION APPROACH

4.1 Mass Accident Data

4.1.1 Data Requirements

The advantage of old mass accident data is that it includes large numbers of vehicles without side beams which were involved in accidents when they were still "young." Beginning with the 1973 models, all cars contained side beams. Present and future accident data collection efforts encounter an ever decreasing number of non-side beam vehicles as their presence in the car population-at-risk diminishes. Also, all non-side beam vehicles are now relatively old. The older information which can be found in mass accident data contains higher proportions of non-side beam vehicles for comparison with side beam vehicles. In addition, the non-side beam vehicles in older accident data are not consistently older relative to the side beam vehicles, which is the situation in more recent data. Mass accident data are accumulated by individual states and each state determines the detail and format of its files. The larger states have automated their data gathering, and those are the data bases considered here. We have found two mass accident data bases which have sufficiently detailed information for, at least, a superficial analysis of the effects of side beams--Texas and North Carolina. In another large and detailed data base, the New York State VSDSS data, it is not possible to identify side door impacts.

The North Carolina data cover about 120,000 accidents per year, involving approximately 220,000 vehicles. Between 1969 and 1972, point of impact is identified but damage severity (which reflects intrusion) is not. Starting in 1973, the TAD vehicle damage rating is also given.

The Texas accident data cover about 500,000 accidents per year, involving approximately 800,000 vehicles. From 1971 on, vehicle make and model can be identified in sufficient detail and vehicle damage according to the TAD scale is given.

The main purposes to which mass accident data will be applied include:

- An analysis of the accident experience of side beam and non-side beam cars, so that any obvious differences due to factors other than side beams may be detected; and
- An analysis of possible reporting biases in minor accidents due to age differences between side beam and non-side beam vehicles, and possibly similar differences in the tendency to have a vehicle towed.

The variables which are required from mass accident data files are:

- Vehicle make
- Vehicle model
- Vehicle model year
- Accident year
- Accident severity
- Vehicle point of impact (with sufficient accuracy to distinguish passenger compartment from other side impact points).
- Driver injury
- Driver age.

Two additional variables which are not required but which would allow somewhat finer analyses are:

- Occupant injury severity
- Occupant seating position.

4.1.2 Data Acquisition

Mass accident data files can be acquired from the relevant administrative agencies of individual states. Although the format of accident data varies widely among the states, those data bases which are automated are generally available on magnetic tape computer files. In addition to acquiring copies of accident tapes, all file coding manuals which are relevant for each year's data should be obtained. In the case of North Carolina, edited versions of the state's accident tapes have been created and are maintained by the Highway Safety Research Center of the University of North Carolina.*

4.1.3 Data Preparation

Once data tapes and coding manuals have been obtained, the data must be edited so that the proposed analyses can be performed efficiently. This involves the writing of data preprocessing programs which will standardize the different codes used by different states and will reconstruct necessary variables from other related variables which are available. Two important variables which will be reconstructed from vehicle make, model, and model year are: 1) whether the vehicle contains a side beam, and 2) weight of vehicle. The editing procedure will take place in the following steps:

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*The HSRC tapes are proprietary and negotiations may be needed to obtain access to them.

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

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

4.1.4 Data Analysis

The primary purpose of analyzing old mass accident data is to investigate the possibility that factors other than the presence or absence of side beams are affecting the results of an analysis of the effectiveness of adding side beams. That is, differences in the injury experiences in the two populations, cars with side beams and cars without side beams, may be due to other characteristics or factors which have nothing at all to do with the question of side beams. The important other factors to consider include the following:

- Vehicle categories, including weight differences
- Vehicle age
- Vehicle model year
- Driver age,

where each factor is evaluated separately for cars with and without side beams.

These factors assume particular importance in view of the historical record of anticipatory compliance with FMVSS 214. Prior to model year 1969, no vehicles contained side beams. From 1969 through 1972, side beams were selectively introduced into different make/models. Especially during the first few years of the transition period, there was a tendency to introduce side beams into higher priced, heavier cars. From model year 1973 on, all cars contained side beams. Thus, in any analysis a number of population characteristics must be considered. The average age of non-side beam cars is considerably higher than side beam cars. Any reduction in vehicle crashworthiness due to structural aging or fatigue will affect injury statistics. Since younger drivers with greater resistance to injury tend to drive older cars, this additional complication must be considered. During the transition model years from 1969-1973, the characteristics of side beam and non-side beam vehicles of the same age may differ with regard to average vehicle weight, vehicle strength, and other injury-related factors.

In the evaluation of the above factors for vehicles with and without side beams, two measures or ratios will be computed. These are (1) the ratio of injured drivers to the number of drivers involved in an accident, and (2) the ratio of side impacts to total impacts. The analysis of these two parameters will be designed to answer two basic questions:

1. Are there significant vehicle age effects?
2. Are there significant differences in the injury experience during the model years preceding 1969 and following 1972 between models which introduced side beams during 1969-1972 and models which didn't have side beams in this period?

If the answer is, "Yes," to either or both of these questions, the analysis of the NCSS data will have to be planned to take into account the influences of these factors on the side beam analysis. For example, the old mass accident data may indicate that older vehicles have a higher injury rate regardless of the presence or absence of side beams. The data may also show that there is a difference in vehicle characteristics between 1969 and 1972 which influences the injury rate.

Five primary vehicle categories will be defined as shown in Table 4-1. That is, each primary vehicle category from A to E is defined according to the model year from 1969 through 1973 in which side beams were introduced. The side beam introduction dates which form the basis for vehicle category classification are given in Appendix A.

TABLE 4-1

PRIMARY VEHICLE CATEGORIES

Vehicle Category	Model Years with Side Beams				
	1969	1970	1971	1972	1973 & later
A	//////	//////	//////	//////	//////
B		//////	//////	//////	//////
C			//////	//////	//////
D				//////	//////
E					//////

The analysis will be restricted to two-car crashes. In the analysis of injury experience, the weight of each vehicle must be considered. If desired, absolute weight can be included in a later phase of the analysis and evaluated through covariance analysis. However, at least initially, we recommend that the absolute weight of the striking vehicle not be included in the analysis, because we judge its effects to be secondary.

The analysis procedure to be followed can be illustrated with reference to Table 4-2 and Figure 4-1. In this illustrative discussion, the factors of driver age and model year are being "controlled for;" all cases are limited to a given category. For example, the driver age category might be under 25 years old and model year could be 1970.

In the notation in Table 4-2, m is a frequency count of drivers injured and n is count of drivers not injured. In the instance of impact analysis, m is a frequency count of side impacts and n is a count of other impacts. The subscript refers to the vehicle age, i.e., zero indicates less than one year old. The superscripts refer to the vehicle category and whether the struck car contained side beams. Thus, for example, A_{NS} is vehicle category A without side beams. No weight subclassification was needed for Category A. The superscript $1B_S$ refers to the first weight subcategory of vehicle Category B and side beams present in the struck vehicle.

The cube shown in Figure 4-1 illustrates the fact that the accident data with and without side beams will be analyzed separately. For simplicity, only primary vehicle categories A through E are shown, without the weight subdivisions. Six categories of vehicle age are shown. For each cell in the cube, stratified according to side beams, a frequency count will be made of injured and uninjured drivers for a given vehicle age and vehicle category.

The contingency table analysis will proceed as follows: Analyses will be performed separately for the side beam and non-side beam samples. Consider a given row of Table 4-2 for either side beams or no side beams. If there were no effect of vehicle category for a given vehicle age, it would be expected that

$$\left(\frac{m}{m+n}\right)^{A} \cong \left(\frac{m}{m+n}\right)^{1B} \cong \left(\frac{m}{m+n}\right)^{2B} \cong \cdots \quad .$$

TABLE 4-2
SIMPLIFIED CONTINGENCY TABLE ANALYSIS

Vehicle Category	Vehicle Category												
	A_{NS}		A_S		$1B_{NS}$		$1B_S$		$2B_{NS}$		$2B_S$		
0	$m_0^{A_{NS}}$	$n_0^{A_{NS}}$	$m_0^{A_S}$	$n_0^{A_S}$	$m_0^{1B_{NS}}$	$n_0^{1B_{NS}}$	$m_0^{1B_S}$	$n_0^{1B_S}$	$m_0^{2B_{NS}}$	$n_0^{2B_{NS}}$	$m_0^{2B_S}$	$n_0^{2B_S}$	....
1 - 2	$m_1^{A_{NS}}$	$n_1^{A_{NS}}$	$m_1^{A_S}$	$n_1^{A_S}$	$m_1^{1B_{NS}}$	$n_1^{1B_{NS}}$	$m_1^{1B_S}$	$n_1^{1B_S}$	$m_1^{2B_{NS}}$	$n_1^{2B_{NS}}$	$m_1^{2B_S}$	$n_1^{2B_S}$	....
. . .													

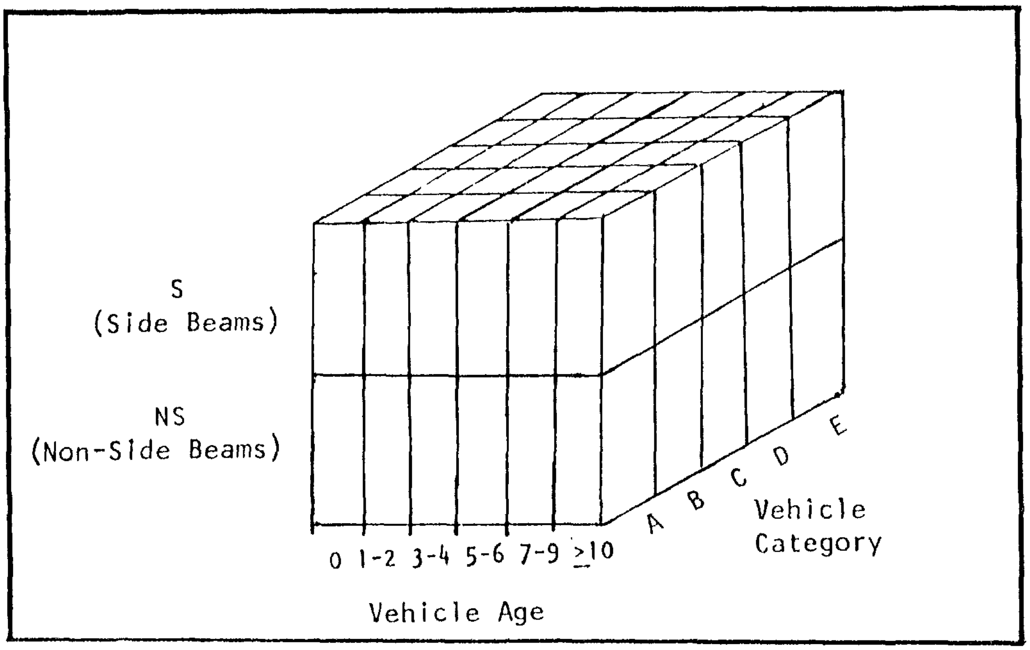

Figure 4-1. Simplified three dimensional analysis of sidebeams presence, vehicle age, and vehicle category.

That is, the ratio of injured drivers to total drivers will not change significantly among vehicle categories. A comparison can be made of the observed and expected number of injuries in each category, where the expected number of injuries is simply the proportion of injuries that would be expected if there were no effects among vehicle categories. For a given cell i, expected injuries E_i are obtained from

$$E_i = r \cdot (m_i + n_i) \quad , \text{ where}$$

$$r = \frac{\sum^{row} m}{\sum^{row} (m+n)} \quad .$$

The ratio r is the sum of the total driver injuries in the row divided by the sum of the total drivers involved in accidents in the row (i.e., for a given vehicle age). The significance of the differences between the observed and expected injuries $(m_i - E_i)$ can be evaluated with a standard Chi-square test. Using the above procedure, the effects of vehicle categories on injuries can be evaluated for each vehicle age class. The identical analytical step as outlined above will also be carried out in the evaluation of side impacts, where, in this case, m is the frequency count of side impacts and n is the count of other impacts.

Using the same approach, an entirely analogous procedure can be undertaken to evaluate the effects of vehicle age. If there were no vehicle age effects, it would be expected that the ratio of injured drivers to total drivers would not change significantly among vehicle age categories within a given vehicle category column,

$$\left(\frac{m}{m+n}\right)_0 \cong \left(\frac{m}{m+n}\right)_{1-2} \cong \left(\frac{m}{m+n}\right)_{3-4} \cdots ,$$

where the subscripts 0, 1-2, and 3-4 indicate the definition of the first three age categories as given in Figure 4-1. The expected number of injuries E_j for a given cell j within a contingency table column illustrated in Table 4-2 would be:

$$E_j = r^1 \cdot (m_j + n_j), \text{ where}$$

$$r^1 = \frac{\sum^{col} m}{\sum^{col} (m+n)} \quad .$$

Again, the significance of the differences between observed and expected injuries (m_j - E_j) can be evaluated with a standard Chi-square test. Thus, the effects of vehicle age classes on injuries can be evaluated for each vehicle category. Collision impact effects can be similarly determined.

