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EVALUATION METHODOLOGY FOR FEDERAL MOTOR VEHICLE SAFETY STANDARDS

Volume II: Technical Findings

Contract No. DOT-HS-6-01519

May 1977

Final Report

PREPARED FOR:

U.S. DEPARTMENT OF TRANSPORTATION
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16. Abstract

This report, Volume II, describes overall study details and presents a thorough discussion of the evaluation plan developed for four Federal Motor Vehicle Safety Standards (FMVSS): FMVSS 301--Fuel System Integrity; FMVSS 208--Occupant Protection; FMVSS 214--Side Door Strength; and FMVSS 215--Exterior Protection.

After a statement of the problem and a description of each standard, applicable technical factors are discussed, alternative evaluation methodologies are reviewed and assessed, the recommended evaluation study design is presented, and finally a plan for implementing the evaluation is provided (includes costs and schedules).

Feasible evaluation plans are provided for three of the standards (FMVSS 301, 208, and 214) but it is concluded that no evaluation scheme should be expected to provide conclusive results for FMVSS 215--Exterior Protection. For FMVSS 215, reliance on indirect surveys or insurance data are the only approaches that may prove acceptable if FMVSS 215 is evaluated.

Within an augmented National Crash Severity Study (NCSS) program, detailed evaluation plans for FMVSS 301, 208, and 214 are described and recommended to NHTSA. Probability of successful evaluation ranges from good to fair, costs range from a low of $37,400 to a high of $1,378,200 and schedules from a few months to three years.

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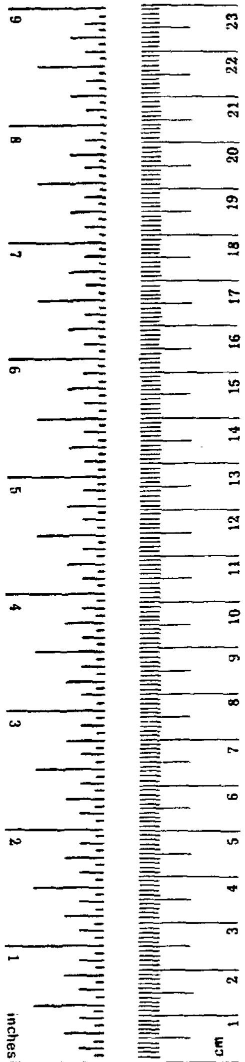
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

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

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



Approximate Conversions from Metric Measures

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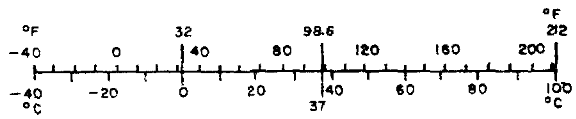
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Section 1

INTRODUCTION AND SUMMARY

1.1 PURPOSE, SCOPE, AND OBJECTIVES

The material contained in this report was developed by Stanford Research Institute (SRI) as part of a study to examine methodologies and develop detailed experimental designs, including measures of effectiveness, for the field evaluation of the following four Federal Motor Vehicle Safety Standards (FMVSS):

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

The intent of the study has been to identify how the effectiveness of these four standards can be determined, relative to mitigating the effects of real-world accidents. An integral part of this determination was assessing the relationships between compliance with the performance requirements of each standard and real-world accident experience. This study was conducted between 1 September 1976 and 31 March 1977 under National Highway Traffic Safety Administration (NHTSA) Contract DOT-HS-6-01519.

1.2 BACKGROUND

Some 40 FMVSSs have been issued under the National Traffic and Motor Vehicle Safety Act of 1966. These interrelated standards are intended to improve motor vehicle safety by establishing minimum vehicle performance requirements that are practicable and based on objective criteria. However, questions have been raised about the cost effectiveness and public acceptance of certain of these standards. These questions, together with recent concerns about energy and economic problems, have indicated the necessity of evaluating the effectiveness of the standards in terms of costs and benefits.

NHTSA has endorsed the evaluation of the FMVSSs. NHTSA policy now states that management decision-making on new and existing standards will, in part, be based on field evaluations of the performance of these standards. This FMVSS evaluation program began with the formulation of detailed plans for the evaluation of the four standards listed above.

The intended safety and economic benefits of these standards are listed below:

FMVSS 301--Fuel System Integrity. To minimize fire hazards resulting from collisions, this standard specifies requirements for the integrity and security of fuel tank filler pipes and fuel tank connections under impact conditions.

FMVSS 208--Occupant Protection. To reduce the number of deaths of vehicle occupants and the severity of injuries, this standard specifies vehicle crash-worthiness requirements in terms of forces and accelerations measured on anthropomorphic dummies in test crashes. It also specifies equipment requirements for active and passive restraint systems.

FMVSS 214--Side Door Strength. To minimize the safety hazard caused by intrusion into the passenger compartment in a side-impact accident, this standard specifies strength requirements for the side doors of passenger cars.

FMVSS 215--Exterior Protection. To prevent low-speed collisions from impairing the safe operation of vehicle systems and to reduce the frequency of override or underride in high-speed collisions, this standard specifies that certain safety systems remain undamaged in such collisons. In addition to the safety benefits derived, this standard is intended to reduce the economic losses resulting from damage to passenger vehicles involved in low-speed accidents.

In addition to this standard, Title I of the Motor Vehicle Information and Cost Savings Act calls for bumpers that will reduce economic loss. A new bumper standard is planned to become effective in 1978 and 1979; it will combine Title I and FMVSS 215 requirements.

1.3 APPROACH

In Task I of this study all forms of the standards being examined were reviewed. This task was followed by four separate tasks (II through V) for each standard, resulting in the development of a final evaluation plan for each standard. The objectives of each of these tasks are outlined below.

1.3.1 Task I--Review of the Four FMVSSs

In this task, references concerning the four standards were reviewed. The sources investigated included background material, specifications, requirements for developmental and compliance testing, and literature in the traffic safety field relating to standards evaluations. A list was compiled and presented to the Contract Technical Monitor (CTM) to verify its completeness.

This review formed the basis for the selection of measures of effectiveness, and for the development of methods and evaluation plans in subsequent tasks. Summary documentation of each standard's objectives and key factors affecting evaluation plan development were prepared before Task II began.

1.3.2 Task II--Feasibility Study

For each standard specified, SRI studied the feasibility of evaluating the standard's effectiveness. Each feasibility study consisted of the elements described below.

The functional relationship between the specifications of the standard and real-world was analyzed, as were the compliance tests, controlled crashes, and real-life accidents to allow appropriate comparisons.

The effectiveness of standards was expressed both in general terms and as quantifiable statistical measures of effectiveness. The general concepts of effectiveness differed among standards but included such measures as injury reduction by type, damage reduction, cost savings, social benefits, and reduction of hazard potential.

The adequacy and availability of existing or potential data to measure effectiveness were also investigated. Existing data were examined for adequacy, and potential sources of data were also explored (e.g., the NASS sampling framework).

A list of cost data needed to determine the costs of safety parts and equipment for each standard was prepared. Manufacturers' cost data submitted to NHTSA, independent sources of cost data such as insurance companies, and other research reports were considered as the basis for cost determination.

Based on the results of these elements, alternative evaluation procedures were compared. The basis for this trade-off analysis was a comparison of the estimated cost of data collection and processing with the expected length of confidence intervals associated with effectiveness measures, and a qualitative assessment of the value of the information derived. A methodology, with justification for its selection, has been recommended for each standard.

1.3.3 Task III--Preliminary Evaluation Study Design

Having established the feasibility of an evaluation plan in Task II, SRI prepared a preliminary design and work plan that included for each standard:

- A definition of "effectiveness."
- A definition of the proposed "measure" of effectiveness, including confidence levels.
- Analytical tools and procedures to measure effectiveness.
- The analytical method selected.
- Constraints and limitations of the selected method.

After completing Tasks II and III, a thorough review and evaluation of each standard was conducted with the NHTSA CTM for completeness, consideration of expected benefits, sampling scheme, data processing, and analysis requirements.

1.3.4 Task IV--Final Evaluation Study Design

During Task IV, SRI prepared a final study design for each standard. These designs take into account the results of Tasks I, II, and III. Each design specifies:

- Data required for evaluation.
- The sampling scheme and requisite sample sizes for various confidence interval lengths.
- Field investigation procedures.
- Analysis and evaluation procedures.

1.3.5 Task V--Implementation Plan for the Evaluation Study

A work plan has been prepared for each final evaluation study design. It includes:

- Requirements for existing data and retrieval procedures.
- An analysis plan for all collected data.
- Time and cost estimates for such study phases as retrieval of past data, data collection, and analysis.

Following the completion of the five tasks, this final report has been prepared to present the study results, up to and including the recommended evaluation study design and plan for each of the four FMVSSs.

1.4 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.

This section summarizes the general conclusions concerning evaluation methodologies reached during the study and the specific conclusions for each FMVSS examined. Evaluation plan recommendations are also outlined for each standard.

1.4.1 General Conclusions

Current studies indicate attempts to explicitly evaluate the overall effectiveness of the four standards. None of these attempts, however, has produced conclusive evidence of effectiveness because of:

- Inadequate accident investigation sample sizes.
- Non representative sample data.
- Other data bases used in analysis that are non representative of all the factors required in evaluation.

In our assessment of methodologies suitable for evaluating the standards, we have concluded that in-depth accident investigations should be an integral part of any definitive evaluation plan. This conclusion results from our conviction that for study results to be accepted by the mixed community of analysts, consumers, and manufacturers, effectiveness must be demonstrated in terms of statistically significant highway accident data.

Computer simulations and analytic models are recognized for their utility as design tools and for their use in exploratory studies. Controlled compliance tests and staged crashes have been determined to be of considerable value when employed with other evaluation methods. Vehicle-to-vehicle staged crashes can certainly provide precise information about selected accident types; however, the cost of replicating a reasonably representative set of real-world conditions is usually prohibitive.

Within the context of our study, the following list ranks the value and credibility of the various evaluation methodologies considered:

- In-depth accident investigation.
- Controlled testing of barrier and staged crashes, and similar tests.
- Surveys of damage observed at check points and of consumers.
- Insurance claim data file analyses.
- Computer simulations and analytic modeling.
- Analysis of data bases other than accident investigations (fire departments, and the like).

Feasibility was established for the evaluation of FMVSS 301--Fuel System Integrity, FMVSS 214--Side Door Strength, and FMVSS 208--Occupant Protection after determining that valid accident investigation data would provide a sufficient basis for evaluation. The relevant cause and effect variables were amenable to direct highway observations, and required sample sizes were not prohibitive.

We conclude that no evaluation scheme, based on current methodologies and feasible data collection procedures, should be expected to produce conclusive results for FMVSS 215--Exterior Protection. The primary difficulty is that direct observations of low-speed, low-damage accidents cannot be obtained. In fact, such accidents are frequently unreported to police or insurance companies. Alternative plans that rely on qualified, indirect surveys or insurance data are the only approaches that can be undertaken if FMVSS 215 is evaluated.

1.4.2 Specific Conclusions

A summary assessment of the major characteristics of the evaluation plans for each standard follows. Two factors are presented for each standard:

- Probability of successful evaluation.
- Estimated cost of evaluation.

A successful evaluation is an analysis that produces statistically meaningful results, based on observations of all relevant cause, effect, and explanatory variables. The results must be reported in a manner that is understandable by the technical and nontechnical communities. Estimated costs are the total values, based on costs estimates for each task in the implementation plans.

	FMVSS			
	301	208	214	215
Probability of success	Good	Good	Fair	Poor
Cost	$1,003,000	$294,000	$37,400 to $1,378,200	$383,000

1.4.3 Recommendations

In accordance with study requirements, all evaluation plans were developed separately and independently, with the understanding that only one of these might be programmed for implementation. However, if more than one of the evaluation plans is implemented, there are both technical and economic reasons for recommending a program that provides for simultaneous evaluation of the several standards. For example, in measuring the relationship between side door intrusion and injury severity (FMVSS 214), the occupant's use of restraints (FMVSS 208) must also be accounted for to eliminate the effects of confounding factors. In general, the data requirements for the various standards overlap.

One of NHTSA's accident investigation studies, the National Crash and Severity Study (NCSS) provides a timely and useful framework for the more sharply focused data collection evaluation requirements. In addition, NCSS data collection procedures can be easily modified regarding sample sizes, type of accidents, and organization of the data to satisfy evaluation plans that are developed. Evaluation plans for FMVSS 301, 208, and 214 can be recommended to NHTSA without qualification, and all can be implemented within an augmented NCSS program. A brief outline of each plan is presented below.

FMVSS 301--The procedural steps require the selection of a random sample of 1200 tow-away accidents involving 1974-1976 model vehicles and a comparable sample of 1200 1977-1979 vehicles to determine if post-crash fuel leakage differs significantly between the two groups of model years. This could be achieved during 1 year in a fully operational NCSS program. Concurrent with this random sampling, all crash-fire occurrences will be investigated, the completion of these fire investigations will require 3 years of NCSS operation. However, a logical decision point occurs when the analysis of fuel leakage in the sample of 2,400 tow-aways is complete. If no significant difference in fuel leakage is detected between pre- and post-standard vehicles, we recommend that sampling of fire events be discontinued because the effectiveness of the standard will be established only if both fuel leakage and fire incidents are reduced. If a significant difference in fuel leakage does exist, the investigation of fires must continue.

FMVSS 208--Four areas of evaluation are recommended. They are:

- Evaluation of active restraint factors.
- Evaluation of risk-taking factors.
- Evaluation of passive restraint factors.
- Continuing studies.

Briefly, we recommend that: for active restraints, certain results documented by the Highway Safety Research Center (HSRC) and the Highway Safety Research Institute (HSRI) be accepted and further quantified (e.g., confidence limit determination), that certain hypotheses be studied by using the existing Restraint System Evaluation Program (RSEP) and Multidisciplinary Accident Investigation (MDAI) files with other hypotheses studied by using NCSS data, and that an overall update be made within NCSS and finally repeated for NCSS. Passive restraints will also require accident analysis, but the analysis must await sufficient use of this system.

FMVSS 214--The recommended evaluation plan is a sequential process with two decision points that, based upon observed results, provide analysts with opportunities to continue or to discontinue further testing.

Stage 1 is a compliance test of pre-standard vehicles and a comparison of derived data with available test results for post-standard vehicles. The evaluation process will continue only if significant differences exist.

Stage 2 consists of vehicle-to-vehicle staged crashes designed to determine whether or not there is a measurable difference in side door intrusion between pre- and post-standard vehicles under fixed crash conditions. The evaluation will continue if such a differential exists.

Stage 3 consists of accident investigations on a stratified sample of 4000 side impacts. This investigation will determine the relationship between intrusion and injury severity and will measure the difference in occupant injury severity between pre- and post-standard vehicles.

FMVSS 215--The only technique determined to be potentially acceptable for estimating the characteristics of all bumper-area-involved impacts is a large survey (25,000) of vehicle owners or principal operators conducted at locations that minimize driver inconvenience and maximize the probability of unbiased responses. Motor vehicle inspection facility locations seem the best choice to achieve both objectives. They allow owners/operators to be surveyed while they are already waiting in line for vehicle inspection. This arrangement will also take advantage of the pre-inspection environment, which is expected to be conducive to obtaining reasonably accurate response to survey questions.

When the survey data for bumper-area-involved impacts have been obtained and the results analyzed, a careful comparison of these results with existing insurance and staged crash data (augmented by the technical judgment of qualified automotive engineers and damage evaluators) is expected to produce reasonable estimates of bumper involvement percentages for varied angles of impact and damage cost categories for each model year to be evaluated. If the survey results obtained from vehicle operators are consistent with insurance data in the areas of overlap between the two data bases, then a reasonable basis will have been established for placing confidence in the newly determined unreported accident data.

If this evaluation basis is successfully established, the most serious objections to a Transportation Systems Center (TSC) type analysis (such as the controversial $250 and $600 bounds for different damage effects) will be eliminated. Total direct benefits for FMVSS 215 can then be determined: pre- and post-standard model year vehicles will be compared by calculating insured loss differences for all cost categories and proportionately adding estimates of unreported damage loss (both owner-repaired and unrepaired) obtained from the analysis of a broad-based survey of vehicle owners.

Section 2

REVIEW OF FOUR FEDERAL MOTOR VEHICLE SAFETY STANDARDS

2.1 INTRODUCTION

In the Task I review, we outlined our understanding of four FMVSSs and identified currently available information relevant to this study. A report was produced to serve as a basis for discussions with the NHTSA CTM and other individuals, and to identify the basic information to be examined in more detail in succeeding tasks, particularly in the Task II Statement of Work. The following factors were briefly addressed for each standard: history and intent, description, applicability, compliance testing, docket commentary, accident experience, and references.

A review of the history and intent of each of the four standards is presented here in the order deemed most appropriate for evaluation; this order is maintained throughout the report. Preliminary technical considerations are also set forth.

2.2 FMVSS 301--FUEL SYSTEM INTEGRITY

2.2.1 History and Intent

Motor vehicle fire, although involved in relatively few accidents (It accounts for approximately 1% of all fatalities.), is disproportionately feared by the public because these fires, when they do occur, are often spectacular and lethal. It is difficult to identify the number of such involvements, however, and much more difficult to measure the number and extent of injuries, the physics of real-life accidents, the sources of fuel leakage, and the sources of ignition. The incorporation of fuel evaporation emission control systems in many vehicles beginning in 1970 has complicated fuel system design. Some of these changes have helped to prevent fuel leakage, but added fuel system components also offer more opportunities for damage to the overall fuel system.

FMVSS 301 is intended to limit fuel spillage during and after motor vehicle crashes in order to reduce deaths and injuries occurring from vehicle fires. "Fuel spillage" is defined as the fall, flow, or run of fuel from the vehicle; however, the definition does not include wetness resulting from capillary action.

The original standard issued on February 3, 1967 [32, Federal Register (F.R.) 2416] and amended on July 14, 1970 (35 F.R. 11242), called for application to passenger cars of a frontal longitudinal impact at 30 mph into a fixed collision barrier with the loss of no more than 1 oz of fuel (similar to the fuel used in the vehicle) during impact, and a discharge rate of no more than 1 oz/min after termination of impact.* This standard became effective September 1, 1970. Key changes to the standard have occurred and are listed below.

On August 20, 1973 (38 F.R. 22397), the following changes were adopted to become effective September 1, 1975. The standard was extended to all vehicles with a Gross Vehicle Weight Rating (GVWR) of 10,000 lb or less; a fuel spillage allowance of 1 oz/min for a 15-min period was set for both impact and roll-over tests; a static roll-over test was specified for passenger cars as of September 1, 1976 and for multipurpose passenger vehicles, trucks, and buses with a GVWR of 6000 lb or less as of September 1, 1976; vehicle fuel loading during these tests was specified at 90 to 100% of capacity.

On March 21, 1974 (39 F.R. 10588), the standard was upgraded substantially by specifying a 4000-lb rear-moving barrier crash, a lateral-moving barrier crash, and a frontal-barrier (nonmoving) crash, including impacts up to 30° in either direction from the perpendicular; Stoddard solvent was specified as the fuel to be used during testing.

On November 15, 1974, the standard was again amended. The amendments included: limitation of standards application to vehicles using a fuel

*A conversion table of English measures to their metric equivalents is given in Appendix A.

with a boiling point above 32°F; specification that vehicles were not to be altered during the test sequences (Repairs were not allowed after the barrier crashes and before the static roll-over tests); an axle loading specification; removal of test dummies during the roll-over test; and disengagement of the parking brake during the rear-moving barrier crash test. Clarification was made at this time that a single vehicle need meet only one crash test that was followed by a static roll-over. The November amendments included denials of many petitions in the preamble. The preamble stated that fuel system integrity needs had been clearly established and that sufficient lead time had been allowed for compliance.

Finally, on August 6, 1975 (40 F.R. 33036), the standard was amended to extend the current 15-min fuel spillage measurement period to 30 min. It also specified that fiftieth percentile test dummies be placed in seated positions during frontal and lateral barrier crash tests, and that they be restrained by means installed in the vehicle.

2.2.2 Technical Considerations

During our review of docket submissions and research reports, we identified many technical factors that were carefully examined during the Task II feasibility study for this standard. They included: the many ways in which a vehicle can be impacted or penetrated in real-life accidents that could affect fuel system integrity; the variations in body styles and annual design changes; the difficulties in reproducing test results, especially during roll-overs; and the possibilities for alternative or additional specifications for fuel system components that can be tested by laboratory procedures. Such laboratory tests, like those for brake hose, would involve lines, connectors, and straps. Fuel tanks would be tested separately for penetration resistance and weld strength.

Due to the larger classes of applicable vehicles affected by FMVSS 301 than by FMVSSs 214 and 215, a broader base of vehicles will be available in the future on evaluation of this standard. Passenger cars for 1970 to 1975 models were required to comply only with the perpendicular frontal barrier crash at 30 mph, whereas 1976 models were subject to such special requirements that they may have been eliminated as evaluation candidates. 1977 and later cars will probably provide a second large set of vehicles for evaluation purposes.

Other vehicle classes (multipurpose passenger vehicles, trucks, and buses) fall into similar categories: Pre-1977 vehicles constitute a pre-standard class; 1977 model vehicles represent a single, special requirements class; and 1978 and later models possibly constitute a second large set of vehicles for evaluation purposes.

2.3 FMVSS 208--OCCUPANT CRASH PROTECTION

2.3.1 History and Intent

To reduce both the number of fatalities and the severity of injuries of vehicle occupants, FMVSS 208 specifies vehicle crash-worthiness requirements in terms of the forces and accelerations measured on anthropomorphic dummies in test crashes; it also specifies equipment requirements for active and passive restraint systems.

A comprehensive review and summarization of the documents created to present, support, and refute the many complex elements associated with this standard was not possible within Task I resources allocated. A summarization of the rule making associated with FMVSS 208 can best be obtained by reviewing the series of preambles in the current version of the standard published in the Federal Register.

The original version of FMVSS 208, with the purpose described above, was proposed in January 1968. The present form of the standard, which was introduced in 1972, required one of three options to be provided for each vehicle: a completely passive system for front, side, and roll-over crash protection; a passive restraint system for frontal crashes with lap belts for side and roll-over crashes; or a lap and shoulder belt system at front outboard positions, with lap belts for all other positions.

An ignition interlock system, designed to force the attachment of seat belts before the vehicle could be started, was implemented in 1973 for 1974 models. However, Congress voided this requirement in 1974, stipulating at the same time that future occupant restraint system requirements, other than seat belts, be submitted for its approval before rule making took place.

At present, the direction NHTSA will take to continue improvements in occupant crash protection is unclear. Much of the current controversy concerns a passive restraint system called the air bag, a cushion system that rapidly inflates upon an impact involving sufficient force to require occupant protection. Former Secretary of Transportation Coleman and the automotive industry agreed to make relatively large numbers of automobiles with passive restraint systems available to the public at reasonable costs. Once placed in operation, these systems are intended to provide a basis for research into their effectiveness in real-life incidents.

2.3.2 Technical Considerations

Technical considerations associated with FMVSS 208 include: injury criteria (acceleration at center of gravity of both head and upper thorax, and force transmitted axially through each upper leg); a dynamic roll-over test; seat belt assemblies (both active and passive); warning systems; test conditions covering vehicle load placement and weight, seat and seat back adjustment positions, doors, windows, and tops; anthropomorphic test devices; and pressure vessels and explosive devices.

2.4 FMVSS 214--SIDE DOOR STRENGTH

2.4.1 History and Intent

When the proposed rule making for FMVSS 214 was announced on October 14, 1967, development and testing of improved door structures was well under way at General Motors (GM). The first beam-type door structures appeared in 1969 model year vehicles, whose manufacture began in mid-1968. Table 2-1 illustrates the introduction dates of door reinforcement beams in the vehicles manufactured by the major U.S. auto companies. Researchers, the automotive industry, and the public had been aware of

Table 2-1

INTRODUCTION DATES OF DOOR REINFORCEMENT BEAMS*

Make	Line	Series	Model Year
AMC	Javelin	SST, Basic, AMX	1971
GM			
Buick	Buick	Electra, LaSabre	1969
	Special/Skylark	Riviera	1971
		Skylark, GS	1970
Cadillac	Cadillac	Calais, DeVille	1969
		El Dorado, Fleetwood El Dorado	1971
		Fleetwood Brougham, 60, 75	1969
Chevrolet	Chevelle	Concours, Malibu, Nomad, Greenbriar	1970
	Chevrolet	Bel Air, Biscayne, Caprice Impala Brookwood, Kingswood	1969
	Monte Carlo	Monte Carlo	1970
Oldsmobile	F-85/Cutlass	F-85	1970
	Oldsmobile	Delta 88, 98	1969
	Toronado	Toronado	1971
Pontiac	Firebird	Firebird, Esprit, Formula, Trans Am	1970
	Pontiac	Bonneville, Catalina, Executive Grand Prix	1969
	Tempest/LeMans	Le Mans	1970
Chrysler			
Dodge	Challenger	Challenger	1970
		Challenger RT	1971
Ford			
Ford	Fairlane/Torino	Gran Torino	1972
	Ford	Custom, Galaxie, LTD Brougham	1971
	Mustang	Mustang, Grande	1971
	Thunderbird	Thunderbird	1972
Lincoln	Lincoln	Continental	1971
Mercury	Cougar	Cougar	1971
	Mercury	Marquis, Monterey	1971
	Montego	Montego	1972

*Source: Center for the Environment and Man, Incorporated, "Evaluation of Motor Vehicle Safety Standards," NTIS PB 226-074 (December 1973).

the special vulnerability of vehicle occupants to injury from accidents involving vehicle side structures.

This vulnerability was demonstrated by the era's aggressively shaped vehicles and roadside objects, which sometimes provided spectacular (and thus "newsworthy") penetration of the relatively slim and often weak side structures of passenger vehicles. The wording, appearing in the announcement of proposed rule making, reflected this vulnerability: "requirements to limit the amount of intrusion or penetration on exterior impact."

Research (both completed and in progress) and docket submissions on FMVSS 214 indicate the nature of accidents involving vehicle side structures and the injury severity resulting from those accidents. However, the precise role of penetration or intrusion in injury severity has not yet been clearly established, except in the relatively few cases when severe or fatal injuries were primarily caused by a penetrating object. Severe penetration is usually accompanied by extensive damage to other vehicle components and multiple occupant injuries.

The current version of FMVSS 214 was issued on October 30, 1970 (35 F.R. 16801) and is quite similar to the notice of proposed rule making issued on April 23, 1970 (35 F.R. 6512). The only significant changes entailed restricting the application of the standard to passenger cars (the original specified passenger cars, multipurpose passenger vehicles, trucks, and buses); a slight lowering of minimum low-level crush forces; a slight modification of minimum crush resistance forces at intermediate levels of crush (The considerable difference of opinion over a weight bias factor termed "equivalent crush resistance" caused it to be discarded); and the setting of a ceiling on minimum peak crush forces, eliminating a requirement for forces that increased indefinitely as vehicle weight increased.

The stated purpose of FMVSS 214 is to "specify strength requirements for side doors of a motor vehicle to minimize the safety hazard caused by intrusion into the passenger compartment in a side impact accident." Thus, the stated intent is (1) to reduce intrusion into the passenger compartment, and (2) thereby to reduce injury severity. Therefore, a complete study to determine the effectiveness of FMVSS 214 must identify (1) the degree to which the standard has reduced passenger compartment intrusion and (2) the degree to which occupant injury is related to passenger compartment intrusion. A basic description of the relationships between occupant injuries and vehicle characteristics follows.

2.4.2 Technical Considerations

A thorough review of docket submissions and research reports has resulted in the identification of technical factors that needed to be considered carefully during the feasibility study of this standard. Some of these factors are listed below, with brief comments as appropriate.

- Role of occupant seat structures--The standard specifies removal of seats for the compliance test. However, real-world accident and controlled crash tests indicate that occupant protection in side impacts is related to seat design and location.
- Occupant movement characteristics--Numerous comments suggest that performance requirements for this standard should more closely correspond to occupant behavior during side impacts. The forces generated by the high deceleration rates of human body components are the primary cause of many injuries in side impacts, and vehicle structures that lessen or smooth-out these forces appear to improve occupant protection significantly.
- Dynamic compliance testing--Many research reports suggest that because a dynamic test would be more realistic than the present static test, it would encourage the development of side structures that would be more effective in reducing occupant injuries during side impacts. Duplicating dynamic testing situations is necessarily problematic, but recent crash research indicates progress in recreating real-world accidents by means of controlled crashes.
- Door reinforcement designs--As a consequence of the compliance test manufacturers have increased door strength and resistance to crush, but have not necessarily increased side-body resistance to injury-causing damage. The test device does not involve lower or upper vehicle body portions that are frequently involved in side impacts with fixed objects, nor does it involve the body side pillars involved in many vehicle-to-vehicle side impacts. Some door beam designs may, in fact, increase penetration during collision by raising bumpers above lower body portions.

- Vehicle movement--The effects of vehicle movements during side impacts on injury severity do not appear to be well-defined at present. The transfer of forces to the ground, the portion of force absorbed by the striking and the struck vehicle, and the vehicle movement relative to vehicle weight all affect the forces to which vehicle occupants are subjected. Increased door rigidity may increase occupant injury if rebound speeds are increased; alternatively, it may reduce injuries if it induces more vehicle deflection.
- Role of striking object--The aggressiveness of the striking object is an important intrusion factor that is not fully considered in the present compliance test. The striking test object now most closely corresponds to a fixed object, such as a pole or tree, and to an angle impact by a relatively smooth (nonaggressive) striking vehicle. Impacts involving larger areas are frequent in real-world accidents but are not well-simulated by the compliance test.

Many of these factors interact with one another, but all must be considered separately during the feasibility study to establish the basis for potential evaluation methodologies.

An important step in the evaluation of the effectiveness of FMVSS 214 is identifying subsets of the vehicle population that can be used to provide a basis for comparison of door strengths. As described above, door beams were implemented for the 1967 to 1973 models without being subjected to any standard compliance test to indicate their comparative strengths. Therefore, additional compliance tests are required to determine the door strength of 1973 and earlier models. (Carefully selected manufacturers' test data could also be used if available.) Without additional tests, only 1974 and newer models are available for comparison between compliance test performance and real-world accidents.

Although it may be possible to use other data to measure effectiveness, it will become more difficult to examine injury-severity and door strengths relationships as we depart from measures relating to the compliance test for the standard. In the feasibility study for this standard, the compliance data for tested vehicles in the 1974 and later time frame will be compared with the real-world accident experience for those models, and the extent to which this comparison is valid will be determined. Of course, all of the technical considerations listed earlier must be examined, as well as other injury-related factors, such as interior padding effectiveness, use of restraints, door depth between exterior and interior surfaces, and arm rest design.

2.5 FMVSS 215--EXTERIOR PROTECTION

2.5.1 History and Intent

The automobile bumper was originally created to protect motor vehicles from damage in low-speed accidents. The bumper design was generally unsophisticated but effective--a beam held by spring-like supports. The system did not absorb energy (unless parts were permanently bent or broke under collision forces); rather, its form stored energy for release in a rebound motion when struck. By combining an extended position and high-strength materials, low-speed collision forces were spread over a sufficient period of time and space to prevent severe damage. When the bumper heights of two cars matched, they also served as a reasonable "Braille parking device."

As modern automobiles became more stylish, the bumper's protective nature tended to be sacrificed to designs that more attractively matched vehicle shapes. Bumpers were moved closer to body sheet metal and other vulnerable parts, and were often made of lighter weight materials as they grew larger. The results of these changes were increased low-speed collision damage of bumpers and other unprotected parts, and increasing cost to the motoring public, both directly and indirectly through increasing insurance costs.

The announcement of proposed rule making for FMVSS 215 was published on November 24, 1970 (35 F.R. 17999), following a public meeting held on April 2, 1970. The intent of the standard was to prevent low-speed collisions from impairing the safe operation of vehicle systems and to reduce the frequency of override or underride in collisions at higher speeds. Many comments to the docket were received and considered by NHTSA as evidenced by the first standard requirements published.

The initial standard was issued on April 16, 1971 (36 F.R. 7218), to take effect on September 1, 1972 (for the 1973 models). The standard required that 1973 model cars withstand low-speed barrier impacts at the front (5 mph) and the rear (2.5 mph) without damage to lighting, fuel, exhaust, cooling, or latching systems. The same standard required that, beginning with 1974 models (effective September 1, 1973), cars be able to withstand both barrier impacts and repeated pendulum impact tests with a front impact speed of 5 mph and a rear impact speed of 4 mph over a range of heights from 16 to 20 in. The pendulum impact device simulated the shape of an opposing "fairly hostile" bumper and equalled the weight of the vehicle being tested. Two vertical plane surfaces were also specified for the pendulum impact device, the lower surface (A) was 3 in. behind the outermost edge of the striking face, and the upper surface (B) was 1.5 in. behind the striking face edge. These faces were not allowed to touch the vehicle during testing. Corner impacts (at 30° from the longitudinal) were also required with the pendulum device at speeds of 5 mph in the front corners and 4 mph in the rear corners.

Continuation of dockets inputs, petitions, and NHTSA considerations resulted in the changes to the standard outlined below. On June 22, 1971 (36 F.R. 11852), the following changes were made: license plate lights were exempted; the corner impact speed was reduced to 3 mph at both the front and rear of the vehicle; the opposing bumper shape was made less aggressive; the pendulum tests were to precede the barrier tests; the vehicle's hood, trunk, and doors (not just their latching systems) were to remain normally operable; "leaks" were substituted for "open joints"; and a notice proposing a "no functional damage" requirement was published in the Federal Register (36 F.R. 11868).

On October 21, 1971 (36 F.R. 20369), the following additional changes were issued: 5-mph protection to meet the damage criteria was required for both front and rear impacts beginning with the 1974 models (effective September 1, 1973) for all passenger cars. Cars with wheel bases of 115 in. or less were exempted if they were convertibles, without a back seat, or "hardtops" (without a "B pillar" above the bottom of the window opening). Corner impacts below 20 in. were delayed until the 1976 model year;

engines were required to be running at the start of a barrier impact; and lighting requirements were broadened to "applicable requirements of FMVSS No. 108," thereby eliminating a need for reference to headlamp adjustment.

Further modifications continued to be made as summarized below. On December 15, 1971 (36 F.R. 23802), the lighting requirement was changed to its original form, pending further comment and study, and the phrase "suffer no damage" was deleted from the description that specified that vehicle components must remain operable. On August 19, 1972 (37 F.R. 16803), trailer hitch removal was allowed, and headlamp aiming requirements following testing were made more specific but less stringent in regard to filament breakage. On August 15, 1974 (39 F.R. 29369), a pressure vessel performance criterion was issued to protect bystanders. (No separation of fragments from the vessels was allowed.) This requirement was limited to "exterior protection systems" to exclude wheel suspension shock absorbers and similar devices not intended to be regulated by the standard.

On August 30, 1974 (39 F.R. 31641), the exemption of certain vehicles with wheel bases of 115 in. or less from the pendulum impact requirements was extended from September 1, 1974 to November 1, 1974. On May 13, 1975 (40 F.R. 20823), changes were issued to reduce the number of front and rear longitudinal pendulum impacts from 3 to 2, based on average vehicle bumper-involved accident histories, and to delay until September 1, 1976 the "low-corner" (below 20 in.) impact requirements for vehicles with wheelbases of more than 120 in.

In addition to these revisions to FMVSS 215, Title I, of the Motor Vehicle Information and Cost Savings Act (Public Law 92-513) includes a damageability standard that calls for no vehicular damage as a result of barrier and pendulum tests. Current and proposed test requirements relating to exterior vehicle protection were examined in detail during the feasibility study for FMVSS 215.

