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A Statistical Evaluation of the Effectiveness of FMVSS 301: Fuel System Integrity

Report No. 7 of 7

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CONTRACT TECHNICAL MANAGER'S ADDENDUM

Prepared for the National Highway Traffic Safety Administration in support of a program to review existing regulations, as required by Executive Order 12291 and Department of Transportation Order 2100.5. Agency staff will perform and publish an official evaluation of Federal Motor Vehicle Safety Standard 301 based on the findings of this report as well as other information sources. The values of effectiveness and benefits found in this report may be different from those that will appear in the official Agency evaluation.

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16. Abstract

This is the Final Report on the statistical evaluation of FMVSS 301 Fuel System Integrity). It is one of seven statistical evaluations conducted under this contract. The seven Standards are:

1. FMVSS 108: Side Marker Lamps (only)
2. FMVSS 202: Head Restraints
3. FMVSS 207: Seat Back Locks (only)
4. FMVSS 213: Child Seating Systems
5. FMVSS 214: Side Door Beams
6. FMVSS 222: School Bus Seating and Crash Protection
7. FMVSS 301: Fuel System Integrity

FMVSS 301 is a death-and-injury reduction Standard which includes requirements (effective 1 January 1968) on the limits of leakage from the fuel tank, filler pipes, and fuel tank connections during and after 30 mph frontal barrier crashes.

The data available for analysis did not permit examining the frequency of fuel system rupture and/or fuel spillage nor the bottom line result of injury and death reduction due to FMVSS 301. The 109 post-crash fire cases available from the National Crash Severity Study file permitted a descriptive analysis by Standard period, car weight, impact site, object struck, type of collision, driver injury, etc. On the other hand, data from mid-1971 through 1978 crashes in North Carolina did permit an analysis of the effectiveness of FMVSS 301 through logistic regression procedures.

The logistic regression models controlled for speed, impact site, and vehicle age within Standard status. The final model provided a negative estimate (-0.28 with a standard error of 0.143) of the effectiveness of FMVSS 301 where the effectiveness estimate represented the percentage reduction in post-crash fire rates for the Post-Standard cars (i.e., 1969-75 model year vehicles). Clearly the initial version of FMVSS 301 did not have the desired effect of reduced post-crash fire rates.

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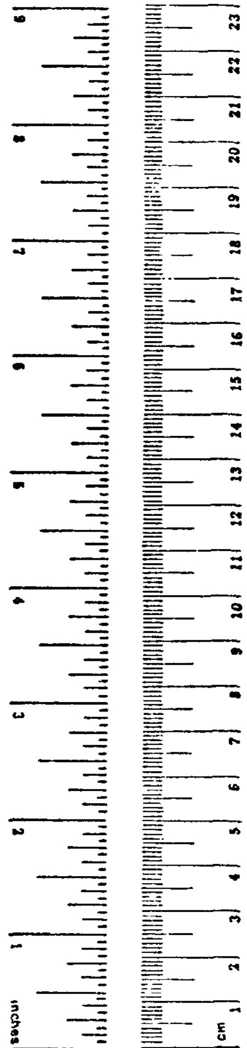
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

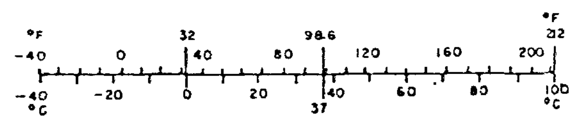
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

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



Approximate Conversions from Metric Measures

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



EXECUTIVE SUMMARY

This is the Final Report of the statistical evaluation of Federal Motor Vehicle Safety Standard (FMVSS) 301: Fuel System Integrity.

FMVSS 301 is a death-and-injury reduction Standard which includes requirements (effective 1 January 1968 for the initial version) on the limits of leakage from the fuel tank, filler pipes, and fuel tank connections during and after 30 mph frontal barrier crashes. With several admendments to the original Standard, all 1978 model vehicles up to 10,000 lbs. GVWR must also meet requirements in a static rollover test as well as side and rear impact tests.

To fully evaluate the Standard, the following measures would be required:

- Fuel leakage occurence and rate of leakage in the following: pre-1968 and post-1968 cars and post-1976 vehicles in the 6000-10,000 pound GVWR range in frontal crashes; pre-1976 and post-1975 cars in rollover crashes; pre-1977 and post-1976 cars in side and rear crashes and post-1976 vehicles in the 6000-10,000 pound GVWR range in rear impacts; and all 1978 vehicles up to 10,000 pounds GVWR in frontal, side, rear and rollover crashes;
- Post-crash fire rates for the above-defined Pre- and Post-Standard vehicles;
- Occupant death and injury rates for the same Pre- and Post-Standard vehicles attributable to post-crash fires.

However, data does not currently exist to adequately determine and compare any of the preceding. The most that could be done was to examine post-crash fire incidence for pre-1968 vs. 1969-75 model passenger cars.

The data available to examine this relatively infrequent event derived from two files: (1) the National Crash Severity Study file; (2) North Carolina police-reported accidents for the period mid-1971-1978. As there were but 109 post-crash fire cases on the NCSS file, the primary effectiveness evaluations were made using the North Carolina accident data.

From the (limited) NCSS data, comparisons by various measures of accident severity indicated that post-crash fire rates were generally higher for more severe accidents. Thus, for example, post-crash fire rates were relatively high for single vehicle accidents, for rural accidents, for accidents when vehicles collided with trucks or fixed objects, and for accidents involving a fatality. Furthermore, driver injury comparisons showed that, as might be expected, the proportion of serious injuries using either the KABCO scale or overall AIS was higher for vehicles involved in post-crash fires.

To obtain the appropriate North Carolina accident data, the narratives for nearly 917,000 accidents involving passenger cars in North Carolina during the years mid-1971 through 1978 were read by the computer to select those cases involving "fire". From the 5778 narratives containing the pre-selected search words (i.e., caught *fire, burn, flame, fire, explode), those 1635 (reportable) cases involving cars in pre-crash fires (e.g., fires started by the driver dropping a lit cigarette) and those 3499 cases clearly not fire-involved (e.g., car hit a fire hydrant) were deleted from the "post-crash" narrative file. This yielded an eventual file of 644 cars in post-crash fires with information on accident year, model year, size, speed, impact region, etc. There was some additional final screening necessary to make valid comparisons between the 1965-67 and the 1969-75 model cars in post-crash fires.

The basic measure of effectiveness of FMVSS 301 in preventing fires is defined as follows:

$$\hat{E} = \left(\begin{array}{l} \text{Effectiveness} \\ \text{of FMVSS 301} \\ \text{(post-crash fires)} \end{array} \right) = 1 - \frac{\left(\begin{array}{l} \text{rate (per 1000 cars) of} \\ \text{post-crash fires in} \\ \text{Post-Standard cars} \end{array} \right)}{\left(\begin{array}{l} \text{rate (per 1000 cars) of} \\ \text{post-crash fires in} \\ \text{Pre-Standard cars} \end{array} \right)}$$

where Pre-Standard represents 1965-67 model year cars and Post-Standard (original version) includes 1969-75 model year cars.

After creating the file, examining the data, and computing crude effectiveness estimates and their standard errors, logistic regression models -- appropriate for rare events -- were fit to the data using certain control variables suggested by statistical screening of the data.

More specifically, variable selection was carried out to determine those variables important to control for in the logistic regression analysis. Of the variables considered, speed and impact site were clearly most important to control for. Thus speed (<50 mph vs. $\geq$50 mph or unspecified) and impact site (front, side, rear, vs. other) were controlled for in the subsequent modelling. As age of vehicle was considered important a priori, models were fit controlling for vehicle age as well as accident year.

The primary analysis restricted the data to cars that were in the 4-9 year age range. Outside this range, the accident years did not allow for cases in both the Pre- and Post-Standard comparison groups simultaneously. With this restriction, the study population was as follows:

POST-CRASH FIRE RATES AND STANDARD
ERRORS FOR PRE- AND POST-STANDARD
CARS - AGES 4-9 YEARS

Model Years	Number of Cars in Crashes N	Number of Post-Crash Fires N	Post-Crash Fire Rate (per 1000) $\hat{r}$	Standard Error s
65-67 (P)	179,677	99	0.551	0.0554
69-75 (S)	292,226	165	0.565	0.0440
Total	471,903	264	0.559	0.0344

Logistic regression models that were linear in the parameters were fit to the data controlling for speed, impact site, and vehicle age within Standard status categories. The parameter estimates and their standard errors are given in the following:

PARAMETER ESTIMATES (STANDARD ERRORS) FOR THE LOGISTIC
REGRESSION ON FIRE RATES FOR THE VEHICLE AGE RANGE 4-9

Effect (Parameter β)	Estimate ($\hat{\beta}$)	Standard Error (s)
Mean (β_1)	-6.396	0.266*
Standard (β_2)	0.251	0.143†
Front-unspecified impact (β_3)	-0.389	0.099*
Side-unspecified impact (β_4)	-0.496	0.124*
Rear-unspecified impact (β_5)	-0.243	0.143†
Speed (β_6)	-1.548	0.134*
Vehicle age (β_7)	0.033	0.045†

*Significant at α = 0.01
†Not significant at α = 0.05

From the estimate of the effect of the Standard ($\hat{\beta}$ = 0.251), it is seen that the adjusted effectiveness estimate is -0.28 with a standard error of 0.143 as compared to a crude effectiveness estimate of -0.025 with a standard error of 0.095 (calculated from the former table). Clearly, the first version of FMVSS 301 was not effective in reducing the likelihood of post-crash fires in Post-Standard cars.

It is of interest to note that vehicle age did not have significant effect on $\hat{r}$ (the predicted post-crash fire rate) for the case with comparable age ranges but it was significant for the unrestricted vehicle age range (0-13 years). Thus, it was even more essential to limit the study population to the 4-9 year old cars.

Several caveats should be considered with respect to the analysis of the North Carolina narrative data. There are potential non-sampling errors arising from the following sources:

(i) Use of police accident narratives. It is likely that the magnitude of the problem of post-crash fire is underestimated either due to the police failing to mention it in the narrative or to the researcher failing to utilize all the relevant key search words. However, it is not likely that this would differentially occur for the Pre- or Post-Standard cars and thus should not affect the corresponding comparisons.

(ii) Uncontrolled confounding factors. The post-crash fire sample size precluded simultaneously controlling for more than a few confounding factors. The ones utilized were selected by variable screening but it is conceivable that other factors such as "cars with catalytic converters" might have been important to control for.

(iii) Definition of variables. With categorical data, the selection of variable levels can be important such as "speed < 50 mph." An alternative definition (e.g., "speed $\leq$ 55 mph") could possibly have led to different results.

(iv) Exclusion of the oldest cars. The exclusion of pre- 1965 model cars was done to try to minimize any potential age effects. In so doing, the excluded cars were at least seven years old and, on average, much older.

Notwithstanding these caveats, it is apparent that the first version of FMVSS 301 did not have the desired effect of decreasing the post-crash fire rates in Post-Standard cars involved in crashes in North Carolina.

ACKNOWLEDGMENTS

The work being performed by CEM and HSRC in statistically evaluating the effectiveness of seven Federal Motor Vehicle Safety Standards is the product of an interdisciplinary team effort. Under subcontract to CEM, HSRC has principal responsibility for the evaluation of three Standards. Dr. Donald Reinfurt of HSRC had principal responsibility for the overall preparation of this report. Dr. Donald Reinfurt is also Principal Scientist in charge of all work performed by HSRC. Dr. Gaylord Northrop of CEM is Principal Investigator for the study. We wish to gratefully acknowledge the other Study Team members who made contributions to this report. They are:

HSRC	CEM
Dr. George Chi	Ms. Kayla Costenoble
Mr. Amitabh Dutt	Mr. Joseph Reidy
Dr. Richard Stewart	Dr. Hans Joksch
Ms. Jane Stutts	
Ms. Anita Leung	

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ABBREVIATIONS USED

AIS	Abbreviated Injury Scale
CEM	The Center for the Environment and Man, Inc.
FMVSS	Federal Motor Vehicle Safety Standard
GVWR	Gross Vehicle Weight Range
HSRC	Highway Safety Research Center
MDAI	Multidisciplinary Accident Investigation
NASS	National Accident Sampling System
NCA	North Carolina Accident
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
OIC	Occupant Injury Classification
RSEP	Restraint Systems Evaluation Program

1.0 INTRODUCTION

1.1 Background

This report is the seventh in a series of final reports on the statistical evaluation of the effectiveness of seven Federal Motor Vehicle Safety Standards (FMVSS). This work is being conducted under Contract DOT-HS-8-02014, by The Center for the Environment and Man, Inc. (CEM) and its subcontractor, the Highway Safety Research Center (HSRC) of the University of North Carolina. The seven Standards to be statistically evaluated are:

- FMVSS 108: Side Marker Lamps (only)
- FMVSS 202: Head Restraints
- FMVSS 207: Seat Back Locks (only)
- FMVSS 213: Child Seating Systems
- FMVSS 214: Side Door Beams
- FMVSS 222: School Bus Seating and Crash Protection
- FMVSS 301: Fuel System Integrity

The final results from the analysis of the effectiveness of FMVSS 301 (Fuel System Integrity) are presented in this report.

Since its introduction in 1968, the Fuel System Integrity Standard has been modified several times, increasing the difficulty of meeting the test criteria (see Table 1.1). For example, the static rollover test was first proposed in 1973 for the 1976 models; that test criterion was temporarily suspended, while new test criteria were considered. The 1976 models had to meet the frontal crash and static rollover requirements. The 1977 models had to meet front, side, and rear barrier as well as static rollover crash requirements. Vehicles in the 6,000 to 10,000 pound Gross Vehicle Weight Range (GVWR) such as vans or pickups had to meet the passenger car requirements by the 1978 model year.

FMVSS 301 is a death-and-injury reduction Standard which should result from decreased rupturing of the vehicle's fuel system (including the fuel tank, filler system, vent line and fuel lines to the carburetor, fuel pump, and fuel filter) which, in turn, would imply decreased fuel spillage with a corresponding reduction in vehicle fires (which require fuel, an ignition source, and oxygen).

The current status of the Standard is such that the following requirements must be met:

- In the barrier tests for fuel spillage, the vehicle must not lose more than:
  - One ounce by weight during the crash;
  - Five ounces during the next five minutes after the crash;
  - One ounce in any one minute period during the next twenty-five minutes.

TABLE 1-1

APPLICABILITY OF THE STANDARD BY MODEL YEAR

Model Year	Fuel System Integrity Requirements Set by FMVSS 301*
Pre-1968	● No requirements
1968	● Front barrier crash (30 mph) and limited leakage from fuel tank, filler pipes, and fuel tank connections during impact (one ounce) and after impact (one ounce per minute). Effective January 1, 1968.
1971	● In response to air pollution control legislation, auto manufacturers installed evaporative emission-control systems increasing fuel system elements.
1976	● Passenger cars must meet front barrier impact and static rollover test.
1977	● Side and rear barrier impact tests are added to passenger car requirements.
	● Other vehicles up to 6,000 pounds GVWR must meet 1976 pasenger car conditions plus the rear impact test.
	● 6,000 to 10,000 pound GVWR vehicles must meet only the front barrier test.
1978	● All vehicles up to 10,000 pounds GVWR must meet the 1977 passenger car requirements.

* The 1976 modifications were announced in 1973 and manufacturers had considerable lead time to introduce improvements in pre-1976 models in anticipation of the effective date of the Standard. However, there is no evidence to date that manufacturers took advantage of that lead time.

- In the rollover test, fuel spillage is limited to five ounces in the first five minutes at any 90 degree increment or more, and is limited to no more than one ounce during any subsequent one minute period while the vehicle is at rest.
- Currently, passenger cars (1977 model and newer) must undergo 30 mph front barrier and rear moving barrier crashes, a 20 mph lateral moving barrier crash and a static rollover.
- The 1977 model year multipurpose vehicles of less than 6,000 lb. GVWR must undergo only the perpendicular front barrier crash, the rear moving barrier crash, and the static rollover. The 1978 models must meet the current passenger car criteria.

- The 1977 multipurpose vehicles of between 6,000 and 10,000 lb. GVWR must meet the perpendicular front barrier crash criteria. The 1978 models must meet the current passenger car criteria.
- School buses, which are 10,000 lb. GVWR or greater, have to meet a special moving contoured-barrier crash test starting July 15, 1976. The evaluation of the effectiveness of this Standard with regard to these school buses is not within the scope of this project.

The static rollover test occurs after an impact test. The vehicle is rotated about its longitudinal axis in 90 degree increments. Each incremental rotation should take between one and three minutes and the vehicle should remain in each position for five minutes.

A variety of integrated approaches for complying with the requirements of FMVSS 301 have been recommended. The mechanism of compliance involves all of the following:

- <u>Fuel Tank Location</u>. For a front-engine vehicle the most protective location would be the area between the rear wheels above the rear axle and below the rear window. The regions close to the rear fender or either side of the car are more vulnerable to rear end or side impacts. (Mercedes and the VW Dasher have protected or interior fuel tanks, as do many U.S. station wagons.)
- <u>Fuel Tank Material and Shape</u>. Horizontally aligned rectangular flat tank configurations with smoothed contours and corners offer the least hazardous design. The strength of tank walls should take into account fuel capacity and size of car. Alternatives to rigid metal construction include plastic fuel tanks and expandable tanks with corrugated folds which permit altering the geometric shape of the tank.
- <u>Fuel Tank Anchorage</u>. The straps and anchor points for the tank must be sufficiently strong to withstand extreme distortion and inertial forces associated with impact.
- <u>Filler System</u>. In general, the protrusion of the filler neck from the tank should be as short as possible, consistent with the location of the tank. The major change that manufacturers made to initially satisfy the Standard was to upgrade the filler tank cap. Self-sealing breakaway type fittings have been suggested for the filler system and the other outlets from the fuel tank. The vapor vents have float valves to prevent fuel leakage but these could be defeated in rollover accidents.
- <u>Vent Line and Fuel Line</u>. As mentioned above, it has been suggested that all fittings to the fuel tank be of a self-sealing breakaway type. In addition, the location, length, flexibility and strength of the vent and fuel lines all affect the possibility of rupture and fuel leakage.
- <u>Carburetor/Fuel Pump/Fuel Filter Locations</u>. The location of these components in the front end relative to other systems will influence successful compliance with front or lateral moving side barrier tests.

1.2 Objective and Purpose

The initial objectives of this analysis were to: (1) study the nature and magnitude of the fuel spillage problem resulting from the rupturing of some portion(s) of the fuel system; and (2) examine characteristics of post-crash fires to contrast the relative frequency and severity of Pre-Standard (model year 1967 and earlier) vehicle fires with those of Pre-Standard (1969 and later years) vehicles. As significant strengthening of the Standard applied to 1976 and later model vehicles, some limited attention is devoted to this cohort of vehicles.

The primary data source available for analysis is the North Carolina mass accident data for calendar years mid-1971 through 1978 (especially as the study pertains to police narratives indicating post-crash fires). Supplementing this set of police-level data is the recently-collected National Crash Severity Study (NCSS) data, which is intermediate in quality and detail between police-level data and that collected by in-depth accident investigation teams.

The original overall purpose of the evaluation was to contrast the magnitude of fuel spillage and/or vehicle fires in Pre- and Post-Standard vehicles. The analyses carried out in this study focus on difference in post-crash fire rate for Pre- vs. Post-Standard Vehicles.