4.1.4.1 Implications of Mass Accident Analysis

A fairly detailed description of the analysis of the mass accident data has been included in this section because the results of this analysis do provide some important guidance as to what is required in the statistical analysis of NCSS data. The two key questions which the analysis of the mass accident data addressed and the implications of positive and negative answers to these questions are summarized in Table 4-3.

TABLE 4-3

IMPLICATIONS OF RESULTS OF OLD MASS ACCIDENT DATA ANALYSIS

Condition	Answers to Questions		Implications
	1	2	
1.	Yes	Yes	Vehicle categories as defined in Table 4-1 must be included in the NCSS analysis. A definitive evaluation of the vehicle age factor cannot be included in the analysis until 1979 when a sufficient number of older vehicles with side beams will be available for inclusion in an NCSS-type data collection. With the need to include both vehicle age factors and vehicle category factors, the requirements of sample size will significantly increase, perhaps by a factor between 4 and 10.
2.	Yes	No	A definitive evaluation of the vehicle age factor cannot be made for the reasons cited in Condition 1. The analysis of the 1976-1978 NCSS data should proceed. Interpretation of results, however, must be conditioned by the realization that the effects of vehicle age cannot be fully accounted for until an additional data collection in 1979 contains a sufficient number of vehicles with side beams of age comparable to the age of non-side beam vehicles today.
3.	No	Yes	Vehicle categories as defined in Table 4-1 or an aggregation of these categories as indicated by results, must be included as an additional variable in the NCSS data analysis.
4.	No	No	Conduct NCSS data analysis as planned in Section 4.2.

Question 1	Are there significant vehicle age effects?
Question 2	Are there significant differences in the injury experience during the model years preceding 1969 and following 1972 between models which introduced side beams during 1969-1972 and models which didn't have side beams in this period?

Condition 4 represents a negative response to the potential significant effects of vehicle age and vehicle categories. That is, vehicle age was determined not to be a significant factor affecting injury occurrence from the mass accident data, nor was the possible difference in the side beam and non-side beam car populations in model years 1969-1972 judged to significantly affect injury occurrence. It is quite possible that the analysis of mass accident data will yield this result.

Condition 3 is the least complicating circumstance for which some action is required in planning and executing the NCSS data analysis. This condition will mean that the selective introduction of side beams in model years 1969 through 1972 has created a biased population of side beam versus non-side beam cars. The analysis of the injury rates reveals that differences exist which are dependent on other vehicle characteristics than the presence or absence of side beams. The vehicle categories used in the analysis of the old mass accident data (or an aggregation of them depending on the effects analyzed) must, therefore, be included in the analysis of the NCSS data. Other than increasing somewhat the complexity of the NCSS data analysis, the major impact of this requirement will probably be to increase somewhat the number of additional cases of accident data that must be collected in Phase 3 of the study to supplement the NCSS data.

Condition 2 presents more significant complications to NCSS analysis plans. This condition will mean that the vehicle age factor must be controlled for in the analysis of side beam effects on injury experience. This can and should be accomplished in the analysis of the 1976-1978 NCSS data sample. However, if additional data are to be collected to supplement the NCSS sample, it might be wise to delay the field data collection until 1979, when a sufficient number of cars with side beams will be available in the older vehicle ages (7-10 years old). The NCSS data plus Field Data Collection will then contain a balanced number of non-side beam and side beam vehicles in the older age categories. Condition 2 then might delay the final comprehensive evaluation of the effectiveness of FMVSS 214 by about two years.

The severest impact on FMVSS 214 evaluation plans would result from the occurrence of Condition 1. Under this condition, both vehicle age and vehicle category factors significantly affect the analysis of injury experience and must be accounted for in the NCSS analysis and supplementary data collection requirements. The occurrence of Condition 1 would likely delay the final evaluation of

FMVSS 214 by more than two years and increase data requirements by up to a factor of 4 to 10.

4.2 Analysis of Detailed Accident Data

The following sections will describe the recommended methods for analyzing accident data which have sufficient information to evaluate FMVSS 214. The data requirements, acquisition, and preparation to perform the analyses have also been addressed. There exists currently only one source of data which is of sufficient detail and suitable samples: the ongoing National Crash Severity Study (NCSS). The sample size, however, is not sufficient to show the effect of side beams, if it is in the order of magnitude of 10,000 cases. Therefore, we suggest the collection of additional accident data with a similar level of detail. The sections on data requirements and data analysis will be discussed with respect to NCSS data with the understanding that new data must contain corresponding information and will be analyzed using the same approach. Any exceptions to this will be noted.

4.2.1 Data Requirements

The NCSS is an 18-month effort which began in October 1976 and will continue through March 1978. The goal is to collect data on 10,000 accidents by 1978. Data are being collected by seven NHTSA-sponsored organizations in eight locations: Western New York (CALSPAN), Michigan (HSRI), Miami (Univ.of Miami), San Antonio,Texas (SWRI), thirteen other counties in Texas.(SWRI), Kentucky (Univ. of Kentucky), Indiana (Indiana Univ.),and Los Angeles,California (Ultrasystems). The sampling criteria are based on towaway accidents which are divided into three strata. Stratum 1 is sampled at 100 percent and consists of accidents where an occupant's injury requires at least an overnight stay in a hospital (includes fatalities). Stratum 2 is sampled at 25 percent and consists of accidents where an occupant requires hospital attention but does not stay overnight. Stratum 3 is sampled at 10 percent and covers all remaining towaways. NCSS data will be the main source used for the preliminary analysis of FMVSS 214.

The specific NCSS variables needed for the proposed analysis can be divided into three categories as shown in Table 4-4. The first category comprises those data elements which are not directly needed in the analysis but will be used to classify and edit accident data and to construct individual variables needed for the analysis. These preprocessing variables will be described further in Section 4.2.3.

The second category covers the variables which are known to be important for the evaluation analysis. The twelve variables listed in Category 2 of Table 4-4 are directly available on the NCSS file. These variables have been further subcategorized to define their usage in the analysis. In addition, some variables which are known to be important but are not directly available on the NCSS file must be reconstructed from related data which are available. For example, the "Angle of Impact" can be derived from "ΔV Longitudinal" and "ΔV Lateral" both of which are on the file; the presence or absence of an adjacent occupant can be determined from the "Specific Position of Occupants" variable; the presence or absence of a side beam can be derived from Vehicle Make/Model/Year information, etc. In the case of new data collection, these variables may be determined directly rather than by reconstruction.

The third category in Table 4-4 designates those variables which might be useful for the analysis but whose effect is likely to be small or negligible.

TABLE 4-4

NCSS VARIABLES TO BE USED IN EVALUATING FMVSS 214

Category 1	Category 2	Category 3
Pre-processing Variables	Variables Known to be Important	Variables Which are Possibly Important
	Dependent Variables	Dependent Variable
1. Vehicle Make	1. AIS† (overall)	1. Occupant Interior Contact Point
2. Vehicle Model	2. OIC‡ (each injury)	
3. Vehicle Model Year	3. Maximum Extent of Intrusion	
4. Damage Dimensions		Independent Variables
5. Original Dimensions	Stratifying Variables	2. Vehicle Weight
6. Type of Impact	4. Occupant Seating Position	3. Occupant Height
7. CDC*	5. Ejection/Entrapment	4. Occupant Sex
		5. Front Seat Type
	Independent Variables	6. Vehicle Body Style
	6. ΔV Total	7. Area of Intrusion
	7. ΔV Longitudinal	8. Horizontal Area of Severest Intrusion
	8. ΔV Lateral	9. Intruding Component
	9. Impact Speed	10. Window Status
	10. Occupant Age	11. Glass Damage
	11. Restraint System Usage	12. Head Restraints
	12. Adjacent Occupants (from specific position of occupants)	

*CDC - Collision Deformation Classification

†AIS - Abbreviated Injury Scale

‡OIC - Occupant Injury Classification.

These variables should be investigated at a later stage of the analysis to see if any explain a significant portion of the remaining residual variance of the model. The distinction between Categories 2 and 3 is based on our current assessment of the available information;and the assignment of some of the variables is only preliminary. The variables in Category 2 will be incorporated into the model initially and, depending on the results, certain variables may be found to have non-significant effects. At this point, Category 3 variables may be added to or replace Category 2 variables in the analysis. The results of this analysis will be the basis for deciding which variables to collect in a new data collection effort.

4.2.2 Data Acquisition

NCSS Data

Of the seven organizations collecting data for the NCSS, CALSPAN Corporation is editing and preparing the final version of the data. We assume that the NCSS data will be stored on magnetic tapes and that appropriate coding manuals will be available. By the time the proposed analysis is performed, it is expected that NHTSA will have the NCSS data base in operationally usable form.

New Data Collection

In collected new data, not all of the NCSS data items will be necessary. At most, the variables cited above in Table 4-4, will be required, and possibly the initial analysis of the NCSS data may reveal other variables which could be dropped.* In general, in this discussion, it is presumed that the same variables and categories used in NCSS will be used in the new data collection, except where noted below. This section will discuss the following topics in order: data items, data volume, sampling sites, investigation teams, data collection, and data processing.

The following NCSS data items will not be required for FMVSS 214 evaluation:†

- Patient History Outpatient Visits
- Activity Restriction
- Neck Injury (Rear and Rear Corner Impacts)

"Functional Classification of Roadway" is not directly relevant to the reconstruction of ΔV and could be dropped. If the initial analysis of NCSS data for

*It is recognized that there may be other reasons outside the evaluation of FMVSS 214 which make it cost effective to collect all NCSS data items. We have not considered those reasons here, although they should be considered when the time comes to collect new data for FMVSS 214 evaluation.

†The following discussion refere specifically to data items by their NCSS accident data names.

single vehicle crashes reveals no promise, then these accidents and that information need not be collected. We expect the accident of most interest to be the low speed car-car front-side collision. The information required on Restraint Systems is more detailed than is necessary; Malfunctioning Defect, System Defeated, Restraint System Damaged, and Type of Adjustment-Locking System are not needed. Seat Type, but not Seat Performance,data are needed. No data are needed on Fuel Leakage/Fire Hazard. (Of all data collected for NCSS, these eliminations are a small fraction of the total.)

The volume of data required depends on the size of the effect and on the desired confidence level. Table 4-5 is a power table which shows the relationship between sample size, size of the real effect, and the probability of recognizing that effect. In the illustration below, it is assumed:

n_1 = larger sample size

n_2 = smaller sample size

and

$$n_2 = \frac{1}{2} n_1$$

This is approximately the case we expect with the NCSS data where two-thirds of the appropriate crashes will be newer cars with side beams and one-third older cars without. Given:

p_1 = probability of the occurrence of some injury or injury level, etc. in the larger sample

p_2 = probability of the same occurrence in the smaller sample,

then the ratio, r, of the probabilities (p_2/p_1) is a measure of the effectiveness of side beams. Therefore, using Table 4-5, if $p_1 = 0.10$ and $p_2 = 0.15$ ($r = 1.5$) then the larger sample (n_1) must equal 1,000 to have an 80% chance of detecting this difference.*

The initial analysis of NCSS will give a first estimate of the effectiveness of the Standard. Using this estimate and the desired confidence level, one can then determine the absolute number of additional cases required. If the effectiveness is greater in a speed range, or for some other set of conditions, subsequent data collection could be explicitly targeted, thus requiring fewer observations.

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*Results such as these are obtained by postulating the probabilities and sample sizes, and then using the Chi-square test for $\alpha = 0.1$ to determine what is the probability of correctly detecting a difference (P_2/P_1) in probability at the levels of p_1 and p_2.

TABLE 4-5

POWER TABLE FOR UNEQUAL SAMPLE SIZES

($n_1 = 2 \cdot n_2$)

Probabilities			Probability of Detecting a Difference of P_2/P_1 in Occurrence of An Accident-Related Event for With Side Beam (P_1) and Without Side Beam (P_2) Samples								
			Larger Sample Size (n_1)								
P_1	P_2	r	20	50	100	200	500	1000	2000	4000	10,000
0.1	0.15	1.5	0.09	0.12	0.16	0.26	0.52	0.80	0.97	1.00	1.0
	0.12	1.2	0.07	0.07	0.07	0.09	0.14	0.23	0.39	0.66	
	0.11	1.1									0.48
0.25	0.375	1.5	0.12	0.21	0.36	0.61	0.94	1.00	1.00	1.00	1.0
	0.3	1.2	0.07	0.08	0.11	0.16	0.31	0.54	0.83	0.98	
	0.275	1.1									0.91

Consider the following example relating expected effectiveness and sample size. If the following shifts in injury for driver/left side impacts were observed:

TABLE 4-6

HYPOTHETICAL SHIFTS IN INJURY FREQUENCY

Injury Level	0	1	2	3+
Without Side Beam * (P_2)	0.45	0.45	0.06	0.03
With Side Beam (P_1)	0.69	0.25	0.03	0.03
Shift to Next Lower AIS		50%	50%	0

*Based on the rough distribution of AIS found in Appendix C.