2.5.2 Technical Considerations

During a thorough review of docket submissions and research reports, several technical factors were identified that were more carefully examined during the feasibility study for this standard. They included:

- Barrier test versus real-life impact--Peak forces and impact levels differ between barrier impacts and vehicle-to-vehicle impacts. These differences may affect protection from damage at both test and real-world speeds.
- Pendulum test versus real-life impact--Angular forces present in the pendulum test are not present in most real-life impacts.
- Unprotected systems--Other safety-related vehicle components (e.g., windshields, side and rear windows, frame, and battery and mounts) are not necessarily protected by the standard.
- Occupant protection--Added vehicle rigidity and weight to protect the vehicle may be adversely affecting occupant safety by increasing forces on the occupant during an impact.
- Bumper mismatch--This condition still exists and causes unnecessary damage, especially when two colliding vehicles traveling the same direction are braking.
- Pedestrian safety--With pedestrians accounting for 1 in every 5 traffic fatalities, a major problem still exists, especially with respect to vehicle front surface designs.
- Number of test impacts--Although the number of bumper-involved impacts may be low over the life of the average vehicle, parking in urban areas sometimes resembles an amusement park bumper car rides.
- Evaluation factor--Previous studies indicate that the current version of FMVSS 215 is probably cost-effective as currently implemented. However, the cost-effectiveness of more stringent standards, such as "no-damage" and 10-mph impact speeds, is much less clear. Thus, effectiveness versus implementation and operating costs must be carefully examined for each successive model year. The 1972 model year appears to be a reasonable base year to represent noncompliance, and each successive model year, beginning with 1973, will be examined for increased protection in conjunction with incremental costs. Models exempted from certain requirements (as noted in earlier descriptions) will also be carefully examined to determine whether they should be excluded from consideration or evaluated along with vehicles from previous model years.

Section 3

STUDY RESULTS FOR FMVSS 301--FUEL SYSTEM INTEGRITY

3.1 STATEMENT OF THE PROBLEM

FMVSS 301 is intended to limit fuel spillage during and after motor vehicle crashes in order to reduce deaths and injuries occurring from vehicle fires. Therefore, to establish the effectiveness of the standard, an integral part of the evaluation plan must consist of direct observation and analysis of all of the essential causes, effects, and explanatory variables. These will include:

- The national distribution of all accidents, categorized by the variables of impact force vector, vehicle types, age, and the extent and location of damage.
- The frequency of occurrence, source, and extent of fuel leakage, expressed as a function of the variables listed above.
- The frequency and extent of fires that are initiated or augmented by fuel spillage.
- The ignition sources of such fuel-fed fires.
- The injuries, by type and by fatalities that occur as a direct consequence of fires.

An analysis of these factors, based on a sample of highway accidents, would be definitive in the sense that no inference would be required to bridge the gaps created by dissimilar or incomplete data bases. The only extrapolation required would consist of extending observed sample results to the target population--a necessary characteristic of any analytical methodology. The measures of effectiveness would be as follows: (1) the observed conditional frequency of fuel leakage, given the accident conditions, vehicle types, and other variables; (2) the conditional frequency of fuel leakage, given the accident conditions, vehicle types, and other variables; (3) the conditional frequency of fuel-fed fires; and (4) the conditional frequency of fire-related injuries and fatalities. A determination of ignition sources would serve as an explanatory variable, and observations of independent variables such as vehicle age (as distinct from model year) could be taken into account to eliminate the possibility of confounding effects. The effectiveness of the standard would be established if analysis revealed a significant decline in at least measures of effectiveness (1) and (2) above between pre- and post-standard vehicles.

3.2 DESCRIPTION OF THE CURRENT STANDARD

FMVSS 301 establishes requirements to improve the integrity of motor vehicle fuel systems by reducing fuel spillage during and after crashes to reduce deaths and injuries that result from fuel-fed vehicle fires. 1976 model passenger cars must meet the requirements of the perpendicular frontal barrier crash at 30 mph and of the static roll-over test; 1977 and after models must meet all requirements of the standard. 1977 model vehicles (multipurpose passenger vehicles, trucks, and buses) with a GVWR of 6000 lb or less must meet the requirements of the perpendicular frontal barrier crash at 30 mph, the rear-moving barrier crash at 30 mph, and of the static roll-over test; 1978 model and later must meet all requirements of the standard. 1977 model vehicles of more than 6000 lb but not more than 10,000 lb GVWR must meet the requirements of the perpendicular frontal barrier crash at 30 mph only; 1978 models and later must meet all requirements of the standard.

Fuel spillage in any fixed or moving barrier crash test must not exceed 1 oz from impact until motion ceases, must not exceed 5 oz in the 5 min following cessation of motion, and must not exceed 1 oz during any 1-min period for the next 25 min. Roll-over fuel spillage is limited to 5 oz during the first 5 min of testing at each 90° increment of vehicle rotation; it cannot exceed 1 oz during any 1-min period in the remainder of the test periods. Only one barrier crash test of any type and the static roll-over test are required of any vehicle, but the vehicle may not be altered between tests.

Frontal barrier crashes, either perpendicular or at any angle up to 30° from the perpendicular to the line of travel of the vehicle, at 30 mph are specified. A 30 mph rear-moving barrier crash, and a 20 mph lateral-moving barrier crash test, with specific test dummy or equivalent constraints are also specified. A static roll-over test is specified as well; the vehicle is rotated about its longitudinal axis (kept horizontal) at a uniform rate (1 to 3 min) through successive increments of 90°--the vehicle is held at each position for 5 min.

The fuel tank is to be filled to between 90-95% capacity with Stoddard solvent, with the rest of the fuel system filled with the same fluid to normal operating level. Electrically driven fuel pumps must be operating at the time of the crash. (Engines cannot be operated because of the fluid used.) The parking brake must be disengaged, the transmission in neutral, and the tires inflated to manufacturers' specifications. Approximate vehicle test loads are also specified.

3.3 DISCUSSION OF TECHNICAL FACTORS

3.3.1 Analysis of Relationships

Two kinds of damage to fuel system components are possible in a frontal impact. Direct damage resulting from sheet metal crush and other vehicle deformation is one kind; for example, a part of the radiator bracket as it is pushed back toward the engine might sever the fuel line. This type of fuel system damage would occur mainly at the front of the vehicle in the region of greatest damage. The other kind of damage would result from the impact acceleration. An example would be the failure of a fuel tank mounting and resultant separation of the fuel line. This type of damage could occur anywhere on the vehicle.

Measures taken to ensure compliance with FMVSS 301 have included relocation of fuel system components to avoid locations vulnerable to damage, strengthened connections, stronger mounting components, redesigned tank vents and fillers, and so forth. For vehicles with front-mounted fuel tanks, the tank itself has been protected.

Except for vehicles with front-mounted tanks, it is not clear that a frontal-barrier impact is a severe test of fuel system integrity. Many vehicle models may not require extensive modifications solely to pass frontal-barrier impact tests. This would affect any attempt to evaluate the effectiveness of the standard because absence of design modifications to meet the requirements of the standard would imply no difference in real-world performance.

Vehicles manufactured between September 1, 1975 and August 31, 1976 are subjected to an additional static roll-over test following the perpendicular barrier collision. The object of this test is to ascertain that the vehicle's fuel leakage is limited when it is not in an upright position. Compliance with this provision of the standard requires subtle redesign of carburetor vents, fuel filler caps, and evaporative emission control systems.

Vehicles manufactured after September 1, 1976 are subject to additional compliance testing, which has resulted in significant design changes concerning fuel tank protection in rear and side collisions.

Three criticisms can be made of the present compliance test. First, the flat vertical planes of the fixed and moving barriers do not resemble the actual vehicles involved in real-world vehicle-to-vehicle crashes. This could be significant if, in rear-end collisions, the impacting vehicle's bumper underrode the other vehicle's bumper. Second, the side impact test is directed toward the passenger compartment. It would be more effective if the test could be applied at any point along the side of the vehicle; this would constitute a better test of the integrity of a side-mounted filler pipe or side-mounted tank, for example. Third, the static roll-over test only partially simulates a dynamic roll-over situation. Although the standard requires that no more than a specified amount of fuel be lost when the vehicle in the test is not upright, it cannot account for damage that might occur to the fuel system in a real roll-over. A dynamic roll-over test was considered in a notice of the proposed rule making but was deleted when objections were raised about the difficulties of detecting and measuring fuel spillage when the test vehicle is rolling over at 30 mph.

FMVSS 301 as a whole, and not just the compliance test, can be criticized for failing to address the problem of ignition sources, because its stated intent is to "reduce deaths and injuries occurring from fires . . . ."

3.3.2 Fuel System Factors

Although three basic elements are required for a fire (fuel, ignition source, and oxygen), an unsafe condition can be assumed to exist in the presence of any ignitable liquid or vaporized fuel spillage. This assumption is a reasonable one, considering the abundance of oxygen in the environment and the potential ignition sources that are plentiful in practically all environments. Besides the electrical and exhaust systems of the vehicle, many uncontrolled external sources such as a flame from a flare, cigarette, or burning tire exist; sparks from a broken power line; and during collisions, sparks generated by friction of metal parts scraping against each other or the pavement.

3.3.2.1 Fuel System Components and Hazards

Fuel tanks and fillers--Automobile fuel tanks are now usually placed on the opposite end from the engine. Front-engine vehicles generally have the tanks placed between the rear bumper and the rear seat of the vehicle, and older vehicles have tank locations nearer the rear bumper. The fuel filler cover and connecting filler pipe usually terminate on a rear vehicle surface (rear of the trunk deck or bumper) or on either side of the rear fenders. Rear-engine vehicles generally have the fuel tank under the front hood on either the bumper side or the passenger compartment side of the front storage compartment. The filler cover and pipe usually terminate at some location near the tank within the front storage compartment for front-mounted tanks. Pickup trucks usually have fuel tanks behind the seating area; they are filled from the driver's side of the cab.

The tanks are usually held in place with two straps, although some are bolted directly to other sheet metal components. The filler pipe may be hardmounted to the tank or may be a flexible connector from the filler cap to the tank.

Fuel lines--Fuel lines are generally steel welded tubing leading from the vehicle fuel tank to the fuel pump. Fuel is then carried to the carburetor fuel injectors through solid steel lines or flexible rubber lines. A few vehicles use steel mesh over rubber lines in the engine compartment.

Fuel pumps--Most vehicles operate with engine-mounted, cam-actuated fuel pumps: When the engine stops, the pump stops. Some vehicles use electric fuel pumps near the fuel tank; some of these operate only when the engine runs, but others operate as long as electric power is supplied either by the ignition switch or a separate switch.

Carburetor--Fuel distribution to the engine cylinders is performed either by a carburetor(s) and intake manifold combination, or by fuel injectors. The carburetor draws fuel from one or two bowls whose fuel level is regulated by a float mechanism. This reservoir of fuel comprises the primary fire hazard posed by the carburetor. (Fuel injectors have no such reservoir and thus pose no similar hazard.) These fuel bowls are vented directly to the atmosphere or to the engine air cleaner.

Evaporative control systems--Most pre-1971 vehicles have fuel vents open directly to the atmosphere. Since 1971 (1970 in California), however, fuel vapor emissions have been controlled in closed fuel systems. Tanks are vented into some form of liquid-vapor separator, where vapors are stored either in a carbon canister, in a storage tank, or in the engine crank case; liquid is returned to the tank. Vapors are thus stored until the engine is started; then they are drawn into the combustion air stream.

Hazards--Fire potential exists wherever the integrity of the fuel system described above is breached or when a vehicle attitude is maintained which allows fuel to leak from vents (as in a roll-over). The types of hazards to the fuel system are: any shock or impact loading that ruptures a fuel system component; deformation of a vehicle component that impacts a fuel system component; roll-over causing spillage from vents or nonvehicle parts (such as loads or roadside objects) impacting exposed fuel system, compression forcing fuel from vents, and failure of connectors.

3.3.2.2 Electrical System Components and Hazards

Battery--"The storage battery, having the greatest energy in the electrical system, possesses the system's highest capacity to cause fires if displaced, shorted, or otherwise disturbed by crash damage."[1] The battery may be located in many different locations; generally, however, it is mounted near the engine. Many vehicles have no protection for the heavy battery cables, but some have rubber or plastic covers that slip over the terminals. These covers provide protection from accidental shorting and also reduce the formation of corrosion deposits on the terminals. Shorting of the battery terminals due to metal deformation is a serious fire hazard.

Starting equipment--This equipment only receives current when the vehicle is started, and as a result presents no significant hazard.

Alternators, generators, and voltage regulators--These components are fairly sturdy and the primary hazard is the exposed terminals that are present on some vehicles. (Others have protected terminals.)

Vehicle wiring--All vehicles have large numbers of current-carrying wires, with the greater hazard presented by higher current levels. Some wiring is well-protected, but much of it is routed in exposed locations. In a crash environment, these wires can easily be severed or crushed through their protective insulation, resulting in sparking. Protected circuits (usually lower-amperage circuits) have fuses or circuit breakers that will quickly eliminate sparks, but high-amperage circuits are frequently not similarly protected.

High-voltage ignition sources--These systems are well-insulated because of the presence of high voltage and thus are relatively well-protected from accidental exposure that results in sparking. They also continue to operate only as long as the engine runs, and accidents severe enough to damage these components usually stop the engine as well.

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[1] "Fuel Tank Protection," Fairchild Hiller (1969).

Vehicle lights--Motor vehicle headlights have heated filaments that may continue to burn for as long as 30 s after the bulb is broken (i.e., if the filament remains intact and electrical current is present).

3.3.2.3 Other Ignition Sources

Friction sparks during collision present a possible ignition source in the presence of spilled fuel. These are made up of burning or hot metal particles abraded from the vehicle by contact with the pavement or other vehicle. Hot surfaces such as exhaust manifolds (near the engine) and catalytic converters (operated at very high temperatures) provide potential sources of ignition or at least increased fuel evaporation if spillage is present. Overheated brakes also present a potential ignition source as do wheel-bearing failures--these may cause tire fires, which could serve to ignite spilled fuel. Engine backfires can also potentially ignite fuel, but this situation is unlikely to be present in a collision.

External ignition sources include high-tension lines, flares set out for warning, or flames from matches used by bystanders to light cigarettes.

3.3.2.4 Countermeasures

N. Johnson[2] (and others) have examined the effectiveness of countermeasures for vehicle fires, based on preventing fuel leakage and on eliminating electrical system ignition sources. Fuel leakage countermeasures (and approximate manufacturers' component costs) include: safety tanks ($35 to $50), filler check valves ($2 to $5), fuel shut-off valves ($2 to $5), fuel line and fitting improvements ($5 to $10), fuel line rerouting ($0), and fuel tank relocation ($0). Electrical ignition source countermeasures include: inertial switches ($5 to $10) and battery terminal shields ($1 to $2). Consumer costs (as described in Section 3.5), would be approximately four times these figures.

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[2] N. Johnson, "An Assessment of *Automotive Fuel System Fire Hazards*," Summary Report, Contract HS-800 623 (December 1971).

A cost-benefit analysis was performed by Johnson and others on two groups of these countermeasures. The first, combining essentially all of the measures, was considered to approach 100% effectiveness, but it was found to be only about 50% cost-effective, based on minimum burn fatality and fire accident estimates. A second group, including only the electrical system countermeasures, was considered about 85% effective and would be cost-effective within 5 years with benefits exceeding costs from then on. All of these results were based on minimum fire estimates (625 fire-caused fatalities and 5000 vehicle crash fires). If actual fire loss values should be higher, greater savings are foreseen.[3]

3.4 REVIEW AND ASSESSMENT OF ALTERNATIVE EVALUATION METHODOLOGIES

To assess overall analysis feasibility and to structure a rationale for an evaluation plan, available methodologies were reviewed. The results of this review, described below, focus on separate methodologies; however, no firm conclusions about the precise structure of a complete evaluation plan are drawn. The nature of the problem suggests that serious attention should be directed toward existing data bases, current and future in-depth accident investigation programs, and, to a more limited extent, analytic models and controlled tests (fixed and moving barrier, roll-over, and the like).

3.4.1 Existing Data Bases

From the literature, two reports have been used as a frame of reference for an expanded survey. The first report, by Cooley[4] in 1974, presented an excellent analytic evaluation of the strengths, biases, and limitations of eight major research efforts which were directed toward

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[3] N. Johnson et al., "Spilled Ignition Sources and Countermeasures, Summary Report," Ultrasystems, Incorporated, NTIS PB 246 281 (September 1975).

[4] P. Cooley, "Fire in Motor Vehicle Accidents," HSRI Special Report (April 1974).

analyses of motor vehicle fires before 1974. It also described existing data bases and their associated limitations. Most important, though, Cooley concluded that "no single body of data exists with which to accurately assess the national problem of fires in motor vehicle accidents." And "neither police organizations nor such agencies as state fire marshall divisions generate adequate records."

The second report by Austin et al[5] studied post-crash factors in automobile collisions in 1972-73. This report was a product of the Multidisciplinary Highway Crash Investigation Team of the University of Utah. It was not designed to evaluate FMVSS 301 per se but contained useful background data regarding vehicle fuel leakage and fires, and clearly demonstrated the feasibility of evaluating FMVSS 301 in the field through highway accident investigations.

Other sources of data investigated include the Highway Loss Data Institute (HLDI), National Safety Council (NSC), State Accident Reporting Systems, California Fire Incident Reporting System, National Fire Protection Association (NFPA), and finally, the University of Michigan's Multidisciplinary Accident Investigation Files (MDAI). During the investigation of existing data sources, two criteria were uppermost: First, could the data be exclusively used to evaluate FMVSS 301 (i.e., was requisite information collected between 1973 and 1976). Second, if the data did not satisfy the first criterion, could the data base be used in stratifying accidents to minimize the number of cases that must be sampled to evaluate the standard in the field. A summary of this investigation follows.

HLDI--Officials of HLDI were contacted, and the objectives of this study were reviewed at length. It was discovered that pertinent insurance data can only be traced to claims submitted since mid-1972 and that the occurrence of motor vehicle fires has not been consistently noted or the causes recorded. Thus, neither criteria could be satisfied.

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[5] J. A. Austin et al., "Study of Post-Crash Factors in Automobile Collisions," Final Report, University of Utah Auto Crash Team, Contract DOT-047-1-063 (April 1975).

NSC--The NSC Statistics Department indicated that no provision exists for reporting collisions that involve fires or fuel leakage on the various state forms that it receives. Discussions with NSC librarians also indicated that, to the best of their knowledge, no fuel leakage or fire-related accident data bases were developed between 1973 and 1976. Again, neither criteria could be satisfied.

State accident reporting systems--In the majority of states, a sample of accidents (usually all accidents over a certain dollar property damage) are reported to a central location where they are transcribed and entered in a data base. Ten states were selected to evaluate the extent of the information reported. Reporting forms for these states were checked for items relevant to evaluation of the standard and the results are presented in Table 3-1. From our evaluation, it is obvious that state accident data bases alone cannot be used to evaluate the standard. Only one state--North Dakota--records vehicle fires, but even here no information is reported on the source of the fire, fatalities, or injuries caused by the fire. In some cases not even the vehicle year is noted.

To use state accident data bases in the stratification of accidents does not appear worthwhile in view of inherent difficulties. Only half of the states sampled note damage severity (i.e., whether the vehicle was disabled by the collision), and areas of damage to the vehicle are only noted in four states.

Thus, before we can develop a stratification of accidents, modification or augmentation of police report forms is required.

Other state reporting systems--California is one of only a few states (four or five) that has a centralized data base for reporting fires to which a fire department responded. Information recorded includes:

- Property classification.
- Act causing fire ignition.
- Type of material first ignited.
- Fatalities or injuries as a direct result of the fire.

From this source then, a yearly estimate can be obtained for fuel-fed vehicle fires that resulted from a collision, and fatalities of injuries that

Table 3-1

STATE ACCIDENT REPORTING INFORMATION

State	Crash Conditions (rear-end, etc.)	Damage Areas	Fire	Fuel Leakage	Damage Severity (tow-away or disabled vehicle)	Type of Vehicle	Year of Vehicle	Speed at Impact
Arizona	X				X	X	X	X
California	X	X			X	X	X	
Iowa	X					X	X	
Kentucky	X					X		
Montana	X	X			X	X	X	
New Jersey	X					X		
North Dakota	X	X	X		X	X	X	X
Oregon	X					X	X	
Pennsylvania	X	X			X	X	X	
Virginia	X					X	X	X

directly resulted from a fire to which the fire department responded. This data file was accessed for 1975, and it was found that, in 323 cases of collision-induced, fuel-fed vehicle fires, 36 fatalities and 63 injuries occurred. This represents 0.07% of total reported California vehicle accidents and 0.9% of total reported motor vehicle fatalities.

Because the California data base is biased toward fire occurrence rather than the vehicle or type of collision, no information can be obtained on vehicle model, year, ignition source, direction of impact, or speed at impact. Thus, it is impossible, using these data, to link vehicle fires to compliance or noncompliance with FMVSS 301.

NFPA--Although NFPA has collected fire data since 1935, it has not recorded the causes of fires in motor vehicles; it also associates reported fatalities with the fire rather than specifically indicating whether they were caused by the fire. Moreover, reporting by fire departments to NFPA is voluntary and based on fires over a set dollar value.

MDAI--The MDAI files for 1967 through 1975 were searched with the following results:

- Number of fires--Of 8171 accidents, only 150 (1.8%) included fires.
- Extent of fire--Of 8171 accidents, 51 (0.6%) were minor, and 68 (0.8%) were major.
- Origin of fire--45 (0.6%) fires originated in the fuel tank; 42 (0.5%) in the engine; and 18 (0.2%) in other places.
- Fuel level at impact--2611 (32%) accidents had half a tank or more; 2378 (29%) had less than half a tank; and for 3182 (39%) this information was unknown.
- Fuel tank retention--In 7858 (96%) accidents, the tank was fully retained.
- Fuel tank deformation--7147 (87%) accidents were reported with no deformation; 941 (12%) yes; and 83 (1%) unknown.

- Fuel leakage--7476 (91%) accidents were reported with no leakage; 601 (7%) yes; and < 2% unknown.
- Fuel leakage from tank--7473 (92%) were reported as not applicable; 307 (4%) as yes; 292 (4%) as no; and 99 (< 1%) as unknown.

The data shown in Table 3-2 were extracted from the current MDAI files. These data are not nationally representative because they are biased in the direction of high-severity accidents. However, subject to these limitations, they reveal no evidence of any trend in postcrash fuel leakage incidents across the calendar years 1967 to 1975.

3.4.2 Controlled Tests

Consideration was given to controlled experiments, wherein the following procedures could be employed:

- An engineering analysis of a selected sample of pre- and post-standard vehicles could be performed to determine if and where changes have been made to fuel system components, consistent with the objectives of preventing fuel leakage in frontal collisions.
- The absence of apparent changes would strongly suggest that staged crashes would not reveal any difference in the amount of fuel leakage between pre- and post-standard vehicles.
- If significant changes were discovered, then a sample of pre- and post-standard cars could be subjected to various barrier and roll-over tests, depending on which version of the standard was being evaluated. If, for example, the current version was being evaluated, the tests could parallel compliance tests at similar speeds but would differ in two respects. First, a moving barrier resembling the front of a car with a protruding bumper, could be developed and could be adjusted so that the bumper height would be about 3 in. lower than the standard bumper height to simulate hard-braking conditions. Second, for side impacts, the moving barrier could be aimed at any point on the side of the vehicle to test the most vulnerable fuel system component. Because the object is to evaluate fuel system integrity, the moving barrier would be aimed ahead of the passenger compartment for a front-mounted tank. Conversely, it would be aimed at the rear fender for a rear-mounted tank.

Table 3-2

FUEL LEAKAGE BY YEAR OF COLLISION

Response	1967	1968	1969	1970	1971	1972	1973	1974	1975	Total
Unknown	3	13	13	12	21	13	9	7	3	94
Yes	1	3	59	96	142	121	102	65	12	601
No	43	163	369	860	1643	1794	1522	828	254	7476
Total	47	179	441	968	1806	1928	1633	900	269	8171

Source: MDAI file.

- Differences in performance of the two groups of vehicles, as measured by the occurrence of fuel leakage would enable evaluation of the effectiveness of the standard in preventing fuel leakage, but it would not provide information on fire occurrence.

3.4.3 In-Depth Accident Investigations

In the past, accident investigations have had three limitations that restrict their use in evaluating FMVSS 301. The first has been a bias toward high-severity accidents; second, their sampling size has been too small to draw valid statistical conclusions--particularly in the case of early model vehicles; and third, they have not represented the national population.

However, two recent programs under development by NHTSA appear to avoid these prior limitations and could provide a frame of reference in an evaluation of FMVSS 301. One is the National Crash Severity Study (NCSS), which is designed to collect 10,000 accidents over the program period. The program has been collecting data since October 1976 and is scheduled to continue through March 1978 (18 months duration). No results from this study are currently available, and extension of the data collection to ensure meeting sample size goals is being considered. This schedule offers an opportunity to use NCSS immediately. At last count, the total program budget was 2.5 million with 100% sampling of fatalities (estimated at 600) and 25% minor injuries (AIS $\leq$ 2), or 2500.

Figure 3-1 shows the NCSS Fuel Leakage/Fire Hazard Supplement to be used by the investigating team. Other available data considered important include automobile make and model, year, weight, and occupant injuries.

Figure 3-1

FUEL LEAKAGE/FIRE HAZARD SUPPLEMENT

(Complete form only if fuel leakage or vehicle fire occurred.)

FUEL LEAKAGE

DID FUEL LEAKAGE OCCUR?	
Yes	1
No (Skip to Fire Section)	2
Unknown	9

WHICH VEHICLES LEAKED FUEL?	Veh. 1	Veh. 2
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9

TYPE OF FUEL LEAKAGE	Veh. 1	Veh. 2
Gasoline	1	1
Diesel	2	2
Other (Specify) ______	3	3
Combinations (Specify) ______	4	4
Not Applicable	8	8
Unknown	9	9

LOCATION OF LEAK	Veh. 1	Veh. 2
Engine Compartment		
Unknown Location	01	01
Carburetor	02	02
Fuel Pump	03	03
Fuel Lines	04	04
Other (Specify ______)	07	07
Passenger Compartment		
Fuel Lines	11	11
Other (Specify ______)	17	17
Fuel Tank Area		
Tank	21	21
Fillerneck	22	22
Fuel Lines	23	23
Other (Specify ______)	27	27
Leaks in More than One Area (Specify ______)	31	31
Not Applicable	98	98
Unknown	99	99

FIRE HAZARD

DID A VEHICLE FIRE OCCUR?	
Yes	1
No (Form Completed)	2
Unknown	9

WHICH VEHICLES WERE INVOLVED?	Veh. 1	Veh. 2
Yes	1	1
No	2	2
Not Applicable	8	8
Unknown	9	9

FIRE SOURCE	Veh. 1	Veh. 2
Fuel Leakage	1	1
Electrical Short	2	2
Other Vehicle	3	3
Other (Specify ______)	4	4
Not Applicable		8
Unknown	9	9

FIRE ORIGIN	Veh. 1	Veh. 2
Engine Compartment		
Unknown Location	01	01
Carburetor	02	02
Fuel Pump	03	03
Fuel Lines	04	04
Battery	05	05
Wiring	06	06
Other (Specify ______)	07	07
Passenger Compartment		
Fuel Lines	11	11
Instrument Panel	12	12
Other Wiring	13	13
Other (Specify ______)	17	17
Fuel Tank Area		
Tank	21	21
Fillerneck	22	22
Fuel Lines	23	23
Wiring	24	24
Other (Specify ______)	27	27
Not Applicable		98
Unknown	99	99

EXTENT OF VEHICLE INVOLVEMENT	Veh. 1	Veh. 2
Engine Compartment Only	1	1
Passenger Compartment Only	2	2
Fuel Tank Area Only	3	3
Engine + Pass. Area	4	4
Pass. + Fuel Tank Area	5	5
Engine + Fuel Tank Area	6	6
Entire Car	7	7
Not Applicable		8
Unknown	9	9

WAS FIRE FED BY VEHICLE FUEL SYSTEM?	Veh. 1	Veh. 2
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9

WAS FIRE EXTINGUISHED?	Veh. 1	Veh. 2
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9

DID VEH. OCCUPANT SUSTAIN BURN INJURIES?	Veh. 1	Veh. 2
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9

11

The second program is the National Accident Sampling System (NASS) that will, when implemented beginning in 1980, collect a nationally representative sample at a projected rate of 20,000 accidents per year. This program, obviously, cannot provide a timely evaluation of FMVSS 301.

3.5 EVALUATION STUDY DESIGN

3.5.1 Background and Rationale

This section first describes several data collection procedures considered as a basis for an evaluation of the effectiveness of FMVSS 301. It then recommends one for implementation.

From a review of the literature and current methodologies it is apparent that data obtained from accident investigations can provide the basis for a definitive evaluation of FMVSS 301, and this type of analysis will not be greatly enhanced by an augmented program of controlled testing or simulation modeling. It is also clear that existing data bases contain inherent limitations that preclude definitive evaluation of this standard at this time. These limitations occur because of inadequate sample sizes, nonrepresentative samples and, in general, because the data sources compiled by state and national agencies do not adequately represent all of the factors required for evaluation. Thus, an analysis based on a composite of these disparate data sources would lack credibility because of the inference that would have to be exercised to compensate for suspected biases and to extrapolate to essential factors that have not been measured.

3.5.1.1 Constraints and Requirements

From an analytic point of view, neglecting cost considerations for the moment, the best procedure would be to collect a representative sample of all accidents. This would permit direct observation and analysis of all the cause and effect factors relevant to FMVSS 301. Such a sample, however, must be quite large: Data would be recorded for all types of accidents, including numerous minor damage cases in which the probability of fuel leakage is small. For example, a nonstratified, random sample of approximately 50,000 accidents would be required* to be reasonably certain of detecting a 50% reduction (as detailed below) in the number of postcrash vehicle fires between pre- and post-standard vehicles. Furthermore, the sampling procedure would have to be extended over 4 to 5 years to separate the effects of vehicle age and model year by such techniques as regression analysis (i.e., a 1977 model may have an increasing probability of postcrash fuel leakage with age). We note, however, that a mechanism for implementing an extensive data collection procedure of this type will exist within the proposed NASS framework if the projected sampling rate of 20,000 accidents per year is achieved. The NASS stratified cluster sample design will provide nationally representative accident data on a continuing basis and the NCSS and Collision Performance and Injury Report (CPIR) data forms will provide adequate information on crash conditions, vehicle types, fuel leakage, fire, and injuries and fatalities.

If cost and time constraints had not been crucial for this study, we would have recommended a detailed plan, based on the preceding outline of a sample of all reported accidents collected within the NASS program. However, from our understanding of NHTSA requirements, and to ensure economic feasibility, we have established guidelines that any recommended plan should be designed to be implemented within 3 years, and that it must use existing data collection programs if available. With these constraints in mind, a plan for evaluating FMVSS 301 within the NCSS program was developed. NCSS sampling is reasonably representative of the national population, and adequate data are being collected. However, augmentation of the current sampling rate will be required to achieve the desired statistical precision.

The time and data guidelines indicated above impose certain limitations on the extent and quality of a feasible evaluation plan, but we believe them to be fully acceptable. In particular, the following conditions must be met.

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*A simple computing algorithm for determining required sample size is given in Appendix B.

- Data collection will be restricted to 1974 through 1979 models.
- The effectiveness of FMVSS 301 will be based on a comparison of pre-1977 and post-1976 models.
- The effectiveness of the standard will be based primarily on the frequency of postcrash fuel leakage and the frequency of fuel-fed fires. Burn-related injuries and fatalities will also be measured, but sample sizes will not be increased to ensure that an observed differential in these infrequent events is statistically significant.

The restriction on data collection to the 1974-1979 models acknowledges that the age of a vehicle may correlate with postcrash fuel leakage. A recent status report (February 5, 1975) from the Insurance Institute for Highway Safety (IIHS), for example, states that study results reveal a high correlation between the probability of fire and vehicle age, possibly reflecting vehicle deterioration over time. The IIHS sponsored study is not confined to postcrash fuel-fed fires, and it is likely that much of this correlation is accounted for by noncrash-induced electrical malfunctions, carburetor fires, and the like. But the possibility of a postcrash fuel leakage correlation with age exists, and a thorough study to separate the effects of model year and age would require an unacceptable time for data collection. Thus, we have restricted our attention to the 1974-1979 models and have assumed that fuel leakage dependence on age is minimal or nonexistent during the first 3 years of a vehicle's life.

The comparison of pre-1977 and post-1976 vehicles between 1974 and 1979 is a logical consequence of the restrictions on data collection described above. However, this comparison is further justified by an evaluation of compliance results that suggest early versions of the standard had little impact on vehicle design, and that the most noticeable effects on fuel leakage will result from rear-barrier and side-impact compliance tests applied to post-1976 vehicles. This reasoning is also partially born out by the Austin study that concluded no differences in fuel leakage were noted in pre-1975 vehicles.

The selection of the frequency of fuel leakage and the frequency of fire as primary measures of effectiveness, rather than the frequency of burn injuries and fatalities, is based on two considerations. The first is that burn injuries and fatalities are rare occurrences and that investigations of such events must necessarily be extended over a long period. For example, if 1000 burn fatalities per year occur in pre-1977 model vehicle crashes, and if the sampling scheme covers 1% of the national population, then we would expect a maximum of only 10 burn fatality investigations in any given year. The second consideration is the reasonable assumption that the frequency of burn-related injuries and fatalities should not vary greatly with model year when crash and fire conditions are fixed.

3.5.1.2 Three NCSS-Based Alternatives

Based on these considerations, three alternative evaluation plans were considered. All can be implemented in an extended NCSS program. The criteria for estimating required sample size were based on the frequency of occurrence of fuel leakage and fire events for all reported accidents taken from the Cooley report. The frequency of fuel leakage in a tow-away accident was derived from an in-house SRI study of California State Police records that showed that 56% of all reported accidents were tow-aways. The following percentages are estimates applicable to pre-1977 vehicles:

- Postcrash fuel leakage--2.5% of all reported accidents and 4.6% of all tow-away accidents.
- Fuel-fed fires--0.1% of all reported accidents and 0.18% of all tow-away accidents.

For study design purposes, the required sample sizes must be estimated, based on predicted reductions in the probability of post-1976 vehicle fuel leakage in tow-away accidents. The required sample sizes are indicated below for various hypothetical reductions in the probability of fuel leakage, subject to the condition that there be at least a 0.9 probability of detecting this reduction with the conventional test for equality of proportions. In all cases it is assumed that equal numbers of pre-1977 and post-1976 vehicles comprise the total sample.

Percent reduction in probability	50	40	30	20
Total sample size	2,224	3,704	6,988	16,620

In the Cooley report, it was assumed that a considerable reduction in fire fatalities would occur in vehicles complying with FMVSS 301 specifications for rear impacts. Specifically, it was assumed that, for side and rear impacts all fire fatalities in moderate crashes and half the fatalities in severe crashes would be eliminated. These assumptions appear to be reasonable and are consistent with our design criterion that bases sample sizes on a 50% reduction in fuel leakage probability.

A brief description of three options follows. The only prestratification requirements specify equal numbers of pre- and post-standard vehicles, and full sampling of crash-fire events.

- Option 1--Conduct level 2 investigations on a sample of all reported accidents within the jurisdiction of the NCSS to obtain the requisite information on fuel leakage as a function of crash conditions and other variables. Using the sample size criterion, 4100 accidents would be sampled--2050 pre-1977 and 2050 post-1976 vehicles. In addition, investigate 100% of the reported crash-fire events. There will be approximately 25 of these per year over a 3-year period (assuming an exposure rate of 27,000 accidents per year in the NCSS and that new model cars are being introduced at the rate of 10% per year).
- Option 2--Obtain the cooperation of investigating police, as in the Austin study, so that fuel leakage incidents and vehicle types will be identified and formally recorded on supplementary data forms. MDAI investigations would cover all crash-fire events and would sample fuel leakage accidents to determine crash conditions. On a judgmental basis, 1000 investigations would be required. The records of cooperating police must be accessed to determine the ratio of fuel-leakage accidents to total reported accidents.
- Option 3--Select for investigation 2400 accidents from all reported tow-aways. Investigate 100% of all reported crash-fire occurrences.

The difficulty in obtaining a sufficient sample size of postcrash fires is characteristic of each of these options because, with an estimated NCSS exposure rate of 27,000 reported accidents per year and a standard that reduces fires by 50% in post-1976 vehicles, we may expect 25 fire accidents to be reported each year. An adequate sample size can be obtained by expanding the area of NCSS sampling to achieve a greater exposure rate or by extending the present NCSS program to last for 3 years. The alternative of augmenting MDAI investigations by state police records and data compiled by fire protection agencies is not acceptable for the reasons discussed under alternative methodologies in Section 3.4.1.

Option 1 would provide the most complete information for evaluating FMVSS 301 because sample results would describe the entire distribution of reported accidents, and the frequencies of fuel leakage and fire would be unbiased estimates of the corresponding probabilities in the NCSS target population. The major disadvantage is the large sample of accident investigations (4100) required, many of which involve no fuel leakage and no injuries. MDAI teams concentrate investigative effort on the serious, injury-producing accidents, and the implementation of Option 1 would require an extensive reorientation and augmentation of the NCSS effort.