1.3 Scope

Using the available 10,851 cases on the NCSS file, the analysis of FMVSS 301 was limited to a detailed descriptive analysis of the 109 cars involved with post-crash fires. Due to problems involved with obtaining data on fuel leakage, the indicated 189 cars with fuel leakage could not be assumed representative of the population of cars in crashes with fuel leakage and thus were not considered appropriate for analysis.

Although lacking in injury detail, mass accident data from North Carolina for calendar years mid-1971 through 1978 were examined using a narrative search capability to derive estimates of post-crash fires rates for the following variables;

> overall, Pre- and Post-Standard model year groups, age of vehicle, size of vehicle, impact site, accident configuration (including rollovers), accident speed, driver injury

as well as certain rates controlling for age of vehicles at time of accident.

Investigation of the fuel spillage aspect of FMVSS 301 was not feasible using the North Carolina mass accident data.

This Final Report on FMVSS 301 concentrates on investigating differences between post-crash fire rates in the Pre- and Post-Standard vehicles using primarily North Carolina mass accident data where the former includes 1965-67 model year cars while the latter includes 1969-75 models. Differences across each of the previously mentioned variables (e.g., vehicle size, vehicle age, crash configuration) for the Pre- and Post-Standard cars are presented. The extent to which FMVSS 301 can be evaluated using the NCSS file is discussed.

1.4 Approach

1.4.1 Data Sources

In general, fire and/or fuel spillage are relatively rare events in motor vehicle collisions (Cooley, 1974). As such, even the occurrence of a vehicle fire is rarely captured in police-level data other than most likely in the officer's narrative description. Fuel spillage would not be reported in police-level data unless it was spectacular and was reported in the officer's narrative description. In addition, the detail of injury information provided by police makes this potential data source less-than-ideal for evaluating the effectiveness of most of the components of FMVSS 301.

Of all the candidate data sources for evaluating the effectiveness of this Standard, the recently-collected NCSS data appeared to offer the most promise. The NCSS was a multi-year effort which began in October 1976, and continued through March 1979. The goal was to collect Level 2-type (or intermediate-level) accident investigation data on over 10,000 towaway accidents. This accident data was collected by seven NHTSA-sponsored organizations in eight locations: Western New York (CALSPAN), Michigan (HSRI), Miami (University of Miami), San Antonio, Texas (SwRI), thirteen other counties in Texas (SwRI), Kentucky (University of Kentucky), Indiana (University of Indiana), and Los Angeles, California (Dynamic Sciences).

The composite of these areas has an urbanization distribution closely representing that of the entire United States with the areas widely distributed across the nation. However, as the sample is purposive rather than random, extrapolations to national totals or rates must be viewed with caution.

The data base represents a stratified probability sample of police-reported towaway accidents (i.e., at least one automobile was not drivable and hence was towed from the scene) where, for each area, the sampling frame represents approximately 10,000 accidents annually. The sampling criteria results in the following three strata:

(i) 100 percent of those accidents involving the transport to a treatment facility and overnight hospitalization or death of at least one towaway-involved automobile occupant;

(ii) A 25 percent systematic random sample of accidents which involved transport of at least one towaway-involved automobile occupant to a treatment facility but not overnight hospitalization; and

(iii) A 10 percent systematic random sample of all other police-reported towaway accidents (where at least one car was not drivable).

To the extent obtainable, each case contains information on all vehicles and occupants involved in the accident. For the "applicable" or case car(s) which is any towed (i.e., non-drivable) automobile involved in an accident meeting one of the sampling criteria, there is maximum information which includes the following reports (when appropriate):

Police	Seat Performance
Environmental	Fire (see Figure 1-1)
Off-Road Object Struck	Rollover
Vehicle	Interview
Side Structure	Medical and Surgical Procedures
Passenger Compartment Intrusion	Overall Summary Report

Variables from the summary report and from the subsequently computerized fire supplement constitute the master file of 10,851 NCSS cases that were available for this analysis.

The North Carolina mass accident data contains information on over 130,000 police-reported highway crashes annually. The reporting threshold in North Carolina is a minimum of $200 property damage and/or personal injury. The information is reported on a standard form used statewide (see Figure 1-2). What made this data source appealing as an additional data source is the fact that nearly all police narratives have been computerized since mid-1971. Although it is expected that the officer may not observe fuel spillage --- much less describe it in the narrative --- it is felt that he will report the occurrence of motor vehicle fires (both pre- and post-crash) in his narrative describing what happened in the accident. It is this premise on which examination of North Carolina mass accident data was carried out. The fact that the overall post-crash fire rates for the North Carolina data resemble those reported by Cooley (1974) tends to lend support to that premise.

(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		
Gasoline	1	1
Diesel	2	2
Other (Specify ____________)	3	3
Combinations (Specify ____________)	4	4
Not Applicable	8	8
Unknown	9	9
LOCATION OF LEAK		
Engine Compartment		
Unknown Location	01	01
Carburator	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		
Fuel Leakage	1	1
Electrical Short	2	2
Other Vehicle	3	3

FIRE SOURCE (Con't.)	Veh. 1	Veh. 2
Other (Specify ____________)	4	4
Not Applicable		8
Unknown	9	9
FIRE ORIGIN		
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		
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?		
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9
WAS FIRE EXTINGUISHED?		
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9
DID VEH. OCCUPANT SUSTAIN BURN INJURIES?		
Yes	1	1
No	2	2
Not Applicable		8
Unknown	9	9

Figure 1-1

FUEL LEAKAGE/FIRE HAZARD SUPPLEMENT FOR NCSS CASES PRIOR TO APRIL 1, 1978. (THE REVISED FORM USED AFTER THIS DATE IS SO LENGTHY THAT IT IS NOT INCLUDED HEREIN.)

In filling out these items on the back use the following examples:

1. LOCALITY
   1. Business
   2. Residential
   3. School & playground
   4. Open country
2. SPEED LIMIT
3. ROAD FEATURE
   1. Bridge or underpass
   2. Driveway
   3. Alley intersection
   4. Intersection of two roadways
   5. Non-intersection median crossover
   6. End or beginning of divided highway
   7. Other
4. ROAD SURFACE
   1. Concrete
   2. Smooth asphalt
   3. Coarse asphalt
   4. Gravel
   5. Dirt or sand
   6. Other
5. ROAD DEFECTS
   1. Loose material on surface
   2. Holes, deep ruts
   3. Low shoulders
   4. Soft shoulders
   5. Other defects
   6. Road under construction
   7. No defects
6. ROAD CONDITION
   1. Dry
   2. Wet
   3. Oily
   4. Muddy
   5. Snowy
   6. Icy
7. LIGHT CONDITION
   1. Daylight
   2. Dusk
   3. Dawn
   4. Darkness (street lighted)
   5. Darkness (street not lighted)
8. WEATHER
   1. Clear
   2. Cloudy
   3. Raining
   4. Snowing
   5. Fog
   6. Sleet or hail
9. TRAFFIC CONTROL
   1. Stop sign
   2. Yield sign
   3. Stop and go signal
   4. Flashing signal with stop sign
   5. Flashing signal without stop sign
   6. R. R gate and flasher
   7. R. R. flasher
   8. Officer
   9. Other device
   10. No control present
10. OBJECT STRUCK (first only)
   1. Tree
   2. Utility pole
   3. Fence or fence post
   4. Guardrail or guardpost in median
   5. Guardrail or guardpost on shoulder
   6. Bridge
   7. Underpass
   8. Traffic island, curb, or median
   9. Sign or sign post
   10. Animal
   11. Ditch bank
   12. Parked vehicle
   13. Pedestrian
   14. Other object
   15. None
11. SOBRIETY
   1. Had not been drinking
   2. Drinking-ability impaired
   3. Drinking-unable to determine impairment
   4. Unknown
12. PHYSICAL CONDITION
   1. Ill
   2. Fatigued
   3. Asleep
   4. Other physical impairment
   5. Restriction not complied with
   6. Normal
   7. Condition not known
13. CHEMICAL TEST
14. PEDESTRIAN ACTION
   1. Crossing at intersection
   2. Crossing not at intersection
   3. Coming from behind parked vehicle
   4. Walking with traffic
   5. Walking against traffic
   6. Getting on or off vehicle
   7. Standing in road
   8. Working in road
   9. Playing in road
   10. Lying in road
   11. Other
   12. Not in road
15. VEHICLE MANEUVER
   1. Stopped in travel lane
   2. Parked out of travel lanes
   3. Parked in travel lanes
   4. Going straight ahead
   5. Changing lanes or merging
   6. Passing
   7. Making right turn
   8. Making left turn
   9. Making U turn
   10. Backing
   11. Slowing or stopping
   12. Starting in roadway
   13. Parking
   14. Leaving parked position
   15. Other
16. VEHICLE DEFECTS (List one or more)
   1. Defective brakes
   2. Defective headlights
   3. Defective rear lights
   4. Defective steering
   5. Defective tires
   6. Other defects
   7. Not known if defective
   8. No defects detected

DMV-349 (Rev. 11/15/76)

TRAFFIC ACCIDENT REPORT
N. C. Division of Motor Vehicles
MAIL – Raleigh, N. C. 27611

LOCATION

Date of Accident ______ 19 ___ Day of Week ______ Hour ______ A.M. ☐ P.M. ☐

Do not write in this space

Accident Occurred In ______ County ☐ In ☐ Near City or Town of ______

Outside City or Town ______ Miles ☐ ☐ ☐ ☐ (N E S W) of ☐ Limits ☐ Center

Patrol Area

On ______
Hwy. No. (I., U.S., N.C., R.P., R.U.) If No., or within corporate limits, identify by name

☐ Miles ☐ Feet ☐ ☐ ☐ ☐ (N E S W) At or From ______ Toward ______
(0 Ft. if Intersec.) Hwy. No., or Adjacent County Line — Hwy. No., City, or Adjacent County Line

ACCIDENT TYPE

Ran off Road			Non-Collision in Road		Collision of Motor Vehicle in Road With:						
1. Right	2. Left	3. Straight Ahead	4. Overturn	5. Other in Road	6. Pedestrian	7. Parked Vehicle	8. Train	9. Bicycle	10. Animal	11. Fixed Obj.	12. Other Obj.

Collision of M.V. in Road With Another M. V.									
13. Rear End Slow or Stop	14. Rear End Turn	15. Left Turn Same Roadway	16. Left Turn Cross Traffic	17. Right Turn Same Roadway	18. Right Turn Cross Traffic	19. Head On	20. Sideswipe	21. Angle	22. Backing

No. of Vehicles Involved ☐

VEHICLE NO. 1

Driver: ______ (*First* / *Middle* / *Last Name*)
Address: ______
City: ______ State ______ Zip Code ______
Is above address same as on Driver's License? Yes ☐ No ☐
Race/Sex: ______ Driver's Lic: ______ State: ______
Date of Birth: ______ (Month Day Year) Specify Restriction: ______
Member of Armed Forces Yes ☐ No ☐ Veh. Year: ______ Veh. Make: ______ Veh. Type: ______
Lic. Plate No. ______ State: ______ Year: ______
VIN ______ ODOM. ______
Owner: ______
Address: ______
City: ______ State: ______ Zip Code: ______
Parts Damaged (TAD) ______ Amount of Damage $ ______
Vehicle Drivable: Yes ☐ No ☐
Removed to: ______
Address: ______
By: ______ Authority: ______

VEHICLE NO. 2 or PEDESTRIAN

Driver: ______ (*First* / *Middle* / *Last Name*)
Address: ______
City: ______ State: ______ Zip Code ______
Is above address same as on Driver's License? Yes ☐ No ☐
Race/Sex: ______ Driver's Lic. ______ State: ______
Date of Birth: ______ (Month Day Year) Specify Restriction: ______
Member of Armed Forces Yes ☐ No ☐ Veh. Year: ______ Veh. Make: ______ Veh. Type: ______
Lic. Plate No. ______ State ______ Year: ______
VIN ______ ODOM. ______
Owner: ______
Address: ______
City: ______ State: ______ Zip Code: ______
Parts Damaged (TAD) ______ Amount of Damage $ ______
Vehicle Drivable: Yes ☐ No ☐
Removed to: ______
Address: ______
By: ______ Authority: ______

Other Property Damaged ______ Amt. of Dam. $ ______ Owner and Address ______

INJURY SECTION INSTRUCTIONS

Give injury class, restraint used, race, sex and age of all occupants in the space corresponding to the seat occupied. Names and addresses are necessary for persons who were injured. For type of Restraint (Res.) used. N – None, L – Lap Belt, LS – Lap and Shoulder, S – Shoulder Belt only, YR – Child Restraint System.

K=Killed	A=Incapacitating	B=Nonincapacitating – Injury other than K or A evident at the scene	C=No visible sign of injury but complaint of pain, momentary unconsciousness	O=No injury

SEAT	Inj cl	Res usd	Race sex	Age	INJURED NAMES AND ADDRESSES (First Name / Last)	SEAT	Inj cl	Res usd	Race sex	Age	INJURED NAMES AND ADDRESSES (First Name / Last)
Left Front					DRIVER 1	Left Front					DRIVER 2 OR PEDESTRIAN
Center Front						Center Front					
Right Front						Right Front					
Left Rear						Left Rear					
Center Rear						Center Rear					
Right Rear						Right Rear					
Total No. Occupants					Total No. Inj.	Total No. Occupants					Total No. Inj.

Injured taken to: ______

WITNESSES Name ______ Address ______ Phone No. ______
Name ______ Address ______ Phone No. ______

Arrests: Name ______ Charge(s) ______ (Cit. No.) ______
Name ______ Charge(s) ______ (Cit. No.) ______

Sign Here ______
Officer's Rank and Name — Number — Department — Date of Report

ADDED BY ______ (Initial)

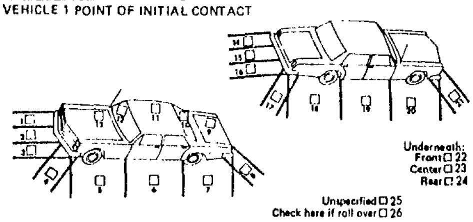
MARKS

Figure 1-2. NORTH CAROLINA ACCIDENT REPORT FORM (FRONT SIDE).

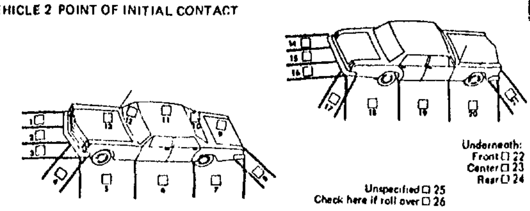
In filling out these items on the back use the following examples:

1. LOCALITY
   1. Business
   2. Residential
   3. School & playground
   4. Open country
2. SPEED LIMIT
3. ROAD FEATURE
   1. Bridge or underpass
   2. Driveway
   3. Alley intersection
   4. *Intersection of two roadways*
   5. Non-intersection median crossover
   6. End or beginning of divided highway
   7. Other
4. ROAD SURFACE
   1. Concrete
   2. Smooth asphalt
   3. Coarse asphalt
   4. Gravel
   5. Dirt or sand
   6. Other
5. ROAD DEFECTS
   1. Loose material on surface
   2. Holes, deep ruts
   3. Low shoulders
   4. Soft shoulders
   5. Other defects
   6. Road under construction
   7. No defects
6. *ROAD CONDITION*
   1. Dry
   2. Wet
   3. Oily
   4. Muddy
   5. Snowy
   6. Icy
7. LIGHT CONDITION
   1. Daylight
   2. Dusk
   3. Dawn
   4. Darkness (street lighted)
   5. Darkness (street not lighted)
8. WEATHER
   1. Clear
   2. Cloudy
   3. Raining
   4. Snowing
   5. Fog
   6. Sleet or hail
9. TRAFFIC CONTROL
   1. Stop sign
   2. Yield sign
   3. *Stop and go signal*
   4. Flashing signal with stop sign
   5. Flashing signal without stop sign
   6. R. R. gate and flasher
   7. R. R. flasher
   8. Officer
   9. Other device
   10. No control present
10. OBJECT STRUCK (first only)
    1. Tree
    2. Utility pole
    3. Fence or fence post
    4. *Guardrail or guardpost in median*
    5. Guardrail or guardpost on shoulder
    6. Bridge
    7. Underpass
    8. Traffic island, curb, or median
    9. Sign or sign post
    10. Animal
    11. *Ditch bank*
    12. Parked vehicle
    13. Pedestrian
    14. Other object
    15. None
11. SOBRIETY
    1. Had not been drinking
    2. Drinking-ability impaired
    3. Drinking-unable to determine impairment
    4. Unknown
12. PHYSICAL CONDITION
    1. Ill
    2. Fatigued
    3. Asleep
    4. Other physical impairment
    5. Restriction not complied with
    6. Normal
    7. Condition not known
13. CHEMICAL TEST
14. PEDESTRIAN ACTION
    1. Crossing at intersection
    2. Crossing not at intersection
    3. *Coming from behind parked vehicle*
    4. Walking with traffic
    5. Walking against traffic
    6. Getting on or off vehicle
    7. Standing in road
    8. Working in road
    9. Playing in road
    10. Lying in road
    11. Other
    12. Not in road
15. VEHICLE MANEUVER
    1. Stopped in travel lane
    2. Parked out of travel lanes
    3. Parked in travel lanes
    4. Going straight ahead
    5. Changing lanes or merging
    6. Passing
    7. Making right turn
    8. Making left turn
    9. Making U turn
    10. Backing
    11. Slowing or stopping
    12. Starting in roadway
    13. *Parking*
    14. Leaving parked position
    15. Other
16. VEHICLE DEFECTS (List one or more)
    1. Defective brakes
    2. Defective headlights
    3. Defective rear lights
    4. Defective steering
    5. Defective tires
    6. Other defects
    7. Not known if defective
    8. No defects detected

VEHICLE 1 POINT OF INITIAL CONTACT



VEHICLE 2 POINT OF INITIAL CONTACT



1. Locality	9. Traffic Control	Not Operating ☐	Not Visible ☐		VEHICLE 1	VEHICLE 2
2. Speed Limit		DRIVER 1	DRIVER 2 or PED.	15. Veh. Maneuver		
3. Road Feature	10. Object Struck			16. Veh. Defects		
4. Road Surface	11. Sobriety			17. Estimated Speed		
5. Road Defects	12. Physical Cond.			18. Tire Impressions(ft)		
6. Road Condition	13. Chem. Test	YES ☐ NO ☐	YES ☐ NO ☐	19. Distance Traveled After Impact (ft.)		
7. Light Condition						
8. Weather	14. Ped. Action					

INDICATE NORTH

Vehicle 1 was Traveling ☐ N ☐ E ☐ S ☐ W on

Vehicle 2 was Traveling ☐ N ☐ E ☐ S ☐ W on

DESCRIBE WHAT HAPPENED:

Vehicle 1	2	VIOLATION INDICATED
☐	☐	1. No. Violation Indicated
☐	☐	2. Excessive Speed
☐	☐	3. Yield Violation
☐	☐	4. Left of Center
☐	☐	5. Passing Violation
☐	☐	6. Stop S. or Yield S. Vio.
☐	☐	7. Traffic Signal Vio.
☐	☐	8. Safe Movement Vio.
☐	☐	9. Too Close
☐	☐	10. Improper Turn
☐	☐	11. Improper or No Signal
☐	☐	12. Improper Parking Location
☐	☐	13. Other Improper Driving

(describe) ______

EMERGENCY ASSISTANCE INFORMATION

INVESTIGATOR NOTIFIED ______ ☐ a.m. ☐ p.m.
BY ______

INVESTIGATOR ARRIVED ______ ☐ a.m. ☐ p.m.