Thus, using Table 4-7, we can estimate the probability of detecting such a shift for a given sample size. That is, at n_1 = 2000 and n_2 = 1000, the probability of detecting a 50% shift of Level 2 injuries is approximately 80%. However, Level 2 injuries represent only 4 percent of total injuries to drivers in left side impacts,which represent approximately one-half of all side impacts. Therefore, total sample size would have to be 6000 side accidents (3000 x 2).

TABLE 4-7

POWER TABLE FOR UNEQUAL SAMPLE SIZES

Probability of Detecting a Difference $P_2 - P_1 = \Delta$					
P_1	$P_2 = P_1 + \Delta$			Sample Sizes	
	Δ = 0.02	0.05	0.10	Side Beam Cars	Non-Side Beam Cars
0.1	0.06	0.09	0.15	$n_1 = 20$	$n_2 = 10$
0.15	0.06	0.09	0.15		
0.20	0.06	0.07	0.11		
0.25	0.06	0.07	0.10		
0.10	0.07	0.11	0.25	$n_1 = 50$	$n_2 = 25$
0.15	0.06	0.10	0.20		
0.20	0.06	0.08	0.18		
0.25	0.06	0.08	0.16		
0.10	0.07	0.16	0.45	$n_1 = 100$	$n_2 = 50$
0.15	0.07	0.13	0.33		
0.20	0.06	0.12	0.29		
0.25	0.06	0.11	0.26		
0.10	0.09	0.26	0.66	$n_1 = 200$	$n_2 = 100$
0.15	0.08	0.20	0.56		
0.20	0.07	0.18	0.49		
0.25	0.07	0.16	0.44		
0.10	0.14	0.52	0.95	$n_1 = 500$	$n_2 = 250$
0.15	0.12	0.41	0.90		
0.20	0.10	0.35	0.85		
0.25	0.09	0.31	0.79		
0.10	0.22	0.80	1.0	$n_1 = 1000$	$n_2 = 500$
0.15	0.18	0.68	1.0		
0.20	0.15	0.60	0.99		
0.25	0.14	0.54	0.98		
0.10	0.39	0.98	1.0	$n_1 = 2000$	$n_2 = 1000$
0.15	0.30	0.93	1.0		
0.20	0.25	0.87	1.0		
0.25	0.22	0.83	1.0		
0.10	0.75	1.0	1.0	$n_1 = 5000$	$n_2 = 2500$
0.15	0.61	1.0	1.0		
0.20	0.52	1.0	1.0		
0.25	0.46	1.0	1.0		
0.10	0.96	1.0	1.0	$n_1 = 10{,}000$	$n_2 = 5000$
0.15	0.88	1.0	1.0		
0.20	0.81	1.0	1.0		
0.25	0.75	1.0	1.0		

On the other hand, for the 50% shift in Level 1 injuries, at n_1 = 500 and n_2 = 250, the probability of detecting such a shift is at least 80%. These accidents represent about one-third of all driver injuries and (given the above factors) the total sample necessary would be 1500 (750 x 2). With this sample, the probability of detecting a shift in Level 2 injuries is smaller--approximately 40%. Therefore, given the larger sample (approximately 6000) it would be sufficient to detect this large a shift from Level 2 to 1. One can estimate the probability of detecting smaller shifts with Table 4-7. If the initial analysis reveals that the shifts from Level 2 are smaller than expected, the data collection effort could be concentrated more on these, or any other type of accident of interest.

In general, the new data collection sites should be the same eight areas as the earlier NCSS data collection--Western New York, Michigan, Miami, San Antonio, other areas in Texas, Kentucky, Indiana, and Los Angeles. The accidents of most concern will be urban and suburban, front-side collisions occurring at relatively low speeds. It is expected that the results of the initial NCSS data analysis will confirm this requirement. If the data collection effort lasts one year, an average of 375 to 625 cases per site will be required.

The investigation teams should consist of at least two persons capable of collecting data on three major accident elements: Driver, Vehicle, and Environment. Although the individuals required to gather the NCSS data do not have to be as specialized as those on multidisciplinary accident investigation (MDAI) teams, they must carefully follow proper procedures for gathering data at the accident site and in medical followups. The types of individuals suggested for this type of work are ex-police officers or engineering/science graduate students.

In addition to the on-site capability, there are other management requirements which deal with data collection and followup. At each site a mechanism has to be developed to notify the accident investigation teams of the appropriate type of accident. Typically, the local and state police might be contacted at the beginning of each day to see what accidents are available for investigation. The team must go to the site and/or location of vehicles/occupants and collect all the relevant data available. Because of the expected importance of ΔV, data with regard to vehicle and environmental conditions should be collected very carefully. Office work includes completing data forms, doing followup work on injury aspects, and quality control. It is very important that there be complete data on each case; however, too much pressure in this respect can lead investigators to "fabricate" data.

After all the vehicle and environmental data have been recorded, there is a data processing operation which must take place in order to reconstruct ΔV.* Presently CALSPAN Corporation is editing and preparing the final version of the NCSS which involves using their computerized accident reconstruction programs (CRASH and SMAC). At least CRASH would have to be run on the new data to provide a comparable measure of ΔV, and perhaps SMAC could also be used on a subset of the data to see what variations exist. (The SMAC program is iterative, and more complicated and expensive to run.)

In order to minimize the changes required from the initial analysis, the new data should be formatted exactly as the NCSS data tapes, writing blanks where information has not been collected. Thus, any processing programs written for the NCSS data will also apply to the new data.

4.2.3 Data Preparation

NCSS Data

A substantial amount of data pre-processing is necessary to translate NCSS data into the format required to perform the suggested analyses. Part of this effort will consist of recording existing variables onto different scales, particularly in the case of categorical variables. For example, the analysis might limit vehicle weight to five categories, whereas on the NCSS file, vehicle weight is in terms of hundreds of pounds. The other major portion of the pre-processing activity will be the reconstruction of variables needed for the analysis but which are not directly available in the data base. The combination of Vehicle Make, Model, and Model Year variables will be used to reconstruct a number of necessary variables. The most important of these is whether or not a vehicle has a side beam. Prior to the 1969 model year, no vehicles contained side beams. From the 1973 model year on, all vehicles contained side beams. Between 1969 and 1972 model years, side beams were introduced by car model. The other variables to be reconstructed from Vehicle Make/Model/Model Year are: the

*The required accuracy of reconstructed ΔV is discussed in Appendix D.

type of vehicle frame construction, the type of bumper of the striking vehicle, and vehicle weight (when it is missing). These are all determinable production characteristics of individual car models. The exact location and severity of the impact may be decoded from "Damage Dimensions" *versus* "Original Dimensions" with the CDC used as a check. The OIC for each injury will be separated into head *versus* torso injuries, etc. All these transformations will be completed prior to performing the analysis.

New Data

The new data will be formatted exactly as the NCSS data, except that those variables which are not relevant to the present study may be omitted. Therefore, the data preparation procedures developed for the initial NCSS analysis can be applied to the new data also.

4.2.4 Data Analysis

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

The intent of the approach is to discern differences, if any exist, in crash protection afforded vehicles equipped with side beams as opposed to vehicles not equipped with side beams. We will focus on side crashes and examine, for each case, the severity of injury using the AIS scale and the degree of vehicle damage using the extent of intrusion into the side of the struck car. We consider the AIS variable as categorical and the intrusion variable as continuous. It would be preferable, from a statistical aspect, to consider AIS as continuous also, but the scale is not equidistant and this assumption would be invalid. The ramifications of a continuous versus a categorical dependent variable are discussed later in more detail. We wish to predict the chance of falling into a particular cell or interval given levels of a set of explanatory variables. More precisely, we are suggesting the estimation of a functional relationship between the probability of various levels of injury or intrusion and these independent variables. Although gross data tabulations may directly reveal differences in the pattern of injury and intrusion distribution, this aggregation of the data may mask important evidence contained in it.

Estimating a functional form enables at least two ways of discerning the effect of varying levels of the independent variables on the likelihood of a particular injury or intrusion classification. We may first examine the coefficients associated with these explanatory variables and see if they are significant (significantly different from zero) and also if they differ significantly across functions estimated for different data bases. We may, secondly, attempt to "control" the effects of some explanatory variables in an effort to better see the effect of varying levels of others.

Since the coefficients in our fitted model may be expected to be quite different for accidents where the struck vehicle had side beams as opposed to those where the struck vehicle did not, we propose to analyze the groups separately. Further, asymmetries with respect to left and right side crashes and driver vs. passenger injury may necessitate further stratification into separate analyses. This will likely have the unfortunate effect of forcing sample sizes within strata to be too small for satisfactory model prediction. One separation which is necessary is single car from multiple car side crashes. Apart from the fact that single car crashes will be few in number within our data set, they have different physical properties than multiple car crashes and hence involve different (possibly non-comparable) functions of explanatory variables.

Engineering considerations of the forces involved in side crashes suggest that implementation of side beams may result not only in a shift in the distribution of injury severity for such crashes, but may also increase the proportion of head injuries relative to torso injuries, etc.

Measurement Variables

From the previous discussion, the dependent variables will be AIS assignments by injury location (possibly more than one) and extent of intrusion (on a continuous scale). AIS classification and extent of intrusion will be fitted separately to the independent variables.

The continuous independent variables suggested are change in velocity, impacting speed of the striking vehicle, and angle of impact. The discrete independent variables needed are: the type and usage of the occupant's seat restraint, the model year dichotomized into pre- and post-1967, the occupant's age, and the presence of an adjacent occupant. The previous variables are presumed to be important factors governing an occupant's injury in a side impact. In addition, there are other speculative factors which might have an effect. Some examples are:

the width of the striking vehicle, the bumper construction of the striking vehicle, the frame construction of the struck vehicle, the occupant's height, the occupant's sex, the usage of head restraints, etc. A more complete list of these factors which are available on the NCSS data base is shown in Category 3 of Table 4-4. These speculative effects will be introduced individually into the model at a second stage to assess whether they explain a significant amount of the remaining variance.

The Data

The data to be usrd are the NCSS data which are currently being gathered (since October 1976) and/or future accident data with a comparable level of detail. The level of detail inherent in these data will enable us to obtain reliable measurements of the variables indicated above. The data are biased toward more severe injuries and toward urban accidents. In principle, such biases are of no concern if one wants to determine the effectiveness of a Standard in specific situations, and not to extrapolate to the overall effectiveness in "all" situations. In practice, the bias toward severe injuries is a disadvantage while the bias toward urban accidents is an advantage, since we expect the Standard to have its greatest effects in low-speed, less severe injury accidents. Early predictions of the expected size of the data base for this analysis (number of accidents involving side crashes) by AIS classification available from NCSS are given in Table 4-8 below.

TABLE 4-8

ANTICIPATED DISTRIBUTION OF AIS LEVELS IN NCSS SIDE DOOR IMPACTS*

Location	AIS							
	0	1	2	3	4	5	6	Total
Struck in Left Passenger Compartment, or Left Side Distributed	760	780	95	20	5	5	5	1675
Struck in Right Passenger Compartment, or Right Side Distributed	825	670	110	20	5	5	5	1640

*The derivation of Table 4-8 can be found in Appendix C.

Since the cells involving AIS ≥ 4 are sparse we will likely have to combine them into one group. Since best estimates indicate roughly one-third of the accident-involved passenger vehicles at present may be expected not to have side beams (i.e., older cars), we may expect roughly 1,000+ accidents involving such vehicles.

The Basic Model

One recommended analytic method involves fitting a multinomial response model with both continuous and discrete explanatory variables. The notation "p" will be used generically to represent any individual cell probability or any cumulated cell probability and also whether we are fitting AIS classification or extent of intrusion. Typically, the model is expressed in functional structure to yield log p.

The continuous mean effects are:

Impacting Speed of the striking vehicle which is denoted by S and enters quadratically.

Change in Velocity which is denoted by ΔV and enters quadratically.

Angle of Impact which is denoted by α and enters trigonometrically.

The discrete mean effects are:*

Seatbelt Status	B - Categorical
Model Year Group	M - Dichotomous
Occupant Age	A - Categorical
Presence of Adjacent Occupant	J - Dichotomous

Some of these factors are in fact continuous but since their influence is likely to be relatively small, they might be treated as categorical with only a few categories. On the other hand, both the main factor velocity change and angle of impact may be treated as categorical variables with sufficiently many levels. The Model Year Group variable (M) has been included to control for the effect of other safety Standards implemented before 1969 which would affect some non-side beam cars.

The most likely interactions are:

$\alpha \times B, \alpha \times \Delta V, \alpha \times \Delta V^2, \alpha \times S, \alpha \times S^2, \alpha \times M, \alpha \times J$, and $M \times \Delta V$.

*The variable list is only illustrative in that the specific variables included will change as the analysis progresses.