Option 2 is appealing because, if police cooperate by completing supplementary forms to identify fuel leakage and fire, rough estimates of leakage and fire frequencies can be obtained from state records. In addition, MDAI teams may restrict attention to fuel-leakage accidents and conduct a subset of investigations to determine more detailed information on crash conditions, the nature of fuel leakage and on other variables.

However, there are two serious drawbacks to this option--the additional time and coordination required to obtain full cooperation from the police and the limited detail provided in such reporting. No formal mechanism has been established to assure supplemental reporting by all involved police, and such cooperation must necessarily be voluntary. In the Austin study project administrators did rely on supplementary police forms to record data on fuel leakage and fire. One of the authors of the Utah report told us that the effort was at least moderately successful but that even in the small geographical area in which the study was conducted cooperation could not be obtained from all police jurisdictions. Thus, the data were limited. For example, police reported fuel leakage when spillage was noted on the pavement or ground, and they indicated the location as front, central, or rear. If this procedure is implemented in the larger geographical area surveyed by NCSS, we must expect administrative delays and costs, nonrepresentative samples due to the lack of participation by all police organizations, and limited (and perhaps inconsistent) data details.

Option 3 has the advantage of requiring a relatively modest sample size, and the accidents selected for investigation are consistent with those currently being investigated by MDAI teams. The validity of this approach depends on (1) that the incidence of fuel leakage in minor, nontow-away accidents is limited and (2) that this factor can thus be ignored in the evaluation of FMVSS 301. In our opinion, this assumption is reasonable.

Variations of all three options can be constructed by stratification to achieve one or both of two objectives. First, the options may be stratified to obtain a sample that contains the independent variables that may affect fuel leakage and fire incidents. Stratification of this type may improve the power of the tests of the primary hypotheses without increasing sample size. Stratification will also ensure a sufficient sample size for testing secondary hypotheses. For example, if it is desired to conduct stringent statistical tests concerning the differences in fuel leakage incidents among different makes and models, the stratification would be necessary to establish a sufficient sample size in each of the vehicle categories. Such stratification would require greatly increased sample sizes beyond those given in the descriptions of the three options.

3.5.2 Evaluation Plan Specifics

The three options listed in the preceding subsection are all reasonable alternative data collection procedures suitable for evaluating FMVSS 301. However, based on a trade-off analysis, which took into account data quality, administrative difficulties, and cost, we recommend that Option 3 be implemented within an augmented NCSS program. The preliminary evaluation plan is outlined in Figure 3-1. Further details are discussed in terms of the following topics:

- Primary study objectives
- Prestratification and required sample size
- Secondary objectives
- Required data
- Procedural steps
- Analysis
- Nature of augmentation to the NCSS program
- Cost of implementation.

In addition to the primary study objectives and presampling stratification discussed in the preceding subsection, we have considered such stratification variables as vehicle weight, make and model year, and accident types. These have been rejected for two reasons: First, the Utah study, the MDAI file, and a review of the literature reveal no sound basis for assuming a strong relationship exists between the probability of fuel leakage and these potential stratification variables. Second, complicated sample stratification rules are difficult to implement in the field and may, in themselves, become sources of error. Accordingly, the only restrictions are that equal sample sizes of 1974-1976 and 1977-1979 vehicles be taken to evaluate any differential in fuel leakage, and that a 100% sample of accident-fire events be analyzed.

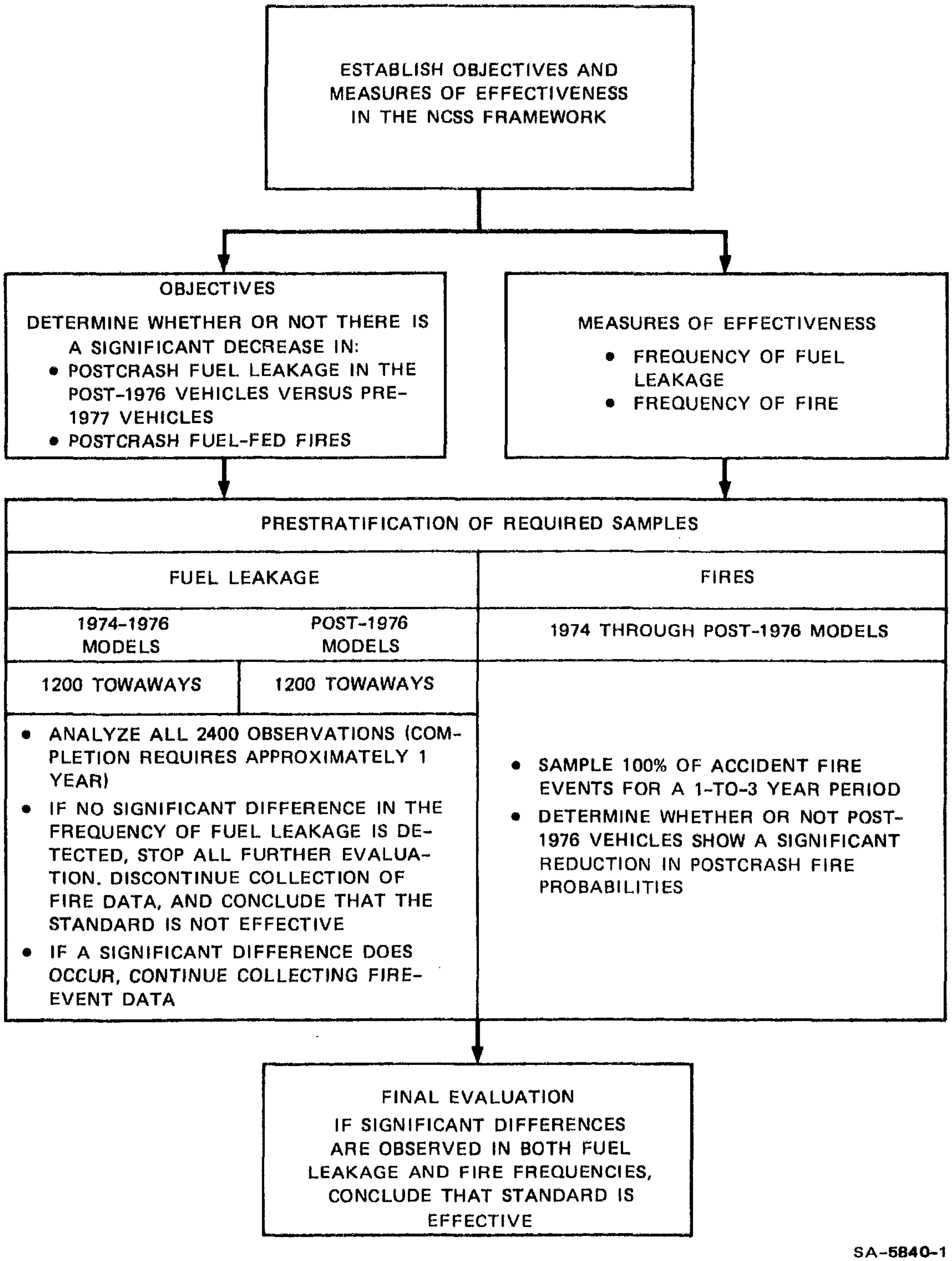

FIGURE 3-2 FMVSS 301 EVALUATION PLAN

Secondary objectives will include comparisons and tabular displays of variables such as vehicle make, model year, weight, accident type, and burn injury type--expressed as functions of fuel leakage by source and extent, ignition source, and type of fire. Statistical tests of significance should be applied to these observed relationships, but such tests will identify only large differences because required sample sizes were calculated only to achieve precision with respect to the primary objectives. In other words, we have not designed an extravagant exploratory study to identify relationships which, although interesting, are not essential to the evaluation of FMVSS 301.

The statistical techniques required are conventional procedures, and no computer software beyond that which is available within the NCSS program needs to be developed. With 2400 observations on fuel leakage incidents and full coverage of post-crash fire, the standard two-sample test for the equality of proportions will provide the most convincing evidence of the effectiveness of the standard. Furthermore, if this simple test does not reveal a significant decline in both fuel leakage and fire, it is doubtful that further tests of hypotheses using multiple comparisons will result in any definitive conclusions concerning overall standard effectiveness. However, statistical tests comparing pre- and post-standard vehicle fuel leakage by extent of leakage, location, and crash conditions, and the multiple comparisons discussed under secondary objectives will be useful in explaining the nature of FMVSS 301 effects. Because these variables are categorical rather than continuous, a nonparametric multivariate procedure such as proposed by Goodman[6] is recommended.

The data being collected within the NCSS program are sufficient to achieve both primary and secondary objective analysis. In particular, the NCSS data supplement on fuel leakage and fire hazard is essential. We recognize, however, that there are operational difficulties in obtaining precise observations on the occurrence of fuel leakage. In current

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[6] Leo Goodman, "The Analysis of Multidimensional Contingency Tables," Technometrics (1971).

practice when accident investigation takes place on scene, detection of fuel leakage is relatively simple. The leakage is visible on the ground. Its location (front, rear) tells the investigator which components to examine, either on scene or later at the junkyard or body shop. The investigator examines suspected components for damage that would result in fuel leakage, such as tank punctures, cracked or separated fuel lines, and leaking gaskets.

When accidents are investigated after the fact, the investigator ordinarily does not examine every fuel system component for damage unless he suspects fuel leakage (e.g., if the collision type is one which frequently causes fuel-system damage such as rear end), or fuel leakage was reported at the scene by police. Chemical (vapor) detectors or mechanical devices do not now exist to assist the investigator in acquiring more accurate data. To avoid fuel leakages being overlooked in current NCSS procedures, the best solution is to ensure that the fuel system of each accident-involved vehicle be thoroughly examined.

The procedural steps require the selection of a random sample of 1200 tow-away accidents involving 1974-1976 model vehicles and a comparable sample of 1200 1977-1979 vehicles to determine if post-crash fuel leakage between the two groups differs markedly. The determination could be made during 1 year in a fully operational NCSS program. Concurrent with this random sampling, all crash-fire occurrences will be investigated. The completion of these investigations will require 3 years of NCSS operation. However, a logical decision point occurs upon completion of the analysis of fuel leakage in the sample of 2400 tow-aways. If no significant difference in fuel leakage is detected between pre- and post-standard vehicles we recommend that the evaluation procedure be terminated because the effectiveness of the standard will be established only if both fuel leakage and fire incidents are reduced. If a significant difference in fuel leakage does exist, the investigation of fires must continue.

3.6 IMPLEMENTATION PLAN

The estimated time to complete Option 3 is 1 to 3 years, depending on fuel leakage variance observed at the end of the first year. Expected cost and resource requirements range between $168,000 to $1,000,000, depending on several assumptions. If the NCSS program is extended through 1979, it is reasonable to assume basic program expenses are already budgeted and need not be taken into account in an evaluation of FMVSS 301. It is necessary, however, to estimate expenses for about 600 noninjury accidents of the tow-away accident population to satisfy analysis requirements. The 600 accidents represent one-fourth of the required 2400 tow-aways and exceed current NCSS investigation plans. Thus, using an estimate of $250 per accident, total costs for investigating noninjury accidents would be $150,000.

If the NCSS must be extended another year to accommodate an evaluation of FMVSS 301, then basic program expenses must be added to the $150,000. A rough estimate of these expenses if $835,000 (i.e., the current annual expense for 3 years--$2,500,000). From a practical viewpoint, this estimate is highly conservative because the extra time will be devoted to collecting approximately 25 vehicle fires, as previously discussed. Yet, we must not be misled by this small number because maintenance of the investigation teams is required, and a continuation of previous data gathering objectives will probably take place. In fact, data needs of other programs could share expenses of the additional year, but we cannot estimate these figures at this time and must assume a program fully dedicated to FMVSS 301.

Total estimated costs of SRI's proposed evaluation plan for FMVSS 301 include the following items:

	Costs
(1) Integration of the plan into the current NCSS Program (1 man-month, at $6,000)	$ 6,000
(2) Collection of 600 noninjury tow-away accidents (600 accidents, at $250 per accident)	150,000

		Costs
(3)	An additional year of NCSS	$ 835,000
(4)	Analysis requirements (2 man-months, at $6,000 per month)	12,000
	Total	$1,003,000

3.6.1 Costs of Safety Parts and Equipment

Complete itemization of direct costs of compliance consists of engineering design, materials, fabrication and assembly (labor), mark-up, service and repair, and test costs. Data sources would include:

- Auto manufacturers.
- Independent estimators (e.g., Rath and Strong).
- DOT.
- Other government sources [e.g., Department of Labor, Office of Management and the Budget (OMB)].
- Aftermarket parts suppliers.
- Service and repair facilities.
- Past studies on service, repair, and replacement rates.
- Cost indices--materials and labor categories.

Given the numerous vehicles produced, it is recognized that this is a difficult if not impossible task. However, the estimate can be simplified by identifying the values for three items included in the manufacture and sale of motor vehicles: materials, fabrication and assembly labor costs, and mark-up. Manufacturer data and independent suppliers must be consulted to obtain accurate cost of compliance values.

An approximate value can be used to estimate the total cost, based on weight of materials. In November 1974, the Austin report gives this value as $1.07/lb. Based on this and other projects, an approximate cost for many motor vehicle components can be obtained by determining the weight of the materials used and their cost; this value would then be estimated as 25% of the total cost. The approximate proportions for the three factors described above are: materials--25%, labor--25%, and mark-up--50%.

The average incremental cost of post-1976 fuel system components (additional valves, tubing and similar components, and other elements), and modifications to the carburetor, evaporative emissions control system, over the cost of comparable components of pre-1977 vehicles, must also be determined. Relocation costs should not be considered as these can be viewed as part of normal model design changes.

REFERENCES FOR SECTION 3

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4. P. Cooley, "Fire in Motor Vehicle Accidents," HSRI Special Report (April 1974).

5. J. A. Austin et. al., "Study of Post-Crash Factors in Automobile Collisions," Final Report, University of Utah Auto Crash Team, Contract DOT-047-1-063 (April 1975).

6. L. Goodman, "The Analysis of Multidimensional Contingency Tables," Technometrics (1971).

Section 4

STUDY RESULTS FOR FMVSS 208--OCCUPANT CRASH PROTECTION

4.1 STATEMENT OF THE PROBLEM

According to a recent NHTSA summary on seat belt effectiveness,[1] studies since 1960 indicate a 40% effectiveness in preventing crash related deaths for lap-belt-only use and a 60% effectiveness for lap/shoulder restraints. For an estimated 1975 use rate of 20% (11% lap; 9% lap/shoulder), a savings of about 3,000 lives in that year was stated. If use had been 60% lap/shoulder and 10% lap only, a possible 1975 saving of 12,000 lives is estimated. Research studies discussed below in this plan also indicate reduction in injury severity. Thus, future studies should not investigate the reduction per se of injuries and death by restraints; rather, these studies should further quantify the reduction. The differences in injury severity (none to fatal) that we wish to detect are as follows:

- Those between no protection and lap only
- Those among concurrent versions of lap only, lap/shoulder, lap/air bag, and air bag only.

Other considerations include:

- Inherent differences between users and nonusers that confound the comparison:
  - Such collision characteristics as accident type, fault, other drivers, and risk-taking factors.
  - Injury severity in relation to age, sex, and size of person.
- Restraint-caused injuries
- Accident profiles:
  - Collision type and speed

[1] "Safety Belt Usage, A Review of Effectiveness Studies," NHTSA (1976).

- Occupant position
- Vehicle size

- Improper use and system malfunction.

4.2 DESCRIPTION OF THE CURRENT STANDARD

To reduce the number of fatalities and the severity of injuries of vehicle occupants, FMVSS 208 specifies vehicle crash-worthiness requirements in terms of forces and accelerations measured on anthropomorphic dummies in test crashes. It also specifies equipment requirements for active and passive restraint systems.

The present standard was introduced in 1972 and requires one of three options be provided for each vehicle: a completely passive system for front, side, and roll-over crash protection; a passive restraint system for frontal crashes with lap belts for side and roll-over crashes; or a lap and shoulder belt system at front outboard positions with lap belts for all other positions. Requirements also specify the types of passive belts (pelvic only or pelvic and upper torso) and readiness indicators for passive systems. Both audio and visual warning signals are specified for active systems (those that require occupant action to activate).

The current standard establishes occupant protection requirements for four classes of motor vehicles: passenger cars, trucks and multipurpose passenger vehicles of 10,000 lb GVWR or less, trucks and multipurpose passenger vehicles with GVWR of more than 10,000 lb and buses.

Three subclasses of passenger cars are defined according to manufacture date. The dates defining the three periods are January 1, 1972-August 31, 1973; September 1, 1973-February 24, 1975; and February 25, 1975 to date.

<u>January 1, 1972-August 31, 1973</u>--Those from January 1, 1972 to August 31, 1973, have three options for meeting the requirements: complete passive protection that requires no action by vehicle occupants; lap belt protection with buzzer-light warning system used at each outboard designated seating position; or lap and shoulder belt protection

with the warning system. No shoulder belt requirements are set for convertibles and open-body vehicles. The buzzer-light warning systems were designed to encourage belt use, but the warning systems have been easily defeated or bypassed.

September 1, 1973-February 24, 1975--Those manufactured from September 1, 1973 to February 24, 1975 have the same requirements, except for the ignition interlock system. The ignition interlock system was designed to force the driver and front seat occupants to fasten their seat belts before starting the vehicle and was implemented on 1974 and 1975 models. Congress voided the requirement in late 1974 (effective February 1975) and also required that future occupant restraint system requirements other than seat belts be submitted for its approval before rule making.

February 25, 1975 to date--Vehicles manufactured after February 24, 1975 have a buzzer-light warning system for the driver's seat belt only, and the buzzer and light only operate for 4 to 8 s. These vehicles also have the original three options for meeting the restraint requirements.

Trucks and multipurpose passenger vehicles with GVWR of 10,000 lb or less manufactured from January 1, 1972 to December 31, 1975 have two options--a complete passive protection system or a belt system. Those manufactured from January 1, 1976 to August 14, 1977 also have two options--the same as passenger cars (September 1, 1973 to August 31, 1976) or a belt system for special vehicles, walk-in van type trucks, motor homes, and vehicles with chassis-mounted campers.

Trucks and multipurpose passenger vehicles over 10,000 lb must have either a complete passive protection system or a belt system if manufactured on or after January 1, 1972.

Buses manufactured after January 1, 1972 must have either a complete passive protection system (driver only) or a belt system (driver only).

4.2.1 Current Revisions

It is difficult to develop an evaluation plan for FMVSS 208 because the standard has been amended frequently since 1972. Five possible courses of action were considered by former Secretary of Transportation Coleman,[2] as outlined in a news release June 9, 1976:

(a) "Continuation of the present three-option version of FMVSS 208 and continuation of research directed toward developing effective passive restraint systems."

(b) "Continuation of the present three-option version of FMVSS 208 and a concurrent proposal for a new traffic safety standard requiring the states to adopt and enforce safety belt usage laws or otherwise achieve a usage level much higher than being experienced today."

(c) "Continuation of the present three-option version of FMVSS 208 while a federally sponsored field test of passive restraints is conducted with the data collected to be used in formulating a future decision on mandating passive restraints."

(d) "Amendment of FMVSS 208 to require passive restraint systems for all automobiles manufactured after a given date, that date to be determined primarily by the amount of lead time needed by manufacturers to comply with the amended standard."

(e) "Amendment of FMVSS 208 to require that automobile manufacturers provide customers with the option of passive restraints in some models."

On January 18, 1977, Secretary Coleman announced[3] the signing of contracts with GM, Ford, Volkswagen, and Mercedes-Benz to conduct a 502,250-car demonstration program of passive restraint systems available to the public at a "reasonable" price. This plan is in line with alternative course of action (c) above. According to Coleman, the demonstration

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[2] DOT News Release, Office of the Secretary of Transportation (1976).

[3] DOT News Release, Office of the Secretary of Transportation (1977).

program was selected rather than a government mandate to enable the public to obtain experience voluntarily. This would avoid premature public rejection and, it was hoped, create such a demand for passive restraints that manufacturers would voluntarily improve the technology and offer them as options.

According to the announcement, GM will offer front-seat protective devices as an option on 300,000 intermediate-sized 1980 and 1981 cars. Ford plans driver-only air bags on no fewer than 140,000 compact models for those years. Mercedes-Benz will import 750 1980 model sedans and 1500 in 1981 that provide driver-only protection. Volkswagen will produce not less than 60,000 vehicles equipped with passive restraints for models 1978 to 1980.

Of interest to this study is the plan for demonstration program evaluation:

> "NHTSA will monitor the demonstration program in cooperation with the participating companies. The monitoring will involve compiling data on accidents involving passive restraint-equipped vehicles, comparing these data with statistics on accidents involving cars equipped with belts, making analyses of all these data, and publishing its conclusions about reliability and effectiveness of passive restraints."

The plans and approach to FMVSS 208 in the coming year may be subject to change under Secretary Adams. Although revisions to FMVSS 208 will affect restraint systems used and involve public enforcement and manufacturing mandates, they do not preclude evaluation of the real world effectiveness of active restraint systems in use since the standard was initiated, nor do they prohibit planning of evaluation of passive systems.

4.2.2 Scope of the Evaluation Plan

The reduction capability (i.e., the reduction in fatalities and injury severity), resulting from the use of restraint systems that meet or exceed the standard's requirements, is the purpose of this evaluation.

This study will also examine the relationships between restraint systems (lap belts, lap/shoulder apparatus, and air bag or cushion systems in use each year) and real-world accident-produced injuries. We have chosen this approach rather than comparing experimental alternatives among the various types of restraint systems.

4.2.3 Compliance Test Discussion

Occupant crash protection requirements are expressed in terms of injury criteria (acceleration at center of gravity of both head and upper thorax, and force transmitted axially through each upper leg) for frontal and laterial tests as described for FMVSS 301. A dynamic roll-over test is used. For passive systems, detailed seat belt assembly requirements are provided; they concern adjustment, latches, and warning system operation. Detailed test conditions are also presented: Vehicle load placement and weight are specified; seat and seat back adjustment positions are set forth; doors, windows, and tops (if movable) are to be fully closed and latched, but not locked; and anthropomorphic test device positioning and covering are specified. Finally, requirements are specified for pressure vessels and explosive devices.

Compliance testing for Standard 208 varies depending on whether active or passive restraints are installed. If an active lap-belt-only system is installed, compliance testing consists of a 30-mph frontal-barrier collision with test dummies restrained by the belts. No complete separation of any load-bearing part of the restraint system is allowed. When passive systems are installed, the compliance test consists of a 30-mph frontal-barrier collision, 30-mph side- and rear-moving barrier collisions, and a 30-mph artificially induced roll-over.

In both of these tests, the test dummies seated in the vehicle must meet the injury criteria specified in the standard. These can be summarized as:

- The Head Injury Criterion (HIC) must be less than 1000.
- The acceleration measured at the center of mass of the thorax must not exceed 60 g, except for periods that cumulatively

total less than 3 ms.

- The axial load on the dummy's upper leg must not exceed 1700 lb.

These injury criteria are based on the results of experiments with cadavers and live subjects. The criteria are intended to correspond to levels of impact that do not produce serious or life-threatening injury. Because the dummy accelerations measured during compliance testing depend on the characteristics of the dummy, some disparity may occur between the dummy's measured accelerations (and hence predicted injury levels) and actual injuries sustained by a human under similar circumstances. Further research with improved dummies may indicate a need to modify the current injury criteria.

4.3 DISCUSSION OF TECHNICAL FACTORS

The case for safety belts was stated quite positively by NHTSA,[4] in 1973 and is supported by considerable analysis of accident investigation data and medical evaluations. The evidentiary information relates to the following collision injury-reducing factors:

- Prevention of ejection.
- Decreased chance of secondary impact.
- Reduced forces in secondary and tertiary collisons.
- Protection of occupants opposite the side of impact.
- Combination with head support to prevent whiplash in rear-end impacts.
- Protection for rear as well as front seat positions.

Analysis of accidents was, at this time (1973), basically conducted through the use of MDAI (Level 3) data maintained by HSRI for NHTSA. More recently, the RSEP data files (Level 2) have become available; they are specifically oriented toward restraint use. Analysis of air bag accidents is rudimentary because relatively few instances of deployment have been recorded to date. In addition to accident investigation

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[4] "The Case for Safety Belts, Experimental and Statistical Evidence," NHTSA (1973).

and analysis, controlled tests have been conducted and compared with accidents; mathematical modeling has also taken place and to some extent validated by results of controlled tests.

Several recent research studies are presented below. These studies are representative of the status of evaluation of restraint systems and contain considerable information. Moreover, the research judgment already made can be used in the evaluation of FMVSS 208. The NHTSA data base capability for evaluation of the active restraints in use is generally applicable and that planned for passive restraints also appears to be suitable. Several relevant studies are discussed here.

4.3.1 Analysis of MDAI Accident Investigations

Data collected from MDAI accident investigations are comprised of subdata files taken from other studies[5,6,7] varying objectives and accident selection criteria. Therefore, the cumulative file may not be considered as representative of nationwide accident experience. Nevertheless, with the appropriate reservations with regard to population definition, data may be selected from these files for analysis. Some results, taken from the referenced studies, are discussed below.

1973 HSRI Study[5]--At the time of this study (1973), there were on file 2676 cases of occupants in accident vehicles equipped with passive restraints. The vehicles in these accidents were studied by various teams: 2036 (75%) were unrestrained; 588 (22%) were lap-only restrained; and 92 (3%) were lap/shoulder restrained. This study is useful because it is one of the few, relatively complete analyses concerning early use of lap restraints only (i.e., without shoulder restraints).

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[5] F. L. Preston and R. M. Shortridge, "A Study of Restraint System Use and Effectiveness," HSRI for MVMA (1973).

[6] D. W. Reinfurt et al., "A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes," North Carolina HSRC, DOT Report HS-801933 (February 1976).

[7] R. E. Scott et al., "An Evaluation of the 1974 and 1975 Restraint Systems," HSRI for MVMA (1976).

The file showed 77% of unrestrained occupants had injuries (overall AIS $\geq$ 1) and 30% had AIS $\geq$ 2, whereas only 68% of the lap-restrained had injuries and 19% had AIS $\geq$ 2. For the lap/shoulder restrained, 64% had injuries, 15% with AIS $\geq$ 2.[5] Because too few lap/shoulder cases were on record when the study was performed, these cases were combined with lap-only for further analysis.

For the unrestrained occupants, the mean injury severity of those injured (AIS $\geq$ 1) was 1.91; for the restrained occupants, 68% had injuries with a mean injury severity of 1.65. Restrained versus unrestrained accidents were compared as a function of type of accident, seat location, speed, vehicle deformation index (VDI) and roll-over. Of the five accident types studied, (single vehicle, head on, intersection, sideswipe, and rear end) single vehicle showed the greatest reduction in mean injury severity when the passengers were belted. For front seat passengers, belted drivers experienced a somewhat greater reduction than right front occupants. The injury reduction at lower speeds was greater, but reduction as a function of VDI was about the same at various levels. Injury reduction in roll-overs was considerable.

For specific types of injuries, the AIS for each injury was studied. (The statements above refer to overall AIS.) Although the mean injury severity reduction was similar for all types of injuries, the incidence of certain types of injuries were of interest. All injuries occurred at least as frequently without belts, except for abdominal and pelvic injuries. The incidence of abdominal injuries with seat belts were higher for women than men in either driver or right front position, but the mean injury severity (AIS $\geq$ 1) when unrestrained was lower for women: 2.23 for unrestrained men, 1.71 for restrained men, 2.13 for unrestrained women, and 1.39 for restrained women.

The contact points for injury, which list the frequency of contact and mean severity of injuries by contact point, were taken from the 1973 HSRI report.

1975 NHTSA Study[8]--This study was undertaken to determine restraint effectiveness as a function of occupant seating position and to determine whether rear seat passengers sustained high injuries due to the lap belt, particularly in smaller cars.

The MDAI file had 7366 occupants on file at the time of this analysis. Of these, 87% were in the front seat, and 13% were in the rear; 1362 (22%) of the front seat occupants wore restraints, and 80 (10%) of the rear seat occupants wore restraints. Although this study reaches conclusions about injury, seat location, and vehicle size, SRI feels that the rear seat belted sample is too small for statistical analysis, particularly when subdivided by vehicle size. However, interesting results do emerge from the data analyzed in this study:

- 16% of the restrained front seat occupants received injuries due to their lap belts, compared with 17% for restrained rear seat passengers. The lap belt injuries were more severe for front seat passengers, however.
- Case studies showed that some seat belt injuries were due to their being worn too loosely.

1976 HSRI Study[7]--A special data collection activity involving the HSRI, CALSPAN, and SwRI MDAI teams, was designed in 1973 to evaluate restraint systems. This collection effort included 1973 to 1975 model vehicles that were involved in accidents between the spring of 1974 and the fall of 1975 (18 months). This study was undertaken to measure the reduction in incidence of severe injury among front seat occupants in 1973 versus 1974 vehicles sold in this country by American manufacturers. The data collection was addressed to this objective. The sampling design indicated 100% sampling of cases in which an occupant was hospitalized. Sampling was 33⅓% for 1973 models and 50% for 1974 and 1975 for the non-hospitalized cases. All samples were drawn from the tow-away accident

[8]E. E. Flamboe, "A Comparison of Injuries Between Lap Belted and Non-Restrained Automobile Occupants According to Seated Position and Vehicle Size," NHTSA (1975).

population. Sample sizes were set by statistical criteria: detection of a 20% difference (1973 versus 1974 model years), level of significance 0.10 and power of 0.90. Each of the three sets of data was analyzed separately. Estimates used for proportions have been weighted by inverse sampling ratios.

Two types of estimates were used--raw proportions and adjusted proportions. For the raw estimates, data were computed with and without finite population correction term, and confidence intervals were produced that were based on normal approximations to binominal. For the adjusted estimates the relation $\hat{p}_{ij} = \hat{\mu} + \hat{r}_i + \hat{s}_j$ was used, where

$\hat{p}_{ij}$ = estimated probability of AIS 2 for an occupant using the i^{th} level of restraint involved in a crash of severity type j,

r_i and s_j = effects of the i^{th} restraint and j^{th} severity type.

The crash severity groupings were derived using the GENCAT program.[7] The effectiveness was computed according to

$$\frac{\hat{p}_1 - \hat{p}_2}{\hat{p}_1}$$

(i.e., reduction by proportion of injured $\hat{p}_2$, compared with $\hat{p}_1$).

Use of restraints in the sample varied from about 30% to 50%, depending on the team's jurisdiction region and the year. The proportion of occupants receiving injuries AIS $\geq$ 2 was compared for 1974 versus 1973, and 1975 versus 1973 models, and for each team.[7] The results did not support reduction based on 1973 for all the teams. Because of the wide range of restraint use possible in 1973 and 1974, these results are not surprising. When the data were recompared by restraint use and type of restraint, the results were statistically significant reductions.

Using the adjusted estimates, quite different estimates of proportion AIS $\geq$ 2 were obtained for restraint use and type of restraint. The effectiveness estimated based on these proportions indicated that shoulder restraints were more effective than lap only. Full to lap restraint only comparisons were also made, and some of the confidence intervals for these estimates are large.[7]

The percentages for injuries by body region were also computed for no restraints, and for lap and full restraints for each team. Results tended to indicate reduction in body areas injured, except for the neck (primarily AIS = 1), chest, and abdominal areas for full restraint use only. The percentage of occurrence of these injuries was less than 15% in all subgroups of restraint use and team.

4.3.2 Analysis of RSEP Data (Level 2)

1976 North Carolina Study[6]--In this study, tow-away accidents were investigated in Western New York, Michigan, Miami, San Antonio, and Los Angeles. Accidents involved 1973 to 1975 model vehicles, all of whose front seats were equipped with restraints. Injuries were studied only for front seat occupants. All vehicles from which at least one front seat occupant went to a medical treatment facility and essentially 50% of the tow-aways in which no front seat occupant went to a treatment facility were sampled. Data were weighted site by site by inverse sampling fractions and are such that there are no missing data for the variables necessary to derive the main study variables--belt use, injury crash configuration, damage severity, vehicle size (weight), occupant age, and seating position. Seating position was later removed as a poststratifying variable because it was determined to be the least correlate among the variables being studied.

A weighted sample of 15,818 occupants resulted from these adjustments. The effects of missing data and suspiciously skewed frequencies were studied extensively. The authors stated that the biases, in terms of national representativeness, were not considered to be extensive.

4.3.2.1 Computation of Estimate

The implementation in 1974 of the integral three-point belts with inertial reels and locking retractors resulted in a change in the use of shoulder restraints; only 5% of passengers used shoulder restraints in 1973, but about 40% used them in 1974 and 1975.[6]

The main variables studied in regard to injury and belt use include:

- Damage severity
- Vehicle age
- Crash type
- Vehicle weight
- Impact site.

The proportion of injured in a stratum, given in percent, are easily converted to a proportion such as p_{ij} discussed above. The notation used in this study, for proportion, is R_k, k being the stratum. Estimates for P_{ij} and R_k are denoted by $\hat{p}_{ij}$ and $\hat{R}_k$. The proportions by damage severity, for "injured" (i.e., AIS $\geq$ 2), are given below in Table 4-1.

Table 4-1

PORPORTION OF STRATUM HAVING AIS $\geq$ 2 BY VEHICLE DAMAGE

Vehicle Damage	Unrestrained	Restraint Use	
		Lap	Lap/Shoulder
Minor	0.056	0.040	0.024
Moderate	0.114	0.079	0.044
Moderately severe	0.254	0.157	0.105
Severe	0.431	0.212	0.205

The smallest sample size for these estimates was for stratum lap restrained, severe damage. This estimate was derived from 113 cases observed, 24 of which had AIS $\geq$ 2 (24/113 = 0.212).

The estimate, $\hat{R}$, was used to measure injury as a function of the number in stratum and proportion of those "injured." "Injured" was first defined as AIS $\geq$ 3, and then as AIS = 6. Strata were collapsed using various criteria, and the estimates given are for unadjusted, Mantel-Haenszel and GENCAT. $\hat{E}$, the estimate of effectiveness was derived as $\dfrac{\hat{R}_i - \hat{R}_j}{\hat{R}_i}$, with j as an improvement over i.

$\hat{R}$ and $\hat{E}$ estimates use the three methods of estimation for increasingly serious definitions of injury. The estimates are calculated for all categories combined and separately for various categories of damage severity, age, crash type, vehicle weight, impact site, and model year. The estimates using categories stratified by damage severity are given in Table 4-2. Again these are the estimates for AIS ≥ 2.

Table 4-2

ESTIMATES FOR AIS ≥ 2 BY VEHICLE DAMAGE

Vehicle Damage	Estimate	Restraint System	Estimation Procedure: Unadjusted	Estimation Procedure: Mantel-Haenszel-Type Estimate	Estimation Procedure: GENCAT and Log-linear Model
Minor	$\hat{R}$	U*	0.056	0.055	0.055
		L†	0.040	0.041	0.042
		LS‡	0.024	0.026	0.024
	$\hat{E}$	U vs L	0.272	0.240	0.243
		U vs LS	0.561	0.530	0.564
		L vs LS	0.397	0.382	0.424
Moderate	$\hat{R}$	U	0.114	0.112	0.114
		L	0.079	0.083	0.081
		LS	0.044	0.047	0.045
	$\hat{E}$	U vs L	0.305	0.257	0.286
		U vs LS	0.615	0.585	0.602
		L vs LS	0.446	0.441	0.443
Moderately severe	$\hat{R}$	U	0.254	0.250	0.251
		L	0.157	0.162	0.169
		LS	0.105	0.135	0.114
	$\hat{E}$	U vs L	0.383	0.351	0.329
		U vs LS	0.586	0.461	0.548
		L vs LS	0.328	0.169	0.326
Severe	$\hat{R}$	U	0.431	0.394	0.419
		L	0.212§	0.249§	0.244§
		LS	0.205§	0.220§	0.208§
	$\hat{E}$	U vs L	0.508	0.369	0.418
		U vs LS	0.524	0.443	0.508
		L vs LS	0.033§	0.118§	0.154§

*U = unrestrained
†L = lap restraint
‡LS = lap/shoulder restraint
§ = figures cited in text

In Table 4-2, the category "severe" of the variable "damage" is interpreted as follows. The estimate $\hat{R}_i$ of the proportion with AIS ≥ 2 is 0.212 for the <u>unadjusted</u> estimate. This corresponds to Table 4-1 shown previously, which indicates that 0.212 of the lap-restrained occupants in accidents with severe damage severity had injuries with AIS ≥ 2. The Mantel-Haenszel and GENCAT <u>adjusted</u> estimates for proportion injured are 0.249 and 0.244, respectively for lap-restrained, severe damage to vehicle. The proportion injured (AIS ≥ 2), $\hat{R}$, estimates for lap and shoulder, severe damage to vehicle, are 0.205, 0.220, and 0.208, for unadjusted, Mantel-Haenszel, and GENCAT, respectively. Checking the unadjusted estimate $\hat{R}_j$ of 0.205 on Table 4-2, this corresponds to the value on the Table 4-1 for lap restrained, severe damage. The unadjusted estimate of effectiveness, lap versus lap and shoulder is, then,

$$\frac{\hat{R}_i - \hat{R}_j}{\hat{R}_i} = \frac{0.212 - 0.205}{0.212} = 0.333,$$

read as $\hat{E}$, L versus LS, "Severe" on Table 4-2. The adjusted effectiveness estimates are 0.118 and 0.154.