AMBULANCE ARRIVED ______ ☐ a.m. ☐ p.m.

OTHER COMMENTS: ______

RESERVED FOR STATE USE:

	DRIVER 1		DRIVER 2	
20. Direction		21. Direction		26.
22. Charge		23. Charge		27.
24. Misc. Action		25. Misc. Action		28.

RESERVED FOR CITY OR OTHER USE:

Figure 1-2. NORTH CAROLINA ACCIDENT REPORT FORM (REVERSE SIDE)

1.4.2 Statistical Analyses

1.4.2.1 NCSS data. After the NCSS file of 10,851 towaway crashes was converted into an SPSS-processable file including the ability to weigh the sample according to the inverse of the sampling proportions, a code book of the major variables of interest (e.g., presence of spillage/fire supplement, Pre and Post-Standard cars, crash configuration, impact site, ΔV, vehicle age) was generated.

From this initial code book, problems with missing data, consistency across teams, and incidence of fuel spillage and/or fire in passenger cars were examined. It was from these initial runs that it became obvious that no adequate statistical analysis of the NCSS data could be carried out to appropriately evaluate any of the components of FMVSS 301. The most that could reasonably be done was to estimate an overall post-crash fire rate and its standard error for the weighed sample of towaway crshes from the eight geographic areas represented by the sampling frame. Additionally, various detailed descriptive comparisons could be made between those 109 cars with post-crash fires and the remaining 16,501 cars that did not catch on fire after the crash.

The question of the incidence of fuel spillage (189 vehicles), let alone the rate of spillage after the crash (e.g., ounces per minute), could not begin to be addressed because of obvious underreporting along with reporting biases and lack of detail in the reports. The available literature suggests that for every post-crash fire case there are about 10 cases with fuel spillage. The observed underreporting of fuel spillage was probably due mainly to notification and subsequent investigation time delays. At that point, the evidence generally had disappeared.

With respect to post-crash fires, the small sample size (N = 109) precluded subdividing the data according to combinations of variables that would be necessary for analysis (e.g., by model year, ΔV (or an appropriate proxy measure), and crash configuration and/or impact site, with age of vehicle being an important variable to control for).

Secondly, there was a problem with missing data. For example, for the 109 post-crash fire cases there were damage and trajectory ΔV's calculated for only 11 cars. The information required for calculating ΔV from the CRASH program was just not available. Similar problems exist for the entire file but not as seriously. Another critical variable which is missing in approximately 43 percent of the post-crash fire cases is the detailed medical information.

Therefore, even if there had been many more post-crash fire cases, estimating injury and death reduction based on a file lacking the necessary detailed injury information would be tenuous at best.

Finally, the initial codebook suggests various biases in the data. For example, Table A-2 in Appendix A provides the distribution of fire supplement submission by investigation team. For those teams with essentially urban sampling frames (namely, Miami and Dynamic Sciences), it would be expected that the rates of post-crash fires would be fairly comparable. However, using the weighted file to provide a picture of all towaway crashes in these areas, the respective rates are 0.12 percent and 0.67 percent. Likewise comparing, for example, the rural areas covered by the University of Indiana and the University of Kentucky, the respective rates are 0.75 percent and 0.43 percent. Whatever the reasons for the differences, they do suggest caution in using the pooled NCSS data for FMVSS 301 evaluation even if there were sufficiently many cases to analyze.

The upshot of these findings is that the NCSS data was able to provide crude (weighted and unweighted) estimates of post-crash fire rates for Pre- and Post-Standard cars along with a detailed descriptive investigation of the 109 individual cars involved with post-crash fires.

1.4.2.2 Mass accident data from North Carolina. At the outset, it was expected that very little information could be obtained from Level 1 or police-reported accident data with respect to either fuel leakage or post-crash fires and subsequent injuries and deaths. However, because of a narrative search procedure developed to scan police accident narratives, the North Carolina mass accident data became the most useful of any data available to investigate differences in Pre- and Post-Standard vehicle fire rates overall and within certain accident subsets such as rear-end crashes, frontals, rollovers, crash speed categories, etc.

As the Standard is an injury reduction rather than an accident prevention standard, rates based on all cars involved in similar crashes are the most meaningful criterion measures. Thus, the denominators of the rates consist of all cars meeting the crash circumstances encountered by the numerator cases which are those cars involved in post-crash fires.

As indicated elsewhere, Level 1 injury data is generally deficient in detail. For example, in North Carolina it cannot be determined from the crash report that an occupant that was killed in a burning vehicle received even minor burns. It is entirely possible that he died from striking an interior object in the vehicle and the fire had nothing to do with his death. Thus, the injury and death reduction attributable to FMVSS 301 cannot be determined from the mass accident data from North Carolina. The best that can be done is to compare driver injury for the vehicles with post-crash fires with those that escape without a fire. However, this can do no more than suggest differences in injury and death rates in the fire vs. the non-fire cases without being able to determine the actual causes.

Briefly, the narratives for nearly 917,000 accidents involving passenger cars occurring in North Carolina during the years mid-1971 through 1978 were read by the computer to select those cases involving "fire". From the 5778 narratives containing the pre-selected search words (i.e., caught*fire, burn, flame, fire, explode), those 1635 (reportable) cases involving cars in pre-crash fires (e.g., fires started by the driver dropping a lit cigarette) and those 3499 cases clearly not fire-involved (e.g., car hit a fire hydrant) were deleted from the "post-crash fire" narrative file. This yielded an eventual file of 644 cars in post-crash fires with information on accident year, model year, size, speed, impact region, etc. Section 4 details additional screening necessary to make valid comparisons between the 1965-67 and the 1969-75 model cars in post-crash fires.

With this screening completed, the various post-crash fire rates for Pre- and Post-Standard vehicles were calculated, crude effectiveness rates of FMVSS 301 in reducing post-crash fires derived, and corresponding confidence limits presented. As significance was attained, control variables were selected and then effectiveness estimates and their standard errors obtained using weighted least squares procedures for categorical data.

1.5 Limitations of the Study

Based on previous work with two NHTSA-sponsored Level 2 accident investigation programs (namely, the Restraint Systems Evaluation Program (RSEP) and the National Crash Severity Study (NCSS)) and due to the rarity of the phenomena under study (fuel spillage and/or vehicle fires), the current investigation of NCSS data was not necessarily expected to provide a statistically sound evaluation of the death and injury reduction effectiveness of FMVSS 301. Of the 10,851 cases on the available file, there were fuel leakage/fire hazard supplements submitted for 239 cars. Of these there were fuel spillage supplements for some 189 cars, while for 109 cars post-crash fires were indicated. Obviously the majority of supplements indicated both fuel leakage and fire, but there were a minority of cases where there was fuel leakage but no fire or vice versa.

The literature suggests that fuel leakage is approximately ten-fold as prevalent as post-crash fires. Clearly this is not the case with this file. Due to the notification delay of a towaway crash occurring and the additional dealy of locating the vehicle which has generally been removed from the scene, it would be expected that evidence of fuel spillage (e.g., odor, obvious reservoirs of gasoline) would be lacking. It is clear that there is an underreporting of fuel spillage with reporting biases highly suspect. Thus, it certainly is not reasonable to investigate even the prevalence of fuel spillage in the NCSS data (and obviously not in the mass accident data from North Carolina) let alone the question of the rate of spillage (e.g., one ounce per minute after impact).

With respect to the post-crash fire reduction expected from the Standard and its modifications, the most that could be done with 109 NCSS cases is a detailed descriptive analysis. Clearly no evaluation of the injury-reducing effectiveness of FMVSS 301 could be carried out as there were but 26 cars out of the 109 involved with post-crash fires in which the occupants sustained burn injuries.

The North Carolina mass accident data is primarily deficient in the level of injury detail provided by the investigating officer. From his report (see Figure 1-2) it is not possible to determine whether an occupant died of burn injuries caused by the post-crash fire or even if he sustained any burn injuries. Thus, this somewhat more plentiful data does not allow for estimation of occupant injury and death reduction attributable to FMVSS 301. It does provide perhaps the best estimates available of post-crash fire rate differences by model year and/or age of car along with a variety of other rates of interest.

1.6 Outline of the Report

The next portion of this report (Section 2) summarizes the results of the analyses that were carried out on FMVSS 301. It includes a description of the measure(s) of effectiveness; an overall measure of effectiveness in reducing post-crash fires along with approximate confidence intervals; an evaluation of these analyses with respect to the extent to which they constitute a complete analysis of the effectiveness of the Standard; recommended additional work in the evaluation of FVMSS 301; and results, conclusions, and recommendations. In short, it summarizes in detail the results of this investigation.

Section 3 presents results based on the 109 post-crash fire cases in the NCSS data file. The primary result is a detailed comparison of these fire cases (weighted and unweighted) with the non-fire cases on the same file.

Section 4 provides a description of the methodology utilized to examine post-crash fire incidence using mass accident data. Limitations imposed by the data are discussed. Comparisons of overall post-crash fire rates along with Standard effectiveness and corresponding confidence intervals are presented. As significance was found, control variables were selected and then effectiveness estimates and their standard errors obtained using logistic regression procedures.

Appendix A provides additional tables of NCSS (weighted and unweighted) post-crash fire comparisons while Appendix B provides model year by accident year data from the post-crash file for North Carolina accidents. Appendix C provides the most applicable data by study subpopulations (or strata).

1.7 References for Section 1

1. Cooley, P. *Fire in Motor Vehicle Accidents*, HSRI Special Report, Highway Safety Research Institute, Ann Arbor, Michigan, April 1974. (UM-HSRI-SA-74-3)

2. Northrop, G.M. *Evaluation Methodologies for Four Federal Motor Vehicle Safety Standards: FMVSS 214, 215, 301, 208.* Hartford Connecticut, The Center for the Environment and Man, Inc., May 1977. (DOT-HS-6-01518, CEM 4207-568).

3. Northrop, G.M. et al. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 301: Fuel System Integrity.* Hartford, Connecticut, The Center for the Environment and Man, Inc., May 1977. (DOT-HS-6-01518; CEM 4207-566).

4. Reinfurt, D.W. *CEM Report 4254-638: Work Plan for the Statistical Evaluation of the Effectiveness of FMVSS 301: Fuel System Integrity*, Highway Safety Reserach Center, Chapel Hill, North Carolina and The Center for the Environment and Man, Inc., Hartford, Connecticut, December 1978. (Contract DOT-HS-8-02014)

2.0 SUMMARY OF ANALYSES PERFORMED ON FMVSS 301

2.1 Measure(s) of Effectiveness

As indicated in Section 1.0, FMVSS 301 is a death and injury reduction standard which would be accomplished by a reduction in post-crash fires which, in turn, would result from reduced leakage in the fuel system (i.e., fuel tank, filler pipes, and fuel tank connections) during generally rather severe automobile crashes such as rollover accidents. The following measures would be required to fully evaluate the Standard:

- Fuel leakage occurrence and rate of leakage in the following: pre-1968, and post-1968 cars and post-1976 vehicles in the 6-10 thousand pound GVWR range in <u>frontal</u> crashes; pre-1976, and post-1975 cars in <u>rollover</u> crashes; pre-1977 and post-1976 cars in <u>side</u> and <u>rear</u> crashes and post-1976 vehicles in the 6-10 thousand pound GVWR range in <u>rear</u> impacts; and all 1978 vehicles up to 10 thousand pound GVWR in <u>frontal</u>, <u>side</u>, <u>rear</u> and <u>rollover</u> crashes;
- Post-crash fire rates for the above-defined Pre- and Post-Standard vehicles;
- Occupant injury and death rates for the same Pre- and Post-Standard vehicles attributable to post-crash fires.

Clearly, as stated in Section 1.0, no data sources exist with sufficient quantity and quality of data in these three areas. Hence, the analysis is limited to the following measure of effectiveness for FMVSS 301:

- Post-crash fire rates (per 1000 cars) for Pre-Standard (P) vs Post-Standard (S) cars where the model years included in these periods are:

  P : pre-1968 model years (i.e., 1965-67 for N.C.)
  S : post-1968 model years (i.e., 1969-75 for N.C.)

  For descriptive comparisons, the data is further examined for the following model-year cohorts:

  P : pre-1968 model years
  S_I : 1969 through 1975 model years
  S_{II}: post-1975 model years

  However, data limitations with respect to S_{II} require restricting any data analysis to S_I.

- The measure of effectiveness of FMVSS 301 in preventing post-crash fires is taken to be the difference in the post-crash fire rates for the Pre-Standard cars vs the Post-Standard cars relative to the post-crash fire rates for the Pre-Standard Cars. That is, the effectiveness of FMVSS 301 in reducing post-crash fires is estimated by

$$\hat{E} = \frac{\hat{r}_P - \hat{r}_S}{\hat{r}_P} \qquad (2.1)$$

where

$\hat{r}_P$ = rate (per 1000 cars) of post-crash fires in Pre-Standard cars

$\hat{r}_S$ = rate (per 1000 cars) of post-crash fires in Post-Standard cars

- Crude and adjusted effectiveness estimates are obtained along with 95 percent confidence intervals.

2.2 Estimated Effectiveness of FMVSS 301

2.2.1 Methods

There were, from the outset, two distinct data sets upon which to carry out the effectiveness analysis of FMVSS 301. The NCSS file consisted of detailed information (Level II) on 10,851 towaway crashes resulting in some 109 cars with post-crash fires and 189 cars with fuel-spillage.

The second data set consisted of police-reported (Level I) accident data for nearly 917,000 accidents occurring in North Carolina between mid-1971 and the end of 1978. From this file, although it was not possible to determine fuel leakage, there were 644 cars involved in post-crash fires where certain additional information was available, namely, model year, car size, speed, impact site, rollover vs non-rollover, and vehicle age (derived from mdoel year and accident year). The final file was somewhat smaller due to vehicle age comparability requirements.

From the (limited) NCSS data, overall crude post-crash fire rates are calculated for the unweighted and the weighted sample along with various rates within certain subsets of the data. From the more useful North Carolina accident data, crude and adjusted (for speed, impact site and vehicle age) effectiveness estimates are calculated along with the appropriate standard errors and associated confidence intervals.

Hence, Section 3.0 presents basically a descriptive analysis based on the NCSS data whereas Section 4.0 provides effectiveness estimates which have been adjusted for speed, impact site and vehicle age using, first, variable selection procedures to determine the relative importance of a number of control variables and secondly, logistic regression procedures which are not only particularly relevant for rare events like post-crash fires but also allow for a combination of categorical and continuous variables as is the case in this study.

2.2.2 Results

2.2.2.1 NCSS Data Excluding unknown model year (N_F = 4; $N_{\bar{F}}$ = number with no fire = 108) and also the 1968 (or Interim) model year (N_F = 5;

$N_{\bar{F}}$ = 910), the corresponding (crude) unweighted and weighted fire rates per 1000 are given by

Unweighted	Weighted
$\hat{r}_P = 6.22$	$\hat{r}_{P,W} = 2.67$
$\hat{r}_S = 6.49$	$\hat{r}_{S,W} = 2.63$
$\hat{r}_{S_I} = 6.29$	$\hat{r}_{S_I W} = 1.74$
$\hat{r}_{S_{II}} = 6.90$	$\hat{r}_{S_{II} W} = 2.81$

Without further investigation, there is clearly no indication of effectiveness of FMVSS 301 from this rather limited data set.

Of perhaps more interest are the post-crash fire rates within a number of vehicle and/or accident variables on the NCSS file. These rates are given in Table 2-1 for vehicle variables and in Table 2-2 for accident variables. To the extent the rates ($\hat{r}_W$) based on the weighted sample represent post-crash fire rates in the population of towed vehicles, these rates are also presented.

Table 2-1

POST-CRASH FIRE RATES (PER 1000 CARS)
BY CAR WEIGHT, AREA OF IMPACT, OBJECT,
STRUCK, AND DRIVER OVERALL AIS

VARIABLE	$\hat{r}$	$\hat{r}_W$	VARIABLE	$\hat{r}$	$\hat{r}_W$
Car Weight			Object Struck		
2000-	7.66	2.42	Other Car	3.86	1.16
2000-2699	6.01	2.88	Truck	12.55	3.82
2700-3299	6.60	3.13	Other Vehicle	0.00	0.00
3300-3899	6.98	2.07	Fixed Object	13.28	4.65
3900+	7.48	1.91	Other Object	11.29	8.56
Area of Impact			Driver Overall AIS		
Front	6.98	2.33	No Injury	1.59	1.05
Side	5.88	1.26	Minor, Moderate	8.13	4.96
Rear	17.80	5.49	Severe, Serious	9.57	8.20
Other	15.36	15.83	Critical, Maximum	51.78	51.28
		Overall	6.56	2.20	

Table 2-2

POST-CRASH FIRE RATES (PER 1000 ACCIDENTS)
BY NUMBER OF VEHICLES INVOLVED, TYPE OF IMPACT,
RURAL VS URBAN, AND ACCIDENT SEVERITY

Variable	$\hat{r}$	$\hat{r}_W$	Variable	$\hat{r}$	$\hat{r}_W$
Number of Vehicles Involved			Rural vs Urban		
Single Vehicle	12.80	5.96	Rural	19.75	8.16
Two Vehicles	9.49	2.56	Urban	6.17	2.30
More Than Two Vehicles	5.51	2.41			
Type of Impact			Accident Severity		
Car/Vehicle:					
Head-on	20.11	6.12	Fatal	61.80	61.80
Side/Angle Side	4.75	1.31	Injury-Hospitalized	14.96	14.96
Rear	12.74	3.68			
Car/Fixed Object:					
Front	11.02	4.47			
Side	23.89	6.26	Injury-Transported to a Treatment Facility	4.33	4.33
Rollover (principal)	13.93	12.39	No transport	1.29	1.23
Other	4.91	2.74			
Overall	10.33	3.61			

2.2.2.2 North Carolina Accident Data After examining the post-crash fire rates, standard errors, effectiveness estimates and corresponding standard errrors (see Table 2-3), it became clear that a more rigorous analysis of the N.C. data was appropriate.

Table 2-3

POST-CRASH FIRE RATES (STANDARD ERRORS)
AND EFFECTIVENESS ESTIMATE (STANDARD ERROR)

Model Year	Population N	Fires n	Fire Rate $\hat{r}$	Standard Error s
65-67 (P)	234,035	136	0.581	0.0498
69-75 (S)	686,947	378	0.550	0.0283
Total	920,982	514	0.558	0.0246
	$\hat{E}_{P,S} = 0.053$	s = 0.095		

Variable selection was carried out prior to fitting models using logistic regression procedures. Of the variables considered (namely, age of car, impact site, speed, and car size), speed and impact site were clearly most important to control for. Thus, speed (<50 mph vs. $\geq$50 mph or unspecified) and impact site (front, side, rear vs other) were controlled for in the subsequent modelling. As age of vehicle was considered important a priori, models were also fit controlling for vehicle age as well as calendar year.