The recommended model is:

$$\begin{aligned}
\log p = \; & \mu \\
& + a_1\Delta V + a_2\Delta V^2 + b_1 S + b_2 S^2 && \text{(continuous)} \\
& + B_i + A_j + M_k + J_\ell && \text{(categorical)} \\
& + c_1\Delta V\sin\alpha + c_2\Delta V\sin 2\alpha + c_3\Delta V\cos\alpha + c_4\Delta V^2\sin\alpha && \text{(continuous} \\
& + c_5\Delta V^2\sin 2\alpha + c_6\Delta V^2\cos\alpha + d_1 S\sin\alpha + d_2 S^2\sin\alpha && \text{interactions)} \\
& + B_i\cos\alpha + M_k\cos\alpha + M'_k\ \Delta V + J_\ell\sin\alpha && \text{(continuous-categorical interactions)}
\end{aligned}$$

The subscript for each of the categorical mean effects runs over the possible categories for this variable. Typical constraints force the sum of these effects weighted by cell size over the indexing subscript to be zero. The interactions of Change in Velocity with Angle and Impacting Speed with Angle enter simply as other continous variables in the model. All the other model interactions combine a continuous and a discrete variable. Such terms are typically a modeling problem and most conveniently are handled as qualitative variables by categorizing the continuous variable (just for the interaction term) and hence forcing the interaction term to be categorical. Again, typical constraints force the sum of these latter interaction effects weighted by cell size over the subscript to be zero as well. The Model Year Group interaction with ΔV ($M'_k\ \Delta V$) contains M'_k because the value of the coefficient will differ from the M_k in its interaction with impact angle ($M_k\cos\alpha$).

Each accident has associated with it a vector of observed independent variables as described and the observed dependent variable is, in the case of severity of injury, either an AIS classification by head injury, by torso injury, or overall depending upon whether we are fitting "p" by location of injury or overall. In the case of degree of vehicle damage, the observed dependent variable is an extent of intrusion value.

Discussion of the Model

The model encompasses twenty independent variables. It is probably too cumbersome to consider all variables at once. We would, therefore, attempt to include more and more variables in a sequential manner beginning with those deemed likely to be most significant (via other considerations) until a sufficient degree of explanation is attained. The two proposed analyses can be applied to any submodel of this overall model.

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

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

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

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

**Discussion of confidence intervals is on pages 4-35, 4-36.

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

$$\underbrace{a_1 \Delta V + a_2 \Delta V^2}_{} + \underbrace{c_1\ V \sin\alpha + \ldots + c_6\ V^2 \cos\alpha}_{}$$

$$\text{by} \qquad \Delta V_g \qquad + \qquad (\alpha \times \Delta V)_{gh}$$

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

There is one further point. Since we have multinomial response cells, the following procedural artifice is needed to formally achieve the binomial response mandated by the log-linear model. The cumulative cells AIS $\leq$ 0, AIS $\leq$ 1, AIS $\leq$ 2, AIS $\leq$ 3 would be fitted in sequence, i.e., in log p, p = P(AIS $\leq$ i) for each of i = 0, 1, 2, 3. Due to the small individual cell sizes, all AIS $\geq$ 4 are grouped and P(AIS $\geq$ 4) is estimated by 1 - P(AIS $\leq$ 3). The estimates of the multinomial cell probabilities are obtained by subtraction, i.e., P(AIS = 1) = P(AIS $\leq$ 1) - P(AIS $\leq$ 0), etc. Engineering calculations with regard to interior forces resulting from an accident suggest that likely shifts in the AIS classification resulting from the side beam standard will be from AIS = 3 to AIS = 2 or 1, AIS = 2 to AIS = 1, and AIS = 1 to AIS = 0. Thus, the AIS $\geq$ 4 cases are not of crucial consequence in the model. Fitting the most populated cells cumulatively and leaving the least populated to the remainder is recommended.

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

For example, suppose we have fit

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

and we wish to "control" the effects of variables j and k to see the effect of variable i. We compute an average

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

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

Finally, it is tempting to suggest a combination of the two analytic approaches discussed. Why not treat α and ΛV as covariates and then attempt to fit a log-linear model in the presence of these covariates? A moment's reflection reveals that log p is then essentially adjusted to

$$\log p - (a_1 \Lambda V + a_2 \Lambda V^2 \ldots)$$

and is no longer a dichotomous variable. It is now a continuous variable and would be fitted to the remainder of the independent variables as a straightforward ANOVA problem. That is, combining the two approaches would become equivalent to the first analysis, and no new insights would be added.

4.2.5 Flow Diagram of Detailed Data Analysis

This section discusses in detail Figure 4-2, Proposed Statistical Analysis Scheme for Evaluating FMVSS 214 (Side Door Beam). This figure describes the step-by-step process we suggest for the analysis. However, to a significant degree exactly what should be done depends on the form of the data and the judgment and experience of the analysts.

For the initial analysis the detailed data base would be NCSS. Later analysis would use newly collected data, either separately or in combination with NCSS data. If the NCSS data show a significant or near significant effect, the new data base should be analyzed independently in order to give an independent confirmation. If there is no indication of an effect, or only a slight indication, from NCSS data, then the old and new data should be analyzed in combination and the new data should also be analyzed separately. The reasons are (1) a small effect may possibly show up in the combined data base, and (2) new data may have greater concentration in the relevant speed ranges. Analysis steps below are keyed to Figure 4-2.

1.0 Initial analysis calls for classification of the gross data in tabulations of side beam or no side beam; (i) by AIS overall, (ii) by AIS for severe injury location, (iii) by AIS for impact location, (iv) by extent of intrusion, etc. Each such tabulation is analyzed as a test of homogeneity. Significant differences indicate that fitting a structural model for the dependent variables (AIS classification or extent of intrusion) on a carefully selected set of independent variables will reveal differences in the impact of at least some of these independent variables. Even failure to reveal significant differences only suggests that such gross aggregation is masking possibly differing response of the dependent variables to specific independent variables.

1.1 Decision on body area classification should be made on the basis of the numbers of injuries by location; that is, whether to use only three categories--shoulder, head/neck, rest of body--or some more detailed categorization scheme. A further decision is whether to analyze injuries per body area per accident (shoulders, etc.), or conditionally based on injury levels--for example, head injury vs. other injury.

It should be noted at this point that the subsequent analyses are done in parallel for driver injuries for left and right impacts, front occupant injuries for left and right impacts, and also rear seat occupant injuries for different impact levels.

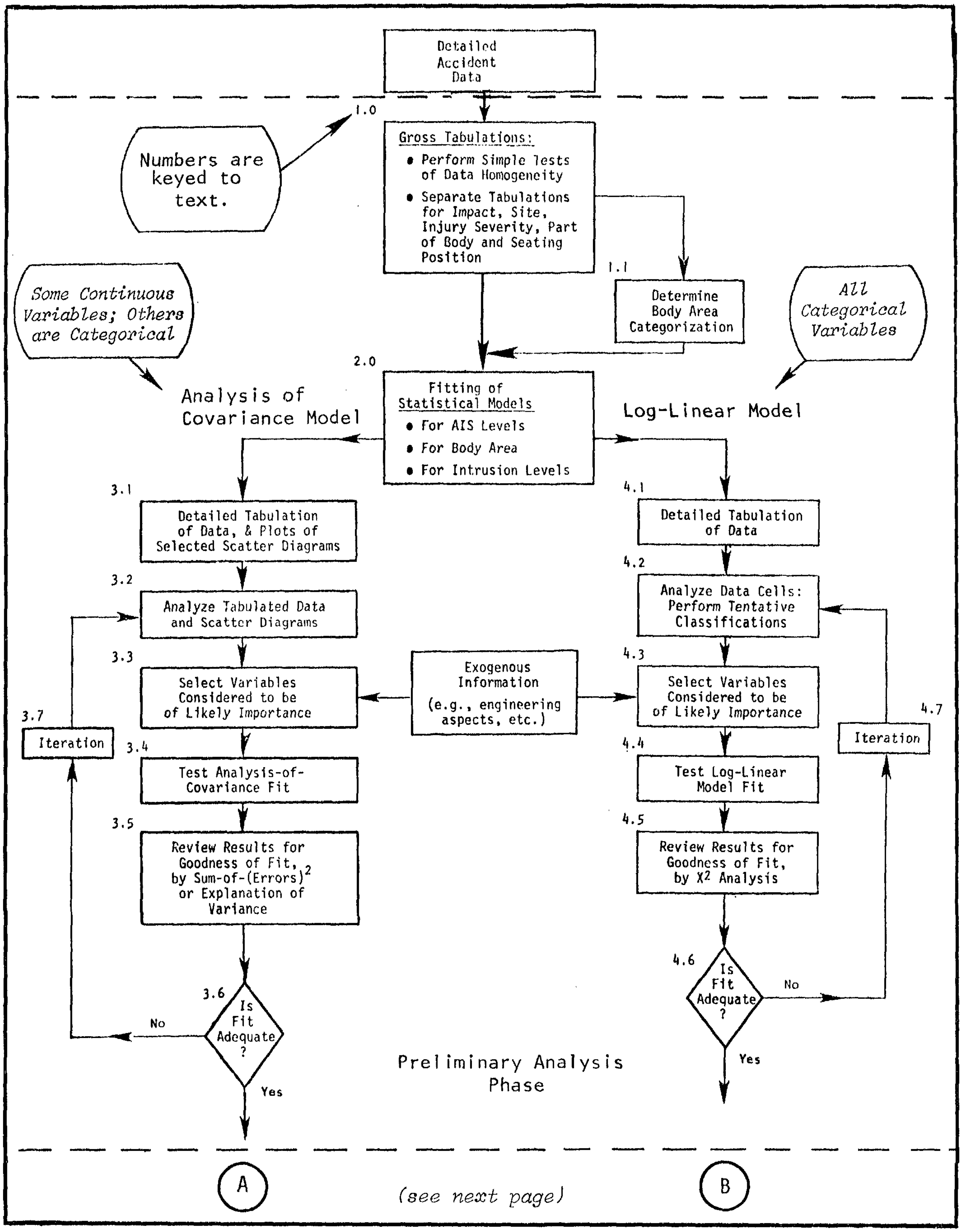

Figure 4-2. Proposed Statistical Analysis Scheme for evaluating FMVSS 214 (Side Door Beams).

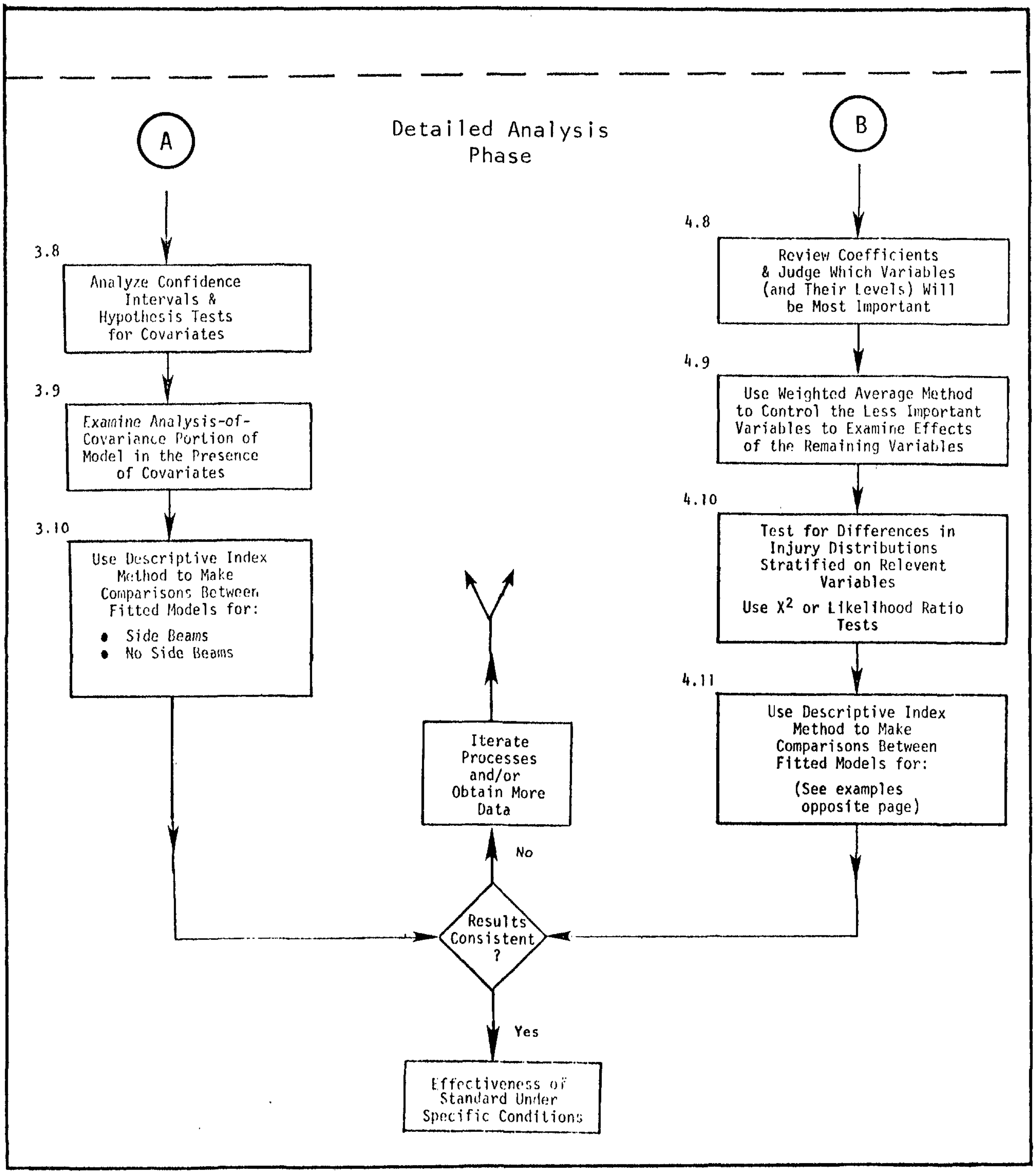

Figure 4-2 (continued).