These same estimates for "injured" are also defined by AIS ≥ 3 and for AIS = 6 (see Reference 6), as well as for data stratified by variables other than damage. No estimates using AIS ≥ 2 as "injured" showed negative effectiveness. Some estimates were negative for AIS ≥ 3 and AIS = 6 as injured, but the number of occupants satisfying these injury criteria in any given stratum is low, even though the sample size was of reasonable size.

4.3.2.2 <u>Conclusions</u>

Summarizing the reporting in this study, several hypotheses were established at the start of the North Carolina study.[6] Results supported by the analysis of these data are as follows:

(1) Hypothesis: Lap only or lap/shoulder restraints are 10% effective.

Conclusion: Exceeded.

(2) Hypothesis: Restraints have no effect in rear-end collisions.

Conclusion: Not as effective as front restraints, but still effective.

(3) Hypothesis: Restraints are less effective in small vehicles.

Conclusion: True.

(4) Hypothesis: Effectiveness decreases as crash severity increases.

Conclusion: False.

(5) Hypothesis: Restraints are less effective for older people than younger people.

Conclusion: False.

1976 SwRI Study[9]--This study covers the data collected at one of the RSEP evaluation sites that contributed to the data base analyzed in the preceding discussion. Team reports such as this one provide additional data not covered in the overall report. In particular, this study identified some aspects of restraint usage:

- Restraints are used more in urban areas.
- Restraints are used less on weekends.
- Use decreased from 1974 to 1975.
- Use varies as a function of model type.
- Occupant height and weight are not a factor in use.
- Drivers use belts more frequently than passengers.
- Vehicle owners use belts more often than nonowner drivers.

4.3.3 Analysis of Air Bag Accidents

1976 Allstate Insurance Co. Study[10] --Allstate cites 82 crashes to date having air bag deployment. Four deaths occurred. Air bag effectiveness figures proposed are 8,000 to 9,000 lives saved (DOT), more than 10,000 lives (NSC), and 500,000 serious injuries reduced (DOT).

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[9] J. R. Cromack et al., "Multidisciplinary Accident Investigation - Special Study of Active and Passive Restraint Systems in 1973-1976 Model Year Vehicles," Vols I and III, SwRI for NHTSA (1976).

[10] "Automotive Air Bags Questions and Answers," Allstate Insurance Company, Automotive Engineering Division (July 1976).

1976 IIHS Study[11]--The IIHS cites 103 crash deployments with 129 occupants, 125 surviving for 250,000 miles driven, in 11,968 air-bag equipped vehicles. Effectiveness figures agree with the Allstate study.

4.3.4 Controlled Tests

As previously mentioned, controlled test procedures, using cadavers and anthropomorphic dummies, have been used extensively in determining the effects of experimental restraint systems. In some current studies, accident investigations are being compared with controlled test results (e.g., Transport & Road Research Laboratory[12]) and controlled test results are being used to validate mathematical models (e.g., CALSPAN[13]). At this time, test and model validation is minimal.

4.4 REVIEW AND ASSESSMENT OF ALTERNATIVE EVALUATION METHODOLOGIES

Table 4-3 shows the alternative methodologies SRI considered for and evaluation methodology for FMVSS 208. Any one or a combination of these methodologies may be used to support specific hypotheses about occupant restraint systems. Each is briefly discussed.

4.4.1 The Alternative Methodologies

The alternative methodologies considered are outlined below.

New data collection and analysis--Based on experience with, and acceptability of, accident investigation as a method for collecting data related to assessment of restraint system effectiveness, the NCSS and upcoming NASS investigations and the Air Cushion Restraint System (ACRS) Demonstration Program[3] would be excellent for future data collection.

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[11] "Press Background Manual on Air Bags," IIHS, Communications Department (August 1976).

[12] J. Wall, R. W. Towne, and J. Harris, "The Determination of Tolerable Loadings for Car Occupants in Impacts," Transport & Road Research Laboratory (1976).

[13] D. E. Massling, G. W. Kostyniuk, and S. M. Pugliese, "Crash Victim Simulation - A Tool to Aid Vehicle Restraint System Design and Development," CALSPAN Corporation (1976).

Table 4-3

ALTERNATIVE METHODOLOGIES

Method	Status	Cost Factors	Suitability for Hypotheses	Inherent Bias	Sampling for Collision Occupant Representativeness	Sampling for National Representativeness
New data collection and analysis	NCSS, NASS, and planned Air bag investigations	Data expensive but already planned	Experiments may be specifically designed	Can be controlled	Capability for improvement slight	Would be obtained
Further study of existing data	RSEP MDAI	Analysis only	Most hypoteses can be tested	Some problems, (e.g., definition of tow-away)	Rear seat use data not available	Close to being obtained; further analysis possible
Evaluation of controlled tests	Sleds, cadavers, etc.	Procedures established but data expensive	Not real-world accidents	Injuries not on live subjects	Can be done but effort would be major	N/A*
Analytic modeling	Computer simulations	Overall evaluation capability in early stages of development	Not real-world accidents	Validation not extensive	Theoretically possible	N/A
Acceptance of existing research judgments	Controlled analysis on active; little on passive	No cost	Many hypotheses have been tested	No newer systems evaluated	No newer vehicles included	Close to being obtained.

*N/A = Not applicable.

No additional costs for data collection are anticipated because these investigations will be made, independent of the results of SRI's recommended plan.

Further study of existing data--Data sources such as state files in which data on restraint use are often missing or, at best, use data are questionable, were not considered. The MDAI files have numerous known biases but should be considered because of the good quality of the use data. The RSEP files are quite good for front-seated belt-restrained or unrestrained occupants, to the extent that variables are present.

Evaluation of controlled tests--In theory, to evaluate FMVSS 208, restrained, simulated live subjects can be compared with unrestrained subjects, for given crash forces. However, problems of comparison of live subjects with, for example, anthropomorphic dummies and the cost of individual data points tend to outweigh the advantages of making truly paired restraint-no restraint evaluations.

Analytic modeling--The relation to real-world conditions is even further removed for analytic modeling than for controlled tests, but costs are considerably less.

Acceptance of existing research--Some research of seemingly good quality has been conducted. The results reported tend to support a general hypothesis of active restraint effectiveness. Data are clearly not available to address a general hypothesis about passive restraint effectiveness. Analyses of many subhypotheses that SRI considers to be important and a quantification of their extent of effectiveness are not adequately covered in the literature.

4.4.2 Evaluation Methodologies Selected

We have eliminated controlled testing and analytic modeling as reasonable alternatives. Although controlled tests and analytic models have been used effectively to examine experimental systems and to study occupant kinematics, these methods are not required for evaluation of FMVSS 208. This conclusion is supported by availability of and potential for further collection and analysis of real-world accident data. The elements of experimental design would include the use of control groups such as those who elected not to use restraints.

As discussed in Section 4.3, the status of research to date on restraint system effectiveness is notably complete for systems now in use. Existing data are still being analyzed productively (e.g., in the North Carolina study[6]), and future data could be of further use. Although they may duplicate existing work in some cases, these data will provide new information in others. Passive restraint systems have not been thoroughly tested for effectiveness because their use is not widespread.

The inherent biases in the existing data have been considered and issues are not entirely resolved. For example, the North Carolina study makes suggestions for further studies:

- That sampling be based on stronger inclusion criteria (e.g., better and more clear-cut definitions of tow-aways).
- That sampling collision and occupant factors, and national representativeness be planned beforehand to eliminate extensive weighting required for analysis.
- That individual teams collect fewer core variables--those anticipated for analysis--to improve the quality of these variables, which often have perishable data.

Based on these and other factors, SRI proposes to address each hypothesis about restraint use to determine:

- Whether existing research results should be accepted and, if so, on what basis.
- Whether further study should be made using existing data.
- Whether analysis of new data is required.

The hypotheses to which methodologies will be applied are given on Table 4-4. Each hypothesis will be discussed in detail in following sections of the report. Each activity will be assigned a data source, cost estimate, possible start time, length of activity, and statistical and sampling procedure requirements The rationale for acceptance of existing results or of existing samples will also be addressed.

Table 4-4

METHODOLOGIES FOR HYPOTHESES

Area of Evaluation	Variables for Hypothesis Testing	Acceptance of Existing Research with Minor Refinements	Further Study of Existing Data for New or Revised Concepts	New Data Collection and Analysis
A. Active Restraint Factors				
1. Front seat injury severity	a. None versus lap	X		
	b. None versus lap/shoulder	X		
	c. Lap versus lap/shoulder	X		
2. Rear seat injury severity	a. None versus lap			X
3. User factors	a. Age	X		
	b. Sex		X	
	c. Size of occupant		X	
	d. Pregnancy			X
4. Type of injury	a. Body region		X	
5. Collision factors	a. Collision angle	X		
	b. Damage severity	X		
	c. Vehicle Size	X		
6. Restraint system factors	a. Improper use			X
	b. System malfunction			X
B. Risk-taking factors				
1. Driver characteristics	a. Age		X	
	b. Sex		X	
	c. Vehicle ownership		X	
	d. Selection of model type		X	
2. Accident characteristics	a. Time of day		X	
	b. Day of week		X	
	c. Type of roadway		X	
	d. Driver at fault		X	

Table 4-4 (Concluded)

METHODOLOGIES FOR HYPOTHESES

Area of Evaluation	Variables for Hypothesis Testing	Acceptance of Existing Research with Minor Refinements	Further Study of Existing Data for New or Revised Concepts	New Data Collection and Analysis
C. Passive restraint factors				
1. Front seat injury severity	a. None versus ACRS*			X
	b. Lap/shoulder versus ACRS			X
	c. None versus lap/ACRS			X
	d. Lap/shoulder versus lap/ACRS			X
2. User factors	a. Age			X
	b. Sex			X
	c. Size of occupant			X
	d. Pregnancy			X
3. Type of injury	a. Body region			X
4. Collision factors	a. Collision angle			X
	b. Damage severity			X
	c. Vehicle size			X
	d. Speed of impact			X
5. Restraint system factors	a. System malfunction			X
D. Continuing Studies				
1. 1977-1981	a. A. above			X
2. 1982-	a. A. above (lap/shoulder only)			X
	b. C. above			X

*ACRS = air cushion restraint system

4.5 EVALUATION STUDY DESIGN

Briefly, we recommend that for active restraints, certain results documented by HSRC and HSRI be accepted and further quantified (e.g., confidence limit determination), that certain hypotheses be studied by using existing RSEP and MDAI files, others by using NCSS data, and that an overall update be made within NCSS and finally repeated on NASS. Analysis of passive restraints will also involve accident analysis but must await sufficient use.

For the data sources described in Section 4.3, SRI suggests the following use of data:

	1973 HSRI Study[5]	1975 NHTSA Study[8]	1976 HSRI Study[7]	1976 HSRC Study[6]	1976 SwRI Study[9]	1976 All-State Study[10]	1976 IIHS Study[11]
Some data will be used and will be further assessed in terms of confidence intervals and methods of estimation.	X		X	X			
Concepts discussed in this study will be considered in further analysis in terms of possible trends and estimates of expected results, but no further use of the data will be considered.		X			X	X	X

For the three studies from which data will be used, Table 4-5 shows the proportions of injured (AIS $\geq$ 2) in each category of restraint use, the number in each category, and the sampling criteria. Biases for these data based on sampling criteria should be understood so that differences in p-values on the table will be considered relative to these criteria, particularly as they relate to injuries for the whole file. The N values are important because confidence intervals will be based on these values (or on lesser values for further stratification) for comparisons.

Only in the 1976 HSRI study[7] were confidence intervals for p considered. For the p values given on Table 4-5 for this reference, the half widths at the 95% level, without the finite population correction, are shown in parentheses. Note that for all further stratifications, N will become smaller; thus for a given p the intervals have decreased accuracy or, alternatively, the confidence levels will indicate decreased accuracy.

For all effectiveness estimates based on existing data sources that are suggested for addressing one of the hypotheses constituting SRI's evaluation plan, it is proposed that the proportion of AIS $\geq$ 2 be computed for a given stratum of restraint use and other stratifying factors, and that the confidence intervals be computed at the 95% and 99% levels. The effectiveness estimate will then be the difference of two proportions, restraint use A and restraint use B. Both will have the same other stratifying factors, divided by the proportion expected to be greater. For the existing sources, it is of paramount importance that the injury level sampling criteria be stated along with the estimates.

Because data have already been collected for these estimates, no new N values need be obtained for desired confidence intervals. Also, existing injury criteria (AIS scale) will have to be used. For estimates obtained in future data collection activities, N can be set, based on expected p to obtain desired intervals. For most estimates involving new data collection, the references discussed in this report have adequate data to provide an estimate for p.

Table 4-5

PROPORTION OF SAMPLE WITH AIS $\geq$ 2

	Unrestrained	Lap Restrained	Lap/Shoulder Restrained	Sampling Criteria
1973 HSRI Study Proportion Sample size	p=0.293 N=2036	p=0.185 N=588	p=0.154 N=92	• 75% of the file consisted of accidents with injured occupants (MDAI file); all tow-away • Only vehicles that were lap/shoulder restraint equipped • Pre-1974 model vehicles
1976 HSRI Study CALSPAN Team Proportion Sample size	p=0.156 (0.0138) N=2513	p=0.078 (0.0208) N=618	p=0.066 (0.0226) N=748	• 100% sampling of hospitalized cases; 33-1/2 to 50% sampling of nonhospitalized cases; all tow-away • American manufactured vehicles • 1973-1975 model year vehicles • Front seat only
HSRI Team Proportion Sample size	p=0.092 (0.0113) N=2737	p=0.049 (0.0162) N=615	p=0.055 (0.0158) N=897	
SwRI Team Proportion Sample size	p=0.138 (0.0138) N=2737	p=0.064 (0.0167) N=985	p=0.050 (0.0133) N=1242	
1976 HSRC Study Proportion Sample size	p=0.121 N=9242	p=0.074 N=2544	p=0.047 N=4032	• 100% sampling of hospitalized cases; 50% sampling of nonhospitalized cases; all tow-away • 1973-1975 model year vehicles • Front seat only

4.5.1 Evaluation of Active Restraint Factors

Considerable analysis of active restraint factors has taken place for front seat occupants. The study design here is to produce confidence intervals for existing estimates and to produce certain new estimates based on restratification of existing data, along with confidence intervals, for the front seat occupants. New data collection will be required for rear seat occupants, and continuing case-by-case evaluation of certain anomalies is suggested.

Front seat injury severity--Effectiveness estimates may be computed from the 1973 and 1976 HSRI studies and the HSRC studies for lap versus no restraints. From the last two studies, various adjusted estimates were provided and for all three, unadjusted estimates may be derived from the data given in those reports. Estimates are also possible for lap/shoulder versus no restraints and for lap/shoulder versus lap, from the HSRI 1976 and HSRC studies. Confidence intervals should be produced along with the characteristics of the sampling for each study and each estimate.

Rear seat injury severity--No adequate data base for estimates of lap versus no restraints for rear seat occupants appears to be available. SRI suggests that 1974 to 1977 model cars be studied within the framework of NCSS. Because these data will be collected only from October 1, 1976 to March 31, 1978 (18 months) with an estimated 10,000 cases and because rear seat occupancy is far less frequent than front seat occupancy (less than 15% of accidents involve rear occupancy), SRI recommends using the entire file as a data base to maximize the sample size. The estimation procedure should match that used in "Front seat injury severity" above.

User factors--Numerous hypotheses have been proposed about the variation in restraint effectiveness due to physical characteristics of the occupants. Three basic characteristics--age, sex, and size of person--can be evaluated and appear to be adequate to assess user factors. HSRC has concluded that restraints are more effective for older occupants than for younger. The NHSTA 1973 study, the 1973 HSRI study, and others (lap only) have indicated an added risk of abdominal injuries for women and injury to the fetus of pregnant users. However, no real effectiveness estimates have been made, particularly in comparison with total injuries sustained. The 1973 HSRI study concluded that no effectiveness disparity, as a function of size of person, was present for lap use only, but no like analysis for lap/shoulder restraints had an adequate sample size. SRI suggests that lap/shoulder and lap-only effectiveness estimates be developed, based on weight, sex, and height (where available) from the 1976 HSRI and the HSRC data. Confidence intervals should be established for age, sex, and size of person. Although data on pregnancy are available in the HSRI 1976 study, samples of pregnant women are probably inadequate for the development of estimates. SRI recommends that medical evaluations be required for all upcoming NCSS and for any NASS cases involving pregnancy.

Type of injury--Injury data by body region were obtained in the three studies being considered, but no effectiveness estimates were made. Given the limitations of the currently used AIS scale (As new scales are devised they can be used in updates for estimates.), nevertheless some work can be done with this scale to develop ratings that address the trade-off of positive and negative benefits of restraints. Producing effectiveness estimates by body region and comparing them with estimates for the overall injury has been implied in the literature, but less gross comparisons may be made possible by using bivariate data on a specific body region (e.g., pelvis), crossed with overall injury severity. SRI suggests that this be researched.

Collision factors--Data on collision angle, damage severity, and vehicle size are available according to the 1976 HSRI study and HSRC. For collision angle and damage severity, these researchers have studied various derived indices. SRI feels that the use of derived indices based on a number of variables is an excellent approach to the concepts of type and severity of accident. Because at least two types of indices are available for each factor, a comparison of indices using both data files is appropriate. Based on this comparison, a number of derived indices for vehicle size, collision angle, and damage severity should be decided upon, and effectiveness estimates should be recomputed by using both data sources with associated confidence interval computation. Combined indices, based on three of the measures (e.g., vehicle size, collision angle, and damage severity) should also be considered.

Restraint system factors--Many instances of improper use and system malfunction have been cited (e.g., the North Carolina report[6]). Some problems for active restraints have been corrected by public advertising and manufacturing changes. We suggest that medical and engineering judgment by experts continue to play a key role on a case-by-case basis in NCSS. When such a case is indicated by an NCSS investigation team, or another team, the problems on that case should be especially evaluated.

4.5.2 Risk-Taking Factors

Although not extensively reviewed in this report, the characteristics of individuals who use and do not use restraints have been studied. For example, the SwRI report[9] indicates that use is declining; restraints are used less frequently on weekends and in rural areas, with variation by vehicle ownership, occupant position, and model type. In short, the reasonable evidence available suggests the hypothesis that the differences in driver and driving characteristics between users and nonusers may relate directly to accident and injury severity. Injury, however, is being directly related to belt use only (i.e., higher proportions of injuries in unrestrained drivers as functions of other factors of which restraint use may be merely another correlate).

This is a basic question about the purity of the comparisons being made, such as those discussed in Section 4.4.1. The analysis of collision factors is one attempt to account for confounding factors, but this analysis deals only with kinematics. An extreme example would be an unrestrained drunk driver having an accident late at night on a low volume roadway, compared with a restrained alert driver having an accident in the afternoon near a hospital--both accidents would be characterized by the same severity, collision angle, and vehicle size.

Multivariate classifications of such high-risk variables are proposed, to identify driver and accident variables, other than injury, that tend to correlate with the decision not to use restraints. Next, the populations would be stratified by risk groups A, B, C, and so on, whether or not restraints were used. Then, the effectiveness estimates--the proportion injured for A versus B--would be computed. These effectiveness estimates would be based on all accidents on file and would be further stratified by collision factors, as far as the sample size permits. Next, the restraint use variable would be introduced and new estimates produced within each A, B and C category for restraint versus non-restraint use.

This approach would be undertaken for new variables already available in existing files:

- Driver characteristics--Age, sex, vehicle ownership, model type, and others are reportedly available in the HSRI 1973 and 1976 studies and/or the HSRC study.
- Accident characteristics--Time of day, day of week, type of roadway, driver at fault, and others are reportedly available in the same studies.

4.5.3 Passive Restraint Factors

The analysis of ACRS effectiveness should be studied as part of the NHTSA Demonstration Program that has been proposed.[a] The procedure will generally follow that outlined for active restraint factors in Section 4.4.1, with the differences due to the characteristics of ACRS and additional comparisons that must be made because of the quantity and type of the alternative systems available.

Front seat injury severity--Because so few real-world deployments have occurred, air bag effectiveness cannot be assessed at this time. When the Demonstration Program begins, each accident involving an ACRS-equipped vehicle, whether deployment occurred or not, will be compared with two comparable vehicles (model, weight, occupant locations, and the like) involved in similar accidents (angle of impact, VDI, and related factors). In one, restraints will not have been used, and one will have employed lap/shoulder restraints in the NASS. Speed is particularly important for the ACRS because it determines in part whether deployment should or should not have occurred. If good speed data are not collected in NASS, then a damage severity variable should suffice for the matching. When 5000 ACRS-equipped vehicles have been investigated in the Demonstration Program, the computation of estimated effectiveness and confidence levels can begin. These estimates will be derived using the methods described for active restraints for the following comparisons:

- No restraints versus ACRS
- Lap/shoulder versus ACRS
- No restraints versus Lap/ACRS
- Lap/shoulder versus Lap/ACRS.

User factors--The analysis described in Section 4.4.1, User Factors for the data collected, will be repeated.

Type of injury--By the time of the Demonstration Program, new injury scales may be available. The methods for studying injury to a body region as compared with overall injury will have been tried for active restraints (see Section 4.4.1, Analytic Modeling). The analysis should be repeated for passive restraints. Special additional attention should be paid to developing frequencies of injury by body region when deployment occurred, because this new type of restraint is not expected to have the same injury profiles as those of active restraints.

Collision factors--The analysis described in Section 4.4.1, Collision Factors for the data collected will be repeated.

Restraint system factors--Passive restraints' reliability as a function of speed and impact direction are of great concern. Frequencies of deployment by speed and impact direction should be produced with the Demonstration Program data. For accidents in which investigators believe that a system malfunction has occurred, a special medical and engineering investigation and full report should be made in addition to normal reporting.

4.5.4 Continuing Studies

In addition to these measures, we suggest that the hypotheses developed above be reexamined within NCSS on a regular tabulation basis by model year. This reexamination would also apply to NASS. Because it is anticipated that each model year will further develop restraint systems, along with other modifications to reduce injuries, this recommendation would seem to be in order. In view of the work done to date and that recommended in Sections 4.4.1 and 4.4.3, with possible new suggestions coming from Section 4.4.2, this recommendation should entail a routine computer output. For 1977 to 1981, the data tabulations and generation of estimates would be those described above--tabulating for no restraints, and for lap and lap/shoulder restraints for 1972 to 1981 models. For 1982 on, the procedure would be revised to include no restraints, lap/shoulder, lap/ACRS, and ACRS for model years from 1974 on.

4.5.5 Direct Costs of Compliance

The average annual total costs of active restraint system components include the following:

- Lap belts and attachments, including retractors.
- Shoulder belts and attachments, including retractors.
- Reminder systems--lights or buzzers, or both.
- Interlock systems for applicable years.
- Incremental interior padding.

For passive systems, the costs include the following:

- Air bag systems--sensors, inflators, bag materials, and decorative covers.
- Any belts or warning system components at air bag protected positions.
- Incremental dashboard improvements (e.g., knee pads and stoking panels).
- Interior padding improvements at air bag protected positions.

The cost data required are for:

- Materials and fabrication

- Assembly and installation labor
- Mark-up--handling, storage, and profit.
- Lifetime average service, repair, and replacement parts.

Data sources used for obtaining these values include:

- Auto manufacturers.
- Inedependent estimators (e.g., Rath and Strong).
- DOT.
- Other government sources (e.g., Department of Labor, OMB)
- Aftermarket parts suppliers.
- Service and repair facilities.
- Past studies on service, repair, and replacement rates.
- Cost indices--materials and labor categories.

4.6 IMPLEMENTATION

The data collection and analysis required, the time schedule for completion, and the cost estimates for completing the work are given here for each evaluation hypothesis set.

4.6.1 Active Restraint Factors

The factors include:

a. Front seat injury severity

1. Data collection and analysis--Consistent estimates and associated confidence intervals will be computed from HSRI 1973 and 1976 studies and from HSRC data.
2. Time schedule--Computations will be performed from September to December 1977.
3. Cost estimate--$2000 will be required for programming and computer time.

b. Rear seat injury severity

1. Data collection and analysis--New data will be collected from NCSS, and effectiveness estimates and confidence intervals will be computed.

2. Time schedule--Computations will be performed from April to July 1978 (after data are collected).

3. Cost estimate--$10,000 will be required for extracting data and for analysis.

c. User factors

1. Data collection and analysis--Estimates and confidence intervals will be developed from the 1976 HSRI and HSRC sources; pregnant users in NCSS and NASS will be evaluated case by case.

2. Time schedule--Data analysis will take place from June to August 1977 for a case-by-case evaluation.

3. Cost estimate--$11,000 will be required for data and analysis, and $500 will be required for each medical evaluation.

d. Type of injury

1. Data collection and analysis--The 1973 and 1976 HSRI and HSRC sources will be used to study benefit trade-offs by body region.

2. Time schedule--Data analysis will take place from June to December 1977.

3. Cost estimate--$25,000 will be required for further effectiveness analysis and comparison of derived scales.

e. Collision factors

1. Data collection and analysis--Estimates and confidence intervals will be developed by using the same categories for existing sources as those in the 1976 HSRI and the HSRC studies.

2. Time schedule--Analysis will take place from June to September 1977.

3. Cost estimate--$11,000 will be required to study the categories used and to develop estimates.

f. Restraint system factors

1. Data collection and analysis--New data will be collected within NCSS for case-by-case examination of malfunctions and improper restraint use.

2. Time schedule--The data will be analyzed during the data collection period, June 1977 to 1978.

3. Cost estimate--$500 per case is required.

4.6.2 Risk-Taking Factors

These factors include:

a. Driver and accident characteristics

1. Data collection and analysis--Existing files from the 1973 and 1976 HSRI studies and the HSRC study will be used to examine and correlate restraint use.

2. Time schedule--Data collection and analysis will be performed from June to December 1977.

3. Cost estimate--$50,000 will be required for analysis and reports.

4.6.3 Passive Restraint Factors

The factors include:

a. Front seat injury severity, user factor, type of injury, and collision factors

1. Data collection and analysis--New data will be collected from the ACRS Demonstration Program; the data will be statistically analyzed, and estimates will be produced.

2. Time schedule--Preliminary analysis could begin in 1980.

3. Cost estimate--$100,000 will be required for a study covering these topics, plus reporting.

b. Deployment and malfunction

1. Data collection and analysis--A case-by-case study of possible failures will be undertaken to produce statistics on deployment.

2. Time schedule--The collection and analysis will start at the beginning of the Demonstration Program and will continue throughout.

3. Cost estimate--$500 per case will be required when malfunction is suspected; $15,000 will be required to produce deployment statistics.

4.6.4 Continuing Studies

These studies include:

a. For 1977 to 1981

1. Data collection and analysis--An output program will be written to generate estimates from NCSS and NASS.

2. Time schedule--Data collection and analysis will be performed annually.

3. Cost estimate--$5000 will be required to write and test the output program, with $1000 per year for output preparation.

b. From 1982 on

1. Data collection and analysis--Use of NCSS will be continued.

2. Time schedule--Data collection and analysis will be performed annually.

3. Cost estimate--$2000 will be required to revise the program for new restraint types in use, with $1000 per year for output preparation.

4.6.5 Summary of Cost Estimates

Evaluation Hypotheses	Cost per Item	Subtotals	Total
Active Restraint Factors			
1. Front seat injury severity	$ 2,000		
2. Rear seat injury severity	10,000		
3. User factors*	21,000		
4. Type of injury	25,000		
5. Collision factors	11,000		
6. Restraint system factors	10,000		
		$ 79,000	
Risk-Taking Factors			
1. Driver and accident characteristics		$ 50,000	
Passive Restraint Factor			
1. Accident analysis	$100,000		
2. Deployment†	65,000		
		$165,000	
			$294,000

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*Includes evaluations, each at $500, of approximately 20 cases.

†Includes evaluations, each at $500, of approximately 100 cases.

REFERENCES FOR SECTION 4

1. "Safety Belt Usage, A Review of Effectiveness Studies," NHTSA (1976).

2. DOT News Release, Office of the Secretary of Transportation (1976).

3. DOT News Release, Office of the Secretary of Transportation (1977).

4. "The Case for Safety Belts, Experimental and Statistical Evidence," NHTSA (1973).

5. F. L. Preston and R. M. Shortridge, "A Study of Restraint System Use and Effectiveness," HSRI for MVMA (1973).

6. D. W. Reinfurt et al., "A Statistical Analysis of Seat Belt Effectiveness in 1973-75 Model Cars Involved in Towaway Crashes," North Carolina HSRC, DOT Report HS-801933 (February 1976).

7. R. E. Scott et al., "An Evaluation of the 1974 and 1975 Restraint Systems," HSRI for MVMA (1976).

8. E. E. Flamboe, "A Comparison of Injuries Between Lap Belted and Non-Restrained Automobile Occupants According to Seated Position and Vehicle Size," NHTSA (1975).

9. J. R. Cromack et al., "Multidisciplinary Accident Investigation - Special Study of Active and Passive Restraint Systems in 1973-1976 Model Year Vehicles," Vols I and III, SwRI for NHTSA (1976).

10. "Automotive Air Bags, Questions and Answers," Allstate Insurance Company, Automotive Engineering Division (July 1976).

11. "Press Background Manual on Air Bags," IIHS, Communications Department (August 1976).

Section 5

STUDY RESULTS FOR FMVSS 214--SIDF DOOR STRENGTH

5.1 STATEMENT OF THE PROBLEM

FMVSS 214 specifies strength requirements for motor vehicle side doors to minimize the hazards caused by intrusion into the passenger compartment in a side-impact accident. Therefore, to conclude that the standard is effective in terms of its stated intent, analysis results must demonstrate that intrusion incurred by post-standard vehicles in compliance is significantly reduced when compared with prestandard vehicles. In addition, occupant injury severity which is directly related to the decrease in measured intrusion must be reduced. The estimate of intrusion differential between pre- and post-standard vehicles must be based on observations of independent variables. This will provide reasonable certainty that the intrusion differential is due to compliance with FMVSS 214 and not to extraneous or confounding variables. Therefore, the two fundamental relationships that must be considered in an evaluation plan are:

- The measured side-door intrusion into the passenger compartment incurred in side-impact accidents, expressed as a function of vehicle types and crash conditions--primarily the impact force vector.
- The severity of occupant injuries, given as a function of intrusion, vehicle type, crash conditions, and occupant compartment configuration.

5.2 DESCRIPTION OF THE CURRENT STANDARD

FVMSS 214 establishes three minimum crash resistance forces over three corresponding depths of external door surface crush for any side door used for occupant egress. The standard applies to all passenger cars and became effective January 1, 1973. The three minimum crush resistances are:

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

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

5.3 DISCUSSION OF TECHNICAL FACTORS

5.3.1 Injury Causation Factors

Injury to the occupant of a vehicle is caused by the impact of the occupant with the interior of the vehicle (excluding cases of ejection and total penetration by external objects). This condition is true whether the interior surfaces are deformed or are undamaged. Exterior surface deformation is only significant to injury causation when it acts as an energy absorber or is a cause of interior surface deformation.

The severity of injury is related to the speed of occupant-interior impact and to the degree of crush of the struck interior surfaces. Both of these variables affect the acceleration of the occupant and the post-impact speed of the vehicle (i.e., lower acceleration rates result in lower injury severity).

A basic question is "What is the effect of side door strengthening as implemented by the auto manufacturers on the severity of injury."[1] Considering the previous statements, if the crushability of the interior surfaces of the vehicle remains unchanged, the effect to be analyzed is the speed of the occupant-interior impact. For a stationary vehicle struck by a moving vehicle, this speed is determined by the rate at which the struck vehicle is moved sideways and the rate at which the interior surface is deformed, relative to the sideways speed of the vehicle.

If the additional rigidity provided by a door beam increases the sideways speed of the struck vehicle (compared with a nonbeam-struck vehicle), the increased speed may be offset by a reduction of interior surface deformation. If the increased rigidity does not increase sideways speed (indicating that more of the striking forces are absorbed by the striking vehicle) and interior surface deformation is reduced or eliminated, injury levels should be reduced.

Tests performed by GM[2] indicated that increased rigidity does not increase sideways speed in a common dangerous side impact (45° vehicle-to-vehicle collision). The tests showed that the relative velocity of a dummy's head and the inside of the vehicle is basically the same with or without the side impact structure. Without the improved side structure, energy was absorbed in the collapsing door and deforming sheet metal of both cars; with the beam structure, the same energy was absorbed, with a greater amount of energy absorbed by the front of the striking

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[1] "Evaluation of Motor Vehicle Safety Standards," Center for the Environment and Man, Incorporated, NTIS PB 226-074 (December 1973).

[2] D. C. Hedeen and D. D. Campbell, "Side Impact Structures," General Motors Automotive Safety Seminar (July 1968).

vehicle and a smaller amount absorbed in the side of the struck vehicle. These tests clearly indicate the possibility of relating injury severity to interior surface deformation that results in passenger compartment intrusion by eliminating the effects of vehicle postimpact speed.

5.3.2 Analysis of Relationships

In the present compliance test procedure, a loading device of cylindrical cross section is pressed quasistatically into the middle of the car door to a maximum penetration of 18 in. Although the test requirements are specified in terms of average and maximum loading-device forces over certain distances, it is useful to consider that the average force specifications are equivalent to the energy absorption specifications. Thus, the standard's requirements in effect say that energy absorption in the first 6 in. of loading device travel must be 1125 ft-lb, with 3500 ft-lb in 12 in. of loading-device travel. The maximum force requirement states that in 18 in. of travel, the loading-device force must reach at least twice the weight of the test vehicle, or 7000 lb, whichever is less. This has the effect of requiring heavier cars to be somewhat stronger, but only up to 3500-lb car weight.

A simple comparison can be made in terms of energy absorption between the compliance test and an idealized inelastic collision. To make the idealized collision as similar as possible to the test, it is necessary to consider a collision configuration that produces damage similar to that produced in the compliance test. Thus, the impacting vehicle must contact the center of the door without contacting either pillar. This requires an angled collision in which the front corner of the impacting vehicle strikes the center of the target vehicle door.

We can make an energy calculation, based on a lateral collision in which the target vehicle is stationary. Assuming equal vehicle weights, the energy dissipated in vehicle deformation equals half the kinetic energy of the impacting vehicle, that is,

$$E_d = \frac{1}{4} MV^2 \tag{1}$$

where,

E_d = the energy dissipated or absorbed in deformation.

M = the mass of either vehicle.

V = the impacting velocity.

If the energy absorbed in deformation is assumed to be divided equally between the vehicles, half the energy is absorbed in deforming the target vehicle. Let the target vehicle crush be 12 in., which is more than enough to cause intrusion, and let the energy absorbed by the target vehicle and by the impacting vehicle be just the amount required by Standard 214 (i.e., 3500 ft-lb). Now if M = 3000 lb, and letting E_d = 2 × 3500 ft-lb, we can solve Eq. (1) for V:

$$v = \sqrt{\frac{4\ (7000\ \text{ft-lb}_f)\ (32.2\ \text{lb}_m\text{-ft/lb}_f\text{-s}^2)}{3000\ \text{lb}_m}} = 17.3\ \text{ft/s} = 12\ \text{mph}$$

For a collision between two 2000-lb cars, Eq. (1) yields V = 14.5 mph, and for a collision between two 4000-lb cars, the result is V = 10 mph. If the front of the impacting vehicle is stiffer than the side of the target vehicle, less energy will be absorbed by the impacting vehicle, and the calculation above yields an even lower speed for the same energy absorbed by the target vehicle. This apparent low level of protection is a result of the noninvolvement of the vehicle's pillars.