The primary analysis restricted the data to cars that were in the 4-9 year age range. Outside this range, the accident years did not allow for cases in both the Pre- and Post-Standard comparison groups. That is, there were no 0-3 year old Pre-Standard vehicles nor any 10-13 year old Post-Standard cars. With this restriction, there were 471,903 cars in the study population with 264 cars experiencing post-crash fires.

Logistic regression models that were linear in the parameters were fit to the data controlling for speed, impact site and vehicle age within Standard status categories. The final adjusted effectiveness estimate was -0.28 with a standard error of 0.143 as compared to a crude effectiveness estimate of -0.025 with a standard error of 0.095. Clearly, the first version of FMVSS 301 was <u>not</u> effective in reducing the likelihood of post-crash fires in Post-Standard cars.

It is of interest to note that vehicle age did not have a significant effect on $\hat{r}$ (the predicted post-crash fire rate) for the case with comparable age ranges but it was significant for the unrestricted vehicle age range (0-13 years). Thus, it was even more essential to limit the study population to the 4-9 year old cars.

The bottom line of the analysis presented here is that, based on mass accident data from North Carolina, the first version of FMVSS 301 did <u>not</u> have a significant effect on post-crash fire rates in Post-Standard cars.

2.3 Evaluation of the Effectiveness Analysis

To have reasonably fully evaluated the effectiveness of FMVSS 301 as outlined in the plans proposed by Northrop et. al. (1977) or Braun et al. (1977) in earlier NHTSA contracts would have required data files which are not in existence--namely, NCSS (Level II) data files in the quantity found in multi-year mass accident data (Level I) files. Even then the fuel spillage reduction aspect would not be addressable.

The NCSS data file was primarily useful to confirm and expand upon some of the findings presented by Cooley (1974) regarding differences in post-crash fire rates by rural vs urban, area of impact, single vs multi-vehicle accident, object struck, etc. From the NCSS data, post-crash fires are more likely in single vehicle, rear impact crashes at high speeds in rural areas. Similarly, they are much more likely to occur in crashes where the driver receives either fatal or class A injuries.

The North Carolina mass accident data was reasonably useful for examining the effectiveness of the first version (January 1968) of FMVSS 301 in reducing the frequency of post-crash fires. By using multiple years of accident data, it was possible to control for speed and impact site which were the most important to control for among such vehicle variables as age of vehicle and size of car. The resulting logistic regression analysis indicated that, after controlling for speed, impact site, and vehicle age, there was no evidence to suggest that FMVSS 301 had any effect on post-crash fire rates--if anything, they were slightly higher after the Standard became effective.

The main prospect for further research in this area lies in analyzing multi-year, multi-site NASS accident data or additional years of North Carolina narratives for examining the second version of the Standard. The prospect for investigating the fuel spillage reduction component of the Standard does not appear overly promising.

2.4 References for Section 2

1. Braun, R.L. et al. *Evaluation Methodology for Federal Motor Vehicle Safety Standards. Volume II: Technical Findings.* Stanford, California, The Transportation Center of the Stanford Research Institute, May 1977. (DOT-HS-6-01519)

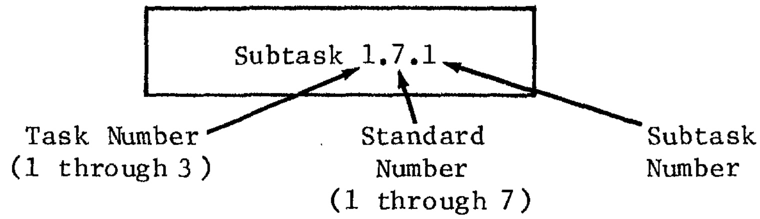
2. Cooley, P. *Fire in Motor Vehicle Accidents.* HSRI Special Report, Highway Safety Research Institute, Ann Arbor, Michigan, April 1974. (UM-HSRI-74-3)

3. Northrop, et al. *Final Design and Implementation Plan for Evaluating the Effectiveness of FMVSS 301: Fuel System Integrity.* Hartford, Connecticut, The Center for the Environment and Man, Inc., May 1977. (DOT-HS-6-01518, CEM 4207-566)

3.0 ANALYSIS OF THE NCSS DATA

3.1 Introduction; Limitations

The proposed analysis of FMVSS 301 (Fuel System Integrity) presented in the Work Plan was based on the detailed accident reports available through the NCSS program and mass accident data from North Carolina starting with calendar year mid-1971. Figure 3-1 is a flow diagram indicating the suggested steps in this combined analysis. The subtask numbering system for the Work Plan (Figure 3-1) is explained as follows:



This numbering sequence was chosen for the following reasons:

- Task Number. All seven Standards involve four (4) Tasks:

  Task 1: Review Methodology and Develop Work Plans

  Task 2: Analysis of Data

  Task 3: Final Analysis and Final Report on the Standard

- Standard Number. For convenience throughout the entire study, the following "Standard Numbers" are used:

  1 = FMVSS 108: Side Marker Lamps

  2 = FMVSS 202: Head Restraints

  3 = FMVSS 207: Seat Back Locks

  4 = FMVSS 213: Child Seating Systems

  5 = FMVSS 214: Side Door Beams

  6 = FMVSS 222: School Bus Seats and Crash Protection

  7 = FMVSS 301: Fuel System Integrity

  (All CEM report numbers will have last digits in the sequence noted above.)

- Subtask Number. Sequential numbers, beginning with "1".

It should be noted at the outset that a successful investigation of the effectiveness of Standard 301 would provide national estimates of fire-related fatalities and injuries (by AIS level) assuming that the Standard had not been

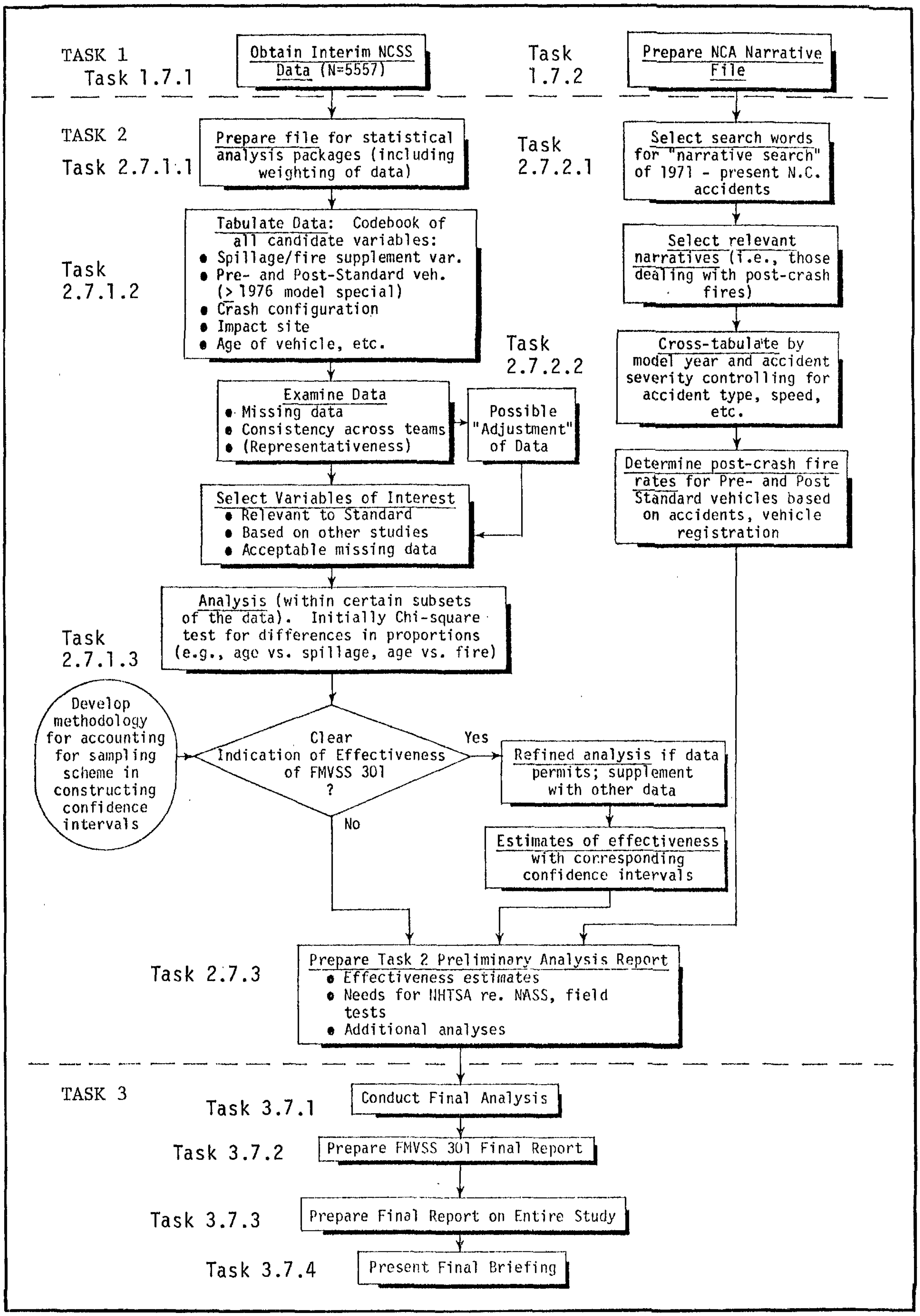


Figure 3-1. FLOW DIAGRAM FOR EVALUATION OF FMVSS 301: FUEL SYSTEM INTEGRITY

promulgated and contrasting that with the estimated (actual) number based on the NCSS data. As will be seen in this section using the NCSS data, there is no suggestion of effectiveness of either the original 301 Standard in 1968 or the supposedly considerable strenghtening of the Standard in 1976 in reducing post-crash fires regardless of impact type. Not only are the effectiveness estimates based on the actual investigations (unweighted) not significant but they are slightly negative. Thus extrapolation using the NCSS data would be meaningless.

Obviously, these analyses are subject to either of two errors; namely, a Type I error which concludes that the Standard has the desired effect when indeed it has no effect or a Type II error which fails to detect an effect which is indeed real. Even though the NCSS data set is of limited size (N=109), it would seem from the reasonableness of the various tables in this section with respect to post-crash fire rates by impact site, accident configuration, speed (as inferred from the speed limit), driver injury severity, time of day, etc., that there are no serious problems with the NCSS data other than sample size. Largely due to sample size limitations, there remains the possibility of having made a Type II error in this analysis of the NCSS data, however.

The remainder of this section presents the results of the data analyses. Here, emphasis is placed on the unweighted fire rates as these represent cases actually investigated rather than an attempt to extrapolate to all towaway crashes. To obtain the weighted rates, it is necessary to multiply by the inverse of the sampling fractions (e.g., by 10 for "Non-transport to a medical facility") which tends to distort certain relatively rare cells. However, both rates are presented in the tables for comparison purposes.

The limited plans for the evaluation of FMVSS 301 using NCSS data as outlined in Section 1.4.2.1 (see also Figure 3-1) exceeded that which could be appropriately carried out with 109 post-crash fire cases (cars). Even when weighting the sample by the inverse of the samplng fractions, there were but 181 cars involved in post-crash fires and 372 cars with fuel leakage detected.

The latter is certainly subject to detection biases that, even if there were enough cases, would render any fuel leakage analyses suspect at best. The former dealing with post-crash fires is evidently representative (see Appendix A) but seriously lacking in quantity (e.g., only 24 unweighted (or 48 weighted) post-crash fires for Post-Standard II cars where FMVSS is most likely to have a demonstrable effect and where the age of vehicle at time of crash is far less of a problem than in the oldest cars).

In lieu of being able to adequately evaluate any of the components of FMVSS 301 using NCSS data, a detailed comparison of the 109 cars involved with actual post-crash fires with the non-fire cases is carried out in Section 3.2.

3.2 Procedure and Results

The NCSS file had a total of 10,851 accident records in it, involving a total of 16,610 cars which were case vehicles (i.e., non-drivable and hence towed away from the crash). In the entire NCSS vehicle-oriented file, there were 109 cars involved in post-crash fires. Since the number of fire cases was too few to carry out an appropriate analysis of the effectiveness of FMVSS 301 in preventing post-crash fires, primarily detailed descriptive statistics were determined for the fire vs. non-fire cases and are presented in this section. (The problems with the 189 fuel leakage cases have been described in Section 1.0.)

Table 3-1 shows the percentage distribution and post-crash fire rates $\hat{r}$ per 1000 cars by model year (grouped by periods relevant to FMVSS 301). Thus, for example, the pre-1968 fire rate was determined as follows:

$$\hat{r}_P = \text{Fire rate (pre-1968)} = \frac{15}{2413} \times 1000 = 6.22$$

The table shows virtually no change in fire rates for Post-Standard I cars (i.e., prior to the static rollover requirement) but a subsequent increase for Post-Standard II cars. The increase in fire rates for Post-Standard II cars is surprising but might be attributable to increasingly many small cars in the population (Datsuns, Hondas, Toyotas) with the general down-sizing of U.S. cars with the continuing fuel crunch. (This is further examined in Table 3-2.)

Also presented in Table 3-1 are the percentage distribution and post-crash fire rates ($\hat{r}_W$) when the observations are weighted by the inverse of the sampling fractions. Under the weighting scheme, Post-Standard I cars appear to have a lower fire rate than Pre-Standard cars. However, Post-Standard II cars continue to have fire rates approximately as great as the Pre-Standard cars.

Table 3-1

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY MODEL YEAR -- UNWEIGHTED, WEIGHTED BY THE INVERSES OF THE SAMPLING FRACTIONS

Model Year	Unweighted			Weighted		
	Fire	No Fire	Fire Rate $\hat{r}$	Fire	No Fire	Fire Rate $\hat{r}_w$
Pre-1968 (Pre-Standard)	15 [14.3]*	2,397 [14.6]	6.22	30 [16.9]	11,199 [13.7]	2.67
1968 Interim	5 [4.8]	910 [5.6]	5.46	14 [7.9]	4,615 [5.6]	3.02
1969-1975 (Post-Standard I)	61 [58.1]	9,631 [58.8]	6.29	85 [48.0]	48,829 [59.8]	1.74
Post-1975 (Post-Standard II)	24 [22.8]	3,455 [21.1]	6.90	48 [27.1]	17,063 [20.9]	2.81
Unknown	4	108		4	578	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent excluding "Unknown" (e.g., $14.3 = \frac{15}{105} \times 100$)

The elevated S_{II} rates could be merely a reflection of the down-sizing trend in the U.S. assuming that the occurrence of a post-crash fire is inversely related to vehicle size. This assumption is clearly not borne-out in the NCSS "fire file". As seen in Table 3-2, the lightest (under 2000 lbs.) cars and the heaviest cars (at least 3900 lbs.) have similar post-crash fire rates which are fairly comparable to those of the intermediate-weight cars. It would seem that car weight differences alone do not account for fire-rate differences.

Table 3-3 shows the fire rates by area of impact. As might be expected rear-end crashes have the highest fire rate followed by frontal crashes. The "Other" category comprises mainly rollover crashes where there is a general area of impact. That post-crash fire rates are elevated for this category is well documented in the literature. It should be noted here though, that in a towaway sample, rear-end crashes are underrepresented since they are less severe and less likely to immobilize the vehicle. As a result, the number of vehicles in rear-end crashes where no post-crash fire occurred has been underestimated in Table 3-3 with respect to all motor vehicle crashes.

Table 3-2

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY CAR WEIGHT -- UNWEIGHTED, WEIGHTED BY THE INVERSES OF THE SAMPLING FRACTIONS

Car Weight	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_w$
< 2000	6 [5.5]*	777 [5.0]	7.66	9 [5.0]	3,710 [4.8]	2.42
2000-2699	13 [11.9]	2,151 [13.8]	6.01	31 [17.1]	10,722 [14.0]	2.88
2700-3299	20 [18.3]	3,010 [19.4]	6.60	47 [26.0]	14,951 [19.5]	3.13
3300-3899	33 [30.3]	4,696 [30.2]	6.98	48 [26.5]	23,187 [30.2]	2.07
≥ 3900	37 [33.9]	4,910 [31.6]	7.48	46 [25.4]	24,098 [31.4]	1.91
Unknown	0	957		0	5,616	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent (excluding "Unknown")

Table 3-3

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY AREA OF IMPACT -- UNWEIGHTED, WEIGHTED

Area of Impact	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_w$
Front	52 [50.0]*	7,399 [58.0]	6.98	79 [44.9]	33,894 [56.6]	2.33
Side	21 [20.2]	3,553 [27.9]	5.88	21 [11.9]	16,596 [27.7]	1.26
Rear	21 [20.2]	1,159 [9.1]	17.80	39 [22.2]	7,065 [11.8]	5.49
Other	10 [9.6]	641 [5.0]	15.36	37 [21.0]	2,301 [3.8]	15.83
Unknown	5	3,749		5	22,428	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent (excluding "Unknown")

As FMVSS 301 changed over the years to apply to differing impact modes (see Table 1-1), it is of interest to examine the fire-rates by model year and impact site (see Table 3-4). Realizing the sample size restrictions and thus the likelihood of random fluctuations, it is still of interest to note the following:

(i) The front impact fire rates are highest for the periods (S_I and S_{II}) following the requirements for fuel system integrity in front barrier crashes.

(ii) The side impact fire rates are highest for the period (S_{II}) following the requirements in side barrier crashes.

(iii) The rear impact fire rates are lowest for the period (S_{II}) following the requirements in rear barrier crashes.

Fire rates by number of cars involved in the accident are presented in Table 3-5. Single vehicle crashes appear to have a higher fire rate than two vehicle crashes (which include trucks as the other vehicle). This can probably be attributed to the fact that single vehicle accidents are, in general, more severe than multi-vehicle crashes.

Table 3-5

PERCENTAGE DISTRIBUTION OF ACCIDENTS AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY NUMBER OF VEHICLES INVOLVED -- UNWEIGHTED, WEIGHTED

No. of Vehicles Involved	Unweighted			Weighted		
	Fire	No Fire	Fire Rate $\hat{r}$	Fire	No Fire	Fire Rate $\hat{r}_w$
Single Vehicle	45 [45.5]*	3,471 [36.6]	12.80	87 [51.8]	14,502 [31.3]	5.96
Two Vehicles	49 [49.5]	5,112 [53.9]	9.49	70 [41.7]	27,295 [58.9]	2.56
More Than Two Vehicles	5 [5.0]	903 [9.5]	5.51	11 [6.5]	4,545 [9.8]	2.41
Total Accidents	99	9,486	10.33	168	46,342	3.61

*Column percent

Table 3-4

UNWEIGHTED (WEIGHTED) POST-CRASH FIRE RATES (PER 1000 ACCS.) BY MODEL YEAR AND IMPACT SITE

Model Year \ Impact Site	Front* N_F	Front* $\hat{r}$ ($\hat{r}_w$)	Side N_F	Side $\hat{r}$ ($\hat{r}_w$)	Rear N_F	Rear $\hat{r}$ ($\hat{r}_w$)	Other N_F	Other $\hat{r}$ ($\hat{r}_w$)	Unknown N_F	Total N_F	Total $\hat{r}$ ($\hat{r}_w$)
Pre-1968 (Pre-Standard)	3	2.6 (1.2)	4	8.7 (2.0)	4	24.7 (10.2)	4	41.2 (38.2)	0	15	6.3 (2.7)
1968 (Interim)	2	4.6 (0.9)	2	11.2 (2.4)	0	0.0 (0.0)	1	31.3 (102.0)	0	5	5.5 (3.0)
1969-1975 (Post-Standard I)	31	7.3 (1.7)	8	3.8 (0.8)	14	19.6 (5.9)	4	10.7 (9.0)	4	61	6.3 (1.7)
Post-1975 (Post-Standard II)	13	8.7 (5.0)	7	8.9 (4.1)	2	9.8 (1.7)	1	7.5 (8.2)	1	24	6.9 (2.8)
Unknown	3		0		1		0		0	4	
Total	52	7.0 (2.3)	21	5.9 (1.3)	21	18.1 (5.5)	10	15.6 (16.1)	5	109	6.6

*For "Front" impacts, cell provides

N_F = number of post-crash fires in NCSS sample

$\hat{r}$ = unweighted post-crash fire rate

$\hat{r}_w$ = weighted post-crash fire rate

"Type of impact" approximates what is generally termed "accident type". As can be observed from Table 3-6, the likelihood of a post-crash fire is elevated for single vehicle accidents (particularly rollovers) and for two-vehicle head-on and rear-end crashes.