2.0 In fitting the model there are certain stratifications of the data across which we expect model coefficients to be quite different. We certainly expect this to be true for sidebeams. Other possibilities include left and right side crash asymmetries, driver vs. passenger injury asymmetries, single car vs. multiple car crashes, etc. If the other independent variables are not likely to be affected by such asymmetrical dichotomies, or if we are prepared to further complicate the model by adding appropriate interaction terms, then the dichotomous variables may be incorporated as additional independent variables in the model. If not, then we stratify the data and fit separate models to each of the two levels. In analyzing the AIS levels, models would be fitted for specific AIS levels and for AIS greater than (or less than) a specified level--AIS>0, AIS>1, etc.

The following examines the left hand portion (Analysis of Covariance) of the flow chart. It is important to note that in the fit, the ANACOVA model on the left hand side is not log p but rather just Y where Y is a categorical variable such as AIS level or intrusion level.

3.1, 3.2, 3.3
Before embarking on formal analysis one needs to acquire a better feel for what the data are like. Scatter diagrams and contingency tables will reveal patterns of concentration of levels of one variable with another. Corresponding correlations and tests of independence would be run to confirm the existence of such non-random patterns. These results in concert with exogenous information (such as engineering considerations, prior study findings, etc.) will enable us to establish a preliminary, informal ordering of the independent variables in terms of their likely importance.

3.4 We then select as a starting subset a "most important" subgroup of these variables (some continuous and some categorical) and proceed to fit the ANACOVA using available program packages.

3.5 We next examine, in terms of the magnitude of the error sum of squares, the goodness of fit. The size of the error sum of squares as a proportion of the total sum of squares reveals the proportion of the total variation still unexplained by the fitted model.

3.6 We then decide if this proportion is small enough to say that the model fit is adequate or if we wish to add in the "next most important" variable and iterate the process (3.7). Ultimately, we will declare the model to be adequately fit,although we do not at all expect to use the full set of independent variables to do so.

3.8, 3.9
We now wish to analyze how significant the fitted variables and associated interactions truly are. The ANACOVA contains both continuous and categorical variables. The submodel involving the categorical variables is called the associated analysis of variance (ANAVA model). The continuous variables (Covariates) and the categorical variables (ANOVA effects) must be studied differently. Confidence sets (individual or simultaneous) are typically developed for the covariates after which the ANOVA is considered in the presence of these covariates. The existance of interaction and main effects is tested by F tests and for significant effects, and contrasted (again, individually or simultaneously) over the levels of these effects help to reveal where the differences lie.

3.10 The descriptive index should describe, for example, the frequency of AIS levels for side beam and no-side beam cars by ΔV range, impact angle, etc., while controlling for all other factors. (See Figure 4-3 below for an example.) The ANACOVA for our experimental situation is particularly disappointing in making comparisons between models. In order to retain a few continuous variables,we have sacrificed the categorical nature of the dependent variables. Although the dependent variables are recorded as say 0, 1, 2, 3, 4 (in the AIS injury case), they must be treated as continuous and approximately normally distributed. The left hand side of our model is no longer log p so that a log probability ratio index is not meaningful. Comparison between fitted models must be accomplished as two sample normal tests which is certainly unappealing. The whole ANACOVA approach is considered unsatisfactory for injury severity and we tend to favor the log linear model instead for intrusion analysis.

The following text examines the right hand portion (Log-Linear Model) of the flow chart. In this case the variables being fitted by the models are the

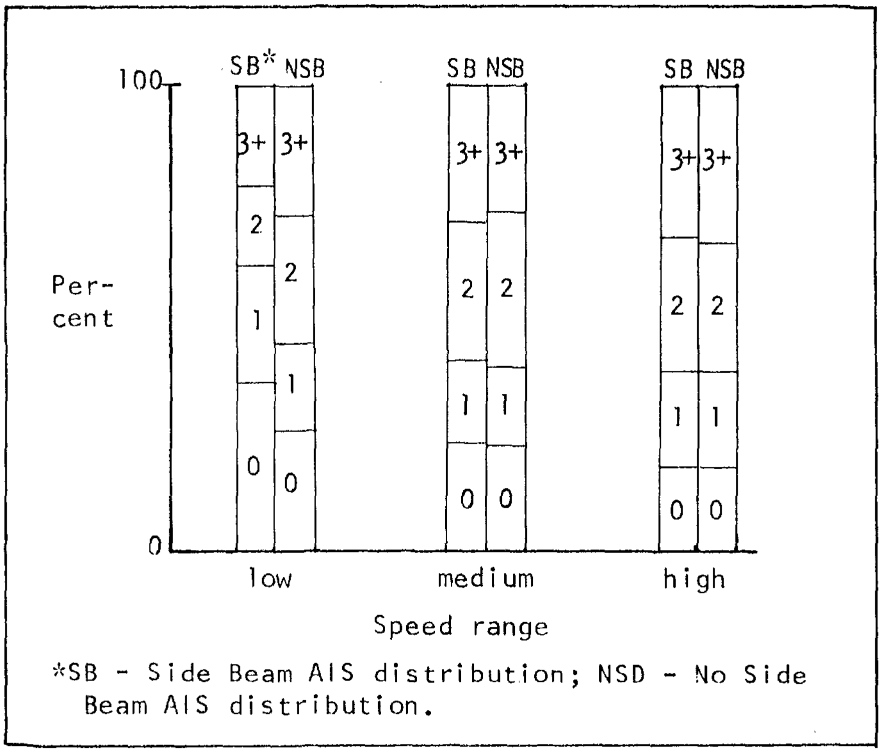

Figure 4-3. Descriptive Index = Hypothetical Distribution of AIS Levels by Speed Range.

logarithm of the probability (log p) for overall AIS levels, or AIS levels for specific body areas, etc., separately for the side beam and no-side beam cases.

4.1 In order to get insight into the structure of the data, we would tabulate the data in various ways, e.g., by speed ranges, weight categories, side beam and no-side beams, etc. Tabulations would then be reviewed for patterns.

4.2 Some rough analysis should be done on the various classification cells: determining means, some simple homogeneity tests, looking for empty cells, etc.

4.3 Based on exogenous information (engineering considerations) and on the rough analysis in 4.2, we would choose a subset of all the variables that we consider of primary importance. We would also decide how to classify its values. This is a similar problem to determining body area classification (1.1); it depends on the distribution of the data and what we consider most important to examine.

4.4 Using an appropriate computer program,we would fit a log linear model to the chosen data and so estimate the various parameters. (This model is described in Section 3 and in detail in Appendix B). A model of this form is what we favor for the analysis. The categorical log linear model to be considered is

$$\log p_{ijk\ \text{etc.}} = \mu + \Lambda_i + M_j + (\Lambda M)_{ij} + N_k + (\Lambda N)_{ik} + (MN)_{jk} + (\Lambda MN)_{ijk}$$

where Λ_i represents the effect of the i^{th} injury classification, M_j is the effect of the j^{th} speed classification, N_k the k^{th} weight classification and similarly for other variables. The interaction terms, e.g., $(\Lambda M)_{ij}$ tell us how one variable reacts differently for different values of the other. For example, $(\Lambda M)_{ij}$ would indicate how injury classification probabilities change at different speeds, while $(\Lambda MN)_{ijk}$ shows how injury classification probabilities are affected by different weight speed combinations.

4.5 We would determine the goodness of fit by an appropriate test, e.g.,χ^2, or Likelihood Ratio.

4.6, 4.7
If we believe the fit is not good enough or if we believe that there is more information in the data, we would return to Step 4.2. If we are satisfied with the model fit, we proceed to 4.8.

4.8 Now that the model has been fit, we would look at the submodels to determine which variables are relevant and which not. (Some of this would be done in Step 4.5.)

4.9 If we feel that a particular variable, while present, is not important, we may weight over the variable to remove its slight effect.

4.10 We now would compare the two cases, side beams and no-side beams. In order to determine whether or not there is a difference between side beam cars and those without, we would proceed to see if a model that allows for different injury probabilities in a given situation between SB and NSB cars gives a significantly better fit to the data than one requiring the same injury probabilities. By a situation we mean a fixed set of values of the other important variables, e.g., speed, weight. To show what we are trying to do, let us suppose the simple case that speed is the only other variable besides injury being considered. Suppose we have classified speed (of striking car) into 10 mph intervals, i.e., 5 mph = (1 to 10 mph), 15 mph = (11-20 mph), etc. Then 15 mph refers to a situation; if speed and weight were considered then (15 mph, heavy car) would be a situation.

What we now wish to see is if given a particular situation (e.g., 15 mph) are the probabilities of the different injury classifications the same or different? Similarly for 25 mph, 35 mph, etc. We would do the analysis over all the speeds together and also for those that might be considered especially important. As an example, suppose we have the following data: (we are restricting it somewhat to have to do less arithmetic in the example).

NO-SIDE BEAM

AIS	0	1	≥ 2		
Speed					
0 - 20	150	150	0	300	*30%*
21 - 40	50	150	200	400	*40%*
≥ 41	50	100	150	300	*30%*
	250	400	350	1000	*100%*
	25%	*40%*	*35%*	*100%*	

SIDE BEAM

0 - 20	400	380	20	800	*40%*
21 - 40	150	300	350	800	*40%*
≥ 41	70	130	200	400	*20%*
	620	810	570	2000	*100%*
	31%	*40.5%*	*28.5%*	*100%*	

Note that although the probability of severe injury is less for side beam cars, they are also less in accidents at higher speeds. The idea is to consider the distribution of injury at each given speed. We derive the following tables:

NO-SIDE BEAM

AIS	0	1	≥ 2
Speed			
0 - 20	50%	50%	0
21 - 40	12.5%	37.5%	50%
≥ 40	16.7%	33.3%	50%

SIDE BEAM

0 - 20	50%	47.5%	2.5%
21 - 40	18.75%	37.5%	43.75%
≥ 40	17.5%	32.5%	50%

If one tests merely the AIS classifications, e.g.,

AIS = 1	AIS = 2	AIS ≥ 2	
250	400	350	NSB
620	810	870	SB

one finds that X^2 = 17.5 (df = 2) which indicates a significant difference, namely, SB are better.

If one does a row by row comparison, one finds that $\chi^2 = 20.95$ (df = 6). However, by looking at each row one sees that there are significant differences at 0-20, $\chi^2 = 12.29$ (df = 2) and at 21-40, $\chi^2 = 8.85$ (df = 2)- but none at ≥ 40. On looking at the data we see no difference at speeds ≥ 40, a definite improvement at 21-40 speeds and a real worsening at 0-20.

Any common weighting scheme would mask these differences.

In practice the problem is more complicated but the idea is the same. By using the log linear model and possibly the Likelihood Ratio test, one can analyze the data in a similar way and obtain more information.

4.11 We have now fit our models and decided to what extent side beams have an effect. As a measure of effectiveness, we recommend the index method discussed earlier and in Appendix B. If the number of final independent variables is not too large, one could create a table of these indices for the various situations, e.g., speed = 30, weight = heavy, etc.

5.0 The results would be examined for various sorts of consistency between and within methods. The comparison between methods is obvious. Within methods we would be interested in symmetry between left side impacts/driver injuries and right side impacts/front right seat occupant injuries, and left side impacts/right side injuries and right side impacts/left side injuries. Consistency in such results would allow possible combination of categories and repetition of the analysis to increase the significance of the results.

The effectiveness of the Standard would thus be estimated given specific accident conditions, e.g., driver injury in right side impact at medium speed, etc.

4.2.6 Heuristic Analysis

A statistical analysis of the data may not reveal important information about the relationship of side beams, injury, intrusion, ΔV, etc. By its very nature this analysis is less formal than the statistical analysis described before. However, we suggest that possible valuable information and insights may be derived from this auziliary analysis. At the minimum, this analysis would include plotting and analyzing:

- Interior collision points
- Injury type by interior collision point
- Injury type by ΔV
- Maximum Intrusion by injury
- etc.