Most vehicle-to-vehicle side impacts involve the pillars directly, and the area of damage on the impacted vehicle is not confined to the door itself. Thus, the actual energy absorption can be much greater for a given amount of crush--and hence, intrusion--than the amount required by Standard 214.

This fact has certain implications for any plan to evaluate the effectiveness of this standard. The standard's strength requirements apply directly to the door and also to the hinges and latches. However, Standard 206 requirements are weaker than the loads on these components implied by Standard 214. Similarly, strength requirements are implied for the pillars because the test loads are fed to the pillars by the hinges and latch. Because the pillars are ordinarily able to withstand greater forces than the door (much greater forces on heavier cars) and because the majority of lateral collisions involve the pillars directly, the actual strength of the door diminishes in importance. Variations in door strength are thus harder to detect in accident data because pillar strength (or lack of it) has a greater effect.

It seems, therefore, that any evaluation of Standard 214 using highway data should be restricted to studying accidents with minimal pillar involvement. In this way, the investigator can satisfy himself that the door was in fact the dominant element in resisting deformation and intrusion, and that the pillars, door sill, or other structures did not act in this capacity.

5.4 REVIEW AND ASSESSMENT OF ALTERNATIVE EVALUATION METHODOLOGIES

5.4.1 Existing Data

Assurance of design and data validity is the most critical problem in the development of an evaluation plan. Validity could certainly be established if a vehicle in compliance with the standard were compared with a similar, counterpart vehicle not manufactured to the specifications of the standard. However, such counterpart vehicles do not exist, and the situation is complicated because the inclusion of a door beam may have affected the design and strength of other structural components (e.g., latches and pillars).

In past studies pre-1969 impacted vehicles have been compared with vehicles known to comply with the standard. However, as noted previously, the independent variables that may affect injuries above and beyond the presence of door beams present both conceptual difficulties and practical problems in data collection. That is, when considering a particular 1968 model vehicle without beams in conjunction with a 1976 model, it is difficult to postulate all of the structural and crash environment variables required for valid comparison.

A review of the current literature reveals several studies that document the statistical comparisons of injuries sustained by occupants of pre- and post-standard vehicles involved in side impact. References include 1, 3, and 4 and, most recently, a preliminary report by CALSPAN[6]. From examination of the data in these reports, two conclusions can be drawn: First; no firm evidence exists to indicate that FMVSS 214 is effective; second, if the probability of side-impact injury severity between pre- and post-standard vehicles has really been reduced, this reduction is probably quite small--on the order of 5%. This estimate is an important consideration in the construction of any subsequent evaluation plan because the detection of very small differences in the real-world environment will require large accident sample sizes.

As an illustration of the result that appear in the literature, the CALSPAN report shows data on 1025 occupants seated on the struck side of pre-standard vehicles, and 1266 similar occupants of vehicles in compliance. The observed probabilities of minor or moderate injuries were 0.122 for pre-standard vehicles and 0.118 for post-standard--a reduction of about 3%. This difference is not statistically significant.

The MDAI file has been considered as a possible source for data analysis related to the standard. Alternatively, it might serve for preliminary analysis, with future data collection specifically designed to address evaluation of the standard. The case vehicle data file uses reasonably detailed variables such as the following:

- Date of collision.
- Internal vehicle objects contacted by occupants.
- Estimated speed prior to and at first impact (case and other vehicle).

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[3] A. J. McLean, "Collection and Analysis of Collision Data for Determining the Effectiveness of Some Vehicle Systems," University of North Carolina (September 1973).

[4] F. S. Preston and R. M. Shortridge, "An Evaluation of Sideguard Door Beams," University of Michigan (September 1973).

[6] "The Effect of Side Door Reinforcement Beams and 5 MPH Energy Absorbing Bumpers on Injury Severity," CALSPAN, Draft Report (May 1976).

- Vehicle country of manufacture, corporation, division, make, body type, model year, weight, body style and structure.
- Vehicle damage index (primary and secondary collisions).
- Sheet metal crush (inches).
- Pillars, door latches and hinges--left, right, A, B, and C pillars (damage and separation).
- Steering column and seat information.
- Passenger compartment damage and occupant contact--door, hardware, armrest, glass, roof, B, C and D pillars.
- O'Clock direction of impact.

Only after Junuary 1974 was a supplementary form included in the MDAI that provides

- Door guard beam presence
- Direct damage to front and rear doors
- Maximum inches of crush to doors
- Beam involvement.

From data for collisions reported by this supplementary form, it is possible to determine the presence of door guard beams. For earlier collisions, presence or absence could be determined for certain models, e.g., the Center for the Environment and Man (CEM)[1] has indicated the year during which side doors were strengthened for several model types. Unfortunately, the model type is not directly retrievable in the MDAI system access, and retrieval requires an additional manual look-up. (However, VIN can be accessed.)

In the absence of a clear-cut with/without criterion or criteria for determining side-door strengthening, a computer run of year of vehicle versus location of impact to determine gross upper estimates for sample sizes if it is assumed for instance that all doors were strengthened in 1967, 1968 and in subsequent years. The year of collision was also determined in the run, to delineate the sample sizes with supplementary reporting.

The following presents the sample sizes by o'clock direction for side impacts and by model year.

	O'Clock Direction	Model Year									
		67	68	69	70	71	72	73	74	75	76
Number of cases											
Right side	2 (front)	24	51	72	138	144	131	99	48	8	0
	3 (direct)	3	19	22	43	31	34	22	16	2	0
	4 (rear)	4	7	7	17	16	9	3	4	3	0
Left side	10 (front)	27	40	53	98	133	106	73	44	5	0
	9 (direct)	7	25	29	55	27	37	33	13	2	0
	8 (rear)	3	6	12	16	14	14	12	5	0	0

These are current figures, and presumably many cases involving 1975 and 1976 vehicles have not been submitted to the file. At any rate, the number of side impacts for model years that could have been pre-standard is very small (e.g., 68 vehicles for the 1967 case were impacted on the side). When the multivariate nature of these data is considered--specifically, the variation in impact characteristics, vehicle body style and structure, and injury severity--this upper estimate of sample size is too small for meaningful analysis.

5.4.2 Accident Investigations

Highway accident investigation designed to satisfy the analytic objectives of an FMVSS evaluation plan could produce a data base that contains the relevant cause and effect variables, including vehicle types, crash conditions, maximum intrusions, and injury severity. For a sufficiently large data base, analysis of variance and regression would provide the appropriate methodologies for testing hypotheses and calculating confidence interval estimates of the intrusion differential between pre- and post-standard vehicles, and of injury severity as a function of intrusion.

For analysis of variance and regression, a probability sample from a well-defined target population is required, as are approximate normality and equal variances within statistical cells, or sets of independent variables. For a complete statistical design, a painstaking attention to detail would be required to ensure that these conditions are satisfied. However, these statistical considerations do not constitute major concerns in feasibility assessment. A probability sample can be defined by using standard sampling and theoretical concepts. Normality and equal variances are either inherent in the characteristics of the data base or can be achieved by suitable variable transformations. In cases when tranformations do not apply, multidimensional contingency tables can always be used, as can the nonparametric counterparts of regression and the analysis of variance. Therefore, the determination of statistical design feasibility will depend almost entirely on basic questions concerning precision.

The accident investigation methodology is appealing because it is complete and directly focused on real-world events. Its major disadvantage is that trained investigators must be used at considerable expense to collect the required sample. However, on balance, it is evident that accident sampling must be an integral part of any evaluation plan. A description of procedures and required sample sizes is given in Section 5.5.

5.4.3 Analytic Modeling

Our assessment of the utility of analytic models in evaluating FMVSS 214 included a consideration of large computerized simulation models, such as the Simulation Model of Automotive Collisions (SMAC), and smaller models designed specifically to evaluate the degree of intrusion as a function of side-door strength and impact vector.

The general conclusion, however, is that the extrapolation of model results to real-world conditions would lack credibility. SMAC, for example, was eliminated from further consideration because its representation of vehicle deformation, although adequate for describing vehicle collision kinematics, lacks the refinements necessary to simulate such details of vehicle structure as door reinforcements. The development of a closed equation analytic model would require an extensive iterative process of validation and model refinement, and even then a capability for valid extrapolation would not be assured.

5.4.4 Controlled Testing

Controlled testing, which includes standard compliance test equipment and procedures and dynamic vehicle-to-vehicle staged crashes, suffers from the same inherent limitations as analytic modeling. That is, there is no plausible method for extrapolating test data to attain the desired result--the estimation of the reduction in injury severity. However, among all methodologies and procedures considered, staged crashing provides the best mechanism for obtaining realistic, precise, and simultaneous measurement of compartment intrusion, and impact force and direction. Therefore, a staged crash experiment designed to compare pre- and post-standard vehicles could produce definitive results that would satisfy the first analytic objective--the determination of the intrusion differential between pre- and post-standard vehicles under fixed crash conditions.

5.5 EVALUATION STUDY DESIGN

5.5.1 Background and Rationale

It is difficult to conceive of any methodology other than accident investigation that will permit a credible determination of the relationship between door intrusion and injury severity. Yet any evaluation plan that is based solely on a random sample of all reported side-impact accidents must necessarily involve large, and perhaps prohibitive sample sizes. Sample size requirements are ordinarily prior rough estimates of the reduction in injury probability that is likely to exist in the real-world environment--or alternatively the magnitude of the difference of interest to the decision maker--and of the desired probability of detecting such values.

The following shows required sample sizes for various specifications, as calculated from the algorithm given in Appendix B.

True percent reduction in injury probability	Required Sample Sizes: 0.95 test power	0.90 test power	0.85 test power
3	111,960	88,248	74,384
5	40,054	31,576	26,614
10	9,852	7,766	6,546
15	4,300	3,392	2,858

In each case it is assumed that equal numbers of pre- and post-standard vehicle side impact accidents are collected, and that the probability of an AIS injury severity value between 1 and 3, inclusive, is 0.3 for pre-standard vehicles*. Thus, from the first table entry, if post-standard vehicles contribute to a 3% reduction in side-impact injury probability, 111,960 accidents must be sampled to obtain a 0.95 probability (test power) that the results will be assessed as significantly different from zero. Data and conclusions in the current literature (Section 5.4) indicate that the true reduction in injury probability does not greatly exceed 5%; therefore, the required random sample size is at least 30,000.

A large sample size is required, primarily because there is no firm basis for stratifying the vehicle-accident population into subsets. This, in turn, prevents investigators from focusing on vehicle types and accident conditions in which the greatest differences exist. For example, if there is a 5% average reduction in injury probability over the entire population of side impact accidents, it is likely that this reduction will not uniformly represent all conditions. Rather, selected pairs of pre- and post-standard vehicles, and certain crash conditions (e.g., oblique side impacts at 15 to 35 mph) will probably show a much greater than average variation in both intrusion and injury rates. If these accident conditions and vehicle types can be identified, then prestratification will concentrate investigative effort in areas of primary interest, and sample size may be reduced. There are, of course, recognized operational difficulties in any extensive prestratification scheme, but in view of the prohibitive random sample sizes associated with a simple comparison of pre- and post-standard vehicles, the stratification concept must be given serious consideration. A second procedure that will increase the amount of information obtained from small accident samples is obtaining direct estimates of the correlation between intrusion and injury severity when crash conditions are held fixed. If a strong

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*This estimate is compatible with the CALSPAN data discussed in Section 5.4.

correlation is established, then a probable injury mechanism will be identified, even though the overall injury reduction may be small.

Both of these procedures suggest the need for a multistage evaluation plan. Controlled testing before accident sampling, for example, can provide information concerning the nature and causes of intrusion, and this information may be used to prestratify or to assess the feasibility of intrusion-injury severity correlation analysis.

In the selection of a recommended evaluation plan, the cost of analysis and test implementation was not a dominant factor; no dollar value was placed as an upper bound on test design. However, economic efficiency was a major consideration, subject to the conditions that the evaluation plan must have a high probability of leading to definitive conclusions and that the implementation should be completed within a reasonable time.

Based on these considerations and on the discussion of alternative methodologies (Section 5.4), a three-stage evaluation plan is recommended. The first stage is an extended compliance test applied to pre-standard vehicles; the second stage is a program of static and dynamic testing; and the third stage is accident sampling and analysis. This three-stage design promises two desirable features:

- Two decision points are built into the process to allow the evaluation to be terminated at the end of the first or second stage if preliminary results shows that the measured intrusion differential between pre- and post-standard vehicles is too small to be detected in subsequent highway accident investigations.
- If a significant intrusion differential is observed in controlled testing, the vehicle types and crash conditions associated with this differential can serve as the basis for stratifying the accident population, and sample sizes will be minimized as a result.

The flexibility of this procedure should ensure quality and efficiency, but it also introduces an element of uncertainty, which is inherent in such multistage designs. The basic decisions are whether to continue with subsequent stage evaluations or to stop to draw final conclusions. Therefore, the maximum time required for the entire process can be determined. Furthermore, it is quite probable that specific information will be developed during the first and second stages, and that this information will be useful in finalizing the details of additional test requirements. In the following description of the evaluation plan, we have included estimates of sample size, cost, and time required for each stage. However, we recommend that the analysts conducting the tests be afforded sufficient latitude to develop precise decision criteria and the specifics of subsequent stage design.

5.5.2 Evaluation Plan Specifics

In the remainder of this section, the stages of the evaluation plan, outlined in Figure 5-1 are discussed in terms of objectives and rationale. Further details, including schedule and cost estimates, are given in the implementation plan, Section 5.6.

5.5.2.1 Compliance Test

The proposed compliance test will primarily determine whether or not convincing evidence supports the hypothesis that the extent of interior compartment intrusion differs significantly between pre- and post-standard vehicles. Secondarily, the test will provide a basis for selecting vehicle types for use in subsequent stage evaluations.

To achieve these objectives, we recommend that all compliance test data on post-standard vehicles be collected, and that a sample of pre-standard vehicles be subjected to the same testing procedures. If pre- and post-standard crush resistance values differ significantly, it would be concluded that differences in intrusion between pre- and post-standard vehicles exist and can be measured, and that the evaluation plan should be continued to the next procedure involving staged crashes. If, however, significant passes of the compliance test are observed, it would then be concluded that minimal intrusion differentials occur, and required measurements in the real-world would not be possible. Most important, the effectiveness of the standard as far as intrusion is concerned would be essentially zero. Should this latter event occur, the evaluation could be terminated because further work would probably produce inconclusive results.

COMPLIANCE TEST

- COLLECT POST-STANDARD TEST DATA
- TEST EIGHT PRE-STANDARD VEHICLES
- COMPARE TEST DATA DISTRIBUTIONS
- DECISION CRITERION: STOP, OR CONTINUE EVALUATION

↓

STAGED CRASHES

- CONDUCT 12 VEHICLE-TO-VEHICLE CRASHES
- ANALYZE MEASURED INTRUSION
- DEVELOP FIELD MEASUREMENT METHODOLOGY
- DECISION CRITERION: STOP, OR CONTINUE EVALUATION

↓

ACCIDENT INVESTIGATIONS

- IDENTIFY FEASIBLE PRESTRATIFICATION VARIABLES
- SAMPLE 4000 SIDE IMPACTS (NATIONAL CRASH SEVERITY STUDY)
- COLLECT INTRUSION AND INJURY DATA

↓

ANALYSIS OF RESULTS

STATISTICALLY VERIFY WHETHER OR NOT THE STANDARD IS EFFECTIVE

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FIGURE 5-1 FMVSS 214 EVALUATION PLAN

The criterion that forms the basis for the decision to proceed, or to stop evaluation, will depend on the variability of the compliance test values so derived. Table 5-1 lists (in incomplete form) crush resistance values for selected post-standard vehicles. From an examination of these data, a reasonable decision criterion would be to proceed if the average value for the sample of pre-standard vehicles is less than 80% of the average for post-standard vehicles; if the value is not less than 80% further evaluation should be discontinued.

For the selection of pre-standard cars, we recommend that two- and four-door hardtops and sedans manufactured by GM and Ford Motor Company be used. This selection is based on percentage distributions of these body styles (more than 80% of vehicles in operation) and the percentage of the market held by these companies. Moreover, approximately 65% of the cases cited in a recent study on tow-away accidents involved these manufacturers' cars.

Based on these factors, an adequate representation of the pre-standard population could be achieved by the following sample of eight vehicles.

The number of pre-standard vehicles needed would then be as follows:

	1963	1964	1965	1966
GM	4-door sedan	2-door sedan	4-door hardtop	2-door hardtop
Ford	4-door sedan	2-door sedan	4-door hardtop	2-door hardtop

5.5.2.2 Staged Crashes

If compliance test results provide prior evidence of an intrusion differential, the second phase of evaluation should involve vehicle-to-vehicle staged crashes. These controlled tests should be designed to:

- Determine whether or not intrusion differs measurably between pre- and post-standard vehicles under fixed crash conditions.
- Develop and determine the precision of field-measuring procedures.

Table 5-1

COMPLIANCE TEST VALUES
FOR SELECTED POST-STANDARD VEHICLES

Vehicle	Side	2250 lb, 6-in. Intrusion	3500 lb, 12-in. Intrusion	2 X Weight or 7000 lb Maximum
1974 Dodge Monaco	LF	3520	5707	9500
(2-door hardtop)	RF	3440	5813	9900
1974 Plymouth Valiant	LF	3596	5583	9790
(4-door sedan)	RR	3754	5493	9710
1974 Ford Maverick	LF	3128	4361	9480
(2-door sedan)	RF	2857	4649	8400
1973 Buick Electra	LF	3121	6253	13900
(4-door hardtop)	RR	3088	5656	12075
1974 Pontiac Catalina	LF	2667	4787	10800
(4-door hardtop)	RR	3200	5640	11550
1974 Chevelle Malibu	LF	3147	4520	10400
(2-door hardtop)	RF	3013	4627	7400
1974 Chevelle Malibu	LF	2745	5187	11875
(4-door sedan)	RR	3048	5231	11590
1974 Olds Cutlass	LF	3307	5053	9200
(2-door hardtop)	RF	3413	5067	8700
1974 Pontiac Firebird	LF	3051	4980	9650
(2-door hardtop)	RF	3071	5105	10200
1974 Chevrolet Impala	RF	2387	4140	10300
(2-door hardtop)	LF	2567	4313	8950

- Provide a numerical basis for calculating the correlation between compliance test data and measured crash-induced intrusion.

The staged crash design factors should be based on the results of the compliance test and selected so that the greatest possible intrusion differential will be observed. For planning purposes, we recommend that 12 crashes be conducted at a single fixed-impact angle of 30°, and at two impact speeds--15 and 30 mph. In addition, we recommend that six vehicle types be tested, including three pairs of pre- and post-standard vehicles. Each pair would consist of one pre-standard and one post-standard vehicle of the same body style and approximate weight; the pre-standard vehicle would have a low compliance test rating (as observed in phase one) and the post-standard vehicle would have high crush resistance values. This selection, is intended to produce large differences in intrusion. The bullet vehicle type should be consistent throughout the test; we recommend a 1971 intermediate class vehicle, with our choice based primarily on economic considerations.

With conventional photography and pre-crash determinations of center lines and reference points, it will be possible to measure the maximum value and area of intrusion accurately. The next step will be to relate this information to the capabilities of the individuals who investigate real-world accidents under less than ideal conditions.

Discussions with several experienced MDAI investigators, indicate that the current delineation of intrusion consists of measuring the movement of the inner door panel toward the interior of the vehicle. Given the damaged location of the door panel, calculating the amount of intrusion requires the determination of the original undamaged profile of the panel. Current practice depends on estimating the undamaged profile, generally by sighting along a line from the A pillar to the B pillar, assuming these pillars are undamaged. A more accurate method, which is practicable for some vehicles and difficult on others, is determining the longitudinal centerline of the vehicle and measuring from the centerline to the damaged door panel. Comparison with the undamaged door panel opposite gives the degree of intrusion. If both doors are intruded, measurements made of the damaged vehicle can be compared with those made of an identical vehicle to obtain the intrusion. Investigators and analysts have stated that such measurements are accurate to within 1 to 2 in., but precise measures of bias and variability are not available.

To enhance the field-investigation capability, first, a consistent method of measuring intrusion should be explored and developed during the staged-crash phase of evaluation. For example, a simple porcupine panel with movable needles could be placed over the door to obtain an intrusion profile. The panel may be one- or two-dimensional; however, it would seem that a one-dimensional panel is most appropriate for field use. For reference, the other door, assuming it is not damaged in any way during the accident could be used to set the "porcupine" panel and establish a reference point. Then, the accident investigator would simply place the panel over the intruded door to measure the degree of intrusion. Second, estimates of bias and variability should be obtained by testing the capabilities of a group of trained investigators. To do this, 12 investigators (preferably those currently employed in the NCSS program) should independently measure the staged crash intrusion results, using standard, or newly developed, measurement techniques. The 144 observations, thus obtained, would provide good estimates of means, biases, and statistical variances. All of these factors would be of considerable importance in the final statistical analysis of accident data.

Finally, the compliance test results obtained in Phase 1 should be correlated with the maximum intrusion observed in staged crashes. The calculation of statistical correlations is a simple task, and if strong correlations exist, the compliance test values may be used for prestratification in subsequent accident sampling designs.

This discussion has presented our recommendations concerning the program of staged crashes. However, other alternatives might also be considered. For example, if a clear relationship between exterior-interior intrusion and vehicle type and impact vector is established, then a new deformation index might be developed to assist accident investigators to reconstruct real-world crash conditions more accurately.

But the outcome of such experimentation is uncertain, and the cost would be high--at least 36 vehicle-to-vehicle crashes would be required. For these reasons, we have rejected this alternative.

5.5.2.3 Field Accident Investigations

If the staged crash experiment demonstrates that differences in intrusion do occur between pre- and post-standard vehicles, the final stage of the evaluation must be field accident investigation. This type of investigation will determine the relationship between injury severity, as measured by the AIS, and intrusion. It will also determine the degree of reduction in injury probability attributable to FMVSS 214.

The most critical problem that must be addressed in the accident sample design is that of prestratification. As indicated above, prior stratification of the accident population into subsets in which pre- and post-standard vehicles exhibit the greatest difference in intrusion and injury severity can greatly reduce the required sample size. These prestratification criteria should be developed from knowledge gained from compliance testing and from staged crashes. Although prestratification presents no conceptual difficulties, there are recognized operational problems because the selective investigation of particular types of accidents requires the cooperation of investigating police. However, it should be possible to prestratify the accident population by identifying accidents by impacted vehicle (pre- and post-standard), impact speed (15 to 35 mph and above), and angle of impact. These factors are tentative and, as stated before, the specifics should be determined from the results of previous testing.

Under these conditions, an estimated sample size of 2000 pre-standard and 2000 post-standard vehicle side impact accidents is required. We also recommend that the NCSS be augmented, with the collection of requisite intrusion data. In this way, pre- and post-standard injury severities can be correlated with intrusion and the effectiveness of the standard determined.

As NCSS format currently exists, data will include areas of intrusion, the specific horizontal area of severest intrusion, the intruding component (maximum of three, with one indicating maximum extent of intrusion). It will also identify impact speeds and vehicles. Thus, it appears the NCSS has the potential of providing almost all of the required data, except for the number of minor injury accidents investigated. NCSS will only collect 2500 minor injury accidents; but because 4000 are required for this evaluation scheme, the data collection must be expanded.

Because NCSS is already under way with about 3 months of data collection completed, the augmented samples and data collection procedures, which will take place in the remaining 2 years, offer distinct advantages. Whether or not 2 years of data collection are required is unclear, 1 year may be entirely sufficient, considering the accident population necessary for this evaluation. For example, in 1973*, there were 35 million pre-standard cars on the road, and in 1975† this number diminished to 25 million. Extrapolating to years 1976 through 1979 suggests a population of 21 million cars in 1976 and 14 million cars in 1979. If generally accepted percentages of vehicles involved in accidents (20%) and percentages of side-impact accidents (31%) are used, we estimate about 1 million side-impact accidents of pre-standard cars between 1977 and 1979. If adequate team coverage is assumed, a year effort would seem satisfactory.

Note that there is an alternative to the recommended sequential scheduling of phases of the evaluation plan. The proposed accident sampling is to be initiated only after the results of staged crashing confirm the existence of an intrusion differential. Another acceptable procedure would begin accident sampling concurrently with the compliance tests. However, the accident investigation costs may be wasted if preliminary results show that pre- and post-standard vehicles do not differ

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*1973 values are obtained from MVMA's 1973 report

†1975 values are obtained from the 1976 Automotive News Annual Report.

with respect to intrusion. Nevertheless, this approach will be advantageous if it reduces the time required for implementing the plan.

5.5.3 Analysis of Results

Although requisite analysis will be conducted throughout the evaluation plan with qualitative as well as quantitative assessments, this final stage will be primarily concerned with statistical verification of the standards effectiveness. It will include a review of previous compliance tests data, the results of staged crashes, and accumulated accident data. Moreover, identified intrusion will be correlated with measured severity through the use of statistical procedures such as regression analysis. Then the results will be documented. In summary, the process will:

- Accumulate data from compliance tests, controlled testing, and accident investigations.
- Computerize relevant accumulated data.
- Examine the quality and characteristics of data elements, selecting an appropriate statistical software package--such as SPSS.
- Conduct numerical analysis, drawing conclusions regarding effectiveness.

5.6 IMPLEMENTATION PLAN

Essential elements of SRI's recommended plan to evaluate FMVSS 214 are described below. They include a schedule showing total time required to complete major milestones, total estimated implementation costs with associated costs itemized by procedure, and data collection and analysis requirements.

A time-phased schedule is presented in Figure 5-2, and total costs are listed in Table 5-2. About 33 months are required to complete an evaluation of FMVSS 214. It may be possible to reduce this schedule if field-accident investigations require a shorter period; however, we cannot plan for this before the fact. Total implementation costs are $1,402,200, although the evaluation could terminate upon completion of

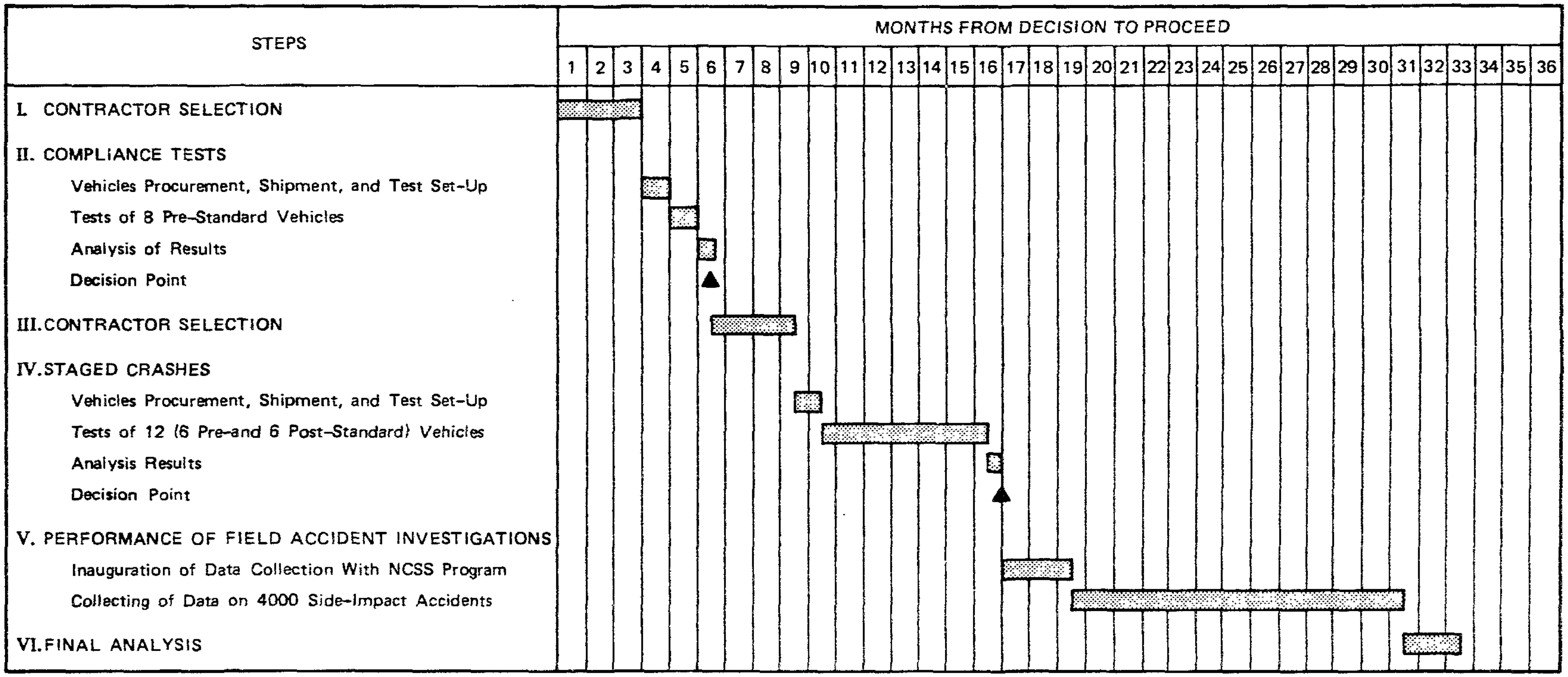

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FIGURE 5-2 FMVSS 214 EVALUATION AND IMPLEMENTATION PLAN compliance tests ($37,400 or 2% of the total) or staged crashes ($334,000 or 24% of the total).

Table 5-2

FMVSS 214--SIDE DOOR STRENGTH:
TOTAL EVALUATION AND IMPLEMENTATION COSTS

Phase	Activity	Cost	Percent
I	Contractor selection	N/A	>
II	Compliance tests of 3 pre-standard vehicles	$ 37,400	>2
III	Contractor selection	N/A	
IV	Staged crashes of 12 vehicles (6 pre- and 6 post-standard)	$ 334,800	24
V	Field accident investigations	$1,006,000	72
VI	Final analysis and report	$ 24,000	<2
	Total	$1,402,200	100

5.6.1 Compliance Tests of Pre-standard Vehicles

Compliance testing of pre-standard vehicles will include the following steps:

- The available compliance test results to date will be obtained.
- A contractor's services will be procured to:
  - Purchase eight pre-standard vehicles.
  - Ship and prepare these vehicles for testing.
  - Test the pre-standard vehicles.
  - Document results.
  - Salvage or dispose of the vehicles tested.
- The pre-standard vehicles purchased will include:

Manufacturer	1963	1964	1965	1966
GM	4-door sedan	2-door sedan	4-door hardtop	2-door hardtop
Ford	4-door sedan	2-door sedan	4-door hardtop	2-door hardtop

- Test results (by NHTSA personnel) will be analyzed, and it will be determined whether or not average forces over 6, 12, and 18 in. intrusion were less than 80% of that specified by the standard.
- It will be decided whether the evaluation should proceed or terminate.
- Specific activities, schedules, and estimated costs are as follows:

	Activity	Cost	Schedules (weeks)
1.	Contractor selection (modify existing contract, if possible)	N/A	2 to 12
2.	Review of available compliance test results	(Included in analysis)	N/A
3.	Procurement of 8 pre-standard vehicles ($1,500 average cost per vehicle)	$12,000	2
4.	Shipment and preparation for test ($1,000 average cost per vehicle)	$ 8,000	2
5.	Compliance tests ($2,000 average cost per vehicle)	$16,000	4
6.	Analysis of test results (0.5 man-month at $6,000 per man-month)	$ 3,000	2
7.	Salvage or disposal of vehicles tested ($200 savings per vehicle)	($ 1,600)	1
	Total	$37,400	11 (excludes Activity 1)

5.6.2 Vehicle-to-Vehicle Staged Crashes

The vehicle-to-vehicle staged crashes will include the following steps:

- Services of a contractor will be procured for the following activities:
  - Based on review of compliance test results of both pre- and post-standard automobiles, 24 vehicles will be purchased.
  - Vehicles purchased will include 6 pre-standard, 6 post-standard, and 12 1970 or 1971 post-standard vehicles as bullet test vehicles.
  - Vehicle-to-vehicle staged crashes will be conducted at two speeds, 15 and 30 mph. An impact angle of 30°, where maximum intrusion is expected to occur, will be used.

- A consistent intrusion measurement technique, using 12 trained accident investigators will be developed. Based on investigators' estimates of intrusion, their results will be compared with instrument data, and a measurement technique using rulers or a "porcupine panel" will be developed.
- Test results will be documented and forwarded to NHTSA.
- The vehicles tested will be disposed of.

- Test results by NHTSA personnel will be analyzed to determine if differentials between pre- and post-intrusion exist. Statistical correlations between compliance results and intrusion will be calculated.
- It will be decided whether the evaluation should proceed or be terminated.
- Specific activities, schedules, and estimated costs are as follows:

	Activity	Cost	Schedule (weeks)
1.	Contractor selection	N/A	12
2.	Procurement of 6 pre-standard vehicles ($1,500 average cost per vehicle)	$ 9,000	0.5
3.	Procurement of 6 post-standard vehicles ($5,000 average cost per vehicle)	$ 30,000	0.5
4.	Procurement of 12 post-standard vehicles (1970-71 models) as bullet vehicles ($2,000 average cost per vehicle)	$ 24,000	2
5.	Shipment of vehicles and preparation for test ($1,000 average cost per vehicle)	$ 24,000	1
6.	Conducting of 12 staged crashes ($20,000 per crash)	$240,000	24
7.	Intrusion measurement development	$ 4,800	1
8.	Analysis of test results (0.5 man-month at $6,000 per man-month)	$ 3,000	2
	Total	$334,800	44

5.6.3 Accident Investigations in the Field

Field-accident investigations will include the following steps:

- The objectives of the FMVSS 214 program will be incorporated into the NCSS program.

- Expansion of NCSS data collection activities (minor injury accidents investigations increased to 4,000) will be negotiated.
- Accident investigation teams will be provided with the intrusion measurement technique developed during the staged crashes.
- Data for 2000 accidents of pre-standard vehicles will be collected.
- Data for 2000 accidents of post-standard vehicles will be collected.
- The collected data will be forwarded to NHTSA on a scheduled basis.
- Specific activities, schedules, and estimated costs are as follows:

	Activity	Cost	Schedule (weeks)
1.	Expansion of the NCSS program	(Included below)	10
2.	Collection of accident data on 2000 pre-standard vehicles ($250 average cost per vehicle)	$ 500,000	52
3.	Collection of accident data on 2000 post-standard vehicles ($250 average cost per vehicle)	$ 500,000	(included in Item 2)
4.	Forwarding of periodic data reports to NHTSA (1 week each quarter at $1,500 per week)	$ 6,000	(included in Item 2)
	Total	$1,006,000	62

5.6.4 Final Analysis of All Results

The final analysis of test results will include the following steps:

- Data will be accumulated from compliance tests, controlled testing, and accident investigations.
- Relevant accumulated data will be computerized.
- The quality and characteristics of data elements will be examined, and an appropriate statistical software package, such as SPSS, will be selected.
- Numerical analysis will be conducted, and conclusions regarding effectiveness will be drawn.

The estimated level of effort required to accomplish the final analysis is the equivalent of 4 months at $6,000 per month (over a two-month period), or $24,000.

5.6.5 Costs of Safety Parts and Equipment

A complete itemization of direct costs of compliance would consist of engineering design, materials, fabrication and assembly (labor), mark-up, service and repair, and test costs. Data sources would include:

- Auto manufacturers.
- Independent estimators (e.g., Rath and Strong).
- DOT.
- Other government sources (e.g., Department of Labor, OMB).
- Aftermarket parts suppliers.
- Service and repair facilities.
- Past studies on service, repair, and replacement rates.
- Cost indices--materials and labor categories.

Because of the large number of vehicles produced, however, a reasonable estimate can be obtained by identifying the values for three items included in the manufacture and sale of motor vehicles: materials, fabrication and assembly labor costs, and mark-up. Manufacturer data and independent suppliers must be consulted to obtain accurate cost of compliance values. However, it is recognized that this is a difficult if not impossible task.