Table 3-7 presents fire rates by object struck. Fire rates for impacts with fixed or "other" objects are relatively high compared to impacts with

Table 3-7

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY OBJECT STRUCK -- UNWEIGHTED, WEIGHTED

Object Struck	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_W$
Other Car	40 [37.0]*	10,329 [63.1]	3.86	64 [35.6]	55,081 [67.4]	1.16
Truck	20 [18.5]	1,574 [9.6]	12.55	26 [14.4]	6,778 [8.3]	3.82
Other Vehicle (e.g., motorcycle)	0 [0.0]	757 [4.6]	0.00	0 [0.0]	4,390 [5.4]	0.00
Fixed Object	37 [34.3]	2,749 [16.8]	13.28	52 [28.9]	11,130 [13.6]	4.65
Other Object	11 [10.2]	963 [5.9]	11.29	38 [21.1]	4,403 [5.4]	8.56
Unknown	1	129		1	502	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent (excluding "Unknown")

another vehicle (excluding trucks). This is consistent with Table 3-5 where single vehicle accidents had the highest fire rates.

In Table 3-8, the rural-urban fire rates are presented. The fire rate for rural accidents is considerably higher than the rate for urban accidents. This was expected since in general rural accidents are much more severe than urban accidents.

Table 3-6

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS) BY TYPE OF IMPACT -- UNWEIGHTED, WEIGHTED

Type of Impact	Unweighted			Weighted		
	Fire	No Fire	Fire Rate $\hat{r}$	Fire	No Fire	Fire Rate $\hat{r}_W$
Car/Vehicle:						
Head-On	18 [18.4]*	877 [9.4]	20.11	21 [12.6]	3,408 [7.5]	6.12
Side/Angle Side	13 [13.3]	2,722 [29.0]	4.75	19 [11.4]	14,469 [31.6]	1.31
Rear	14 [14.3]	1,085 [11.6]	12.74	26 [15.6]	7,031 [15.4]	3.68
Car/Fixed Object:						
Front	23 [23.5]	2,065 [22.0]	11.02	38 [22.8]	8,464 [18.5]	4.47
Side	14 [14.3]	572 [6.1]	23.89	14 [8.4]	2,222 [4.9]	6.26
Rollover (principal)	9 [9.2]	637 [6.8]	13.93	27 [16.2]	2,153 [4.7]	12.39
Other	7 [7.1]	1,420 [15.1]	4.91	22 [13.2]	7,996 [17.5]	2.74
Unknown	1	108		1	599	
Total	99	9,486	10.33	168	46,342	3.61

*Column percent (excluding "Unknown")

Table 3-8

PERCENTAGE DISTRIBUTION OF ACCIDENTS AND POST-CRASH FIRE RATES (PER 1000 ACCIDENTS) BY AREA -- UNWEIGHTED, WEIGHTED

Area	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_W$
Rural	58 [58.6]*	2,879 [30.4]	19.75	85 [50.6]	10,326 [22.3]	8.16
Urban	41 [41.4]	6,604 [69.6]	6.17	83 [49.4]	36,010 [77.7]	2.30
Unknown	0	3		0	6	
Total Accidents	99	9,486	10.33	168	46,342	3.61

*Column percent (excluding "Unknown")

Another measure of the seriousness of an accident is accident severity as measured by the worst injury sustained by an occupant in a towed (or case) vehicle. Table 3-9 shows the fire rates for different levels of accident

Table 3-9

PERCENTAGE DISTRIBUTION OF ACCIDENTS AND POST-CRASH FIRE RATES (PER 1000 ACCS) BY ACCIDENT SEVERITY -- UNWEIGHTED, WEIGHTED

Accident Severity	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_W$
Fatal	33 [33.3]*	501 [5.3]	61.80	33 [19.6]	501 [1.1]	61.80
Injury-Hospitalized	51 [51.1]	3,357 [35.4]	14.96	51 [30.4]	3,357 [7.2]	14.96
Injury-Transported to a Treatment Facility	11 [11.1]	2,531 [26.7]	4.33	44 [26.2]	10,124 [21.8]	4.33
No Transport	4 [4.0]	3,097 [32.6]	1.29	40 [23.8]	32,360 [69.8]	1.23
Total Accidents	99	9,486	10.33	168	46,342	3.61

*Column percent

severity. The rates in this table clearly again indicate elevated post-crash fire rates for the more serious accidents.

Table 3-10 presents the driver injury severity distribution and corresponding post-crash fire rates for each of the driver injury severity strata.

Table 3-10

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY DRIVER INJURY SEVERITY -- UNWEIGHTED, WEIGHTED

Driver Injury Severity	Unweighted			Weighted		
	Fire	No Fire	Fire Rate $\hat{r}$	Fire	No Fire	Fire Rate $\hat{r}_W$
No Injury	7 [6.7]*	6,050 [40.2]	1.16	46 [26.1]	45,765 [62.1]	1.00
C	5 [4.8]	2,511 [16.7]	1.99	14 [8.0]	11,861 [16.1]	1.18
B	16 [15.4]	3,386 [22.5]	4.70	28 [15.9]	11,314 [15.4]	2.47
A	46 [44.2]	2,642 [17.5]	17.11	58 [33.0]	4,232 [5.7]	13.52
Killed	30 [28.8]	469 [3.1]	60.12	30 [17.0]	472 [0.6]	59.76
Unknown	5	1443		5	8,640	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent (excluding "Unknown")

Given that a post-crash fire occurred, it was about four times as likely that the driver died in the crash as opposed to receiving severe injuries and perhaps fifty times as likely as escaping uninjured. Although not shown in Table 3-10, only 26 drivers (out of 109) were indicated as receiving burn injuries. Broken down by standard eras (and limited by sample sizes), the burn injury rates (per 1000 cars) were 0.01, 0.02 and 0.02 for P, S_I, and S_{II}, respectively.

Overall AIS reflects the total injury severity for an individual as measured by the Abbreviated Injury Scale. Although it is more precise than the

KABCO scale, it generally suffers from having a greater proportion of "unknown" injury severity than the usual police injury scale (KABCO). Table 3-11 presents post-crash fire rates by driver overall AIS categories. The results are not comparable with those found in Table 3-10.

Table 3-11

PERCENTAGE DISTRIBUTION AND POST-CRASH FIRE RATES (PER 1000 ACCS.) BY DRIVER OVERALL AIS -- UNWEIGHTED, WEIGHTED

Driver Overall AIS	Unweighted Fire	Unweighted No Fire	Unweighted Fire Rate $\hat{r}$	Weighted Fire	Weighted No Fire	Weighted Fire Rate $\hat{r}_W$
No Injury (OAIS=0)	10 [14.1]*	6,299 [52.9]	1.59	49 [37.4]	46,565 [78.5]	1.05
Minor, Moderate (OAIS=1,2)	35 [49.3]	4,271 [35.9]	8.13	56 [42.7]	11,226 [18.9]	4.96
Severe, Serious (OAIS=3,4)	10 [14.1]	1,035 [8.7]	9.57	10 [7.6]	1,209 [2.0]	8.20
Critical, Maximum (OAIS=5,6)	16 [22.5]	293 [2.5]	51.78	16 [12.2]	296 [0.5]	51.28
Unknown	38	4,603		50	22,988	
Total	109	16,501	6.56	181	82,284	2.20

*Column percent (excluding "Unknown")

3.3 Summary and Conclusions

Of the 16,610 cars in the NCSS file, 109 were involved in post-crash fires. This ruled out a detailed statistical analysis for evaluating the effectiveness of FMVSS 301. For example, there were but 24 post-crash fire vehicles (Table 3-1) in the Post-Standard II category (48 when weighted by the inverse of the sampling fraction), and thus no meaningful comparisons could be made between post-crash fire rates for these cars and Pre-Standard or Post-Standard I cars under, for example, different crash configurations, impact sites, etc. Hence this section was devoted primarily to presenting descriptive statistics for fire rates for various accident and vehicle characteristics.

In general, comparisons by various measures of accident severity indicated that post-crash fire rates were higher for more severe accidents. Thus, for example, post-crash fire rates were relatively high for single vehicle accidents, for rural accidents, for accidents when vehicles collided with trucks or fixed objects and for accidents involving a fatality. Furthermore, driver injury comparisons showed that, as might be expected, the proportion of serious injuries using either the KABCO scale or overall AIS was higher for vehicles involved in post-crash fires.

In summary, even considering the sample size limitations of the NCSS data file, the post-crash fire rates are elevated for those crash types, impact sites, environmental conditions, and accident severity (as measured by driver injury) where expected. Nevertheless, there is no evidence of any effectiveness of FMVSS 301 in reducing the incidence of post-crash fires in Post-Standard cars based on the 109 post-crash fire NCSS cases.

4.0 ANALYSIS OF NORTH CAROLINA POLICE ACCIDENT DATA

4.1 Background and Data Limitations

At the outset, the primary effectiveness evaluations were to be based on the NCSS data. However, using all of the NCSS cases available for analysis (N = 10,851 accidents), the data was found limited with respect to quantity and quality of fuel spillage (N = 189 cars) and of post-crash fire (N = 109 cars) case information. The fuel spillage cases clearly suffered from considerable underreporting judging from the number of post-crash fire cases. That this is the case might be anticipated due to time delays in locating and inspecting the case vehicles allowing any evidence of fuel spillage to disappear.

Both fuel spillage and post-crash fire cases suffered from missing data problems (e.g., ΔV, detailed injury information sufficient to identify burn injuries) and from evident team-wise reporting differences (see Section 3.2 and Appendix A).

As a result, an alternative accident data set became more and more important to strengthen somewhat the evaluation efforts of FMVSS 301. North Carolina police accident data constitutes this secondary data base. The accident report forms for most states do not include a check box to indicate that a fire has occurred, since they fortunately occur in very few cases. North Carolina is one state that does not have such a check box; and even if it did, additional detective work would be required to separate the passenger car post-crash fires from all other fire cases.

Since no standard accident report form can include blanks or check boxes for all data items that might someday be of interest, some years ago a narrative search program was developed which can scan hundreds of thousands of computerized police narratives to locate that subset which contains one or more key search words related to a topic of interest. Thus, to use the capability in North Carolina, the researcher scans a thesaurus referred to as The Computer Dictionary for candidate key search words or phrases. Having identified the words or phrases that the officer is most likely to use in describing the phenomenon of interest, these key words provide the input data for the narrative search program. The search program then reads all of the narratives in the subset of interest and prints out the complete narratives and accident case numbers of all cases that contain one or more of the search words or phrases.

Using this much smaller subset of narratives, the researcher then disregards all irrelevant narratives (in this case, those involving pre-crash fires and those involving, say, fire hydrants or fire stations). The remaining subset then constitutes the data base of interest. The full accident record for these cases is obtained by matching accident case numbers of the narrative subset with the case numbers on the entire accident file.

It is clear that, to be able to appropriately utilize the capability, the phenomenon of interest must first be one that the policeman is highly likely to describe in his narrative. Secondly, the more obvious the key or associated words, the more likely that the vast majority of such incidents will be identified.

For the application herein, both criteria should readily be met. If there is a vehicle fire, it would seem very likely that the officer would mention it in his narrative. There is evidence that such is the case from a series of statewide accident reporting workshops that have been conducted for municipal police officers in North Carolina. With respect to the search words related to vehicle fires, "caught*fire", "fire", "burn", "flame" and "explode" would appear to be obvious candidates. Thus, it would seem that the narratives selected should quite adequately describe the nature and degree of the post-crash fire problem for North Carolina.

There are clearly some limitations with the mass accident data of North Carolina. With respect to extrapolating to the United States, the estimates would be expected to be liberal, since North Carolina is much more rural than the nation as a whole and post-crash fires are much more likely to occur on open rural roads with relatively high speeds involved.

Secondly, the level of injury detail in the North Carolina police data is clearly inadequate to identify and quantify burn injuries. Thus, the question of the effectiveness of FMVSS 301 in reducing injuries and fatalities due to post-crash fires is not able to be investigated using this data.

Finally, there is no opportunity to investigate the question of fuel leakage, let alone the rate of such leakage. There is often a delay in the officer's arriving at the scene of the accident, allowing potential leakage to discontinue. Secondly, among his many responsibilities at the scene is to aid the injured, assist in traffic flow, conduct interviews (drivers, witnesses), and obtain environmental, vehicular, and driver and occupant information for the required report form. Thus, he may not have much of an opportunity to <u>investigate</u> rather than <u>report on</u> the accident. With these considerable demands, he is almost certainly likely to fail to note fuel leakage in his narrative description. Hence, the spillage reduction effectiveness of the

Standard is beyond the grasp of mass accident data analyses -- even using the narrative search capability.

4.2 Procedure

North Carolina began computerizing report narratives in mid-1971. Since that point, virtually every word (including misspellings) that officers have used in their narratives has been computerized along with the accident report case number for linkage purposes.

After a number of years worth of narratives had been computerized, a Computer Dictionary was created which serves as a thesaurus for the researcher. Basically, it is a compilation of every word used in the equivalent of a year's worth of accidents (N = 130,000) along with the frequency of narratives in which each word appears. In actuality, it represents a sample of the narratives from mid-1971 through the end of 1978. Going through this listing generally provides the researcher with the key search words and/or phrases that he should use in his narrative search. In this case, the obvious search words were "caught*fire", "fire", "burn", "flame" and "explode".

The accident years represented by the analysis are mid-1971 through 1978. The entire period was selected in order to have as large a sample of post-crash fires as possible. It should be noted that, since every other narrative was keypunched in 1978 due to a lack of data processing personnel, denominator data (i.e., all cars involved in accidents during the study period) consists of every other reported crash in 1978.

Thus, the narratives for nearly 917,000 crashes involving passenger cars in North Carolina during the period mid-1971 through 1978 were scanned by the computer to select those cases involving "fire". This resulted in a listing of 5778 narratives containing one or more of the search words. These narratives were, in turn, read to extract irrelevant cases such as those 1635 cases involving pre-crash fires (e.g., fires started by dropped cigarettes) or those 3499 cases clearly not even involving fires (e.g., car hit a <u>fire</u> hydrant or accident occurred in front of the <u>fire</u> station) or which lacked information critical to the analysis such as car model year.

The resulting "post-crash fire" narrative file was then matched with the accident file through the accident case number to obtain the complete record for each vehicle involved. An additional screening of cases in both the post-crash fire file and the population-at-risk file excluded those cases which lacked certain information deemed essential to the investigation. The critical variable screened on was model year of the car (for assignment as a Pre- or Post Standard car). Note that, when the VIN was not decodable, the police model year designation was utilized.

It should be noted that Pre-Standard cars include model years up through at least 1967. As the first level of the Standard was to apply to cars manufactured after January 1, 1968, it was not possible to ascertain whether the 1968 models for a particular manufacturer were half Pre- and half Post-Standard cars or whether they were all Post-Standard cars (i.e., whether the changes necessitated by FMVSS 301 were made at the beginning of the model year or at mid-year). As such was the case, the 1968 models are deleted from any Pre- vs. Post-comparisons.

Secondly, since the accidents occurred during the period from mid-1971 through the end of 1978, model year cars from the early sixties (say up through model year 1964) were, at a minimum, seven years old (if model year 1964 and accident year 1971) and, at a maximum, 18 years old (if model year 1960 and accident year 1978). As the Post-Standard cars were generally much younger at the time of the crash <u>and</u> since the likelihood of post-crash fire might well be related to vehicle age <u>and</u> since there were relatively few of these vehicles in either the accident population or the post-crash fire population, the pre-1965 model cars were deleted from the study group.

Thirdly, the Post-Standard cars represent two separate cohorts of vehicles -- those including model years 1969 through 1975 and those including model years 1976 and later (see Table 1-1). Notationally, the two cohorts will be indicated by S and S', respectively. As there are but 25 post-crash fires involving S' cars, it is obvious that they must either be combined with the 1969-75 model cars in any meaningful analysis or deleted from the study group. There is ample evidence that the vehicle modifications imposed by the static <u>rollover</u> test were much more stringent than those imposed by the initial 30 mph <u>frontal</u> barrier crash (January 1, 1968). In addition, the S' cars in the accident file are at most three years old. Again, to the extent that vehicle age is a factor in pre-crash fire occurrence, the inclusion of these generally newer cars would bias any comparison with the generally older Pre-Standard cars. Thus, with respect to fuel systems, it would appear that S and S' cars are not reasonably comparable and thus the 25 S' cars have been <u>deleted</u> from the subsequent analysis. As more years of accident data are available, it is anticipated that a study of the effect of the upgrading of FMVSS 301 with the

1976 model cars will be carried out. However, such an investigation is not possible with the existing data.

With these deletions at both ends of the model year range (pre-1965 and post-1975), the remaining portion not only contains the bulk of the data but allows for an optimal comparison between Pre-Standard (P) and Post-Standard (S) vehicles. This final screening results in a post-crash fire file with 514 cars and a population-at-risk file of 920,982 cars with the same detailed information in both files.

Having created these working files, cross-tabulations were generated for a number of variables in order to obtain the post-crash fire rates of interest. As these are post-crash phenomena, the appropriate denominators of the various rates are cars involved in similar types of crashes or of similar age or of the same size, etc., rather than mileage exposure or exposure based on vehicle registration. Thus, for example, the post-crash fire rate estimates for the Pre-Standard (1965-67 model) cars are given by the ratio of Pre-Standard cars in post-crash fires to the totality of Pre-Standard cars involved in crashes during the exposure period (mid-1971 through 1978).

To examine the effectiveness of FMVSS 301 in reducing post-crash fires, the following effectiveness measure is used:

$$\hat{E} = \frac{\hat{r}_P - \hat{r}_S}{\hat{r}_P} \tag{4.1}$$

where

$\hat{r}_P$ = rate (per 1000) of post-crash fires in Pre-Standard cars

$\hat{r}_S$ = rate (per 1000) of post-crash fires in Post-Standard cars

Corresponding approximate standard errors of these estimates are derived using a Taylor series expansion of (4.1). The details will appear in the following section containing results.