Such frequency plots with relation to injury location, injury severity, interior intrusion and collision point would provide interesting and possibly informative material independent of the results of the statistical analysis.

4.3 Other Data Sources

There are some additional sources of accident data besides mass accident data and the NCSS. A data collection effort similar to the NCSS was conducted in 1974 and 1975 as part of the Restraint Systems Evaluation Program (RSEP). That study focused on towaway accidents of 1973-1975 model year vehicles. Only the market class of the striking car is collected, so the reconstructed ΔV is a gross estimate, not comparable to the ΔV reconstructed for the NCSS data base. Therefore, the use of RSEP data is not recommended for evaluation of FMVSS 214.

NHTSA-sponsored Multidisciplinary Accident Investigation Teams (MDAI) collect very detailed information on accidents and the Highway Safety Research Institute (HSRI) of the University of Michigan consolidates the data. The investigated accidents, however, are intentionally selected in a non-representative manner (mostly severe) and the small sample size limits its usefulness for evaluating FMVSS 214.

Two other data sources, which are compiled by NHTSA, have been rejected in the evaluation of this Standard. The National Accident Summary (NAS) does not collect sufficient information to be of use and the Fatal Accident Reporting Systems (FARS) is obviously limited to fatal accidents.

5.0 COST DATA AND SAMPLING PLAN

5.1 Background

FMVSS 214 was introduced in October 1970 with an effective date of January 1, 1973. Manufacturers had been installing side door guard rails in some cars since the 1969 model year. Figure 5-1 shows the incremental design changes used to meet the Standard. The door beams are approximately eight inches high, two inches deep and run from hinge to lock pillar on every door. They are parallel to and approximately 10 inches above the lower door sill. The pillar support is for local reinforcement for the door pillar. Therefore, the two primary physical items which are introduced to satisfy the Standard are the side beams and the pillar supports. The side beams themselves are made up of several components. The minimum components are the channel beam and the end plates. Domestic models have corrugated sheet metal for additional reinforcing and in vehicles with wide doors a center plate may be added. The pillar to floor reinforcement is not required on 2-door sedans.

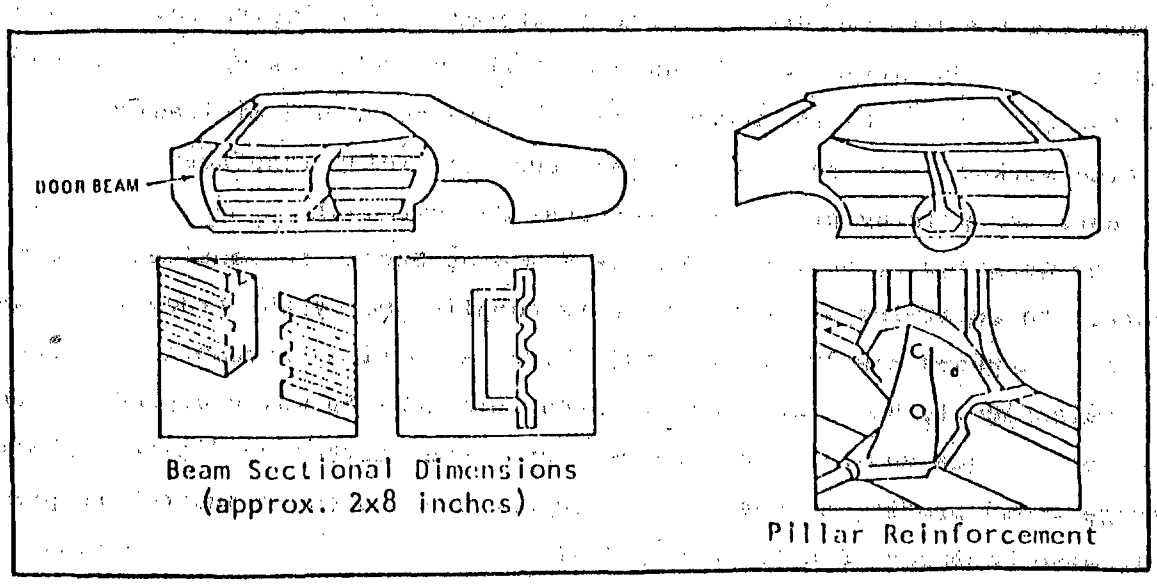

Figure 5-1. Sketches of design changes required.*

In determining the costs of performing the above physical changes, NHTSA has stated that to measure the consumers' out-of-pocket costs the cost categories should be:

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*Source: *Benefit and Cost Analysis Methodology - MVP Rulemaking Programs*, NHTSA Technical Report, August 1972.

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

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

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

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

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

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

†CEM Report 4194-574, *Program Priority and Limitation Analysis*, Dec. 1976, Contract No. DOT-HS-5-01225.

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

Another point of concern with regard to the collection of data on cost items is the periods of comparison--one model year before the effective date *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 over-estimate the cost of the Standard.

5.2 Relevant Cost Items

Costs of the following items--channel beams, end plates, corrugated sheet metal, pillar reinforcement plates and center plates--must be included in order to determine total cost. At the very least (1) direct and (2) indirect manufacturing, and (3) capital investments for these must be considered. Consumers certainly pay for the (4) manufacturers' markup (5) dealers' markup and (6) taxes when they purchase the vehicle. However, we feel that these latter items are not obtainable with sufficient reliability. Lifetime operating and maintenance costs are part of the total cost of the design change. However, only out-of-pocket costs are to be estimated.

The manufacturing costs are a function of:

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

Capital investments including testing should be amortized over the useful life of the equipment and estimated level of production. Manufacturer and dealer markups, and taxes are percentage amounts applied to the base cost.

5.3 Frequency Sampling Plan

Since side door guard beams are the universal method of compliance throughout the industry, cost variations among manufacturers should be less for FMVSS 214 than for the other three Standards this project will review. We do expect real differences according to body styles and car classes. For example, the cost of four short beams in a 4-door sedan should differ from the two longer beams in a 2-door hardtop. Similarly, we expect the cost of a large luxury car's side beam to differ from a subcompact's side beam. For these reasons, we propose a three-dimensional categorization for cost data acquisition:

Exhaustive Cost Acquisition Plan:

1. Manufacturer: GM, Ford, Chrysler, AMC, Volkswagen, Toyota
2. Market Class: Subcompact, Compact, Intermediate, Full Size, Luxury, Specialty
3. Body Type: 2-Door Hardtop, 2-Door Sedan, 4-Door Hardtop, 4-Door Sedan, 2-Door Hatchback, 4-Door Station Wagon.*

This three factor design with six levels for each factor would yield a 6 x 6 x 6 = 216 element matrix. Such an extensive design would be impractical for a number of reasons. It would require gathering data on a minimum of 216 models to obtain one value in each cell. Data collection cost would be prohibitive. Also, there would be many cells for which data do not exist.† For example, Chrysler does not produce a 2-Door Hatchback; AMC does not produce a 4-Door Hardtop, etc. One means of alleviating this would be collapsing two categories into one, such as 4-Door Station Wagons into 4-Door Sedans (if the doors are identical) or separating the two foreign manufacturers from the four American manufacturers.

Data gathering cost considerations will probably limit the number of models sampled to between 15 and 25. This necessitates making certain assumptions about the variance of cost data and about the representativeness of the stratification used. For a first cut, one may make the following simplifying assumption: that all variances in the cost of installing side door guard beams are randomly distributed regardless of manufacturer, body type, or market class. In this case, stratifying the sample strictly by sales volume would minimize the standard error of the estimated average cost. The following stratified sampling plan using "stratification before selection" could be used to accomplish this.

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*Additional investigation may show whether this classification can be further aggregated.

†A preliminary estimate is that there are between 150 and 300 different American-made car bodies in the current model year.

Each car model/body type would be assigned its percentage of total market share as determined by sales volume. Then, if it were desired to choose a sample of 15 models, they would be chosen according to a weighting scheme based on their market share. To illustrate, assume the market shares are as given in Table 5-1.

TABLE 5-1

SAMPLE DISTRIBUTION OF MARKET SHARES

	Impala 2-Door Hardtop	Ford 4-Door Sedan	Pinto 2-Door Hardtop	Impala 4-Door Sedan	Valiant 2-Door Hardtop	• • •
Market Share	.035	.033	.030	.030	.025	• • •
Probablity Interval	$0.<x\leq.035$	$.035<x\leq.068$	$.068<x\leq.098$	$.098<x\leq.128$	$.128<x\leq.153$	• • •

If a sample of 15 model/body types were needed, random numbers from a uniform distribution would be generated on the interval [0, 1], and the probability interval in which the random variate "x" fell would determine the model/body type chosen. This procedure would continue until 15 unique model/body types were chosen.

The problem with the above sampling plan is that it could result in a particular manufacturer, body type, or market class not being represented at all.

If this event should occur, a more refined approach would be to stratify further by manufacturer and market class, ensuring that each category be represented. For example, a 6 x 6 Latin Square design would detect differences among manufacturers, body types, and market classes. This is shown in Figure 5-2 below.

Manufacturer	Sub-comp.	Com-pact	Inter-med.	Full Size	Lux-ury	Spec-ialty
GM	A	B	C	D	E	F
Ford	B	F	D	C	A	E
Chrysler	C	D	E	F	B	A
AMC	D	A	F	E	C	B
Volkswagen	E	C	A	B	F	D
Toyota	F	E	B	A	D	C

Note:

A, B,...F represent body styles

Figure 5-2. Sample Latin Square Design for cost data acquisition.

The number of possible 6 x 6 Latin Squares to choose from is large (approximately 813 million, including permutations), and a procedure exists for randomly selecting one.* In addition, the assignment of body types to the letters A, B,... F must be determined. These selections are made on the basis of a constructed stratification procedure rather than purely randomly, so that representativeness is maintained. There are still some problems with this procedure, such as what to do with cells which have no cost data (Volkswagen-luxury class, for example). However, in the event that this more refined approach is required, statistical techniques exist to account for such incomplete Latin Square designs.

*R.A. Fisher and F. Yates, *Statistical Tables for Biological, Agricultural and Medical Research*, 5th ed., London: Oliver and Boyd, 1957.

6.0 WORK PLAN

The work plan for the evaluation study of FMVSS 214 is divided into three phases and a total of five tasks. Phase 1 (Tasks 1 and 2) includes the analysis of mass accident data and an analysis of costs to the consumer for implementation of FMVSS 214. Phase 2 (Task 3) is concerned with the NCSS data analysis. Phase 3 (Tasks 4 and 5) deals with the new data collection and analysis of the NCSS and new detailed accident data. The logical sequence of tasks and subtasks is shown in Figure 6-1. The time sequencing of tasks and estimated resources required (personnel and data processing) are given in Figure 6-2.

Task 1 is concerned with the acquisition and analysis of existing mass accident data files such as those from North Carolina or Texas. The mass accident data should cover a period beginning as early as possible after 1968, and extend at least through 1972 or later. Vehicle weight and side beam information will be derived from make/model data; collision configurations will be derived from vehicle damage data. The main purposes of analyzing mass accident data will include (1) an analysis of accidents other than side impacts for side beam and non-side beam cars to detect factors independent of side beams, and (2) an analysis of possible reporting biases in minor accidents due to age differences between side beam and non-side beam vehicles. It is estimated that the Task 1 effort will require professional resources of one person-year and $5000 for computer processing.