An approximate value can be used to estimate the total cost based on weight of materials. In November of 1974, this value was $1.07/lb. Based on this and other projects, an approximate cost for many motor vehicle components can be obtained by determining the weight of the materials used and their cost, and by then estimating this value as 25% of the total cost. The approximate proportions for the three factors described above are: materials-25%, labor-25%, and mark-up-50%.

REFERENCES FOR SECTION 5

1. "Evaluation of Motor Vehicle Safety Standards," Center for the Environment and Man, Incorporated, NTIS PB 226-074 (December 1973).

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3. A. J. McLean, "Collection and Analysis of Collision Data for Determining the Effectiveness of Some Vehicle Systems," University of North Carolina (September 1973).

4. F. S. Preston and R. M. Shortridge, "An Evaluation of Sideguard Door Beams," University of Michigan (September 1973).

5. "The Effect of Side Door Reinforcement Beams and 5 MPH Energy Absorbing Bumpers on Injury Severity," CALSPAN, Draft Report (May 1976).

Section 6

FMVSS 215--STUDY RESULTS FOR EXTERIOR PROTECTION

6.1 STATEMENT OF THE PROBLEM

The purpose of FMVSS 215 is to reduce damage incurred in low-speed collisions, and to reduce the frequency of override and underride in collisions at all speeds. Existing compliance and barrier tests[1] present convincing evidence that the standard is potentially effective in reducing damage in selected low-speed collisions to date. However, no adequate data are available for estimating total benefits, particularly over the real-world service life of affected vehicles.

A serious problem that has prevented adequate evaluation of FMVSS 215 has been the lack of data describing the characteristics of low-speed crashes in the real world. The desired data would identify the frequency of occurrence and the extent of damage (including repair costs) for each vehicle model as a function of: vehicle age; location, angle, and speed of impact; type of object impacted; and setting. The setting might include such designators as: urban, suburban, or rural; business, residential, or open area; freeway, highway, street or off-street parking area; heavy, moderate, or light traffic conditions; and weather effects.

In this study, methodologies were evaluated to determine the feasibility of an evaluation plan whose primary objective is estimating direct benefits, expressed in terms of total differential repair costs attributable to FMVSS 215 that are incurred in bumper-involved accidents at all speeds. A secondary objective, based on the stated intent of the standard, is to estimate that portion of the total differential associated with a reduced probability of override and underride in post-standard

[1] S. Richardson et al., "Damage Resistant Bumpers," Transportation Systems Center, Research Paper RP-SP-30 (July 19, 1974).

vehicles. This last issue has <u>not</u> been considered separately because this intent cannot be practically separated from the basic damage problem considered in this study.

The following three sets of parameters are required to evaluate the direct effects of FMVSS 215 in real-world accidents:

- R_i: The actual, average dollar repair costs for given accident-involved vehicle types and crash conditions. The subscript i denotes categories of independent variables. Thus, for example, the i^{th} category may be all direct front-vehicle-to-fixed-object collisions at speeds less than 5 mph for a specific vehicle type.

- ΔR_i: The difference in average repair costs attributable to FMVSS 215. That is, ΔR_i is the difference between actual repair costs in post-standard vehicles and the costs that would have been incurred without the implementation of the standard. This difference may be positive, negative, or zero.

- t_i: The real-world accidents of type i that occur during any given year or period in which the standard is to be evaluated.

Assuming these estimates can be derived, total direct benefits would be expressed as

$$\sum_i AR_i \ t_i$$

A second major problem in an attempt to evaluate FMVSS 215 is that no single type of existing data sources (e.g., insurance, police, or special study motor vehicle accident files) contains information on all accidents that may involve bumpers. Figure 6-1 presents a hypothetical distribution of bumper area involved accidents of this problem, using insurance data as the reporting criteria. This sample distribution illustrates five components, which taken together, sum all bumper area involved accidents as a function of dollar loss:

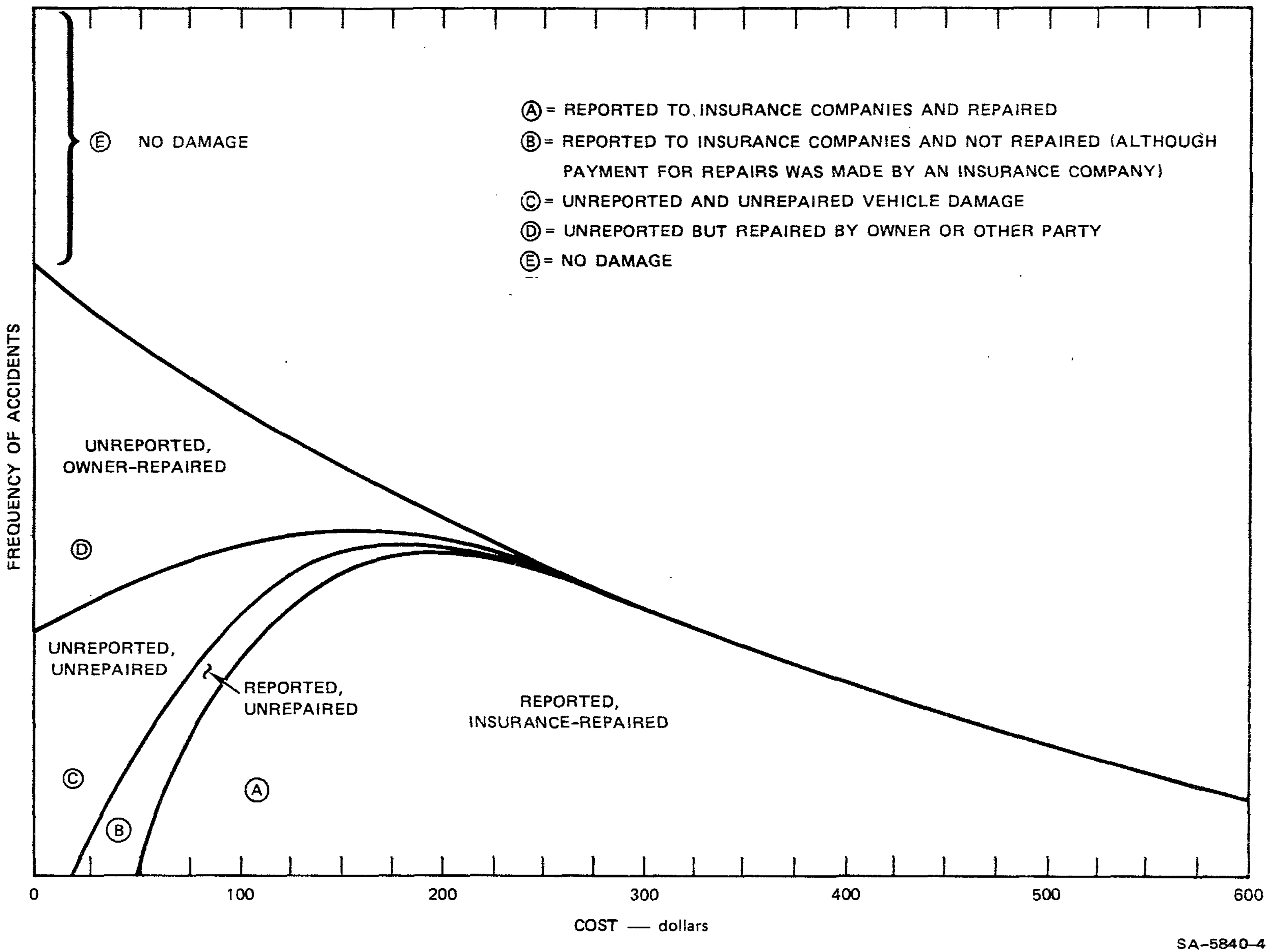


FIGURE 6-1 SAMPLE DISTRIBUTION OF ALL BUMPER AREA INVOLVED ACCIDENTS

Ⓐ Reported to insurance companies and repaired.

Ⓑ Reported to insurance companies and not repaired, although payment for repairs was made by an insurance company.

Ⓒ Unreported and unrepaired vehicle damage.

Ⓓ Unreported but repaired by owner or other party.

Ⓔ No damage.

Only Areas A and B will be represented in insurance data files. Another complication is that the unit cost of repair for a fixed type of damage may be slightly lower for noninsured repair by garages or much lower for repairs by the owner or other party (Area D). Unrepaired damage poses a similar problem in that the value of such damage probably depends heavily on the attitude or economic condition of the person suffering the loss (Area C). Thus, the frequency of damage versus cost for Areas C and D depends heavily on who estimates the value of the damage. Even more difficult would be estimating the value of Area E (no damage) incidents, which would require an almost completely subjective analysis.

The major task for any evaluation plan is, therefore, to obtain the best estimates possible for the size of all of the areas indicated above (A-D) and to compare such data for pre- and post-standard models.

An additional consideration involves vehicle speed at impact. Although it is very desirable to identify vehicle speed and to categorize incident frequency as a function of speed, this is now virtually impossible. For reasonable confidence intervals, only sophisticated crash recorders or extensively applied photographic techniques appear capable of obtaining sufficient speed information for the wide range of possible low-speed accidents. Such costly techniques should only be used for much broader problem areas than the evaluation of bumper standards. Furthermore, existing estimates of vehicle accident speeds contained in police and other data files are not sufficiently accurate for use at low speeds.

Because accurate impact speed information is now unavailable and will probably be prohibitively expensive to obtain in the near future, frequency of incidence will be primarily expressed as a function of the dollar value of impact damage, subject to considerations given above.

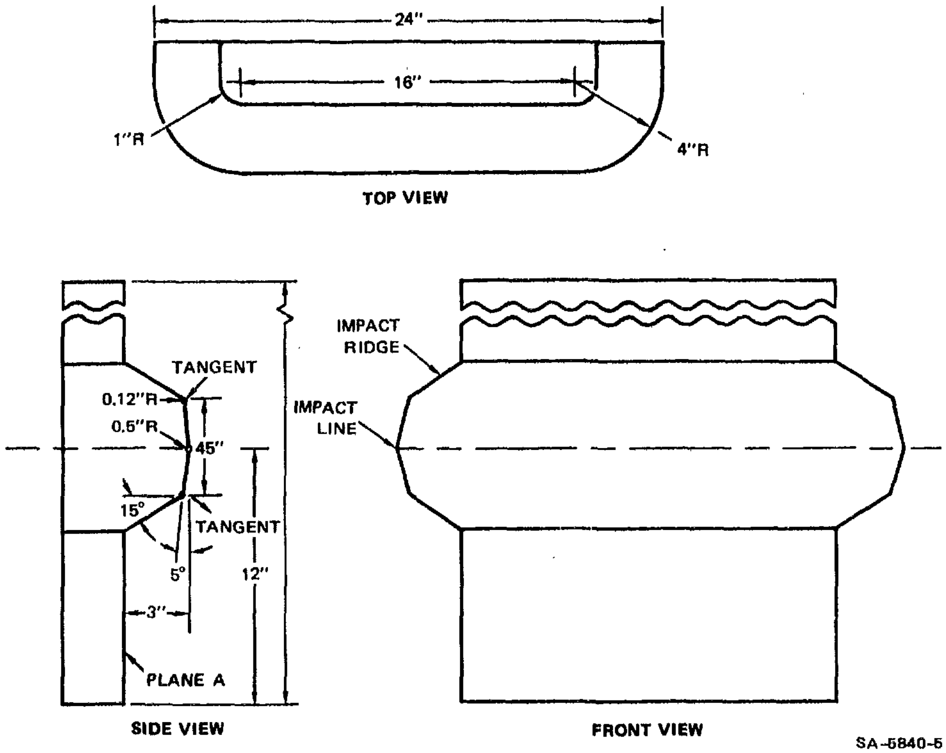
6.2 DESCRIPTION OF THE CURRENT STANDARD

6.2.1 Part 571--Exterior Protection

FMVSS 215 establishes requirements for the impact resistance of passenger car front and rear surfaces, thereby affecting to some extent the configuration of those surfaces. Vehicles manufactured on or after September 1, 1972 (the 1973 model) must resist specified types of damage in longitudinal crashes into a fixed barrier at 5 mph in a forward direction and at 2.5 mph in a rearward direction. Those vehicles manufactured on or after September 1, 1973 (1974 and later model passenger cars) must resist specified types of damage impacts by a pendulum test device applied longitudinally to front and rear at 5 mph and 30° from the longitudinal to front and rear corners at 3 mph, at heights between 16 to 20 in. The pendulum test device (see Figure 6.2) presents a nearly open V contact face with its point toward the vehicle. It is 4.5 in. thick and tapers for 3 in. to a thickness of about 6 in., with a lower vertical surface (Plane A) 3 in. behind the striking face point. The V contact face and the tapered surfaces up to the vertical surfaces define an "impact ridge." An upper vertical surface (Plane B in Figure 6.3) begins 6 in. above the V of the striking face and is directly above the point of the V. This latter surface (Plane B) is only present for impacts at the 20-in. height. For impacts between 20 and 16 in., the only upper vertical surface (see Figure 6.2) is recessed 3 in. from the point of the striking face (similar to the lower face--Plane A). Vehicles are not allowed to touch any part of the pendulum device, except the impact ridge.

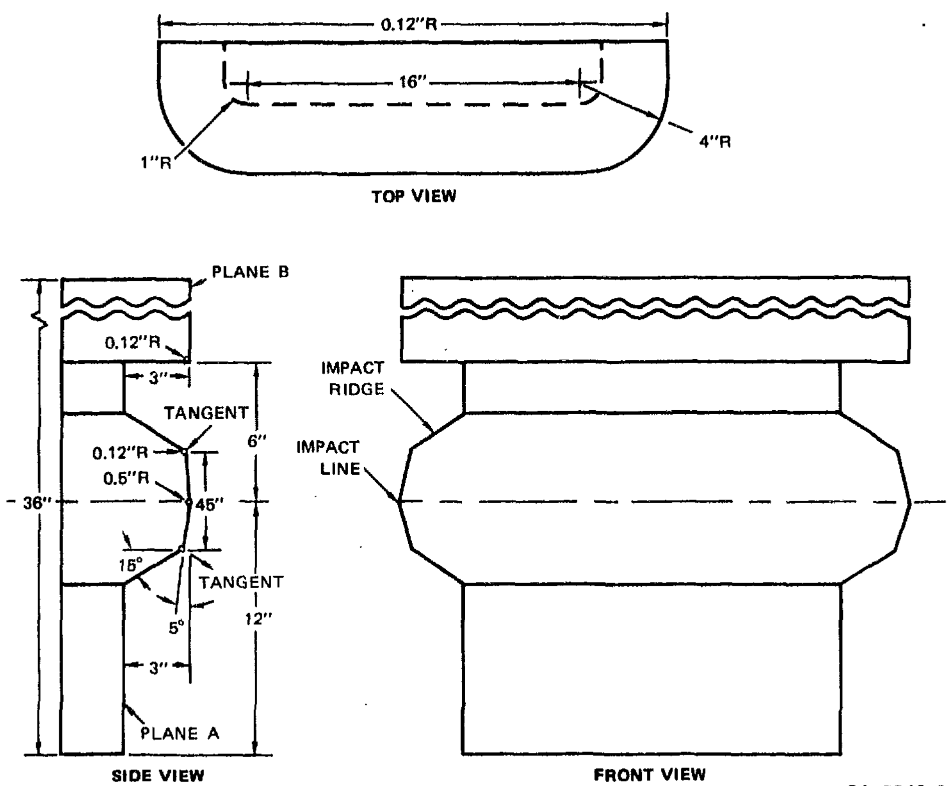
Two pendulum impacts are applied to both front and rear surfaces at any height, provided that the two impacts to either face are separated either by at least 2 in. vertically or more than 12 in. horizontally. One front and rear corner are impacted at 20 in., and the other front and rear corners are impacted at any height between 16 and 20 in. with the pendulum configuration restrictions indicated above.

Vehicles with wheelbases of more than 120 in. were exempted until September 1, 1976 from the corner pendulum test between 16 and 20 in.,



SA-5840-5

FIGURE 6-2 PENDULUM TEST DEVICE (BETWEEN 16-in. and 20-in. IMPACT HEIGHT)



SA-5840-6

FIGURE 6-3 PENDULUM TEST DEVICE (20 in. IMPACT HEIGHT) but they had to meet the 20-in. corner test. Vehicles manufactured between September 1, 1973 and October 31, 1974 with (1) 115-in. wheelbases or less, (2) those convertibles that have no "B" pillar (hardtops) above the lower edge of the window opening, or (3) those that have no seating behind the front seats are exempted from the pendulum test requirements but not the barrier test requirements.

The protective criteria include: Each lamp of reflective device must be free of cracks and must meet visibility requirements of S4.3.1.1 of FMVSS 108; headlamps must be adjustable as specified by Society of Automotive Engineers (SAE) practices and standards; after testing, the vehicle's hood, trunk, and doors must operate normally; fuel and cooling systems must have no leaks or constricted fluid passages, and all sealing devices must operate normally; the exhaust system must not leak or be constricted; the vehicle's propulsion, suspension, steering, and braking systems must remain in adjustment and operate normally; the vehicle may only touch the impact ridge described earlier; and no fragments may be separated from a pressure vessel as a result of impact.

6.2.2 Part 581--Bumper Standard

Title I, Motor Vehicle Information and Cost Savings Act (Public Law 92-513) established the requirement for a "no damage" bumper standard. In response to this requirement, on March 4, 1976 NHTSA issued a new standard, Part 581--Bumper Standard, to limit damage to vehicle bumpers and other vehicle surfaces in low-speed crashes. The new standard will replace FMVSS 215 for vehicles manufactured on or after September 1, 1978. The new regulation incorporates the safety requirements currently contained in FMVSS 215 and also specifies limitations on damage to nonsafety-related components and vehicle surface areas. The requirements for impact resistance are intended to reduce physical damage to the front and rear ends of passenger motor vehicles from low-speed collisions "to obtain the maximum feasible reduction of costs to the public and to the consumer . . ."

For vehicles manufactured after September 1, 1978 (to August 1, 1979), no surface covering materials may be separated and no permanent deviations in original contour may be caused by the barrier and pendulum tests (as in FMVSS 215); damage to the bumper face bar, and the components and associated fasteners that directly attach the bumper face bar to the chassis frame is excepted. No breakage or release of fasteners or joints, except as described above, will be allowed.

Vehicles manufactured after September 1, 1979* must meet the previously described requirements with damage limited to the bumper face bar. The allowed face bar damage is a maximum of 0.75-in. permanent deviation from its original contour and position, relative to the vehicle frame ("set"), and a maximum permanent deviation ("dent") of 0.375 in. from its original contour on the areas of contact with the barrier face or pendulum impact ridge.

A key feature of the new standard (Part 581) is the allowance of contact between vehicle and the surfaces A and B of the pendulum device, providing that such contact does not exceed 2000 lb on the combined surfaces. This feature allows the use of "soft-face" bumper systems, which potentially offer savings to the consumer because of reduced weight and increased resistance to damage. The potential value of this type of bumper system is indicated by the automatic exemption of manufacturers† from compliance with FMVSS 215 (specifically the "no contact with other than the pendulum impact ridge" requirement) if their vehicles comply with Part 581--Bumper Standard requirements before September 1, 1978.

Given this situation, care must be taken during evaluation studies of FMVSS 215 effectiveness to ensure that vehicles exempted from the 215 requirements are properly handled. In addition, we note that Part 581--Bumper Standard contains all of the FMVSS 215 requirements, except for the pendulum device vertical faces A and B contact restriction.

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*A current NHTSA proposal may extend this date to September 2, 1980.

†This proposed exemption is not yet in effect, but passage is expected.

6.3 DISCUSSION OF TECHNICAL FACTORS

6.3.1 Comparison of Standard Requirements and Real-World Considerations

In each of the compliance tests for FMVSS 215 the energy management in the bumper system must be sufficient to prevent damage to safety-related equipment. This energy requirement is proportional to vehicle weight in all tests. In the barrier test, the energy is equal to the vehicle's kinetic energy at 5 mph. In the pendulum test, the energy requirement is equal to half the kinetic energy that the vehicle would have if it were moving at 5 mph (longitudinal impacts) or 3 mph (corner impacts). It is not necessary that all the energy be dissipated. A portion may be stored elastically and reconverted to kinetic energy, resulting in a degree of rebound.

Standard 215, as currently effective, says nothing about damage to the bumper system or vehicle sheet metal, as long as the safety-related components are protected. It is clear, therefore, that compliance does not guarantee that a vehicle will not be damaged in low-speed collisions.

Vehicle manufacturers have responded to Standard 215 with bumper designs in steel, aluminum, rubber, and plastic, and with energy absorbers using hydraulic cylinders and elastomeric materials. Not surprinsingly, these designs differ in manufacturing cost, weight, and damage resistance, although they are all designed to be effective in preventing damage to the safety-related components.

The effectiveness of the standard will be judged by the reduction in repair costs for low-speed collisions. Therefore, even though it is not treated in the standard, the damage resistance of the bumper system itself becomes important. Assuming that all bumpers protect the safety-related components, an inexpensive bumper that needs replacement after a low-speed collision may be judged more effective than a more expensive one that also has to be replaced. A no-damage bumper would be judged most effective, unless it was so expensive that its cost negated the benefit.

Bumper mismatch in parking and other low-speed situations has undoubtedly been improved by the introduction of Standard 215. Before the standard was issued no standard existed for bumper height. Imported vehicles tended to have lower bumpers than domestic models, and all models had a wide variety of bumper heights and shapes. Also, before the standard many bumpers had curved or inclined surfaces that encouraged override or underride, even if the bumper heights matched on initial contact. Flat vertical bumper surfaces are now common on newer cars. Even though the standard effectively controls static bumper height, the height of both front and rear bumpers can vary considerably under conditions of hard braking or carried load. Thus, underride and override can still occur, although with less frequency than before, especially at lower impact speeds.

A frequent criticism of FMVSS 215 is that the barrier and pendulum laboratory tests do not necessarily represent vehicle damage mechanisms most frequently occurring in real-world accidents. However, the almost infinite variety of potential bumper-involved accident configurations and conditions (as described in Section 6.1 and elsewhere in this section) indicate that it would be almost impossible to select "typical" damage mechanisms as a basis for compliance tests.

We suggest that it may be more useful to examine actual accidents and to estimate the frequency of bumper involvement in direct front and rear impacts, as well as in impacts to the four corners of the vehicle. We anticipate that most direct front and rear impacts will involve the bumper for post-standard vehicles (except for impacts with such items as suspended objects or trucks), with a somewhat lesser bumper involvement rate for the corner impacts (sideswipes and other). Moreover, the evaluation plan suggested in Section 6.5 contains provisions for estimating these involvement rates by using accident experience survey data.

The compliance test does not specify collisions between actual vehicles because of cost, repeatability, and representativeness considerations. Although the barrier test is not particularly representative of real collisions, it does establish certain strength and energy requirements for the bumper system. The pendulum tests more closely resemble real collisions because the pendulum impact ridge is not unlike a section of vehicle bumper (although the pendulum ramp angles were inclined to force bumper designs that would not override). An argument could be made for a standardized pendulum weight because lighter vehicles have a certain probability of being struck by heavier cars. However, to do this requires consideration of bumper system force characteristics and compatibility, an area beyond the scope of this effort.

It is reasonable to assume that the pendulum impact procedure of the compliance test adequately simulates low-speed (5 mph) collisions and that the small number of pendulum impacts (two perpendicular and two corner for each front and rear bumper) in the compliance test correspond to the expected number of low-speed collisions during the lifetime of an average vehicle. However, there is still concern that the compliance test does not ensure that a vehicle bumper will withstand a large number of lower speed impacts (2-3 mph) that it might encounter in congested urban parking situations. Thus, a bumper system may fail after many "parking bumps," even though each bumper successfully withstood the four pendulum impacts and the barrier test specified in the compliance test.

6.3.2 Bumper System Factors

This section presents some basic characteristics of bumper systems, including component itemization, design parameters, weight, and costs. Typical front and rear bumper system components include bumper guards; a face bar; a face bar impact strip; face bar reinforcements; energy absorbers or a spring assembly; a filler panel or bumper valance; and various brackets, braces, insulators, sight shields, spacers and fasteners. One of the advantages of a soft-face bumper system is the ease of replacing many of the listed components--as well as others such as grill assembly and panels, fender extensions, headlight housings, air shields and support pieces--by a relatively simple fascia skin supported by an energy management system and a steel backing beam.

The following list identifies many of the characteristics that are considered during the design and selection of bumper systems;

- Capacity--the total energy the bumper can absorb. The standard specifies that 30,000 lb-in. of impact energy must be dissipated for a typical 3000-lb car. Of this impact energy, 15 to 30% is stored in recoverable deformation in the vehicle structure and systems; the remainder must be dissipated through energy-absorbing mountings.
- Uniformity--the measure of uniformity of the deceleration cycle; the ratio of maximum force to average force in the absorber during its working cycle.
- Operating level--the nominal pressure or stress at which the device functions (an indication of energy-absorbing capacity).
- Reversibility--the device's ability to absorb more than one impact.
- Cost.
- Override-underride propensity--the result of complex interactions involving bumper and vehicle variables (impact velocity, braking, suspension, and the like) and the properties of struck vehicles.
- Pedestrian protection--the height of bumper as it affects pedestrian collision, point of impact, trajectory, and kinematics.
- Aggressivity height.
- Mechanical structure, vehicle mass, and kinetic energy load-deflection characteristics.
- Speed velocity and rebound.
- Aging.
- Temperature effects.
- Moisture effects (water, snow, and ice).
- Reliability.
- Maintenance.

Much of the weight and cost data presented below have been obtained NHTSA.[2] The data here are based on 1974 data for 5 mph front and 5 mph rear impacts of steel bumper systems. Weighted average values are based

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[2] R. H. Compton, "Alternative Bumper Systems for Passenger Cars," NHTSA, Document HS-801-326 (1974).

on a distribution by market class of 25% for subcompacts (less than 2800 lb), 23% for compacts (less than 3400 lb) 23% for intermediates (less than 3800 lb), and 29% for standard and heavy vehicles (more than 3800 lb).

Average steel bumper system weights are: front, 101.5 lb; rear, 102.4 lb; for a combined weight of 203.9 lb. In contrast, an average "soft face" system weight of 124.3 lb (Note that manufacturer comments submitted to NHTSA indicated that these weights, including necessary support components, may be somewhat higher than indicated.[3]) compares to a total steel system average weight of 226.5 lb. The soft face system would also replace 22.6 lb of nonbumper steel parts. The estimated cost of the steel system at 226.5 lb is $245, approximately $1.07/lb, including piece costs, assembly, and mark-ups.

This figure is the same as the average amount nine U.S. and foreign manufacturers reported in response to a NHTSA questionnaire on prices charged to new vehicle consumers for 1973, 1974, and 1975 model bumper improvements.

Based on these data, the average total bumper system cost in 1974 dollars is approximately $220. Using TSC[1] estimates of 1974 incremental bumper system cost of $140 more than 1971 costs, we estimate a 1971 bumper system cost of $80 per vehicle. Estimated incremental costs for steel bumper systems from the TSC report are: 1973, $65; 1974, $140; 1975, $155; and 1976, $190. Any evaluation plan will include an up-to-date determination of the incremental costs of new bumper systems for each post-standard model year.

6.3.3 Consumer Impacts of Post-Standard Bumper Systems

A number of distinct advantages should accrue to the consumer as a result of improved bumper systems. They include:

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[3] "Comments of GMC with Respect to Notice of Proposed Rule Making Bumper Standard," General Motors Corporation, Report USG 1223 (March 3, 1975).

- Improved energy management
- Uniform heights
- Recessed fragile components
- Less aggressive face bars

All these factors reduce or eliminate damage in low-speed impacts.

- Less inconvenience when no damage impacts occur.
- Appearance improvements reduction in unrepaired minor damage.
- Insurance cost reductions. (These will continue only if benefits exceed costs.)
- Indirect benefits from incident reduction (e.g., reduction in traffic conjestion, court costs, and lost wages).

Even greater advantages may be possible with "soft face" bumper systems, which can replace other body components such as grill assembly and panels, fender extensions, headlight housings, air shields, and support pieces made of flexible materials. These advantages add to the other potential appearance and maintenance enhancements because no stone "chipping" or minor "dents" will occur.

The disadvantages of present post-standard bumper systems when compared with pre-standard systems include:

- Greater initial cost.
- Greater replacement cost when damaged.
- Increased fuel consumption, due to increased weight.
- Increased tire sizing and wear, due to increased weight.

6.4 REVIEW AND ASSESSMENT OF ALTERNATIVE EVALUATION METHODOLOGIES

6.4.1 Overview

A complete effectiveness assessment of FMVSS 215 would require determination of all costs and benefits associated with implementation of the standard. That is:

- Cost Components--These components include unit costs to the manufacturer and consumer, operating costs over the life of the car, and average finance costs.
- Benefit Components--These components include collision claim reduction, property damage claim reduction, reduced administrative costs to insurance companies, insurance premium

reductions, elimination and cost reduction of accidents not reported to insurance companies (both repaired and unrepaired), reduction of accident costs at speeds slightly above that specified, and increased replacement costs in high speed accidents (a negative benefit).

Both categories are heavily influenced by the type of system employed by a manufacturer; thus, different systems would most likely have different cost-benefit values. However, this study considers only the primary cost elements, which comprise incremental unit production costs to the consumer. Primary benefit elements will comprise reduction in collision and property damage insurance claims, owner-repaired damage, and unrepaired damage. This section examines the utility of alternative procedures for generating direct cost-benefit data suitable for evaluating the effectiveness of FMVSS 215. The accuracy of data collection procedures can be evaluated only in terms of the intended use of data items, and we assume that the direct cost-benefit data developed will be combined with indirect data by NHTSA or others to serve as the basis for a total cost-benefit analysis.

Future studies designed to evaluate the effectiveness of FMVSS 215 or to calculate selected direct costs and benefits must focus on estimating the variability of repair costs and damage attributable to pre- and post-standard bumper design. This is expressed as a function of crash environment variables--in particular vehicle types, and the speed and angle at impact. The following methodologies and data collection procedures were examined in terms of this objective:

- Acceptance of prior research.
- Statistical analysis of accident data bases (insurance and other, both existing and future).
- Controlled tests.
- Simulations and analytic models.
- Analysis of vehicle component replacement notes.
- Surveys and questionnaires.

Various test and data collection procedures investigated to assess their potential contributions to an overall evaluation plan. The methodologies were thoroughly reviewed, and the results are summarized in the following subsections, along with indication of the strengths and limitations of each methodology.

6.4.2 Acceptance of Prior Research

Based on a review of the current literature and a consideration of general analytic methodologies, we find that the TSC report cited in Section 6.1[1] contains the best available cost-benefit model and analysis. We assume that the contents of this report are known. However, the summary below provides a basis for discussion of procedures for collecting new data that are more refined than the TSC data inputs.

The primary benefit data categories include:

- Insurance collision claim reduction.
- Property damage claim reduction.
- Administrative costs.
- Premium reductions.
- Cost reduction of unreported accidents, repaired and unrepaired.
- Reduction of accident costs for speeds above those tested.
- Increased costs of bumper replacement and related damage (a negative benefit).

The cost categories include:

- Unit production costs.
- Operating costs.
- Financing and taxes.

The TSC report concludes that the cost-effectiveness ratio for 1976 vehicles is not significantly different from unity.

6.4.3 Key Variables and Measures of Effectiveness

In the SRI review of the TSC report, it was determined that the documented methodology is appropriate for estimating the effectiveness of FMVSS 215 in reducing vehicular damage in low-speed collisions and for estimating total cost effectiveness. Specific data inputs must, of course, be updated on a continuing basis (i.e., yearly) to accommodate changes in labor cost, production costs, vehicular designs, and the like. In addition, as in any complex study of this sort, it is possible to describe data collection procedures that will produce more accurate data inputs. However, before expensive data collection efforts, designed to improve the accuracy of these cost or benefit data, are undertaken, the decision criterion must be well-defined. In this case, because fatalities and injuries do not play a major role in standard evaluation, the net-benefit measure will serve as a criterion.

The cost-benefit ratio approach provides for rank-ordering alternative bumper and vehicular designs when benefits and costs are not expressed in the same units. This may occur, for example, if secondary benefits such as occupant safety, fuel use, and others are included in the evaluation.

However, the ratio approach has two distinct disadvantages. First, arbitrary accounting decisions may affect the comparison. Quantifiable data inputs may be treated either as positive costs (denominator) or as negative benefits (numerator). Plausible alternative procedures may also change the overall cost-benefit ratio and the rank-ordering of various bumper and vehicular designs. Second, the risk factor is not taken into account. Thus, a major increase in unit production costs that does not substantially increase the cost-benefit ratio may be unacceptable to the decision maker.

For these reasons, we have selected the net benefit measure as a basis for assessing the importance of various input parameters. In particular, we agree with the TSC statement that net benefit is highly sensitive to variations in the discount rate and inflation (labor and production costs) rate, a fact verifiable by simple substitution and arithmetic. However, this variation may be compensated for by annual reassessment of cost data and projection of short-term changes, in accordance with the procedures used in the TSC report.

Although we also agree with the TSC report that net benefits are not highly sensitive to 10% variations in items such as the volume of owner-repaired damage, we reject the possible inference that plausible variations in damage reduction will not strongly affect net benefit calculations.

The primary benefits of FMVSS 215 result from the reduction or elimination of damage in low-speed crashes and many of these are unreported, and hence difficult to estimate. Furthermore, the benefits (positive or negative) associated with damage incurred in higher speed accidents must be estimated from imprecise information concerning the crash environment. From this, we conclude that the estimates of damage reduction at all speeds must be interpreted within the context of broad confidence intervals and that these estimates may become focal points for possible further refinement.

To summarize, we find that:

(1) The TSC report contains an appropriate cost-benefit model suitable for evaluating FMVSS 215.

(2) The effectiveness and cost-benefit analyses of 1973 and 1974 vehicles appears adequate. Updating inputs--primarily to reflect inflation and vehicular design changes--is required for any analysis of 1975, 1976, and later vehicles.

(3) If greater accuracy in data inputs is required, the data collection effort should be directed toward:

- Unit production costs.
- The reduction (or increase) in damage and cost attributable to bumper design, expressed as a function of the crash environment.

6.4.4 Statistical Analysis of Accident Data Bases

Two statistical procedures--both necessarily confined to reported accidents--were considered. The first is a comparison of vehicle and bumper designs in the analysis of variance format, and the second is time-series analysis. The first approach directly compares VDI and CPIR estimates for vehicles in compliance with FMVSS 215 with pre-standard vehicles; relevant independent variables (crash environment, vehicle type, and weight) designed to eliminate confounding effects are also measured.

The direct comparison is conceptually appealing, but it has limited utility for several reasons:

- The VDI and CPIR estimates are associated primarily with higher-speed, injury-producing accidents. As a result, they inadequately represent the low-speed collisions that are of particular interest in evaluating FMVSS 215. They omit no-damage and unreported accidents.
- These estimates, at best, only weakly link repair cost and damage to bumper design.
- Validity is problematic. As stated previously, statistical analysis estimates of the damage cost difference between a post-standard vehicle and its pre-standard counterpart provide only weak assurance that crash conditions were similar. The real question is, of course, what would the repair cost differential be between a post-standard vehicle and the same, hypothetical vehicle designed without the FMVSS 215 requirement? This latter comparison would require a non-statistical, qualitative assessment, and such an assessment, performed retrospectively, would lack credibility.

A time-series analysis of a large, nationally representative data base would be useful if it could be shown that low-damage bumper-involved accidents decline significantly across the calendar years that precede and follow the implementation of the standard. However, to the best of our knowledge, no data exist to support such analyses. Also, the time-series analysis described below in the discussion of insurance claim analysis is inherently limited.

6.4.3.1 Insurance Claim Analysis

A time-series analysis of standardized insurance claim frequencies and cost provides a possible means of establishing baseline estimates of standard effectiveness. However, the procedure would require that other data sources be used to confirm, adjust, and augment the claim analysis. The basic limitations of this approach are:

- Although representative claim data exist in the HLDI files beginning in mid-1972, adequate claim data are not available for the years before 1972. Thus, analysis of pre-standard collision claims would be severely limited. (Data are available only for 1972.)