4.3 Overall Comparison of Post-Crash Fire Rates

Overall estimates of the rate of post-crash fires in automobile accidents vary from study to study and vary according to the reporting threshold used in the study. For the towaway crashes of the NCSS, the overall weighted rate was 2.2 per 1000 cars. Cooley (1974) cites a National Safety Council estimate of 1 fire per 1000 crashes which, since the "average" crash involves approximately

1.6 vehicles, would be roughly equivalent to 0.6 fires per 1000 vehicles in crashes. Cooley also cites a 1969 study by Moore and Negri at the New York State Department of Motor Vehicles which estimates post-crash fires in 0.7 of 1000 crashes or, as before, in 0.44 per 1000 vehicles. Further, Cooley cites a 1970 study by Siegel and Nahum in Southern California which estimates post-crash fires in "less than 5" crashes in 1000 or, as before, in less than 3 vehicles per 1000 crash-involved vehicles.

From the North Carolina mass accident data, the estimate of statewide post-crash fires rates is

$$\hat{r} = \frac{514}{920,982} \times 1000$$

$$= 0.558$$

per 1000 cars (model years 1965-67 and 1969-75) in crashes. Assuming a random sample (over time) of automobile crashes, $\hat{r}$ has a corresponding standard error of

$$s = 0.0246 = \sqrt{\text{var } \hat{r}}$$

$$= 1000 \sqrt{\frac{pq}{N}} = 1000\sqrt{\frac{(0.000558)\ (0.999442)}{920,982}}$$

which is unusually small due to the very large sample size.

Table 4-1 shows the sample sizes, post-crash fire rates ($\hat{r}$) and estimated standard errors for the P vs. S comparison without restricting to subsamples with comparable age ranges (see Figure 4-7). The corresponding (crude)

Table 4-1

POST-CRASH FIRE RATES AND STANDARD ERRORS FOR PRE- AND POST-STANDARD CARS - ALL AGES

Model Year	Number of Cars in Crashes N	Number of Post-Crash Fires n	Post-Crash Fire Rate (per 1000) $\hat{r}$	Standard Error s
65-67 (P)	234,035	136	0.581	.0498
69-75 (S)	686,947	378	0.550	.0283
Total	920,982	514	0.558	.0246

effectiveness estimate using (4.1) is given by the following:

$$\hat{E}_{P,S} = \frac{\hat{r}_P - \hat{r}_S}{\hat{r}_P} = \frac{0.581 - 0.550}{0.581} = 0.053$$

To obtain an estimate of the standard error of $\hat{E}$, a Taylor series expansion of $\hat{E}$ is utilized as described in Reinfurt, Silva and Seila (1976) to obtain

$$\hat{V}_{P,S} = \frac{(\hat{r}_S)^2}{(\hat{r}_P)^4} s_P^2 + \frac{1}{(\hat{r}_P)^2} s_S^2 \tag{4.2}$$

Thus

$$\hat{V}_{P,S} = \frac{(0.550)^2}{(0.581)^4} (0.0498)^2 + \frac{1}{(0.581)^2} (0.0283)^2$$

$$= 0.008956$$

with corresponding standard error $s_{P,S} = 0.0946$. From a confidence interval consideration ($\alpha = 0.05$), this (crude) effectiveness estimate is not significantly different from zero.

As will be seen in Section 4.5, the most appropriate Pre (P) vs Post (S) comparisons are made for the vehicle age range of 4-9 years since, outside this range, there are cars in only one of the study groups. In other words, for the 0-3 age range there are <u>no</u> Pre-Standard cars while for the 10-13 age range there are <u>no</u> Post-Standard cars (see Figure 4-7).

For this subset of the data which will be the focus of the analysis in Section 4.5, the corresponding sample sizes, post-crash fire rates ($\hat{r}$) and estimated standard error (s) are given in Table 4-2. As previously, the crude

Table 4-2

POST-CRASH FIRE RATES AND STANDARD ERRORS FOR PRE- AND POST-STANDARD CARS - AGES 4-9 YEARS (I.E., COMPARABLE PRE AND POST)

Model Year	Number of Cars in Crashes N	Number of Post-Crash Fires n	Post-Crash Fire Rate (per 1000) $\hat{r}$	Standard Error s
65-67 (P)	179,677	99	0.551	.0554
69-75 (S)	292,226	165	0.565	.0440
Total	471,903	264	0.559	.0344

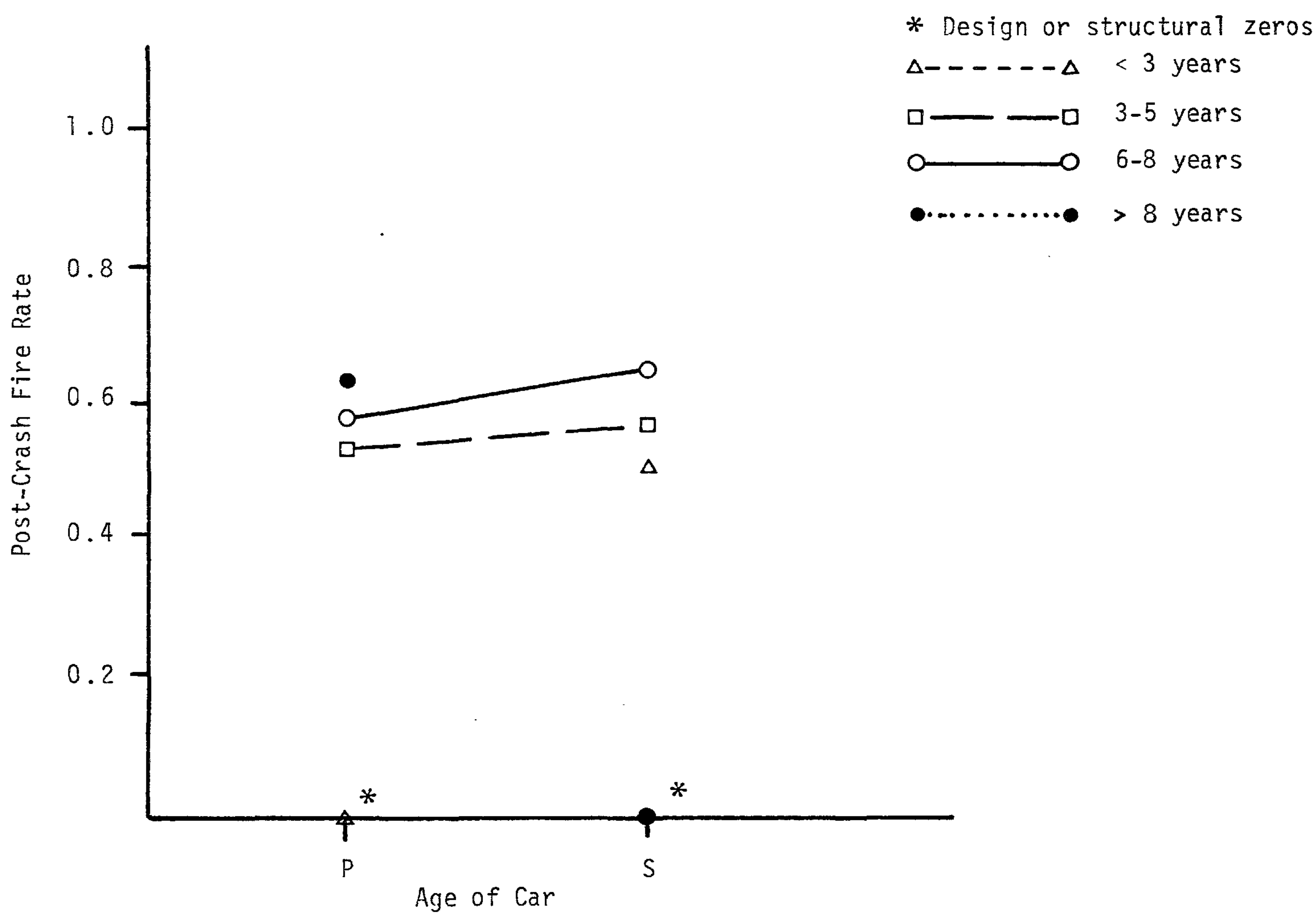


FIGURE 4-1

POST-CRASH FIRE RATES ($\hat{r}$) BY AGE OF CAR AND "STANDARD."

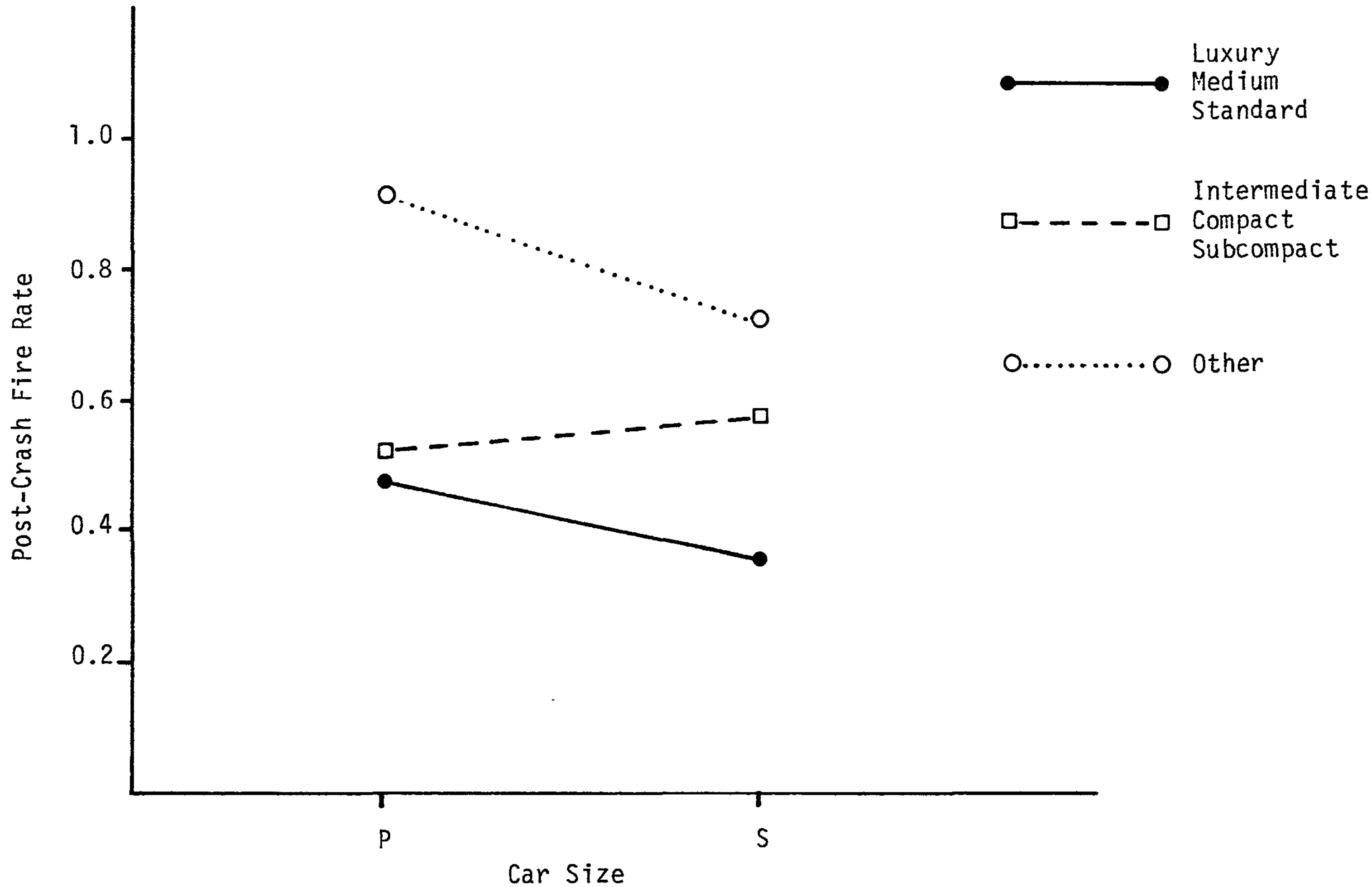


FIGURE 4-2

POST-CRASH FIRE RATES ($\hat{r}$) BY CAR SIZE AND "STANDARD."

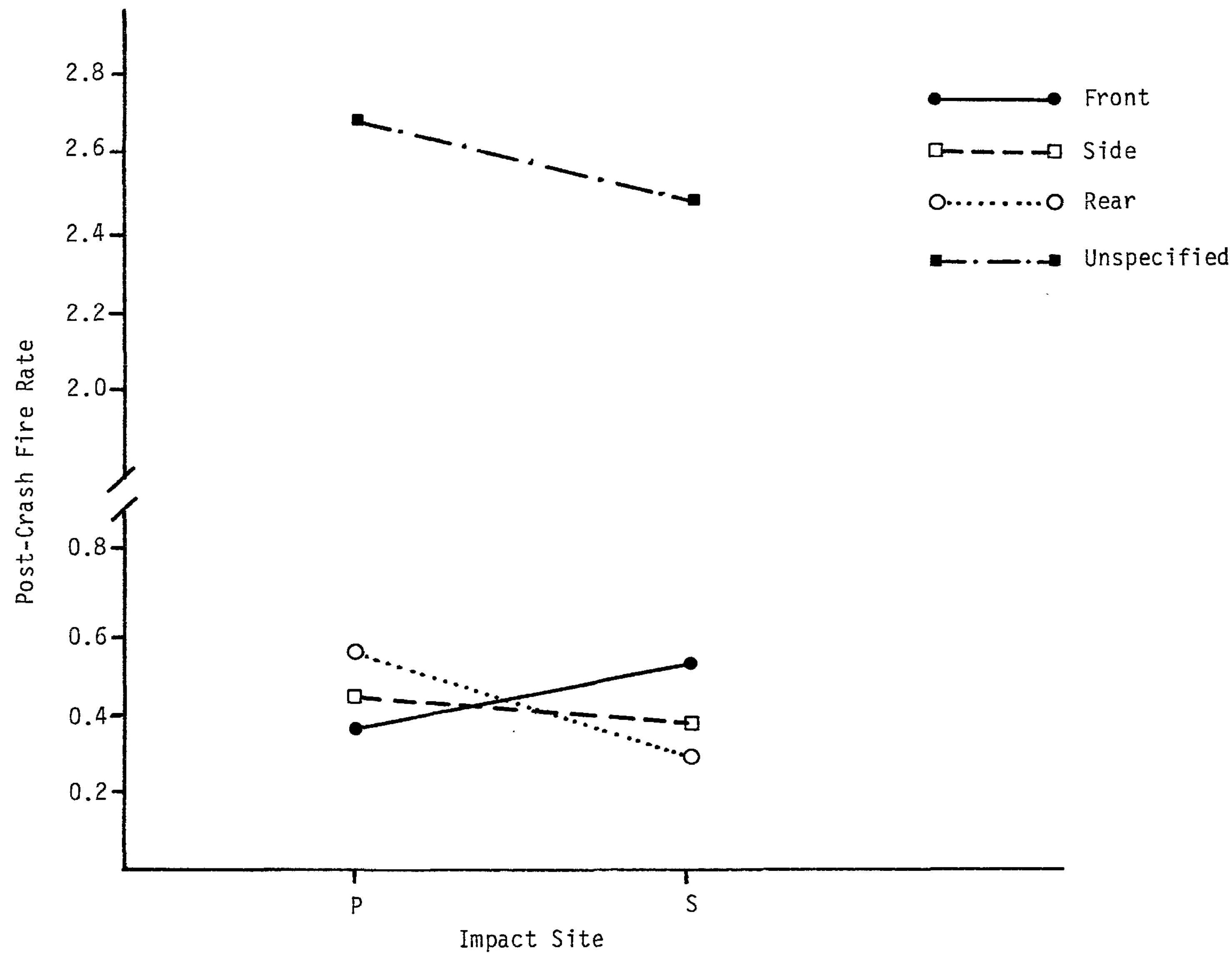


FIGURE 4-3

POST-CRASH FIRE RATES ($\hat{r}$) BY IMPACT SITE AND "STANDARD."

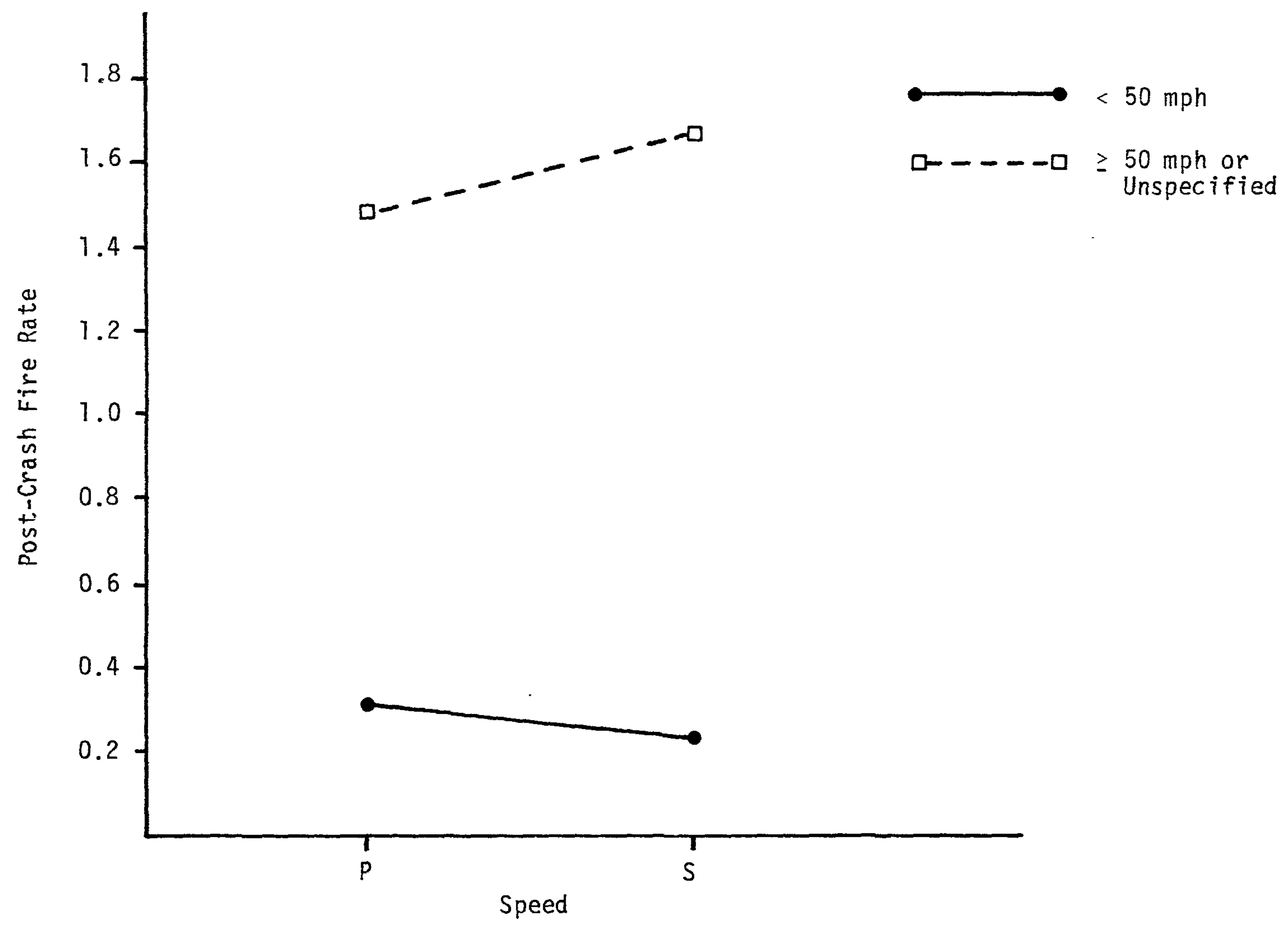


FIGURE 4-4

POST-CRASH FIRE RATES ($\hat{r}$) BY SPEED AND "STANDARD."