Task 2 deals with the determination of direct costs to implement FMVSS 214. Cost categories are confined to direct manufacturing, indirect manufacturing, capital investment (including testing), manufacturer's markup, dealer's markup and taxes.* A frequency sampling plan specifies that cost data will be sampled for between 15 and 25 models. Data must be acquired for each selected car model for one model year prior to introducing side beams, the model year in which side beams were introduced and one model year after introducing side beams. With

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

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

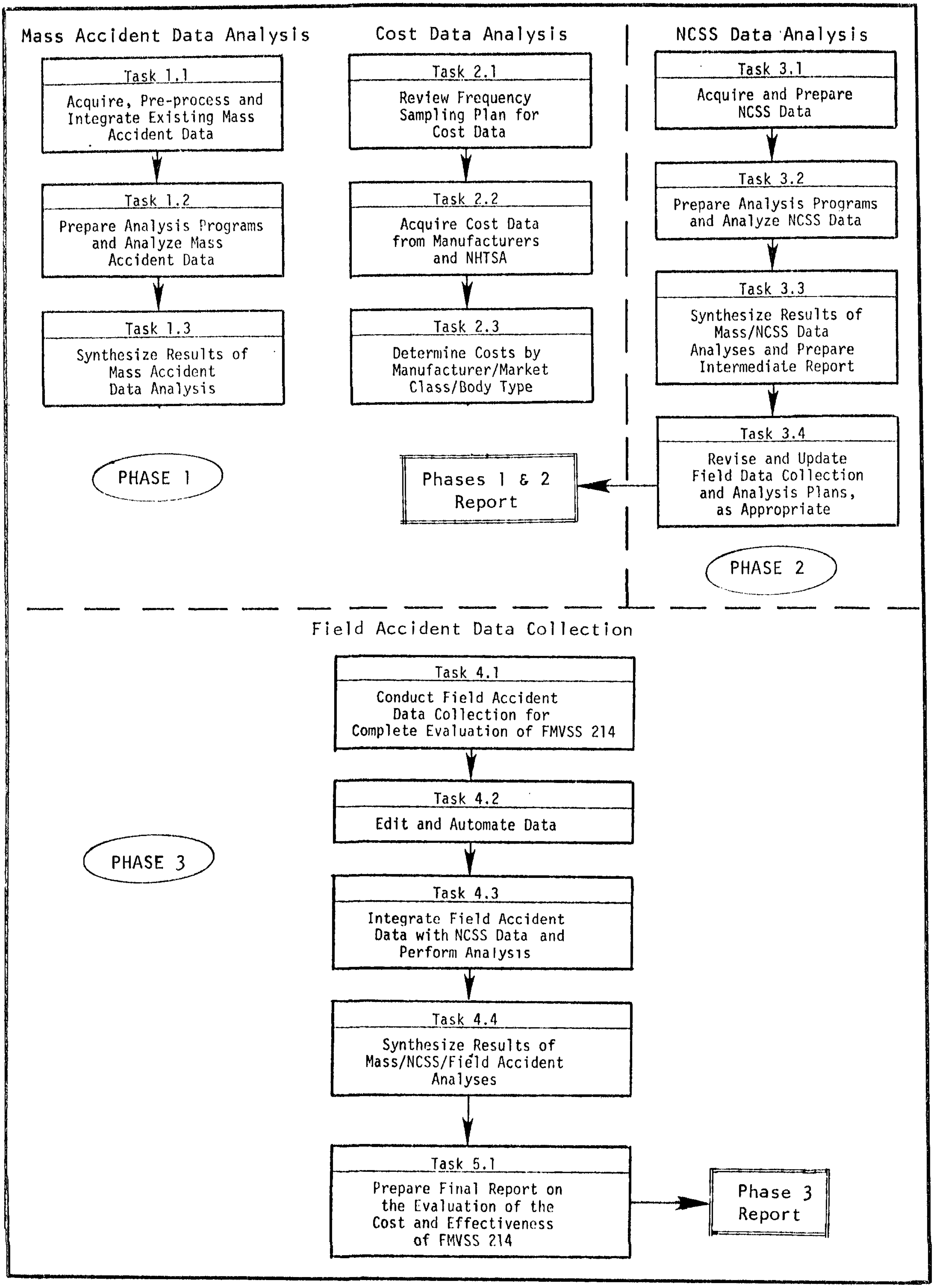


Figure 6-1. Flow chart for study to evaluate FMVSS 214.

Task	Description	Months (3 6 9 12 15 18 21 24 27 30 33 36)	Resources Required: Person-Years	Resources Required: Data Processing
	Mass Accident Data Analysis			
1.1	Acquire & Integrate Data		0.3	$ 2K
1.2	Prepare Analysis Programs and Perform Analysis		0.5	$ 3K
1.3	Synthesize Results		0.2	
			1.0	$ 5K
	Cost Data Analysis			
2.1	Review Frequency Sampling Plan		0.2	
2.2	Acquire Data		0.3	
2.3	Analyze Costs		0.5	$ 1K
			1.0	$ 1K
	NCSS Data Analysis			
3.1	Acquire & Prepare Data		0.4	$ 3K
3.2	Prepare Analysis Programs and Perform Analysis		1.0	$ 5K
3.3	Synthesize Results of Tasks 1, 2, 3: Phase 1 & 2 Report		0.4	
3.4	Revise & Update Phase 3 Plans, as Appropriate		0.2	
			2.0	$ 8K
	Field Accident Data Analysis			
4.1	Conduct Field Data Collection		1.5 - 5.0	
4.2	Edit & Automate Data		0.5 - 2.0	$ 1-3K
4.3	Integrate with NCSS Data and Perform Analyses		0.8	$ 3K
4.4	Synthesize Results of Tasks 1, 2, & 4		0.5	
			3.3 - 8.3	$ 4-6K
	FMVSS 214 Evaluation Report			
5.1	Prepare Final Report on the Results of Tasks 1-4: Phase 3 Report		0.4	
	TOTAL RESOURCES REQUIRED		7.7 - 12.7	$ 18-20K

Figure 6-2. Schedule of tasks and required resources for evaluating FMVSS 214.

an adequate sampling plan, the direct cost to the consumer of the Standard implementation can be obtained for most car model/body types through a statistical analysis of market shares. Task 2 will be completed nine months after the start of the study. It is estimated that one professional person-year will be required for Task 2 work, together with up to $1000 for computer processing.

Task 3 (Phase 2) is directed toward the processing and analysis of NCSS data. The task will be initiated six months after the start of the study, immediately following the analysis of mass accident data. A much more definitive analysis can be planned in this task, making use of inforamtion derived from the Abbreviated Injury Scale, the Collision Deformation Scale for intrusion, ΔV and other detailed factors. Basically, two analytical models will be employed to evaluate both continuous and discontinuous variables. The NCSS data will also be analyzed with a second model, the Log-Linear Model, which accepts only categorical variables. A Descriptive Index Method will be used to distinguish effects for side beams, no side beams, total injury, head injury, torso injury, crash side, occupant seat location, etc. The above factors will also be evaluated with these models and the consistency of results obtained from the two models will be checked.

When the above analysis has been completed, the results will be integrated with applicable Task 1 results. A Phase 1 and 2 report will be prepared, documenting these results and also the cost data analyses obtained from Task 2 (discussed above). It anticipated that the Task 3 analysis might be insufficient for a definitive and unambiguous evaluation of the effectiveness of FMVSS 214, due to the sample size of NCSS data, which is small. The final subtask under Task 2 will be to evaluate the sufficiency of the results to date and revise and update the plans for a Field Accident Data Collection, if required. The final step in Task 3 (and Phase 2) should be completed 15 months following the initiation of the study. It is estimated that two professional person-years will be required for the completion of all work under Task 3, including the Phase 1 and 2 report. Data processing resources required for this task are estimated to be $8000.

Task 4 encompasses the collection, editing and automation of the field accident data and the integration of these data with existing NCSS data for final analysis. The analytical techniques used and the types of analysis performed in Task 4 will be similar to if not identical with those of Task 3. The basic objective of Task 4 is to collect sufficient field accident data so that in conjunction with the NCSS data, a definitive determination of the effects of the Standard can be made. The computer programs developed under Task 3 will be utilized in Task 4. The bulk of the professional resources required for TAsk 4 will be needed to collect, edit and automate the field accident data. The resources required for these efforts (Tasks 4.1 and 4.2) will clearly depend on the number of additional cases that are required, as estimated at the conclusion of Phase 2. It is anticipated that between two and seven professional person-years of effort will be needed for Tasks 4.1 and 4.2. The total professional effort needed for Task 4 is estimated to be within the range 3.3 to 8.3 person-years. A total of $4000-$6000 is required for data automation and analysis.

Task 5 of the study plan is concerned with the preparation of a final report at the end of Phase 3. This report will document in detail and integrate the results of the previous four tasks and will be completed 36 months after the start of the study. It is estimated that the preparation of the Final Report on the evaluation of FMVSS 214 cost and effectiveness will require 0.4 professional person-years. The total estimated resources requires are summarized in Table 6-1.

TABLE 6-1

ESTIMATED RESOURCES REQUIRED FOR FMVSS 214 EVALUATION

Phase	Task	Staffing (person-years)	Computer Processing ($K)	Estimated Schedule (Contract Month)	
				Begin	End
1	1	1.0	5	1	7
	2	1.0	1	1	9
	Subtotal	2.0	6	1	9
2	3	2.0	8	7	15
3	4	3.3 - 8.3	4 - 6	16	34
	5	0.4	0	34	36
	Subtotal	3.7 - 8.7	4 - 6	16	36
Total		7.7 - 12.7	18 - 20	1	36

APPENDIX A

INTRODUCTION DATES OF SIDE DOOR REINFORCEMENT BEAMS

APPENDIX A: INTRODUCTION DATES OF SIDE DOOR REINFORCEMENT BEAMS

Make	Line	Series	Model Year
AMC	Javelin	SST	1971
		Basic	1971
		AMX	1971
GM			
Buick	Buick	Electra	1969
		La Sabre	1969
		Riviera	1971
	Special/Skylark	Skylark	1970
		GS	1970
Cadillac	Cadillac	Calais	1969
		De Ville	1969
		El Dorado	1971
		Fleetwood El Dorado	1971
		Fleetwood Brougham	1969
		Fleetwood Seventy-five	1969
		Fleetwood Sixty Special	1969
Chevrolet	Chevelle	Concours	1970
		Malibu	1970
		Nomad	1970
		Greenbriar	1970
	Chevrolet	Bel Air	1969
		Biscayne	1969
		Caprice	1969
		Kingswood	1969
	Monte Carlo	Monte Carlo	1970
	Vega	Vega	1971
Oldsmobile	F-85/Cutlass	F-85	1970
	Oldsmobile	Delta 88	1969
		98	1969
	Toronado	Toronado	1971
Pontiac	Firebird	Firebird	1970
		Esprit	1970
		Formula	1970
		Trans-Am	1970
	Pontiac	Bonneville	1969
		Catalina	1969
		Executive	1969
		Grand Prix	1969
	Tempest/LeMans	Le Mans	1970
CHRYLSER			
Dodge	Challenger	Challenger	1970
		Challenger RT	1971
FORD			
Ford	Fairline/Torino	Gran Torino	1972
	Ford	Custom	1971
		Galaxie	1971
		LTD Brougham	1971
	Mustang	Mustang	1971
		Grande	1971
	Pinto	Pinto	1971
	Thunderbird	Thunderbird	1972
Lincoln	Lincoln	Continental	1971
		Continental Mark III & IV	1971
Mercury	Cougar	Cougar	1971
		Cougar XR 7	1971
	Mercury	Marquis	1971
		Marquis Brougham	1971
		Monterey	1971
	Montego	Montego	1972
		Montego MX, Brougham, & GT	1972

APPENDIX B

DISCUSSION OF STATISTICAL METHODS

B.1 INTRODUCTION

A number of statistical techniques can be considered as analytical tools to evaluate the effects of implementing FMVSS 214. Four of these techniques are discussed in this appendix.

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

B.2 REGRESSION ANALYSIS

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

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

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

Some examples of general regression would be:

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

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

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

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

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

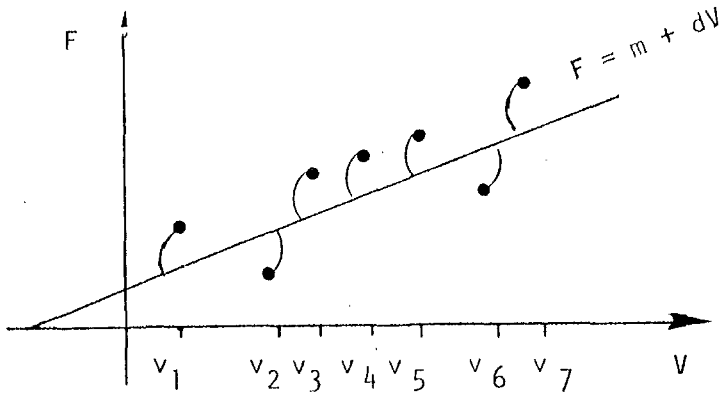
As an example, we might be interested in a model regressing fuel consumption per mile F, on velocity of the vehicle V, the weight W, and the horsepower H. As a first approximation, we would have:

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

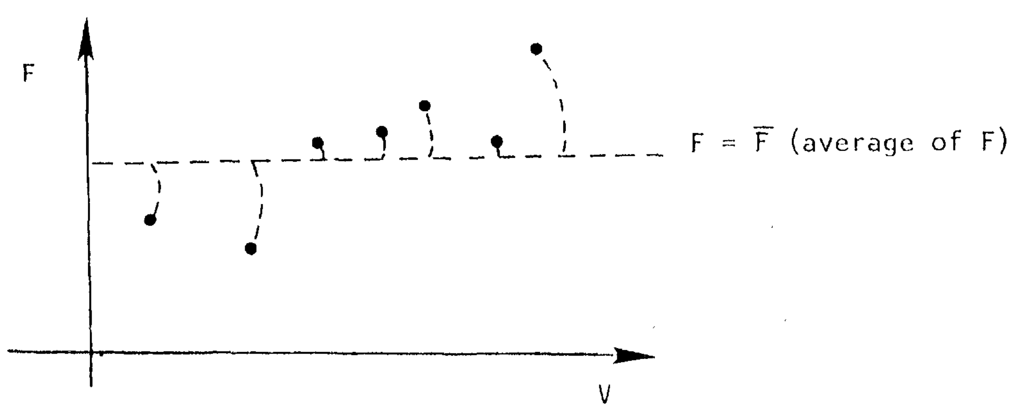
where ε is the random error term. Since each of the independent variables appears as a linear (first degree) term, we call this a linear equation. If we run the experiment under lab conditions and choose the speed, weight and horsepower values, these are considered fixed values and ε is usually assumed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

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

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



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



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

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

B.3 CONTINGENCY TABLE ANALYSIS

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

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

INJURY	SPEED Slow	SPEED Fast	
Slight or None	100 p_{11}	110 p_{12}	210 p_{1+}
Moderate or Severe	50 p_{21}	80 p_{22}	130 p_{2+}
	150 p_{+1}	190 p_{+2}	340

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

The usual chi-square analysis would give*

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

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

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

B.4 LOG LINEAR ANALYSIS

A log linear model can be formulated such that

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

where

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

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

$$\begin{aligned} \log E_{ij} &= \log NP_{ij} = \log N + \log P_{ij} \\ &= \log N + \mu + \Lambda_i + M_j + (\Lambda M)_{ij} \\ &= \mu' + \Lambda_i + M_j + (\Lambda M)_{ij} \end{aligned}$$

where N is the total number of cases.