- No adequate description of the crash environment can be retrieved from the insurance data base. Therefore, cost itself becomes, in effect, a surrogate measure of the accident impact speed, and a validation of this measure from external data sources is mandatory.
- Any sample of insurance claims will not be representative of the entire accident population. Unreported accidents are obviously not included, and, as is well-known, low-cost claims are less frequent because of the deductible amount.
- The trends and patterns revealed by time-series analysis cannot be unambiguously associated with specific factors, such as bumper design, by mathematical analysis. Bumper design can be related to an observed trend only by careful consideration of all major factors affecting claim frequency and cost, and the conclusion must necessarily be an inference.

Several existing computer software packages can be used to implement a time-series analysis. Specifically, it would be possible to access the approximate 200,000,000 claims in the HLDI file, restricting attention to claims that do not exceed $300. Most of the low-speed bumper involved accidents are contained in this subset. A time series, adjusted for seasonal variation, would then reveal apparent trends in standardized claim frequency. A market decline in overall claim frequency could be attributed to FMVSS 215; however, any such conclusion would be based solely on inference unless supported by directional analysis.

The uncertainty and related controversy associated with this type of inference can best be illustrated by reviewing conflicting results in the literature. In a 1973 report,[4] for example, time-related accident statistics were evaluated, and significant reductions in injuries and fatalities were noted for several standards, including 104, 108, 201, and others. In a more recent time-series analysis by Peltzman,[5] the author confidently concluded that safety regulations have had no effect on the

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[4] "Evaluation of Motor Vehicle Safety Standards," Center for Environment and Man, Incorporated (December 1973).

[5] S. Peltzman, "The Effects of Automobile Safety Regulation," J. Pol. Econ. (August 1975).

highway death rate. In our opinion, both report conclusions are heavily weighted by the judgments of the authors, and neither leads to definitive conclusions. But perhaps the best interpretation of time-series analysis is contained in the TSC report.[1] This report notes that a claim reduction from 1972 to 1973 did, in fact, occur, and the authors state

> "while there do not appear to be any major fleetwide vehicle changes other than bumpers which might have effected such change, it should be stated that likewise there is no firm analytic basis on [sic] which to attribute all claim reduction to bumpers."

Time-series analysis is a conventional mathematical procedure, which can be implemented by existing computer programs such as the Bureau of Census X-11 software package and the Box-Jenkins technique. The "time series" is the basic observed relationship between claim frequency (or cost and other claim-related variables) and time. The analytic objective is to decompose this empirical series into functional components that represent seasonal variations and specified variation-causing factors such as FMVSSs, speed restrictions, and the like. The result, after such decomposition, is an underlying trend, with residual random variation.

The TSC report[1] contains an elementary, but convincing time-series analysis, with the conclusion that the 1973 cost reduction, as compared with 1972, was due primarily to FMVSS 215. For evaluation over a longer period, a more sophisticated application of the same basic methodology should produce better results. For example, the time series should include the effects of seasonal variation and the change in speed limits imposed by the energy crisis. The data sample should also be stratified, or disaggregated, to permit separate analyses of claim cost categories (e.g., only claims of less than $300), vehicle types, and other factors. An analysis of this type is definitely feasible because appropriate data can be retrieved from insurance claim files and adequate software analysis programs exist. The limitations cited can be minimized, although not entirely eliminated, by additional data collected according to the procedures described in the following paragraphs.

6.4.3.2 Other Accident Data

We examined the applicability of accident data currently maintained at NHTSA. However, the MDAI-CPIR file has no data variables explicitly related to bumper damage, and to the best of our knowledge no supplementary data forms include this type of information.

A preliminary report of The CALSPAN Corporation[6] did show evidence of a related bumper data file, which presumably is not yet on the HSRI access systems; perhaps this file should be examined through NHTSA. However, the type of test employed (only the front bumper of the striking vehicle, with injury the measure of effectiveness) has only limited utility in evaluating total bumper effectiveness.

Future accident data collection efforts designed to evaluated FMVSS 215 must necessarily concentrate on measurements of repair cost and damage states, expressed as a function of vehicle type, bumper design, and crash environment variables including speed and direction at impact. The limitations of existing data bases make it evident that continuing collection by units such as MDAI teams will be of little value in evaluating FMVSS 215 because of practical difficulties regarding reports of low-damage accidents.

A new program initiated in the NHTSA Office of Vehicle Safety Research could lead to the procurement and subsequent installation of 100,000 low-cost, two-dimensional crash recorders. If this program is implemented, post-crash analysis of recorder data would yield the velocity change due to impact, and damage repair costs could be estimated on site, or in follow-up investigations. This procedure could enhance estimates of crash conditions (i.e., especially higher speeds), but the value of recorders would be limited by unreported low-damage and no-damage accidents.

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[6] "The Effect of Side Door Reinforcement Beams and 5 MPH Energy Absorbing Bumpers on Injury Severity," CALSPAN Corporation, Preliminary Report (May 1976).

As an estimate of the extent of this low-damage limitation, the National Safety Council Accident Facts show that one in four cars was involved in one repaired accident per year during 1972 to 1973. TSC[1] estimated that half of these, or one vehicle out of eight, sustained owner-repaired damage of less than $150 and that 68% of these accidents were front or rear. Although there is no firm basis for estimating the percentage of such owner-repaired damage accidents that are not reported to the police, SRI believes it could easily exceed 25%. Therefore, any of the proposed accident investigation programs that sample the reported accident population will fail to account for many accidents in which benefits from FMVSS 215 are likely to accrue.

6.4.5 Controlled Tests

Included in our examination were barrier and pendulum compliance tests, vehicle-to-vehicle staged crashes, and to a lesser extent scale modeling as a subset of staged crashes.

The barrier test establishes certain strength and energy requirements for a bumper system, but it is not necessarily representative of real-world collisions and has been augmented with a pendulum impact test procedure. The pendulum tests more closely resemble real bumper-to-bumper collisions because the pendulum impact ridge is similar to a vehicle bumper (although the pendulum's ramped races are intended to force the design of wider bumper faces). It is questionable whether or not the test adequately ensures that bumpers will withstand the larger numbers of lower speed impacts (than the two perpendicular, two corner, and one barrier compliance tests) they are likely to encounter in congested urban parking situations.

Test schemes considered with the pendulum impact procedure involved compliance testing of a sample of pre-standard cars and comparing the damage and cost of repair with a similar sample of post-standard cars. The principal difficulty with this scheme is lack of identical automobiles and the variety of designs built before and after implementation of the standard. Thus, only an approximation of ΔR (The cost difference between pre- and post-standard comparable models as described in Section 6.1) could be obtained, and the limitations previously mentioned would still exist.

Another compliance test scheme would involve two identical samples of new cars. The non-standard or absence-of-standard situation in one sample would have to be approximated by removing energy absorbers and reinforcement components from the bumper system. In general, because this modification would only approximate what a manufacturer would build in the absence of the standard, the results would be somewhat questionable. The results would also be model-dependent for the reasons mentioned above.

We could argue for vehicle-to-vehicle staged crashes to assure most likely real-world conditions and to determine repair costs directly as a function of impact conditions. It is difficult, however, to visualize results that would significantly improve those already obtained by IIHS (as recorded in the TSC Study).[1] That is, approximations of ΔR already exist.

We considered the possibility of postulating modified bumper design studies that would identify the most likely design changes or modifications to post-standard vehicles assuming FMVSS 215 did <u>not</u> exist. These studies would require carefully selected vehicle design engineers as representatives of the manufacturers to form part of a DOT/Automotive Industry Task Force specifically chartered to review pre- and post-standard vehicle bumper designs, evolving bumper technology, and procedures normally used in designing bumpers. And, most important, the task force would select the most likely bumper designs without FMVSS 215.

Once representative designs were selected, modified 1977 cars could then be manufactured and used in a comparison of staged crashes with cars equipped in compliance with the standard. Obvious difficulties with this approach include the objectivity of vehicle design engineers, sample size requirements, and limited credibility.

As part of staged crashes we also considered use of scale modeling to reduce the number of full-scale tests required. A set of scale models that contained all the features of production vehicles (engine, frame, sheet metal, and other structural elements) could be built and a parametric study conducted to determine relationships between impact conditions and damage. Nevertheless, overall uncertainties relating impact conditions to damage, and damage to repair costs eliminate scale modeling from serious consideration.

Controlled tests were also considered to assess the override and underride propensities of FMVSS 215 equipped cars. Here, high-speed photography could be used to measure bumper height variations as a function of various braking conditions. And, assuming agreements could be reached on the most likely bumper designs of post-standard cars, relative bumper match or mismatch estimates could be made. Whether or not the results could be extrapolated to real-world accidents or crash conditions because of variety of designs and similar factors is questionable. None of these controlled tests would yield complete answers.

6.4.6 Simulation and Analytic Models

We do not consider computer simulations and analytic models to be effective tools for evaluating standard effectiveness because of the variety of vehicle designs and bumper characteristics, and the uncertainty associated with extrapolating beyond the range of validated empirical data. Such simulations are useful as design tools, however, and would also be expected to be useful for studying bumper system compatibility if such criteria were added to the standard.

6.4.7 Analysis of Vehicle Component Replacement Rates

Among the potential benefits of FMVSS 215 is a possible reduction in the rate of replacement parts required because of collision damage. Possible components affected include headlamps, headlamp frames, parking and signal lamp lenses, grill parts, bumper face bar, fenders, hood, trunk lid, and radiator or supports. Several key problems, however, eliminate consideration of most of these components. They include:

- The possibility of many aftermarket sources.
- Difficulty in determining if replacement is the result of accidents. (Replacement may be due to malfunction or deterioration.)
- Changed model numbers during the production year (e.g., due to improvements).
- Repair of some parts rather than replacement, thereby greatly increasing data collection complexity.

In summary, only signal lamp lenses appear to avoid these problems for several years succeeding aftermarket introduction. However, even an accurate determination of reduction in replacement rates would only be indicative of some reduction in vehicle damage. It will be practically impossible, therefore, to use this information to reach conclusions about the number of undamaged vehicles or the total damage loss reduction resulting from implementation of the standard.

6.4.8 Surveys and Questionnaires

Certainly, the most difficult parameters to estimate are the frequencies of unreported low-speed bumper-involved accidents in which no damage or little damage occurs. Various survey and questionnaire data collection procedures were evaluated, and no combination of these can be recommended with great confidence as the basis for developing reliable estimates of such frequencies. A summary of methodologies is given in the following paragraphs.

Human observers and video coverage of selected congested urban areas have been moderately successful in analyzing pedestrian risk situations in cases when the risk conditions occurred frequently enough to generate sufficiently large samples over an extended period. However, low-speed accidents are distributed over all geographical areas because vehicle-to-vehicle and fixed-object collisions occur in rural areas and in stop-and-go freeway conditions as well as in congested city traffic. The infrequent occurrences of low-damage accidents (in contrast to frequent occurrences of pedestrian risk) and the difficulty in selecting representative crash condition environments precludes the use of this approach as an acceptable methodology.

The wide ranging distribution of questionnaires designed to gather information from the driver population on the frequency and type of low-speed accidents could, in theory, produce a large, nationally representative sample. But no incentive or follow-up survey exists that would ensure reasonable respondent objectivity. Responses would probably be biased toward underestimating accident frequency, and as a result summary statistics obtained from driver questionnaires would lack credibility.

Finally, we considered surveys of garages and body shops, and in-depth investigations of damage to vehicles observed at police check points or vehicle inspection facilities. An extensive survey of repair shops could provide a sample of repair costs by vehicle type, and investigations at check points could provide additional information concerning damage that goes unrepaired. However, neither procedure accurately identifies crash conditions.

Of the procedures considered above, a combination of independent damage observations and surveys of vehicle owners, with both conducted at vehicle inspection facilities, appears to offer a technique that could reasonably be performed but whose results might contain serious biases in terms of data accuracy.

6.4.9 Summary

Table 6-1 sets forth important characteristics for each of the potential evaluation methodologies examined.

6.5 EVALUATION STUDY DESIGN

6.5.1 Overview

An accurate evaluation of the performance of post-standard bumpers critically depends on the difficult task of estimating the cost reduction or elimination of damage in low-speed accidents, many of which are not

Table 6-1

ALTERNATIVE METHODOLOGIES FOR FMVSS 215

Method	Elements	Cost of Study	Suitability of Hypothesis	Inherent Bias	National Representativeness	Major Limitations
Acceptance of existing research	TSC report	None	Good if more empirical data were available	Unknown	Probably good for insurance-reported data	Many assumptions and estimates
Analysis of accidents data bases	Insurance files--HDLI, State Farm	Much data exists, moderate costs	Real-world data limited to reported accidents	Limited to reported accidents	Probably good for insurance-reported data	Only includes reported losses
	Other (MDAI, NCSS, NASS, police data)	Little useful data	Poor	Limited to reported accidents	NCSS, NASS, but others no	Only includes reported losses
Controlled tests	Staged crashes, laboratory tests	Very high because of many real-world combinations	Poor, unless many experiments run	Nonrepresentativeness	No	Too few combinations of incidents for practical evaluation
Simulations and analytic models	SMAC, crash	High	Poor, insufficient model accuracy	Unknown	No	Inadequate accuracy
Analysis of component replacements	Many vehicle components	Moderate	Very limited	Unknown	Yes	Many nonaccident factors for most components
Surveys and questionnaires	Drivers, garages	Moderate to high	Good, many possible	Unknown, reporting bias	Probably not, but attempt possible	Unknown reporting biases

reported either to insurance companies or to the police (see Figure 6-1). Great care must also be taken when examining such reductions (when found) to identify the portion of the reduction that is attributable to effects of the bumper standard.

We are not confident that any of the methodologies investigated will necessarily provide a sufficient basis for estimating the frequency and type of real-world bumper-involved accidents in which little or no damage occurs. None can resolve the question of the damage that would have been sustained in the absence of a bumper standard. An estimate of total benefits derived from FMVSS 215 that is based upon weak surrogate measures, and for which assumptions and inferences are relied on to link disparate data bases and to correct for suspected biases, will probably not be accepted by the community of interested or affected persons. In other words, we do not wish to repeat the deficiencies in the TSC analysis (No criticism of the authors is intended; they clearly documented all assumptions and limitations.) Refinement of the TSC analysis accomplished, for example, by conducting a more sophisticated time-series analysis of insurance claims and by crash testing additional pre- and post-standard vehicles, would be subject to the same criticisms and lack of credibility.

The only technique we determined to be potentially acceptable (at reasonable cost) for estimating the characteristics of all bumper-area involved impacts (Areas A through E of Figure 6-1) is a large survey--25,000--of vehicle owners or principal operators. The survey would be conducted at locations that minimize driver inconvenience and maximize the probability of unbiased responses. Motor vehicle inspection facility locations would satisfy both objectives; the survey could be conducted on vehicles while they wait in line for inspection. This approach would also take advantage of the pre-inspection environment, which is expected to be conducive to reasonably accurate responses to survey questions.

When the survey data for bumper-area involved impacts have been obtained and the results analyzed, we anticipate that careful comparison of the results with existing insurance and staged crash data (augmented by the technical judgment of qualified automotive engineers and damage evaluators) will produce reasonable estimates of bumper involvement percentages for varied angles of impact and damage cost categories for each model evaluated. If the survey results obtained from vehicle operators are consistent with insurance data in the areas of overlap between the two data bases (Areas A and B of Figure 6-1), a reasonable basis will have been established for placing confidence in the remaining areas of the figure (Areas C, D, and E).

If this evaluation basis is successfully established, the most serious objections to a TSC-type analysis (such as the controversial $250 and $600 bounds for different damage effects) will be eliminated. Total direct benefits for FMVSS 215 can then be determined, comparing pre- and post-standard model vehicles, by calculating insured loss differences for all cost categories. Estimates of unreported damage loss (both owner-repaired and unrepaired) obtained from the analysis of a broad-based survey of vehicle owners can then be proportionately added.

As stated elsewhere in this report, we are concerned about the difficulties in performing an accurate evaluation of the effectiveness of FMVSS 215 that will be accepted. We are also concerned that high costs could be incurred for an evaluation plan that appears to require a number of assumptions and weakly supported inferences. We make these comments to enable the reader to fully understand the weaknesses of the plan. If implemented, the plan carries with it the possibility of counterproductive results. Even a successful survey will not identify changes in the propensity-to-repair function for vehicle operators in different calendar years. Given an understanding of this situation, if a decision to pursue an evaluation of FMVSS 215 is made, we suggest that the following plan is the most likely to produce credible results, based on a detailed comparison of the strengths and weaknesses of the potential evaluation methods considered.

6.5.2 Plan Components

Figure 6-4 outlines the evaluation study design, which consists of two parallel research activities. Vehicle owner and operators will be

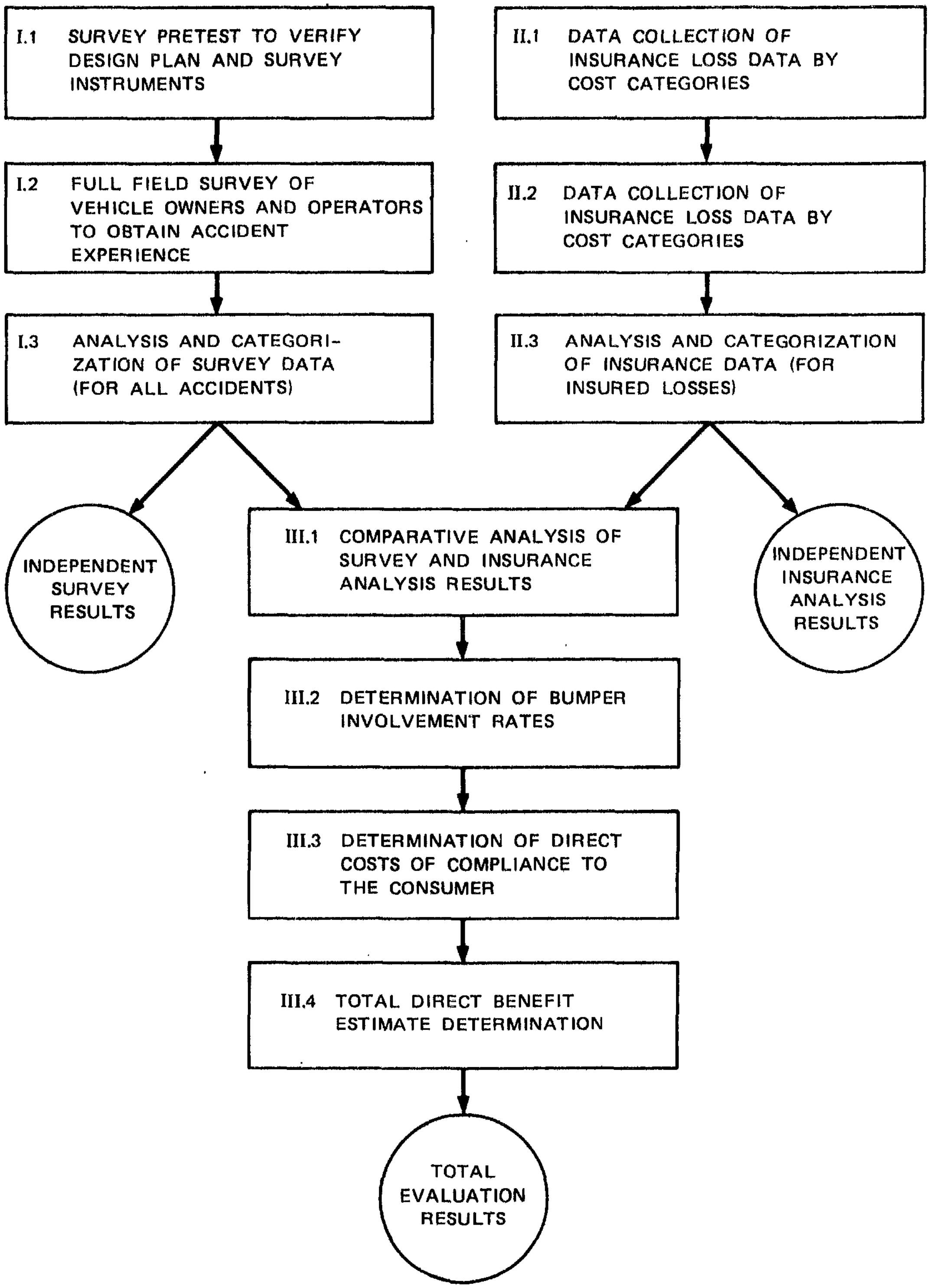


FIGURE 6-4 OVERVIEW OF EVALUATION STUDY DESIGN FOR FMVSS 215

surveyed, followed by data analysis; insurance accident claim loss data will next be collected and analyzed. Results of the survey will then be compared with the results of the insurance claim analysis. If found to be consistent, the two sets of results will be combined in the final analysis procedure.

Before final analysis, estimates will be made of the rate of bumper system involvement for all impact angles and cost categories under consideration. This determination will be based on the survey results, augmented by insurance company data, staged crash test results, and expert engineering and expert damage assessment judgments. Also determined will be the direct costs paid by the consumer for bumper systems produced in compliance with the standard. The final analysis will then estimate the total direct benefits of FMVSS 215 for specific post-standard models.

Pre-standard models go through 1971. Care should be used with 1972 models because some vehicles met manufacturer specified standards for 2.5-mph impacts; 1973 and later model years are post-standard vehicles.

6.5.3 Stage I--Owner/Operator Survey

I.1 Survey Pretest--The survey techniques and questions described in I.2 below should be carefully tested (in an iterative process if necessary) to ensure success of the full survey. Several potential test locations should be selected for the pretest, and an assessment or review should be made of the following factors:

- Inspection facility personnel cooperation.
- Owner/operator cooperation.
- Estimates of response accuracy.
- Adequacy of questions considering program objectives.
- Training requirements for survey questioners.
- Average duration of each interview.
- Adequacy of data handling procedures.
- Ability of professional damage estimaters to work from photographs.

Following a review of pretest results, the detailed program for the full survey should incorporate refinements. Adjustments made after the pretest might apply to: the number and type of sites used, the team size at each site, the number of samples obtained, survey duration, training, data collection procedures, and others.

I.2 Survey of Vehicle Owners/Operators--Incident data collected will be restricted to occurrences within the 12 months preceeding the survey date. This date should correspond as closely as possible with the beginning of the calendar year to assist in comparisons with insurance loss data.

We have made a series of conservative estimates to establish tentative data collection requirements for the survey. The number of repaired incidents per vehicle year is estimated at 0.2, as is the number of unrepaired incidents, for a total of 0.4 survey-reportable incidents per vehicle. However, only 50% of these incidents are expected to involve the front or rear bumper areas; therefore, the potential bumper involved incidents per vehicle year is estimated at 0.2. Thus, one out of every five vehicles considered for the survey is expected to have experienced a reportable incident in the preceding year. A selection of 20 sites (5 states with 4 sites per state) with survey teams operating for 50 days (over a 3-month period) at each site interviewing 25 owner/operators per day (initial questioning of 125 per day, with a 20% qualifying response rate; i.e., having experienced an accident in the last year), will produce a minimum of 25,000 incident reports plus multiple reports for some vehicles. A cooperation rate of 90% is expected from the selected accident-involved persons. Approximately 2500 incidents per model year for a 10-year span of vehicles is anticipated; although newer model years are more numerous and are driven further, they are expected to be somewhat better driven and cared for than older vehicles.

The survey itself will be conducted by two-person teams stationed at the approach lanes to vehicle inspection stations to question vehicle operators waiting for entry. One member of the team will record vehicle year, make, model, VIN, odometer reading, and any visible damage to front and/or rear vehicle surfaces for all vehicles surveyed. Photographs will be taken of any damaged front or rear surface (with license plate covered) for damage analysis off-site if the damage is described as having occurred in the last 12 months. The other team member will determine and record incident information for the preceding 12-month period for front and rear surfaces (including corners) using the following types of questions:

(1) Are you the owner or principal operator? (If "no," the vehicle will be excluded from the survey.)

(2) Has this vehicle been involved in any front, rear, or corner angle incident of any type in the last 12 months? (No further data are required for this vehicle if the answer is no.)

(3) How many no-damage incidents have occurred? What were the conditions? (The type of location, e.g., freeway or parking lot, is included, as is the type of object or vehicle impacted, estimated speed, and angle of impact.) Was the bumper involved in the incident?

(4) Were there any repaired incidents in the last year? If so, how many were there and what was the cost of repair? How long did they go unrepaired? Was the bumper involved in the incident?

(5) The following inquiries would be made when team members observe damage: How many incidents have occurred? When did the incidents occur: What were the conditions? Does insurance cover the damage? Will the owner repair the damage or will it remain unrepaired? What is the estimated time and estimated cost to repair the damage? Was the bumper involved in the incident?

State-operated motor vehicle inspection stations are recommended for the survey sites for several reasons. The inspection program ensures a good cross section of vehicles because there are few exemptions, and carefully selecting several sites within each state can ensure even better representation. The vehicle operator is subjected to little additional inconvenience because a wait in line is the normal situation in most cases. Finally, by conducting the survey before the vehicle is inspected, we anticipate that response accuracy will be improved because of the mandatory nature of the inspection process.

I.3 Analysis of Survey Data--Frequency distributions should be tabulated for accident data in the categories A to E of Figure 6-1, stratified by cost intervals and angle of impact. Estimates should also be made of the bumper involvement rate in each of the listed incident categories. Additional tables can be produced, based on the estimated speed of impact, the interval between damage and repair, and the cost of damage comparisons among insurance-repaired, owner-repaired, and unrepaired damage.

To assist in future research, this information should be prepared and published, as should the results of subsequent analysis.

6.5.4 Stage II--Insurance Accident Claims Analysis

II.1 Collision Cost Frequency--All available HLDI collision claim frequency data should be obtained by model year, calendar year, and dollar loss category. These data should be normalized to constant dollars and accident experience per mile (considering the number of vehicles in each cell and the reduction in exposure, with fewer vehicle miles traveled each year as the vehicle ages).

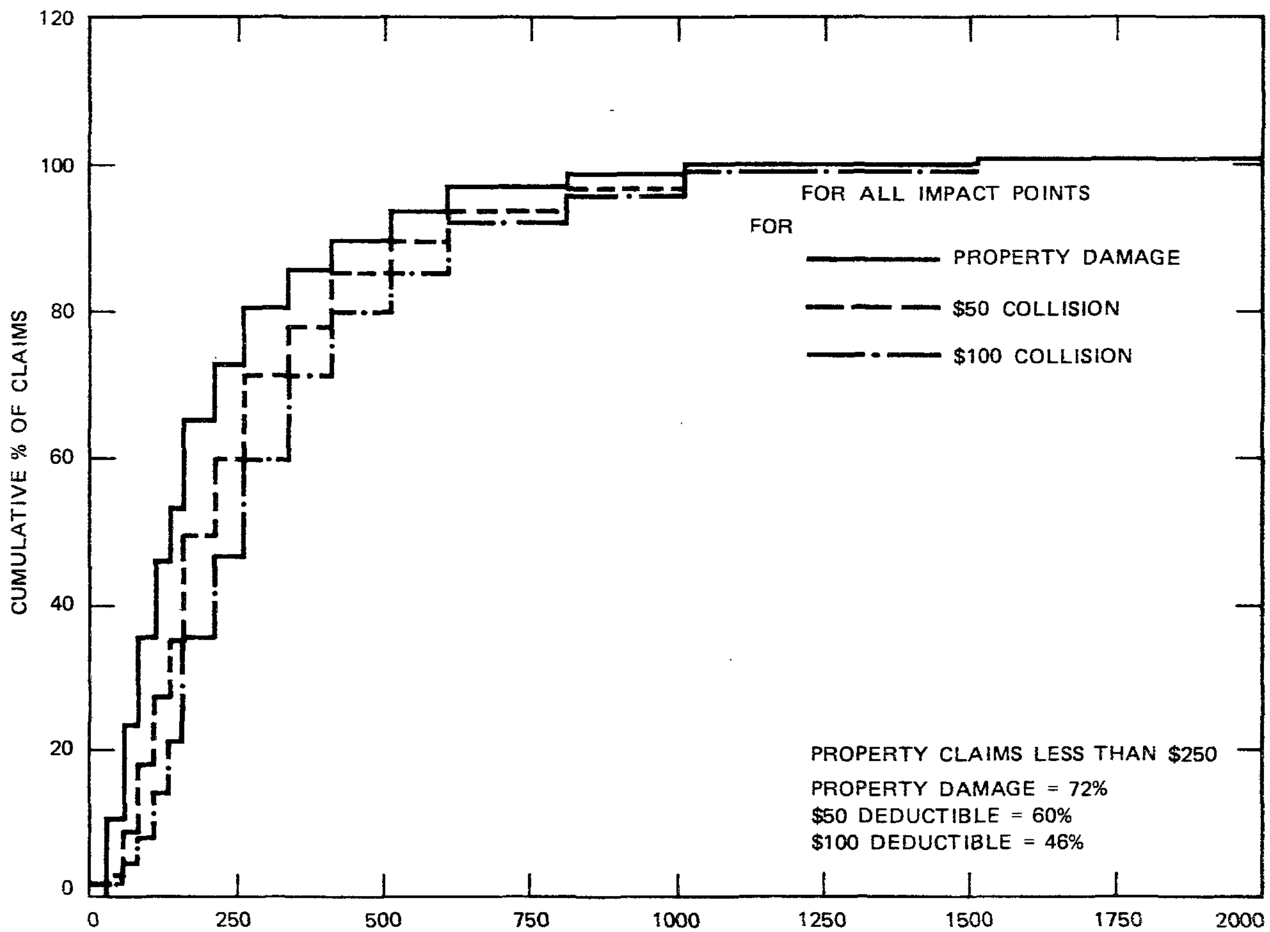
II.2 Distribution by Impact Area--All available impact distributional data should be obtained (e.g., State Farm data) that is comparable with HLDI data by model year and calendar year with dollar loss categories; (See Table 6-2 and Figures 6-5 and 6-6, for illustrations of this type of data). These data should then be normalized to constant dollars. These types of data should be obtained for as many model years as possible because without it, undesirable assumptions must be made concerning directional loss experience for years when data is unavailable.

Table 6-2

DISTRIBUTION OF CLAIMS BY IMPACT POINT, AND BY URBAN AND RURAL AREAS
(1971-1973 Comparison)

Impact Point: Vehicle Location	Percent of Claims, Urban		Percent of Claims, Rural		Percent of All Claims	
	1971 (7,198 claims)	1973 (8,643 claims)	1971 (1,992 claims)	1973 (3,370 claims)	1971 (9,190 claims)	1973 (12,013 claims)
1. Front right corner	11.8	10.9	12.1	11.8	12.0	11.1
2. Front right side	3.8	3.8	3.8	3.6	3.8	3.6
3. Middle right side	5.5	6.3	4.9	5.8	5.3	6.2
4. Rear right side	6.6	7.0	5.8	7.0	6.2	7.0
5. Rear right corner	5.3	7.0	4.6	7.2	5.3	7.0
6. Square rear	14.6	14.6	15.5	13.4	15.0	14.3
7. Rear left corner	6.1	8.1	6.4	7.8	6.2	8.0
8. Rear left side	6.9	6.5	7.0	6.9	6.9	6.6
9. Middle left side	5.2	6.3	5.8	6.3	5.3	6.3
10. Front left side	5.1	4.6	4.9	5.0	5.0	4.7
11. Front left corner	12.4	11.5	12.1	12.2	12.3	11.8
12. Square front	16.1	12.1	16.3	11.9	16.1	12.1
Other	0.6	1.3	0.8	1.1	0.6	1.3
Total	100.0	100.0	100.0	100.0	100.0	100.0
Percent of Claims	78.3	71.9	21.7	28.1	100.0	100.0

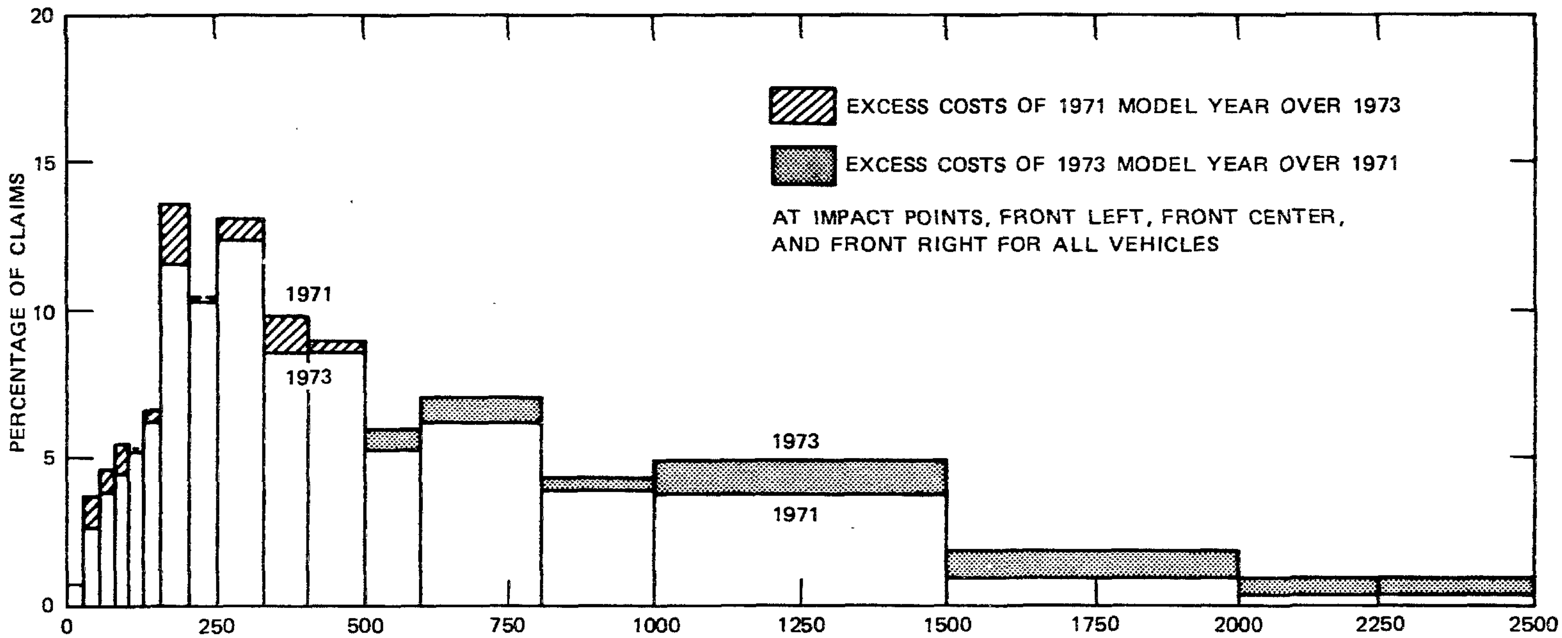
Source: State Farm Insurance Company



SOURCE: State Farm 1971 Data.

SA-5840-8

FIGURE 6-5 VEHICLE REPAIR COST IN DOLLARS



SOURCE: State Farm Data, Richardson, et al.

SA-5840-9

FIGURE 6-6 VEHICLE REPAIR COSTS IN DOLLARS

II.3 Analysis of Insurance Data--Regression and time-series analysis of standardized claim frequencies and cost of claims should be performed. Paired model-to-model comparisons will indicate model-specific changes, and paired calendar year-to-year comparisons will indicate changes due to changes in driving patterns (e.g., the effects of the "energy crisis" in 1974). Comparison of the cost frequency and impact area data will identify shifts in damage location (e.g., direct front and rear percentages would decline if the bumper standard is successful).

A full report of all analyzed data should be prepared and published to assist future research, as well as to serve as a basis for analysis in subsequent stages of this survey.

6.5.5 Stage III--Comparative Analysis and Final Evaluation

III.1 Comparative Analysis of Survey and Insurance Analysis Results--The successful completion of the two preceding stages will produce considerable overlap between the insurance and survey data for the calendar year of survey performance (Areas A and B in Figure 6-1). This overlap can be carefully analyzed to establish the comparability of the two-stage results. The action anticipated after this comparison takes place will be the adjustment of data (if possible) to eliminate identified biases if consistent differences are observed. For example, if consistent under-reporting results from the survey and is substantiated by insurance data or other supporting evidence, a sound basis for scaling the survey data upward may be established. After the completion of data adjustments to ensure comparability, proportionate cost figures derived from the survey for unreported incidents can be combined with the insurance-derived figures to arrive at total effectiveness values for each post-standard model year in the final analysis.