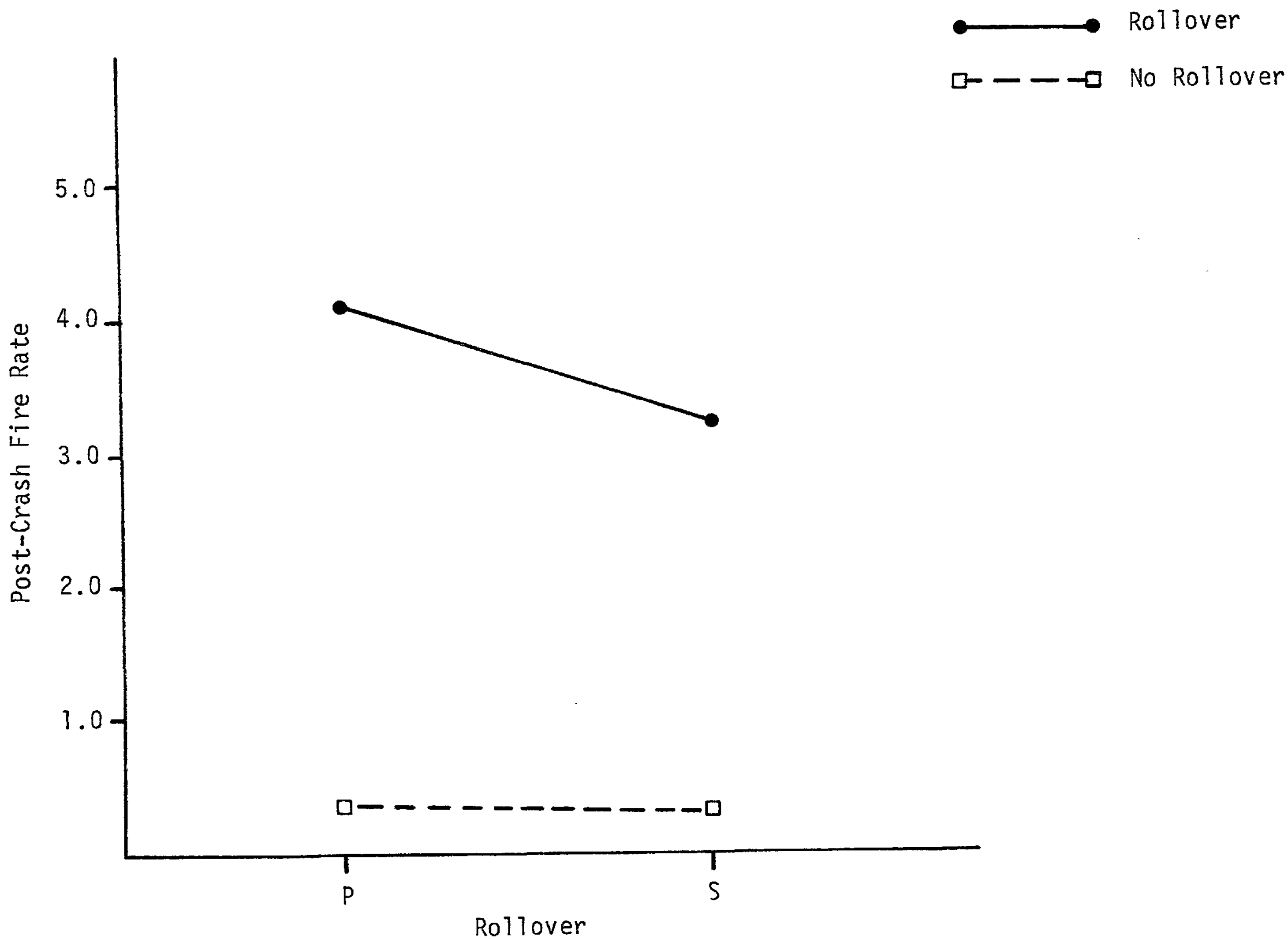


FIGURE 4-5

POST-CRASH FIRE RATES ($\hat{r}$) BY ROLLOVER VARIABLE AND "STANDARD."

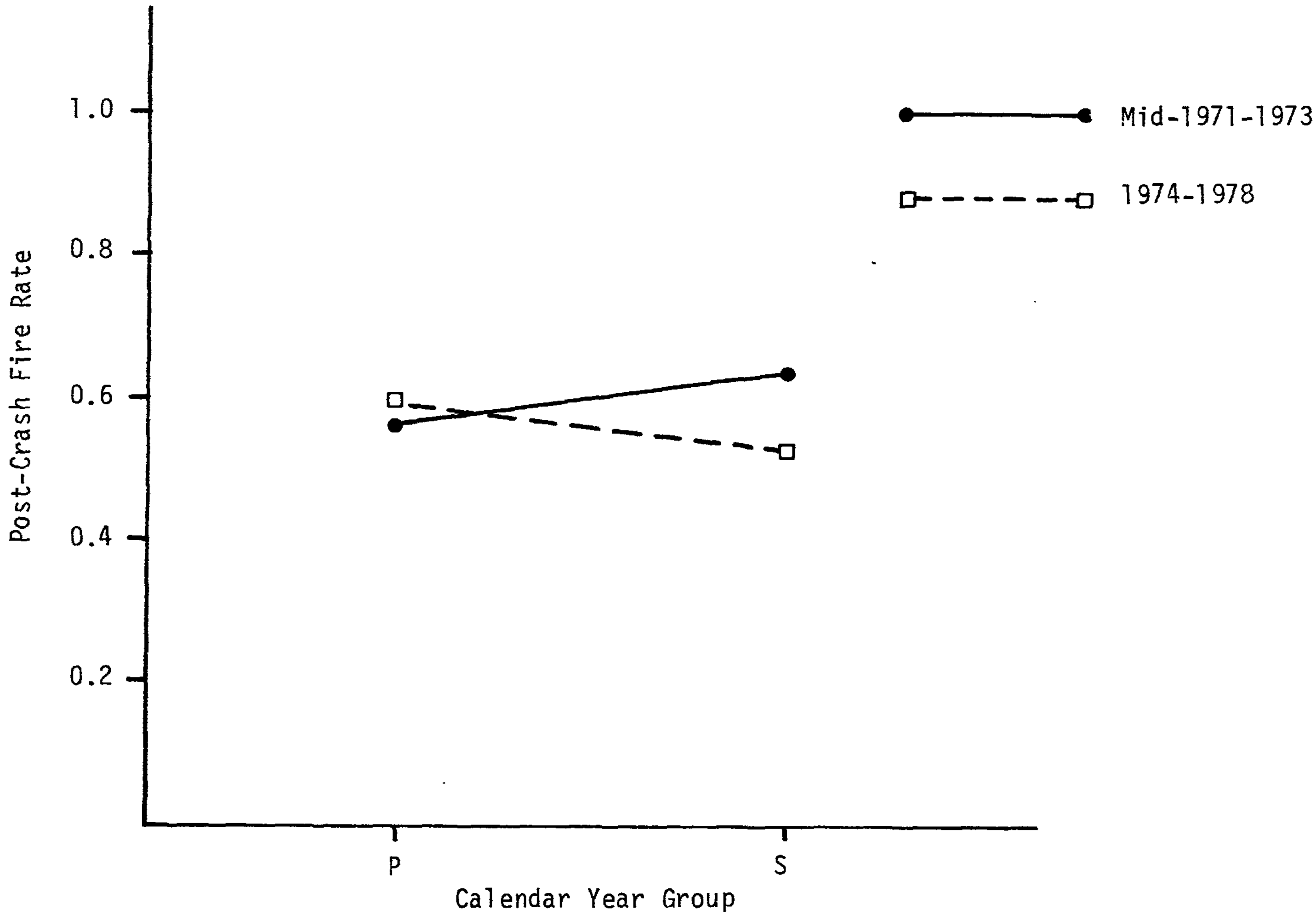


FIGURE 4-6

POST-CRASH FIRE RATES ($\hat{r}$) BY CALENDAR YEAR GROUP AND "STANDARD."

effectiveness estimate is given by

$$\hat{E} = 0.025$$

with estimated variance (from 4.2) given by

$$\hat{V}_{P,S} = 0.010629$$

yielding a standard error of $s_{P,S} = 0.167$. Clearly, from a confidence interval consideration ($\alpha = 0.05$), this (crude) effectiveness estimate is not significantly different from zero.

It is important to note that restricting the study groups to comparable ages (namely, 4-9 years), the effectiveness estimate changes from 0.052 to -0.025. It will further be seen in Section 4.5 that, by controlling progressively for impact site, speed, and age and various combinations of these variables, the effectiveness estimates become progressively more negative as the corresponding strata become more homogeneous within strata with respect to post-crash fire rates while becoming more heterogeneous among strata.

At the outset, the effect of Standard, impact site, speed and vehicle age as well as calendar year and vehicle size will be examined in the following section.

4.4 Selection of Control Variables for the Regression Model

The statistical procedure utilized for examining the effectiveness of FMVSS 301: Fuel System Integrity (Jan. 1968) in reducing post-crash fires was a logistic regression (see Section 4.5) which readily admits a variety of categorical and continuous variables in the model (see Section 4.5). The first step in the process is to identify for inclusion in the regression model those candidate control variables which have the strongest association with the outcome variable, fire occurrence. Also of interest is the relationship between these variables and Standard status (P vs. S).

As a starting point, the relationships between the variables and Standard status on the corresponding fire rates were examined using Figures 4-1 through 4-6 relating to car age, car size, impact site, speed, whether or not rollover was involved, and also calendar year of accident. From the figures, in terms of consistent relationships, it would appear that speed ($<$ 50 mph vs. $\geq$ 50 mph or unspecified) and impact site (front, side, rear vs. unspecified) would be the leading candidates as variables which are important to control for.

Secondly, based on Figures 4-1 through 4-6 and the frequency distribution of post-crash fires within potential control variables, marginal associations between each variables shown in Table 4-3 and the Standard as well as each

Table 4-3

CANDIDATE CONTROL VARIABLES

Variable	Levels
1. Age of vehicle (A_1)	<6 years, $\geq$6 years
2. Age of vehicle (A_2)	<3 years, 3-5 years, 6-8 years, >8 years
3. Impact site (I_1)	(Front & side & rear), unspecified
4. Impact site (I_2)	Front, side, rear, unspecified
5. Speed	(<50 mph), ($\geq$50 mph or unspecified)
6. Size of car (S_1)	(Luxury & Medium & Standard) (Intermediate & Compact & Subcompact) (Other)
7. Accident year (C)	Mid-1971-73, 1974-78

variable and the occurrence of post-crash fires were investigated through a series of two-way contingency tables (see Higgins and Koch, 1977). The results of these analyses are shown in Table 4-3. The χ^2's involving Standard status can be misleading due to the structural imbalance of the data, particularly for age and calendar year, i.e., relatively few "new" Pre-Standard (P) cars due to the difinition of Pre-Standard (i.e., Pre-1968) cars and the accident period ($\geq$ 1971 calendar year) and relatively few "old" Post-Standard (S) cars. Nevertheless, age will be included in the logistic regression as a continuous variable from a priori considerations.

To check for the consistency of the indicated relationship with fire occurrence within Standard levels, a variety of additional Chi-square statistics were calculated (namely, χ^2(var x fire|P), χ^2(var x fire|S), χ^2(var x fire|P) + χ^2(var x fire|S), and the Mantel-Haenszel χ^2).

Table 4-4

ASSOCIATION OF CONTROL VARIABLES WITH OCCURRENCE OF POST-CRASH FIRE AND WITH "STANDARD"

χ^2/d.f. Variable	Post-Crash Fire (yes, no)	Standard (65-67, 69-75)
1. Age of vehicle (A_1)	1.1	359,525
2. Age of vehicle (A_2)	0.6	144,338
3. Impact site (I_1)	425	1,445
4. Impact site (I_2)	143	800
5. Speed	551	269
6. Size of car (S_1)	15	6,597
7. Accident year (C)	0.4	30,831

From this investigation, it was clear that "Speed" should definitely be included in the model -- both from the results shown in Table 4-4 and from the consistency of the relationship with fire occurrence within levels of the Standard.

Having selected "Speed" as a control variable, the next step in the selection procedure involved an investigation of the relationship between the remaining variables (cross-classified with speed) and fire occurrence and also Standard status. The results of this analysis are shown in Table 4-5.

Table 4-5

ASSOCIATION OF VAR x SPEED WITH OCCURRENCE OF POST-CRASH FIRE AND WITH "STANDARD"

χ^2/d.f. Variable	Post-Crash Fire (yes, no)	Standard (65-67, 69-75)
Speed x Age (A_1)	184	120,018
Speed x Impact Site (I_1)	1277	514
Speed x Size (S_1)	121	2,726
Speed x Calendar Year (C)	186	10,302

As is clear from Table 4-5, "Impact Site (I_1)" is the next variable which should be controlled for. That "Speed" and "Impact Site (I_1)" are expected to be about equally important to control for can be seen by examining Tables 4-4 and 4-6. Thus, the modelling in Section 4.5 will control for Standard status, speed and impact site (I_1) as well as age and calendar year from a priori considerations.

Table 4-6

ASSOCIATION OF VAR x IMPACT SITE (I_1) WITH OCCURRENCE OF POST-CRASH FIRE AND WITH "STANDARD"

χ^2/d.f. Variable	Post-Crash Fire (yes, no)	Standard (65-67, 69-75)
I_1 x Age (A_1)	145	120,487
I_1 x Size (S_1)	93	3,007
I_1 x Calendar Year (C)	147	10,455

4.5 Estimation of the Effectiveness of FMVSS 301 in Reducing Post-Crash Fires

Two types of models, a categorical model (Grizzle, Starmer, and Koch, 1969) and a logistic regression model (Klimko and Friedman, 1978) were considered for this analysis. For the application to post-crash fire involvement, the logistic regression model was selected for a variety of reasons. First, it can handle a combination of continuous covariables such as age of vehicle and categorical covariables such as impact site. The categorical model would require categorizing age which discards potentially useful information.

Secondly, with the categorical model, the number of strata represented by cross-classifications of the levels of the variables in the model is severely restricted in this application as there are but 514 cases of post-crash fire in the combined (P+S) sample (all ages). With an expected cell count of at least five, this would limit the number of factor level combinations to approximately 100. From Section 4.4, it would appear that the model should contain a response variable, fire, (2 levels), Standard status (2 levels), speed (2 levels), impact site (4 levels), and calendar year (2 levels) for a total of 64 factor level combinations. This leaves but two levels for age which is clearly inadequate.

Finally, the logistic regression model gives rise to the odds ratio (ω) as a measure of association. Now if

$$\Omega_P = \frac{\text{Pr (Fire}|\text{Pre-Standard)}}{\text{Pr (No Fire}|\text{Pre-Standard)}} = \frac{\text{Pr }(F|P)}{\text{Pr }(\bar{F}|P)}$$

represents the relative risk of fire in crashes of Pre-Standard cars (i.e., Ω_P represents the odds that a fire will result in a crash involving a Pre-Standard car) and Ω_S similarly for Post-Standard cars, then the odds ratio is given by the ratio of the relative risks, i.e.

$$\omega = \frac{\Omega_S}{\Omega_P}$$

$$= \frac{\text{Pr }(F|S)}{\text{Pr }(\bar{F}|S)} \Big/ \frac{\text{Pr }(F|P)}{\text{Pr }(\bar{F}|P)}$$

$$= \frac{\text{Pr }(F|S)}{\text{Pr }(F|P)} \times \frac{1 - \text{Pr }(F|P)}{1 - \text{Pr }(F|S)} \qquad (4.3)$$

In the present context, let x_1 represent Standard status where

$$x_1 = \begin{cases} 1 \text{ if Post-Standard (S)} \\ 0 \text{ if Pre-Standard (P)} \end{cases}$$

and let $x_2, x_3, x_4 \ldots, x_7$ be the set of control variables (namely, x_2, x_3, x_4 for impact site; x_5 for speed; x_6 for age; and x_7 for calendar year). Then one possible representation for post-crash fire rates is given by

$$r = \frac{1}{1 + \exp\left(-\sum_{i=o}^{7} \beta_i x_i\right)} \qquad \text{where } x_o \equiv 1$$

$$\doteq \frac{1}{1 + \exp\left[-(\beta_o + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_7 x_7)\right]} \tag{4.4}$$

so that

$$r_P = \frac{1}{1 + \exp\left[-(\beta_o + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_7 x_7)\right]} \tag{4.5}$$

$$r_S = \frac{1}{1 + \exp\left[-(\beta_0 + \beta_1 + \beta_2 x_2 + \ldots + \beta_7 x_7)\right]} \tag{4.6}$$

The assumption of common parameters $\beta_{o}, \beta_{2}, \beta_{3}, \beta_{4}, \beta_{5}, \beta_{6}, \beta_{7}$ for Pre- and Post-Standard cars is equivalent to the assumption of no synergistic effect of Standard status and the factors $x_{2}, x_{3}, x_{4}, x_{5}, x_{6}, x_{7}$ on fire rates (Fleiss, 1973). The parameter β_1 then measures the effect of the Standard.

Under the assumption expressed by (4.4), the odds that a Pre-Standard car involved in a crash will experience a post-crash fire is given by

$$\Omega_P = \frac{\Pr(F|P)}{1 - \Pr(F|P)} = \frac{r_P}{1 - r_P}$$

$$= \exp(\beta_o + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_7 x_7) \tag{4.7}$$

from (4.5). Similarly,

$$\Omega_S = \exp(\beta_o + \beta_1 + \beta_2 x_2 + \ldots + \beta_7 x_7) \tag{4.8}$$

Thus, the odds ratio becomes

$$\omega = \frac{\Omega_S}{\Omega_P} = \exp(\beta_1) \tag{4.9}$$

$$\log(\omega) = \beta_1 \tag{4.10}$$

which are independent of the x_i's.

For rare events such as post-crash fires, (4.3) becomes approximately

$$\omega \doteq \frac{\Pr(F|S)}{\Pr(F|P)} = \frac{r_S}{r_P} \tag{4.11}$$

But the effectiveness estimate in (4.1) is given by

$$\begin{aligned}\hat{E} &= \frac{\hat{r}_P - \hat{r}_S}{\hat{r}_P} \\ &= 1 - \frac{\hat{r}_S}{\hat{r}_P} \\ &\doteq 1 - \hat{\omega} \\ &\doteq 1 - \exp(\hat{\beta}_1)\end{aligned} \tag{4.12}$$

so that, under this framework, the effectiveness estimate $\hat{E}$ is a function of the odds ratio and is independent of the x_i's.

Thus, for the rare event under study, namely, post-crash fires, the logistic regression model is selected for its ability to accommodate combinations of continuous and categorical covariables, its superiority over the categorical model with respect to limited sample sizes, and its relationship to the desired effectiveness estimate $\hat{E}$ for rare events.