The above χ^2 test tells us that $(\Lambda M)_{ij} = 0$ for all vehicle speeds, Λ_{ij}. Thus, we can say by appropriate analysis that the estimates of the E_{ij} are $\hat{E}_{11} = 92.65$, $\hat{E}_{12} = 117.35$, $\hat{E}_{21} = 57.35$, and $\hat{E}_{22} = 72.65$ and $\hat{\mu} = 4.41$, $\Lambda_1 = -\Lambda_2 = 0.237$, $\hat{M}_1 = -\hat{M}_2 = -0.121$. One can check these values of μ, the $\hat{M}$'s and the $\hat{\Lambda}$'s given the appropriate $\hat{E}_{ij}$'s. While this analysis can be done without the log linear model for this simple case, the model can easily be extended to more variables with the interpretation being similar to the usual analysis of variance. By extending the model we could include other factors such as weight of vehicle.

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

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

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

This type of analysis, which we suggest, is non-standard. Anyone performing this analysis must be knowledgeable and highly trained. Suggestions for this analysis are included in Section 4 which presents the specific model recommended for evaluating FMVSS 214.

B.5 INDEX METHOD ANALYSIS

We recommend fitting the functional mean structure separately for cars with side beams and those without. The problem then is to compare the two situations. As a measure of effectiveness, if P_{SB} and P_{NSB} are the probabilities of a particular event (e.g., AIS $\geq$ 3) for a particular situation (e.g., speed = 20 mph, head restraint up, angle of impact = 90°) consider

$$\log_2 \frac{P_{NSB}}{P_{SB}} = I(SB,\ NSB),\ \text{where I is an index.}$$

If the probabilities are the same, $P_{NSB} = P_{SB}$ then $I(SB,NSB) = \log_2 1 = 0$. If side beams reduce the probability to half of the non-side beam level, i.e., $P_{SB} = 1/2\ P_{NSB}$, then

$$I(SB,NSB) = \log_2 \frac{P_{NSB}}{1/2 P_{NSB}} = \ell n_2 2 = 1.$$

If $P_{SB} = 1/4\ P_{NSB}$, then

$$I(SB,NSB) = \ell n_2 4 = 2.$$

Every doubling of the safety leads the index to increase by one. If the range of the improvement is smaller (e.g., $P_{SB} = 0.95\ P_{NSB}$), then using the logarithm to the base e is suggested, because

$$I(SB,NSB) = \log_e \frac{P_{NSB}}{0.95P_{NSB}} = -\log_e 0.95 = 0.5$$

which gives a 5% improvement. The interpretation of a percentage increase is only useful if the percentage increase or decrease is small (±10%).

We are recommending that the index be used as a function of the situation, not as an overall index. Use as an overall index would require an averaging of the individual values of the index. This averaging is difficult to perform in the sense that the weighting to be used in unclear. For example, if vehicles without side beams tend to travel at higher speeds than vehicles with side beams, how does one weight speed: higher or lower? The choice will affect the overall index. A statement such as "moderate and low speeds lead to some improvement while higher speeds give an index near zero" would be much more informative.

The index method is a possibility but it, too, is an averaging of the probabilities according to some reference population. The choice of the reference population is rather arbitrary.

B.6 APPLICATIONS

We now wish to consider the problems of statistical analysis of the difference between injuries and/or intrusion in side beam and non-side beam cars. Although various possibilities exist, the simplest is to consider a large test of homogeneity. Using the previous analysis, one could have decided which variables are important. If, for example, only speed is considered relevant, one would have for both side beams and non-side beams an r x c table with one factor being injury classification and the other being the various speeds. One could then compare the two r x c tables in a large homogeneity table.

Another possibility is to use a log linear model and fit the model where the side beam has an effect and where it does not. Using the asymptotic likelihood ratio test, one can then see if there is a significant difference. Since there is a subcollection of situations in which differences are expected to be more pronounced, one could just do a test for those also, since nondifferences in other situations could mask the effect.

APPENDIX C

ANTICIPATED DISTRIBUTION OF AIS LEVELS

IN SAMPLED ACCIDENT DATA

C.1 INTRODUCTION

This appendix details the basis for estimating the number of cases of side-impacted vehicle accident data expected from the National Crash Severity Study (NCSS) and the distribution of these cases according to the AIS injury levels. Separate estimates of injury distribution are made for left side and right side impacts. It is to be clearly emphasized that the resultant distributions are approximate estimates of what could be expected to occur.

The estimations are primarily based on the accident experience in the Restraint Systems Evaluation Program (RSEP). The results from this program are compared with results obtained in Michigan and New York State. Results from North Carolina are used in conjunction with the RSEP data in determining the proportion of side impacts and their left side/right side distribution.

AIS Codes

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

H = Required Hospital treatment.
N-H = No Hospital treatment.

I. ALL COLLISIONS

Restraint Systems Evaluation Program (RSEP) [1]

Basic Sampling Plan:

100% for all 1973-1975 model year towaway accidents where at least one front-seat occupant had hospital treatment or died.

50% other 1973-1975 model year towaway accidents based on terminal digit of license plate.

(Note: Data are heavily urban.)

Sample Size: 20,043 "weighted" occupants from Table 109 Vol. II, page 105.

		AIS 0	1	2	3	4	5	6	Total
with stratification	%	50.0	41.4	6.4	1.3	0.2	0.1	0.5	99.9
	N	10,000	8,300	1,300	260	40	20	100	20,020
Assume:	N-H	90%	70%	30%	-	-	-	-	
	H	10%	30%	70%	100%	100%	100%	100%	
without stratification (actual)	%	44.3	43.5	8.9	2.1	0.3	0.2	0.8	
	N	5,500	5,400	1,100	260	40	20	100	12,420
		87.8% (AIS 0–1)		8.9%	2.6% (AIS 3–5)			0.8%	

National Crash Severity Study (NCSS)[2] October 1976-March 1978

Basic Sampling Plan:

100% for all towaway accidents where one occupant was killed or needed overnight hospital treatment.

25% for all towaway accidents where one occupant required out-patient hospital care.

10% for all towaway accidents where no one went to hospital.

Expected Sample Size: 10,000 accidents
13,500 involved vehicles in car-car accidents
24,000 occupants

AIS

		0,1	2	3, 4, 5	6	Total
with stratification	%	75	17	6.7	2.8	100.0
	N	18,000	4,000	1,600	675	24,275
Assume	N-H	80%	20%	-	-	
	H	20%	24% (out) & 56% (in)	100%	100%	
without stratification (actual)	%	90.6	8.1	0.9	0.4	100.0
	N	158,400	14,100	1,600	675	174,775

HSRI - Distribution of AIS Codes for Hospital Patients[3]

Basic Sampling Plan:

1968 and 1969 Washtenaw County, Michigan accidents where victims were taken to St. Joseph Mercy Hospital.

Sample Size: 540 injured
524 non-injured
5 fatalities.

AIS

		0	1	2	3	4	5	6	Total
Actual	%	51	36	7.4	4.0	0.7	0.4	0.5	100.0
	N	541	389	79	43	8	4	5	1,069

CALSPAN - Distribution of AIS Ratings for Police Rated Injuries Using Level 2 and Level 3 Calspan accident files. [4]

Basic Sampling Plan:

Police and MDAI investigated accidents involving a current model automobile or a recent model truck in eight counties in Western New York State. MDAI data biased in that at least one occupant required hospital treatment.

Sample Size: 1618 occupants from Table 3, page 10.

		AIS							
		0	1	2	3	4	5	6	Total
Actual	%	0.9	63	25	7.6	0.7	0.3	2.9	100.4
	N	15	1,019	398	123	11	5	47	1,618

II. SIDE COLLISIONS

RSEP[1] Weighted Observations from Table 109 Vol. II

		AIS							
		0	1	2	3	4	5	6	Total
Struck on Left Side	%	46	47	5.6	1.2	0.4	-	0.5	100.7
	N	1200	1220	150	32	11	-	13	2626
Struck in Right Side	%	50	41	6.7	1.3	0.2	0.2	0.5	99.9
	N	1320	1070	175	34	5	5	13	2626
Side of Car into Fixed Object	%	55	31	8.7	2.6	0.6	0.2	1.8	99.9
	N	530	300	84	25	6	2	17	962

Total observations for all crash configurations: 20,043

Expected NCSS Side Impacted Car-Car Data

Assume 13,500 Involved Vehicles in Car-Car Accidents.

- 4600 vehicles @ 34% Side Impacts from RSEP[1]
- 4000 vehicles @ 30% Side Impacts from North Carolina[5]

- 2300 vehicles struck on Right, 2300 on Left @ 50-50% from RSEP[1]
- 1800 vehicles struck on Right, 2200 on Left @ 44-56% from N.Carolina [5]

From 41% LP + LD and 45% RP + RD in North Carolina [5]

- 920 to 940 vehicles struck in Left Passenger Compartment or Left Side Distributed
- 800 to 1000 vehicles struck in Right Passenger Compartment or Right Side Distributed

At average occupancy of 1.8 occupants/vehicle

- 1675 Occupants in Vehicles Struck in Left Passenger Compartment or Left Side Distributed
- 1640 Occupants in Vehicles Struck on Right Passenger Compartment or Right Side Distributed.

Expected NCSS Side Impacted Vehicle AIS Distribution*

		AIS 0	1	2	3	4	5	6	Total
Struck in Left Passenger Compartment or Left Side Distributed	%	46	47	5.6	1.2	0.4	-	0.5	100.7
	N	760	780	95	20	7	-	8	1675
Struck in Right Passenger Compartment or Right Side Distributed	%	50	41	6.7	1.3	0.2	0.2	0.5	99.9
	N	825	670	110	21	3	3	8	1640

*AIS distribution based on RSEP[1] *Struck in Left Side/Right Side* for data which are more heavily urban than NCSS is expected to be.

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APPENDIX D

ACCURACY OF RECONSTRUCTED ΔV

APPENDIX D: ACCURACY OF RECONSTRUCTED ΔV

Using the CRASH and SMAC programs, CALSPAN has reconstructed ΔV for the NCSS data. In the detailed analysis of FMVSS 214 recommended herein, ΔV is considered to be an important variable. The question arises, however, how accurate the reconstructed ΔV must be for meaningful results. First, note that ΔV is a variable which has not previously been available for analysis of side impacts. Therefore, unless the standard deviation of error is much greater than 20 percent, there is likely to be some additional benefit of ΔV. Second, if the reconstructed ΔV is within about 10 percent of measured values, one would expect that the error in ΔV will not be a critical factor. Some estimate of the error can be made by comparing the computer-estimated values of ΔV to measurements provided by instruments on crash-tested vehicles. In evaluating such comparisons, one should be wary of various levels of errors in different types of side impact crashes, and of consistent errors in particular crash types. Specifically, we are concerned only with errors in reconstructed ΔV for side impact crashes. If the error is within reasonable bounds for side impact crashes, we need not be concerned with errors involved in reconstructing ΔV for other kinds of crashes. Third, the absolute limit to the allowable error depends on the nature of the crash phenomenon, and, to some extent, on the type of analysis used to estimate the effectiveness of the Standard. If ΔV is a good predicting variable (which one expects from a physical analysis of the crash process), then the size of its measurement error is not critical. However, if the weight of ΔV in the prediction equation is low and the estimated measurement error is fairly high, one does not know whether ΔV would have been significant or not. Thus, the real importance of accuracy in reconstructing ΔV depends on the effect ΔV has on the injury and intrusion in side impacts. Also, if the size of the error in ΔV varies directly with ΔV (i.e., greater at high values), then there might be different effects between analyses which use categorical variables *versus* analyses which use continuous variables.