III.2 Bumper Involvement Rates--As described in the introduction to this section, one of the most difficult problems in evaluating FMVSS 215 is to estimate what portion of any observed differences in losses between pre- and post-standard vehicles is due to the standard. The survey described for Stage I provides an opportunity to identify this proportion, and specific questions are included to facilitate this determination. Within the limits of the accuracy of responses obtained from the survey, reasonable estimates should be available for the actual percent of bumper-involved incidents in each cost and impact angle category. These data will make it possible to compare the pre- and post-standard damage experience for both bumper-involved and nonbumper-involved incidents. This information will in turn provide a more reasonable basis for estimating the effects of the bumper standard.

The loss data for both bumper-involved and nonbumper-involved accidents should be tabulated separately from the survey. This information is valuable because, although an overall loss may be experienced (e.g., a 10% reduction for front corner impacts comparing 1977 and 1971), it is possible that there may have been a 25% reduction for bumper-involved impacts and a 5% increase for nonbumper-involved impacts (assuming that only 50% of front corner impacts are found to involve the bumper). Of course, other possible combinations may produce the same net effect; thus, the specific experience for both impact types is needed.

The major difficulty with survey data is determining whether the responses accurately reflect the information required. For this reason, survey results for both insured and uninsured damage to potential bumper involved accidents must be obtained. The overlap between the survey and insurance company loss data can then be compared as indicated in the Stage III.1. Because of the pivotal role played in the overall evaluation plan by bumper involvement identification, great care must be exercised during the survey to obtain answers to this question that are as accurate as possible. The response to this question will also be used to estimate benefits of FMVSS 215 for calendar years other than the one covered by the survey. This factor also makes accuracy important.

Because it is possible (or even likely) that some incident categories will be lightly represented in the survey (e.g., rear corner impact angles), broader cost categories might be used to reduce sample size requirements. Another alternative is to examine insurance company data and staged crash test results to obtain these estimates and to verify the survey involvement rates for other categories. All estimated bumper involvement rates should be reviewed by such qualified experts as automotive design engineers, crash test analysts, and/or damage estimators to establish a reasonable confidence interval for the rates.

III.3 Direct Costs of Compliance--The major disadvantage of FMVSS 215 is the increased cost of bumper systems manufactured to comply with the standard. Section 6.3.2 of this report discusses the basic characteristics of bumper system costs, both to the manufacturer and to the consumer. In the context of an evaluation plan, a careful determination is needed of the costs (comparable to other vehicle system components) passed on to the consumer as a result of manufacturer costs and mark-up. Only original equipment costs to the consumer need be determined, however, because replacement costs will automatically be included with accident damage losses.

Bumper system components included in the costs to be determined include: guards, face bar, face bar impact strips, face bar reinforcements, energy absorbers or spring assembly, filler panel or bumper valance, various brackets, braces, insulators, sight shields, spacers and fasteners, and fascias for soft face systems. For steel systems, the average incremental cost of components by model over average pre-standard (1971) cost should be determined in constant dollars. For soft face systems, the total cost should be calculated, including all support components, and then compared with the total cost of the average pre-standard (1971) system, including any nonbumper components replaced by the soft face system, such as grill assembly and panels, fender extensions, headlight housings, air shields, and support pieces.

Cost data should be separately determined in three categories:

- Materials and fabrication.
- Assembly and installation labor.
- Mark-up--handling, storage, and profit.

Auto manufacturer data should be consulted and verified by means of independent estimators (e.g., Rath and Strong) and other government sources (DOT, Department of Labor, OMB). Government cost indices for specific materials and automotive manufacturer labor rates should be used to convert all cost data to the same constant dollar basis used in the other stages of the overall evaluation plan. Sample incremental bumper system costs are illustrated in Table 6-3.

The costs of new bumper systems frequently drop (in constant dollars) if requirements remain the same while materials and design technology are improved to lower costs. For example, support pieces added to meet a standard may become integral with frame components during longer term (nonannual) model changes. Another example is the technical development of lighter structures with the same strength characteristics. Thus, it is possible for the manufacturer to increase the net benefit to the consumer, even at a fixed standard requirement level, if such improvements are developed and result in lower initial cost by the consumer (in constant dollars).

III.4 Total Direct Benefits--Completion of the preceding steps will produce the data needed to determine the direct benefits, expressed in dollars per vehicle year for each post-standard model in comparison with 1971, a pre-standard model. Assuming that the survey data have been collected for calendar year 1977 and that insurance data are also available for that year, the direct benefits for the 1976 model will be determined. Thus, data collected for the 1976 models will be based on a full year of on-the-road operation. Actual 1977 model data could also be used and extrapolated to the equivalent of a full year of operation.

Because the survey data include the complete (both reported and unreported) loss experience of actual bumper-involved accidents (not just for the six potential bumper involved impact angles) for both 1976 and 1971 models, there is no need to adjust to constant dollars. Thus, the total direct benefits in dollars per vehicle year for 1976 vehicles (T_{76}) can be simply expressed as:

Table 6-3

INCREMENTAL UNIT COST

Model	1971-1973 Models			1971-1974 Models			1971-1975 Models			1971-1976 Models		
	TSC	Manu-facturer	Rath & Strong	TSC	Manu-facturer	Rath & Strong	TSC	Manu-facturer	Rath & Strong	TSC	Manu-facturer	Rath & Strong
Subcompact	$25	$25	$ 65	$108	$112	$ 78	$120	$137	$ 85	$154	$249	$112
Compact	47	47	96	101	103	126	116	131	136	159	242	156
Intermediate	67	67	104	152	156	139	165	182	151	190	-	185
Full Size	84	84	141	149	151	181	162	168	201	215	-	221
Weighted Average	64	64	108	134	137	141	148	160	154	187	282	180

Source: State Farm Insurance Company

$$T_{76} = \Delta C_{76} \cdot F_{76}$$

where, $\Delta C_{76} = C_{71} - C_{76}$ (the difference in average losses for bumper-involved accidents for 1971 and 1976 vehicles)

F_{76} = frequency of 1976 model year accidents (both reported and unreported)

A similar formulation can also be used for the model years 1973 through 1975 ($T_{\text{model year}} = \Delta C_{MY} \cdot F_{MY}$).

More detailed effectiveness values may also be determined by collecting all study data elements in comparable cost and impact angle categories. Benefit evaluations can then be calculated for any individual cost or impact angle category, or for any desired combination of categories. In addition, insurance data may be substituted for the reported accident portion of the survey data if biases are left to exist with the data reported in the survey.

Based on the survey data, ratios of unreported versus reported accident losses can be determined for cost and impact angle categories as a function of vehicle age. These values can then be analyzed and used to make more accurate estimates of the benefits obtained over the average life (10 years) of post-standard vehicles, in contrast to the single year values determined by the survey. These same ratios can be combined with future insurance data to obtain estimates of the effectiveness of FMVSS 215 for post-1976 models.

6.6 IMPLEMENTATION

This section outlines an implementation schedule for the suggested FMVSS 215 evaluation plan. Figure 6-7 presents each of the study design steps described in Section 6.5, along with estimated schedule information (in months), manning requirements (in man-months), and costs (in dollars) for each step.

The implementation begins with the development of a detailed study plan and procedures to be used throughout the project (Step I). Contacts should be established and arrangements made (with NHTSA approval) for the accomplishment of all succeeding steps, including OMB approval of the survey. This step is expected to take approximately 1 calendar month.

Two parallel sets of steps (I.1, I.2, and I.3, and II.1, II.2, and II.3) follow to obtain and analyze the survey data and the insurance file data. Particular attention must be given to the survey pretest (Step I.1) to ensure the success of the full survey. Pretest iterations are expected to be required at several locations to establish an effective survey technique to obtain maximum reliable data. Approximately a 95% response rate is expected after the driver has been identified as the owner or principal operator of each vehicle selected because of the inspection station environment (and after adequate assurance has been given that response data will not be associated with a particular vehicle; i.e., an explanation will be given of why license plates are covered before photographs of damage are taken). The two parallel sets of steps are expected to take approximately 6 calendar months to complete.

The final set of steps (III.1 to III.4) are to be performed after the independent collection and analysis of both the survey data and insurance data. This series of steps results in the completion of the evaluation project and the production of a final report as described in Section 6.5. The final analysis steps are expected to take approximately 5 calendar months to complete.

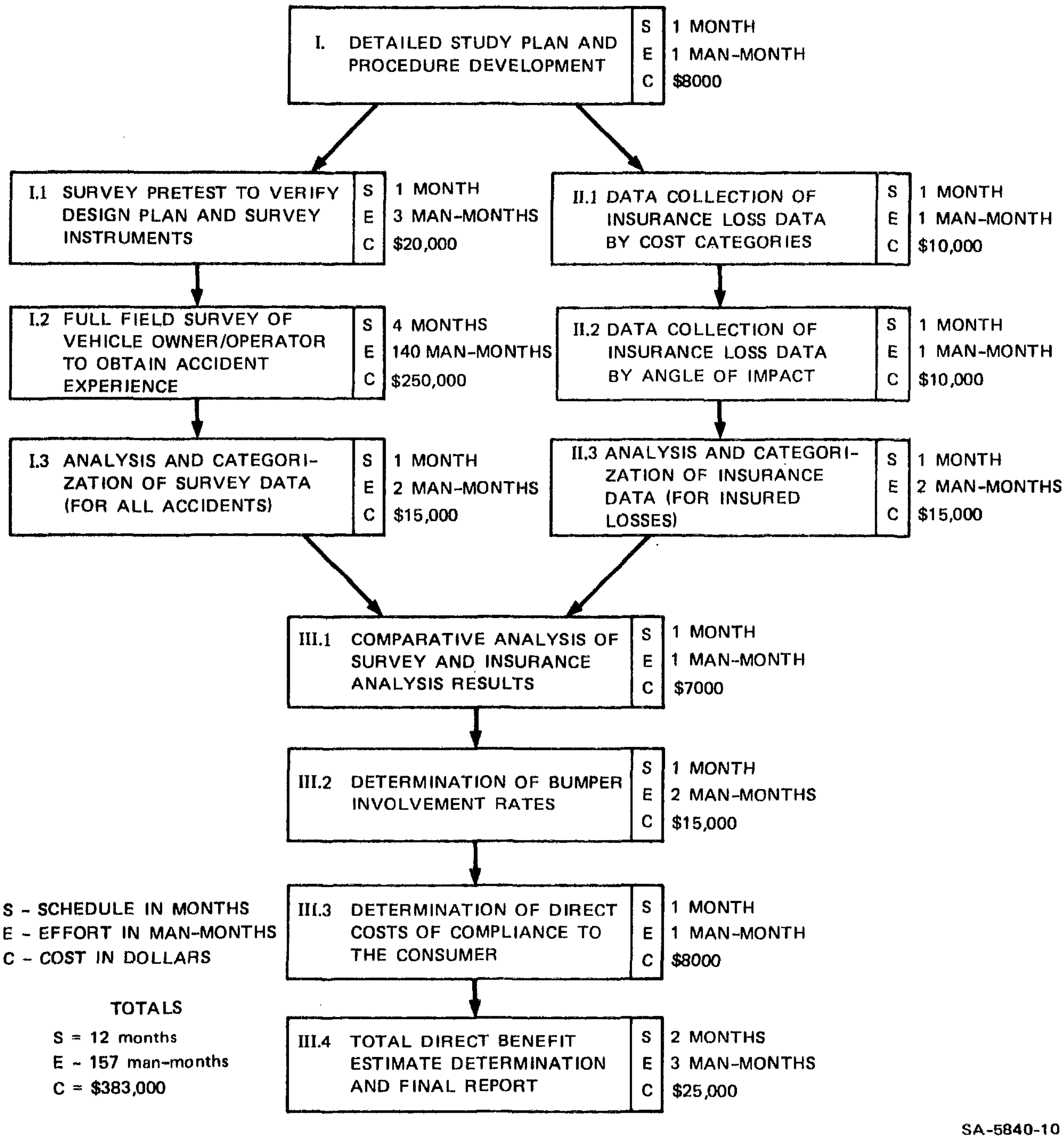


FIGURE 6-7 IMPLEMENTATION PLAN SCHEDULE AND COSTS

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Section 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 GENERAL CONCLUSIONS

This section presents the study's general conclusions concerning evaluation methodologies and specific conclusions for each FMVSS examined. Evaluation plan recommendations are also presented for each standard.

7.1.1 Literature Review

Current studies indicate attempts to explicitly evaluate the overall effectiveness of the four standards. With respect to injury-related Standards 301, 208, and 214, all these studies relied primarily on accident investigation data, and some made peripheral use of such additional data bases as those concerned with fire departments, medical files, police records, and insurance data. None of these attempts, however, has produced conclusive evidence of effectiveness because of:

- Inadequate accident investigation sample sizes.
- Nonrepresentative sample data.
- Other data bases used in analysis that are nonrepresentative of all the factors required in evaluation.

We also note that the inconclusive results in many of these studies could have been predicted at the time of their initiation because preplanned accident sample sizes were too small to satisfy the explicit or implicit design criteria.

7.1.2 Accident Investigations

In our assessment of methodologies suitable for evaluating the various standards, we concluded that in-depth accident investigations should be an integral part of any definitive evaluation plan. This conclusion was derived, in part, from the study objectives that required an evaluation in the real-world environment. For study results to be accepted by the mixed community of analysts, consumers, and manufacturers, we are also convinced that effectiveness must be demonstrated in terms of statistically significant highway accident data.

7.1.3 Methodologies

Computer simulations and analytic models are recognized for their utility as design tools and for their use in exploratory studies. However, they have only marginal value in overall standard evaluations because of uncertainty regarding extrapolations beyond the range of existing empirical data. Controlled compliance tests and staged crashes were determined to be of considerable value when employed with other evaluation methods. If used separately, however, compliance tests afford only limited representation of real-world conditions. This situation is particularly true with FMVSS 215--Exterior Protection because the real-world damage mechanisms involving bumper systems are mostly unknown. For FMVSS 301--Fuel System Integrity, side-related impacts may severely damage filler pipes or side-mounted tanks; and for FMVSS 214--Side Door Strength, not all of the structural features (door supports, pins, and hinges) that limit intrusion are measured; rather, only door-bending strength is tested. Vehicle-to-vehicle staged crashes can certainly provide precise information about selected accident types; however, the cost of replicating a reasonably representative set of real-world conditions is usually prohibitive.

7.1.4 Methodology Ranking

Because efficient evaluation plans may require more than one methodology or data collection procedure, a general assessment of individual utility may be misleading. However, within the context of this study, the following list ranks the value and credibility of the methodologies considered:

- In-depth accident investigation.
- Controlled testing (barrier, staged crashes, and similar tests).
- Surveys of consumers and of damage observed at check points.
- Insurance claim data file analyses.
- Computer simulations and analytic modeling.
- Analysis of data bases other than accident investigations (fire departments and the like).

7.1.5 Evaluation Feasibility

This study established that the evaluation would be feasible for FMVSS 301--Fuel System Integrity, FMVSS 214--Side Door Strength, and FMVSS 208--Occupant Protection. For standards 301 and 208, we determined that valid accident investigation data would provide a sufficient basis for evaluation because the relevant cause and effect variables were amenable to direct highway observations. The sample sizes required were not prohibitive. For FMVSS 214, controlled testing was considered to be a necessary precursor to accident sampling; in this way intermediate factors such as side door intrusion would be identified and quantified, and the required accident sample sizes would thereby be reduced.

We concluded that no evaluation scheme based on current methodologies and feasible data collection procedures should be expected to produce conclusive results regarding FMVSS 215--Exterior Protection. The primary difficulty concerns the inability to obtain direct observations on low-speed, low-damage accidents. Alternative plans, which rely on qualified, indirect surveys or insurance data, are the only approaches that can be undertaken if FMVSS 215 is evaluated.

7.2 SPECIFIC CONCLUSIONS

Assessments of the major characteristics of the evaluation plans for each standard are summarized in this section. Three factors are presented for each standard:

- Probability of successful evaluation.
- Estimated cost of evaluation.
- Key data requirements.

A successful evaluation is an analysis that produces statistically meaningful results, based on observations of all relevant cause, effect, and explanatory variables, and reported in an understandable manner to the technical and nontechnical communities. Prior estimation of the success of a study requires subjective judgment, but it is a prerequisite for the initiation of any evaluation program. The following scale will be used to classify the probability success:

- very poor ≤ 20% < poor ≤ 40% < Fair ≤ 60% < good ≤ 80% < very good ≤ 100%.

Estimated costs are total values, based on cost estimates for each task in the implementation plans. Key data requirements were developed from an analysis of the statement and intent of the standards, compliance tests, and available experiment methodologies.

7.2.1 Cost and Probability of Success

The costs and probabilities of successful evaluation for each standard are indicated below.

	FMVSS			
	301	208	214	215
Probability of success	Good	Good	Fair	Poor
Cost	\$1,003,000	\$294,000	\$37,400 to \$1,378,200	\$383,000

7.2.2 Key Data Requirements

For FMVSS 301 the following data are required:

- Location, type, and extent of fuel leakage as a function of crash conditions. Crash conditions should include impact vector, and types of both vehicles involved.

- Occurrence of fires, their extent, ignition sources, and whether or not they were fuel fed.
- Occupant burn injuries and occupant's seating position, age, sex, weight, and use of restraint systems.

For FMVSS 208 the following data are required:

- Restraint availability in front seat and restraint use.
- Restraint availability in rear seat and restraint use.
- Occupant's age, sex, and size.
- Whether occupant was pregnant.
- Body region of injury.
- Collision angle, damage severity, and vehicle size.
- Improper use of restraints.
- System malfunction.
- Deployment of passive restraints.
- Vehicle ownership.
- Whether the driver was at fault in the accident.
- Model type and year.
- Time of day, day of week, and type of roadway on which the accident took place.

For FMVSS 214 the following data are required:

- Variation in door strengths among pre- and post-standard vehicles.
- Measurements of interior compartment intrusion in side impact accidents, expressed as a function of the speed, location and angle of impact, and type of striking vehicle.
- Injury severity (AIS) of occupants.
- Occupant's seating position, age, sex, size, and whether restraints were used.

For FMVSS 215 the following data are required:

- Insured property damage and collision losses, categorized by cost intervals (increments of $100), including deductible amounts for each calendar year and model.
- Distribution of insured losses by angle of impact, stratified by cost intervals for at least the first year of each model year.

- Estimates of the proportion of damage affected by the bumper standard for post-standard model years, stratified by angle of impact.
- Estimates of the frequency and value of vehicle damage unreported to insurance companies, both owner-repaired and unrepaired, for bumper-area involved accidents.
- An accurate identification* of the distribution of all low-speed accidents, including frequency of occurrence; degree of damage; and circumstances of involvement such as location, angle and speed of impact, description of object impacted and traffic conditions.

7.3 RECOMMENDATIONS

7.3.1 General

In accordance with study requirements, all evaluation plans were developed separately and independently, with the understanding that only one of them might be programmed for implementation. However, if more than one of the evaluation plans is implemented, technical and economic reasons recommend a program that provides for a simultaneous evaluation of the several standards. For example, in measuring the relationship between side-door intrusion and injury severity (FMVSS 214), the occupant's use of restraints (FMVSS 208) must also be accounted for to eliminate the effects of confounding factors. In general, the data requirements for the various standards overlap. One of NHTSA's accident investigation studies, NCSS, provides a timely and useful framework for the more sharply focused data collection evaluation requirements. Also, to satisfy evaluation plans that are developed, data collection procedures can be easily modified in regard to sample sizes, type of accidents, and organization of the data.

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*These data are desirable to have but are extremely difficult and costly to obtain.

7.3.2 FMVSSs 301, 208, and 214

Three evaluation plans can be recommended to NHTSA without qualification, and all can be implemented within an augmented NCSS program. A brief outline of each plan is presented below.

FMVSS 301--The procedural steps require the selection of a random sample of 1200 tow-away accidents involving 1974 to 1976 models and a comparable sample of 1200 1977 to 1979 vehicles to determine if there is a significant difference in post-crash fuel leakage, between the two groups. This could be achieved during 1 year in a fully operational NCSS program. Concurrent with this random sampling, all crash-fire occurrences will be investigated, and the completion of these fire investigations will require 3 years of NCSS operation. However, a logical decision point occurs upon completion of the analysis of fuel leakage in the sample of 2400 tow-aways. If no significant difference in fuel leakage is detected between pre- and post-standard vehicles, we recommend that sampling of fire events be discontinued because the effectiveness of the standard will be established only if a reduction in both fuel leakage and fire incidents is demonstrated. If a significant difference in fuel leakage does exist, the investigation of fires must continue.

FMVSS 208--Four areas of evaluation are recommended. These are:

(1) Evaluation of active restraint factors

- Injury comparison among front seat restraint use--no restraint, lap restraints, and lap/shoulder restraints.
- Injury comparison between rear seat restraint use--no restraints and lap restraints.
- Stratification of injury data by restraint use by occupant factors including occupant's age, size, and sex, as well as pregnancy.
- Analysis of injuries by body region as compred with overall injury by using AIS and restraint use data.
- Stratification of injury data by restraint use by collision angle, damage severity and vehicle size.

- Case-by-case evaluation of accidents in which improper restraint use and/or system malfunction is suspected.

(2) Evaluation of risk-taking factors

- Assessment of the relationships involved in restraint use, injuries, and such driver characteristics as age, sex, vehicle ownership, and model type.
- Assessment of the relationship of restraint use to injuries and accident characteristics--time of day, day of week, type of roadway, and driver at fault.
- Assessment of the relationships involved in driver and accident characteristics.

(3) Evaluation of passive restraint factors. (We note that the planned ACRS demonstration is ideal for NHTSA evaluation of passive restraints.)

- Injury comparison among front seat use--no restraints, lap/shoulder restraints, lap/ACRS, and ACRS.
- Stratification of data for injuries by restraint availability and occupant factors--age, sex, size of occupant, and pregnancy.
- Analysis of injuries by body region by restraint availability as compared with overall injury using improved injury scales.
- Stratification of data for injuries by restraint availability by collision angle, damage severity, and vehicle size.
- Analysis of deployment failures and frequencies by impact speed and collision angle.

(4) Continuing studies

- 1977 to 1981, annual recomputation of (1) above.
- 1982 and annually thereafter, recomputation of (1) above, excluding front seat, lap only, and the factors in (3) above.

FMVSS 214--The recommended evaluation plan is a sequential process with two decision points to allow analysts to continue or to discontinue further testing, with the decision based on observed results.

Stage 1 is a compliance test of pre-standard vehicles and a comparison of derived data with available test results for post-standard vehicles. The evaluation process will continue only if significant differences exist.

Stage 2 consists of vehicle-to-vehicle staged crashes designed to determine whether or not a measurable difference exists in side door intrusion between pre- and post-standard vehicles under fixed crash conditions. The evaluation will continue if such a differential exists.

Stage 3 consists of accident investigations on a stratified sample of 4000 side impacts. This investigation will determine the relationship between intrusion and injury severity, and will measure the difference in occupant injury severity between pre- and post-standard vehicles.

7.3.3 FMVSS 215

Based on purely technical considerations, it is difficult to recommend evaluating FMVSS 215 because the results would depend on qualified indirect measures (see Section 6.5). However, it is recognized that considerations other than technical requirements could properly argue for evaluation; thus, SRI considers a combination of survey and insurance claim analysis to be the most likely to produce acceptable evaluation results for FMVSS 215. Specifics of this plan follow:

The first step in the evaluation plan is the development of a detailed study plan and procedures to be used throughout the evaluation project (Step I).

Two parallel sets of steps (I.1, I.2, I.3 and II.1, II.2, II.3) are performed next to obtain and perform individual analyses of owner/principal operator survey data and insurance accident file data. The two parallel sets of steps are expected to take 6 calendar months to complete.

- I.1--A survey pretest to verify the design plan and to survey instruments.
- I.2--A full field survey of vehicle owner/operators to obtain accident experience.
- I.3--Analysis and categorization of survey data for all accidents.

- II.1--Data collection of insurance loss data by cost categories.
- II.2--Data collection of insurance loss data by angle of impact.
- II.3--Analysis and categorization of insurance data for insured losses.

The final steps (III.1 to III.4) are to be performed after the independent collection and analysis of both the survey data and insurance data. This series of steps results in the completion of the evaluation project and the production of a final report (see Section 6.5). The final analysis steps are expected to take approximately 5 calendar months to complete.

- III.1--Comparative analysis of survey and insurance analysis results.
- III.2--Determination of bumper involvement rates.
- III.3--Determination of direct costs of compliance to the consumer.
- III.4--Total direct benefit estimate determination and the final report.

7.3.4 Summary

From the experience gained with these four standards, SRI believes that all existing motor vehicle safety standards should be examined in order to conclude which standards can, should, or must be evaluated. Then, an overall evaluation program should be developed that enables concurrent determination of the effectiveness of multiple standards when viewed together, with necessary integration of analytical techniques to account for confounding aspects.

GLOSSARY

Active Restraint System--A system that requires some action (e.g., fastening a belt) by the occupant to provide him protection.

Air Bag (also air cushion restraint system (ACRS)--A passive restraint system consisting of bags stored in the steering wheel hub and instrument panel. Upon vehicle frontal impact, the bags inflate to prevent occupant contact with the vehicle interior.

Anthropomorphic Test Device--A test dummy.

Barrier Crash--A test procedure in which a test vehicle crashes into a fixed, collision barrier.

CEM--Center for the Environment and Man, Incorporated.

Corner Impacts--Pendulum impact tests in which the pendulum impacts the corners of the vehicle bumpers.

CPIR--Collision Performance and Injury Report. A form filled out by MDAI investigators containing human, vehicle, and environmental information in coded form suitable for computerization.

CTM--Contract Technical Monitor.

Curb Weight--The weight of a motor vehicle with standard equipment; maximum capacity of engine fuel, oil, and coolant; and, if so equipped, air conditioning and additional weight optional engine.

ΔV--The change in vehicle velocity due to impact with an object or other vehicle.

DOT--Department of Transportation.

Elastomeric Materials--Flexible, elastic materials such as rubber or plastic.

ESV--Experimental safety Vehicle. Vehicles constructed to explore state-of-the-art improvements in vehicle safety, with emphasis on crashworthiness, occupant protection, and accident avoidance.

Fixed Collision Barrier--A flat, vertical, unyielding surface with the following characteristics:

(1) The surface is sufficiently large that, when struck by a tested vehicle, no portion of the vehicle projects or passes beyond the surface.

(2) The approach is a horizontal surface that is large enough for the vehicle to attain a stable attitude during its approach to the barrier and that does not restrict vehicle motion during impact.

(3) When struck by a vehicle, the barrier surface and its supporting structure absorb no significant portion of the vehicle's kinetic energy. Thus, a performance requirement described in terms of impact with a fixed collision barrier must be met, no matter how small an amount of energy is absorbed by the barrier.

FMVSS--Federal Motor Vehicle Safety Standard.

GM--General Motors.

GVWR--Gross Vehicle Weight Rating. The value specified by the manufacturer as the loaded weight of a single vehicle.

HIC--Head Injury Criterion.

HSRC--Highway Safety Research Center.

HSRI--Highway Safety Research Institute.

Ignition Interlock System--A system designed to require the driver and front-seat passengers to fasten their restraints before the engine can be started.

Impact Ridge--The projecting part of the pendulum test device used in the compliance test of FMVSS 215.

Injury Criteria--Analytical measures of injury severity determined from acceleration time histories of a dummy's head and chest.

Intrusion--Reduction in passenger compartment volume due to penetration by an external object.

Kinetic Energy--Energy of a moving mass equal to 1/2 the product of the mass times the square of its velocity.

Level of Investigations--Collection of accident statistics by experimentation of police reports.

Level 3--Same as MDAI.

MDAI--Multidisciplinary Accident Investigation. In-depth investigation of accidents by specialists in human, vehicle, and environmental factors.

Multipurpose Passenger Vehicle--A motor vehicle with motive power (except a trailer), designed to carry 10 persons or less, which is constructed either on a truck chassis or with special features for occasional off-road operation.

NASS--National Accident Sampling System.

NCSS--National Crash Severity Study.

NHTSA--National Highway Traffic Safety Administration.

OMB--Office of Management and Budget.

OSI--Overall severity index.

Outboard Seating Position--A designated seating position in which a longitudinal vertical plane tangent to the outboard side of the seat cushion is less than 12 in. from the innermost point on the inside surface of the vehicle at a height between the seating reference point and the shoulder reference point (as shown in Figure 1 of FMVSS 210) and longitudinally between the front and rear edges of the seat cushion.

Passenger Car--A motor vehicle with motive power, except a multipurpose passenger vehicle, motorcycle, or trailer designed for carrying 10 persons or less.

Passive Restraint System--A system that provides crash protection by means that require no action by vehicle occupants.

Pendulum Impact Tests--Tests specified in FMVSS 215 in which a pendulum weighing the same as the test vehicle is used to impact the bumpers of the test vehicle.

Penetration--The crossing of the external boundary of the vehicle by an external object.

Pressure Vessel--A tank or bottle designed to contain a gas or liquid under pressure.

RSEP--Restraint System Evaluation Program.

SAE--Society of Automotive Engineers.

SMAC--Simulation Model of Automotive Collisions.

Soft-Face Bumper System--A system in which the front and rear of the vehicle are constructed of flexible materials that absorb energy by recoverable deformation.

SPSS--Statistical Package for the Social Sciences.

Static Rollover Test--A test in which the vehicle is secured to a frame and rotated slowly about its longitudinal axis. Such a test is prescribed in FMVSS 301.

Stoddard Solvent--A hydrocarbon, dry-cleaning fluid used in compliance tests of FMVSS 301. For the compliance test, the vehicle's fuel system is filled with Stoddard solvent.

SwRI--Southwest Research Institute.

Test Dummies--Manikins designed to resemble human beings in size, mass distribution, and joint flexibility so as to simulate the dynamic response of a human body to impact accelerations.

Tow-away Accident--An accident resulting in vehicle damage that prevents the vehicle from being driven away from the scene.

TSC--Transportation Systems Center.

VDI--Vehicle Deformation Index. A seven-character code that describes direction of force, location of damage, and severity of damage.

Vehicle Class--Vehicle weight class, an arbitrary division of vehicles into classes based on weight, as subcompact, compact, intermediate, and full size.

Vehicle Side Impacts--Impacts that contact and cause damage to the side of the vehicle.

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Appendix A

METRIC CONVERSION TABLE
(For English measures used in this study)

<u>Length</u>

Inch = 2.5 centimeters

Foot = 30 centimeters

Mile = 1.6 kilometers

<u>Volume</u>

Fluid ounce = 30 milliliters

<u>Mass</u>

Ounce = 28 grams

Pound = 0.45 kilograms

Appendix B

SAMPLE SIZE DETERMINATION

This appendix describes the computational mechanisms that may be used to determine the sensitivity (power) of tests of hypotheses and confidence intervals. In a final evaluation, procedures such as the analysis of variance will be appropriate. However, in establishing preliminary design criteria, it will be sufficient to note that the basic comparisons are between two groups of vehicle types and that the critical measures of effectiveness are binomial (e.g., the presence or absence of fire or fuel leakage).

The following discussion is general and will apply to any two groups of things and to any binomial events and probabilities. However, to simplify the presentation and focus attention on essentials, it will be assumed that the first comparison group consists of post-1976 vehicles and the second of pre-1977 models.

For the post-1976 model group:

N_1: The total sample size of accidents used in analysis.

$\overline{X}_1$: The observed average number (frequency) of accidents possessing a specific characteristic such as fuel leakage, fire, or burn injury.

P_1: The true (unknown) probability of the event measured by $\overline{X}_1$.

In a similar manner, N_2, $\overline{X}_2$, and P_2 are defined for the pre-1977 vehicles.

The hypothesis H, and the alternative are stated as

$$H: \; P_1 = P_2$$

$$Alt: \; P_1 < P_2 \quad .$$

The conventional procedure is to specify α, the probability of rejecting H given that H is true, and then to reject the hypothesis and accept the alternative whenever

$$\frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{\overline{X}_1(1 - \overline{X}_1)}{N_1} + \frac{\overline{X}_2(1 - \overline{X}_2)}{N_2}}} \le Z(\alpha)$$

where $Z(\alpha)$ is defined by the equation

$$\int_{=\infty}^{Z(\alpha)} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt = \alpha \quad .$$

Finally, the power of the test, $1 - \beta$, is the probability of rejecting the hypothesis when the alternative is true. $1 - \beta$ will depend, of course, on the particular value of the alternative; that is, on the values of P_1 and P_2 where, $P_1 \neq P_2$.

The power of the test is a meaningful design criterion used in determining required sample size. An expression which gives the approximate test power is

$$- \frac{P_1 - P_2}{\sqrt{\frac{P_1(1 - P_1)}{N_1} + \frac{P_2(1 - P_2)}{N_2}}} = Z(1 - \alpha) + Z(1 - \beta) \quad .$$

From this, one can compare test power with sample sizes. For example, the following table shows selected calculations that are relevant to the discussion in the preceding subsection. In each calculation the test level α was chosen to be 0.05.

N_1	N_2	P_1	P_2	$1-\beta$
20,000	20,000	.0005	.001	.57
30,000	30,000	.0005	.001	.72
50,000	50,000	.0005	.001	.89
1,500	1,500	.012	.025	.84
1,000	1,000	.012	.025	.69
1,000	1,000	.02	.04	.83

A two-sided confidence interval for the difference between the unknown parameters P_1 and P_2 is:

$$(\bar{X}_1 - \bar{X}_2) \pm 1.96 \sqrt{\frac{\bar{X}_1(1 - \bar{X}_1)}{N_1} + \frac{\bar{X}_2(1 - \bar{X}_2)}{N_2}} \quad .$$

In the procedures above the primary objective is the satistical estimation of a parameter; therefore, the confidence interval can be used as a preliminary design criterion. That is, for any specific data collection effort, a confidence interval can be determined provided that there is a reasonable estimate of the sample variance. Conversely, if the length of the confidence interval is specified, the required sample size can be determined. In those cases where sampling variability cannot be estimated, an appropriate procedure would be multistage sampling. In the simplest form, this would consist of a pilot study to obtain an estimate of sample variance. This estimate then becomes the basis for a second data collection effort designed to achieve the required degree of precision.

In general, if the statistic Z, calculated from a sample of size N is an unbiased estimate of a parameter θ, and if N is sufficiently large (e.g., greater than 30) so that the normal approximation holds, a 95% confidence interval for θ is given by the expression

$$Z \pm 1.9 \ \sigma_Z(N)$$

where $\sigma_Z(N)$, a function of sample size N, is the variance of Z. The length of the interval is $2(1.9)\ \sigma_Z(N)$. Further, if Z is a linear function of independent variables X_i,

$$Z = \sum a_i x_i$$

then

$$\sigma_Z^2 = \sum a_i^2 \ \sigma_{x_i}^{\ 2} \quad .$$

These basics will be applicable for the discussion below.

Insurance Claims--Claim frequencies are ordinarily standardized with respect to a specified number of vehicle miles or insured vehicle years. For a stratified claim sample the standardized claim frequency is

$$f = K \sum a_i \frac{N_i}{K_i}$$

where

K is the standardizing constant (e.g., 100 vehicle years).

N_i is the number of claims in the i^{th} stratum.

K_i is the total exposure for the i^{th} stratum expressed in the same units as K.

A_i is the weight, or population frequency, with $\Sigma a_i = 1$.

It is customary in insurance analysis to assume that the number of claims of Poisson distributed so that the variance becomes

$$\sigma_f^2 = K^2 \sum a_i^2 \frac{N_i}{K_i^2}$$

and an approximate 0.95 confidence interval is $f \pm 1.9\ \sigma_f$.

Repair Cost Analysis--The measure of interest in highway bumper-involved accidents is the average repair cost expressed as a function of vehicle design and crash environment. For a given vehicle type and defined crash conditions (e.g., 10 to 15 mph, front to rear), a 0.95 confidence interval for repair costs is

$$\overline{X} \pm 1.9 \frac{\sigma}{\sqrt{N}}$$

where

$\overline{X}$ is the average observed cost from a sample of N observations.

σ is the standard deviation of the cost distribution.

The value of σ is, of course, unknown but may be estimated in a given data collection effort by the observed sample standard deviation. In cases where it is desired to determine the sample size required to produce (approximately) a confidence interval of desired length, a reasonable upper bound can be obtained by assuming a uniform distribution of costs over the expected range. That is, for accidents producing repair costs ranging from 0 to \$500.00, the assumption of uniformity results in a standard deviation of \$144.00.