Having shown the appropriateness of logistic regression in the present situation, the procedure is now applied to the North Carolina accident data. As mentioned previously, the factors considered in this analysis are Standard status (2 levels), impact site (4 levels), vehicle speed (2 levels), vehicle age, and accident year (2 levels). A simple main effects logistic regression model is fitted as follows:

For each stratum k (k = 1,2,...,M) defined by the cross-classification $(x_1 \times x_2 \times x_3 \times x_4 \times x_5 \times x_6 \times x_7)$ where

$$x_1 = \begin{cases} 1 \text{ if case vehicle is Post-Standard} \\ 0 \text{ if case vehicle is Pre-Standard} \end{cases}$$

$$x_2 = \begin{cases} 1 \text{ if frontal impact} \\ -1 \text{ if unspecified (or general) impact} \\ 0 \text{ if otherwise} \end{cases}$$

$$x_3 = \begin{cases} 1 \text{ if side impact} \\ -1 \text{ if unspecified impact} \\ 0 \text{ otherwise} \end{cases}$$

$$x_4 = \begin{cases} 1 \text{ if rear impact} \\ -1 \text{ if unspecified impact} \\ 0 \text{ otherwise} \end{cases}$$

$$x_5 = \begin{cases} 1 \text{ if speed} < 50 \text{ mph} \\ 0 \text{ if speed} \geq 50 \text{ mph or unspecified} \end{cases}$$

$$x_6 = \text{age of car}$$

$$x_7 = \begin{cases} 1 \text{ if accident year is mid-1971-1973} \\ 0 \text{ if accident year is 1974-1978} \end{cases}$$

let n_k = number of fire cases in stratum k

N_k = total number of vehicles in stratum (or subpopulation) k

The logistic regression model specifies that the post-crash fire rate, r_k, for the k-th subpopulation satisfies the equation

$$r_k = \frac{1}{1 + \exp\left(-\sum_{i=o}^{7} \beta_i x_{ik}\right)} \tag{4.13}$$

where the β_i's are parameters in the model reflecting the effects of Standard status impact site, speed, vehicle age, and accident year on the probability of post-crash fires and $x_{ok} \equiv 1$. The paramters β_i can be estimated via the maximum likelihood method by maximizing the logarithm of the likelihood function, L, where

$$L = \prod_{k=1}^{M} \left[r_k^{n_k} (1 - r_k)^{N_k - n_k} \right]$$

$$= \prod_{k=1}^{M} \left[\left\{ \frac{1}{1 + \exp\left(-\sum_{i=o}^{7} \beta_i x_{ik}\right)} \right\}^{n_k} \left\{ \frac{\exp\left(-\sum_{i=o}^{7} \beta_i x_{ik}\right)}{1 + \exp\left(-\sum_{i=o}^{7} \beta_i x_{ik}\right)} \right\}^{N_k - n_k} \right] \tag{4.14}$$

Initial values for the parameters β_i are needed to start the iteration process. The better the initial values, the quicker the convergence of the iteration process. For this application, initial estimates are obtained using the CATMAX procedure (Stokes, 1980). CATMAX is a SAS module which performs maximum likelihood logistic regression where the logits are formed from the fire rates (e.g., logit = log $\frac{r}{1-r}$).

The procedure is especially applicable to the situation where the frequency counts tend to be small and the normality assumptions required for such procedures as weighted least squares are not likely to be satisfied.

CATMAX involves basically two steps. In the first step, a set of initial values for the β_i is obtained using the method of weighted least squares (Grizzle, Starmer and Koch, 1969). These initial estimates are then used in the second step as starting values for a Newton-Raphson iterative solution for the maximum likelihood estimation of the β_i's.

However, CATMAX is severely limited by its inapplicability to relatively large contingency tables such as is the case here. Thus, the basic contingency table is partitioned into 8 modules with CATMAX estimates of β_i being obtained within each module. The initial values of β_i for the BMDP program are then obtained as an approximate weighted average of these 8 sets of CATMAX estimates. More specifically the initial estimates of the β_i's are given by

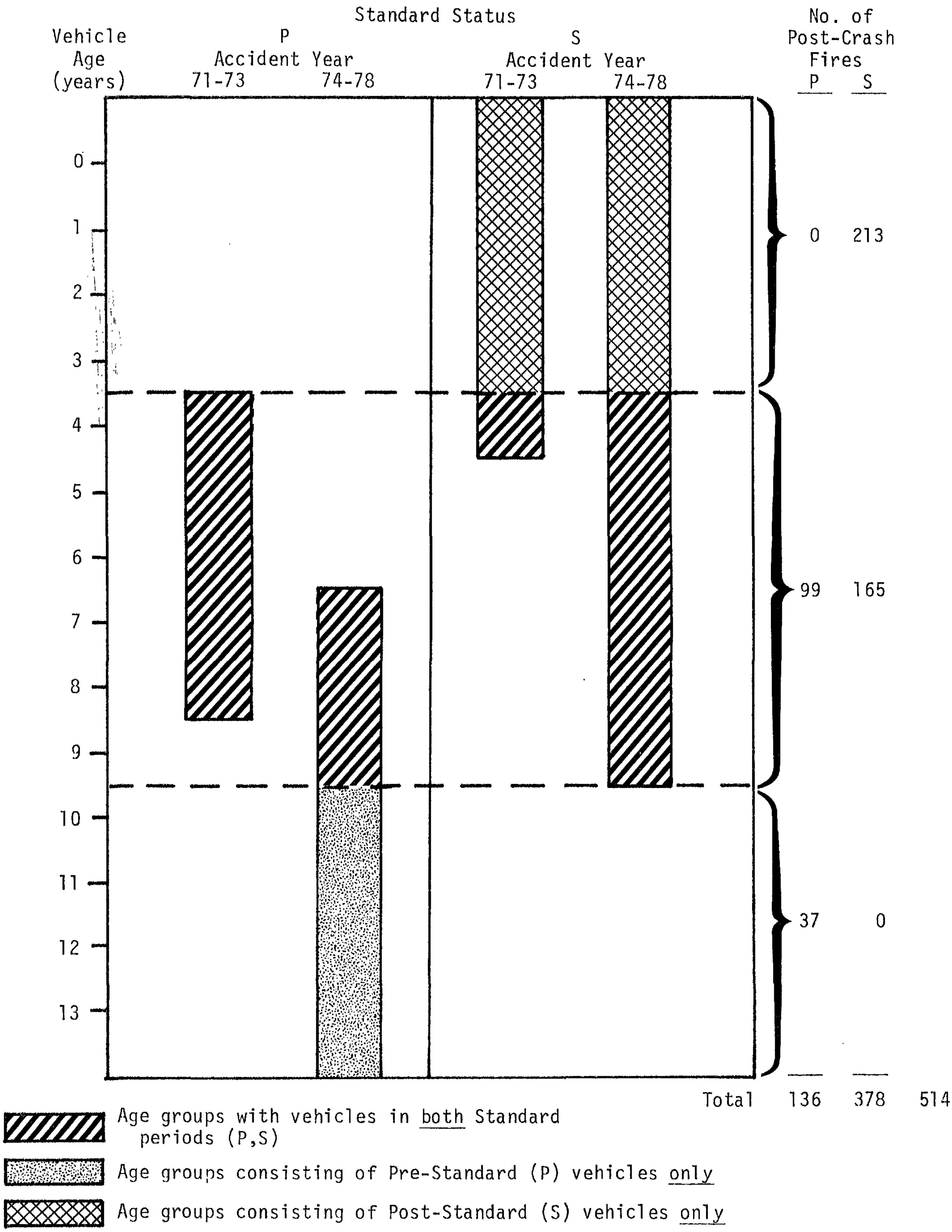
$$\begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \\ \beta_6 \\ \beta_7 \end{bmatrix} = \begin{bmatrix} -5.0 \\ 0.0 \\ -0.6 \\ -0.5 \\ -0.6 \\ -1.0 \\ 0.05 \\ 0.0 \end{bmatrix} \tag{4.15}$$

Given these initial values for the β_i's, the maximum likelihood estimates of the β_i's in the logistic regression model (4.13) are obtained by using the BMDP non-linear regression procedure, BMDP3R.

Now, as can be seen from Figure 4-7, the combined constraints of the Standard status definition (namely, P = 1965-67 model years, S = 1969-75 model years) and the available accident years (namely, mid-1971 through 1978) result in non-comparability between Standard periods at both ends of the vehicle age range (i.e., 0-3 years of age and 10-13 years of age). In other words, there are no "new" (0-3 year old) Pre-Standard cars nor "old" (10-13 year old) Post-Standard cars in the accident data. To the extent that age has an effect on the likelihood of post-crash fire, the most appropriate analysis restricts vehicle age to the 4-9 year age range. This naturally reduces the sample size (see Figure 4-7).

On the other hand, if the Standard has no effect, then using the entire age range (0-13 years of age) provides some indication of the effect of vehicle age on the probability of post-crash fire. Thus, the analyses that follow are carried out at two levels: the first restricts vehicle age to comparable ages (4-9 years old); the latter allows age to assume the values of 0 to 13.

Figure 4-7
VEHICLE AGE BY ACCIDENT YEAR DISTRIBUTION



The variable selection of Section 4.4 along with Figure 4-7 suggests that calendar year period is not an important variable with respect to post-crash fire occurrence. The logistic regression with calendar year included in the model shows that the effect of calendar year is not significant (see Table 4-7).

Table 4-7

LOGISTIC REGRESSION ESTIMATE OF CALENDAR YEAR EFFECT ($\hat{\beta}_c$) AND ITS STANDARD ERROR (s_c)

Vehicle Age	Calendar Year Effect $\hat{\beta}_c$	Standard Error s_c
4-9 (Restricted)	-0.121	0.156
0-13 (Unrestricted)	-0.114	0.106

Thus, the model is simplified by deleting the calendar year effect (i.e., the subpopulations are collapsed over accident or calendar year).

The logistic regression model which is then fit to the data is given by (4.13) and includes effects for the overall mean (β_o), Standard (β_1), impact site (β_2, β_3, β_4), speed (β_5), and age (β_6). Using the corresponding CATMAX estimates as initial values for the β_i's, the logistic regression program (BMDP) yields a model with parameter estimates and their standard errors as shown in Table 4-8.

Clearly, for comparable age groupings (4-9), impact site effects (β_2, β_3) and speed (β_5) significantly affect the probability of post-crash fire given a crash whereas there is no differential effect for rear vs. unspecified impact site (β_3). This latter result is at first surprising considering Figure 4-3. However, the data in Table 4-8 excludes 213 new (0-3 year old) vehicles and 37 old (10-13 year old) vehicles that are included in Figure 4-3. Neither age (4-9 year range) nor Standard has a significant effect on the post-crash fire rates. And from the sign of the coefficient estimate (β_1) <u>if anything</u> the post-crash fire rates appear higher for the Post-Standard cars!

The fit of the logistic regression model is satisfactory from either of two considerations. From the ordinary measure of fit provided by the residual mean

Table 4-8

PARAMETER ESTIMATES (STANDARD ERRORS) FOR THE LOGISTIC REGRESSION ON FIRE RATES FOR THE VEHICLE AGE RANGE 4-9

Effect (Parameter β)	Estimate ($\hat{\beta}$)	Standard Error (s)
Mean (β_0)	-6.396	0.266*
Standard (β_1)	0.251	0.143†
Front-unspecified impact (β_2)	-0.389	0.099*
Side-unspecified impact (β_3)	-0.496	0.124*
Rear-unspecified impact (β_4)	-0.243	0.143†
Speed (β_5)	-1.548	0.134*
Vehicle age (β_6)	0.033	0.045†

*Significant at $\alpha = 0.01$
†Not significant at $\alpha = 0.05$

square, the goodness-of-fit statistic has a p-value of nearly 0.2 where

$$\text{Residual Mean Square} = \text{RMS} = \sum_{k=1}^{M} \frac{(o_k - e_k)^2}{e_k} \Big/ \text{d.f.} = 1.159$$

with

o_k = observed number of post-crash fires in subpopulation k

e_k = number in subpopulation k predicted by the model

M = number of subpopulations

= 96

d.f. = degress of freedom

= M − (no. of parameters in the model)
= 89

To obtain the corresponding p-value, it should be noted that (d.f.) RMS is the Pearson Chi-square statistic so that

$$(d.f.)\ RMS \sim \chi^2_{(d.f.)}$$

Because the proposed model is relatively simple (namely, linear in the parameters) and since the e_i are small in most subpopulations, the indicated fit is considered most adequate.

Alternatively, the fit can be judged from the scatter plot of the subpopulation odds ratios. From Fleiss (1973), "if the odds ratio or its logarithm is stable across many different kinds of populations, then one may reasonably infer that the (corresponding) logistic model is a fair representation of the phenomenon under study (post-crash fire rates)." Figure 4-8 provides the scatter plot for this data. With but a few exceptions, the plotting points do cluster around the line $\hat{\Omega}_S = \hat{\Omega}_P$ with, if anything, a tendency to fall just above the line. The clustering is consistent with an adequate fit while tending to fall just above the line is consistent with, <u>if anything</u>, a slightly higher risk of fire in Post-Standard cars.

The corresponding estimate of the effectiveness of the first stage (January, 1968) of FMVSS 301: Fuel System Integrity is given by

$$\hat{E} = 1 - \exp(\hat{\beta}_1) = 1 - \exp(0.251) = -0.28$$

using expression (4-12) along with the parameter estimate of the effect of the Standard from Table 4-8. Although it might be argued that the significance test for the effectiveness of the Standard might be two-sided (i.e., $H_0: \beta_1 = 0$ vs $H_1: \beta_1 \neq 0$), it would seem most reasonable to test the hypothesis that the Standard had a positive effect (i.e., $H_0: \beta_1 \leq 0$ vs $H_1: \beta_1 > 0$). Under such a framework, approximate 95% confidence bounds for the effectiveness of the Standard are given by

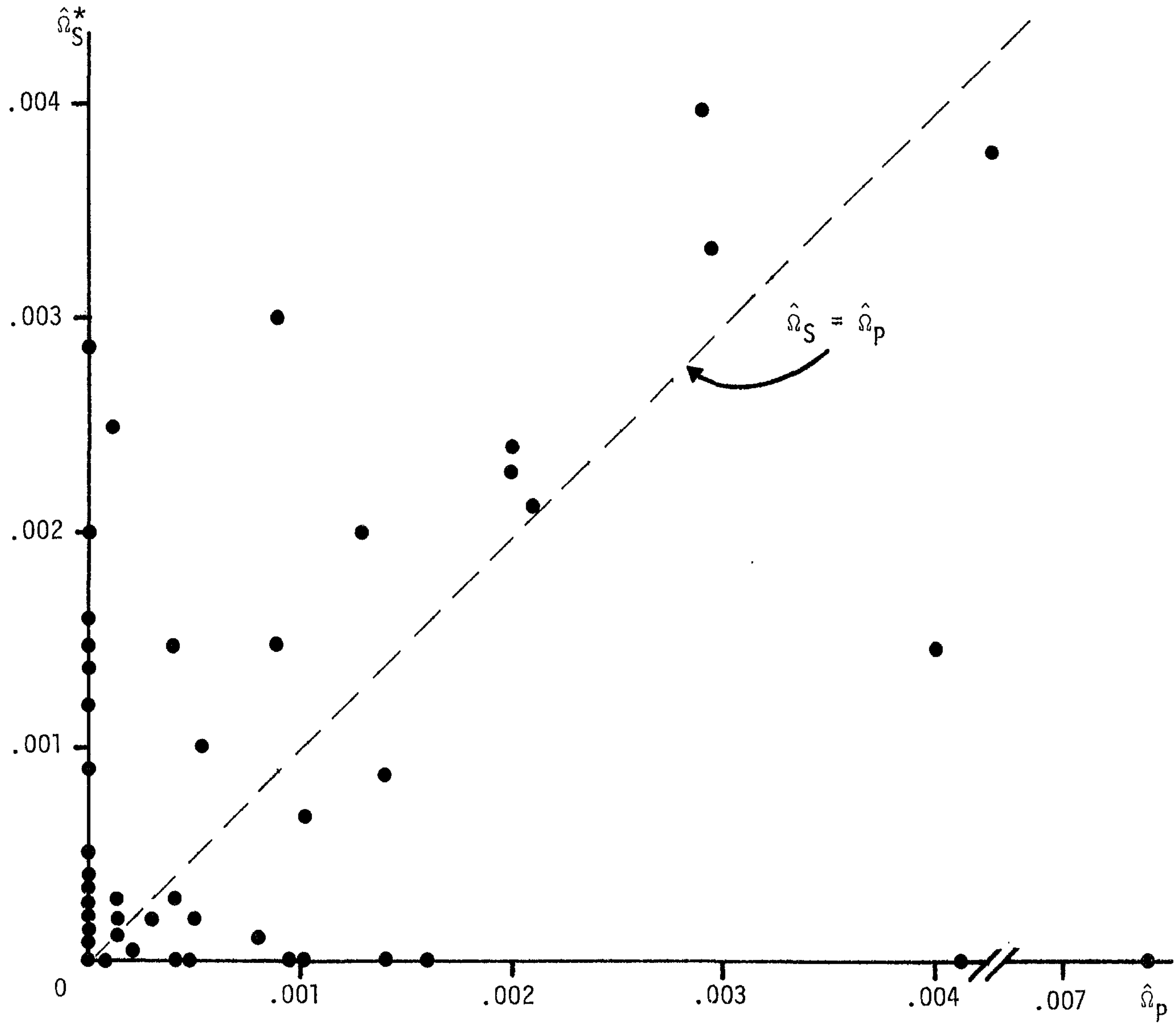
$$(-0.63, -0.01) = (1 - \exp[\hat{\beta}_1 + 1.662\ s_1],\ 1 - \exp[\hat{\beta}_1 - 1.662\ s_1])$$

where

$$\hat{\beta}_1 = 0.251$$
$$s_1 = \text{s.e.}(\hat{\beta}_1) = 0.143 \quad \text{(from Table 4-8)}$$

Figure 4-8

SCATTERPLOT OF ESTIMATES OF RELATIVE RISK OF FIRE (P) VS. RELATIVE RISK OF FIRE (S)



$$* \quad \frac{Pr(F|S)}{Pr(\bar{F}|S)} \hat{=} \hat{\Omega}_S \quad , \quad \frac{Pr(F|P)}{Pr(\bar{F}|P)} \hat{=} \hat{\Omega}_P$$

and

$$t_{0.05,89} = 1.662$$

As is evident, from this data, the first stage of FMVSS 301 did not have the desired effect of reducing post-crash fire rates in Post-Standard (1969-1975 model) cars (p-value < 0.5).

Finally, for comparison purposes and to further examine the effect of vehicle age, a logistic regression was carried out over the unrestricted age range (0-13 years). The resulting estimates are given in Table 4-9. Here,

Table 4-9

PARAMETER ESTIMATES (STANDARD ERRORS) FOR THE LOGISTIC REGRESSION ON FIRE RATES FOR THE UNRESTRICTED VEHICLE AGE RANGE 0-13 YEARS.

Effect (Parameter β)	Estimate ($\hat{\beta}$)	Standard Error (s)
Mean (β_o)	-6.570	0.106*
Standard (β_1)	0.267	0.146†
Front-unspecified impact (β_2)	-0.313	0.078*
Side-unspecified impact (β_3)	-0.501	0.100*
Rear-unspecified impact (β_4)	-0.338	0.118*
Speed (β_5)	-1.552	0.106*
Vehicle age (β_6)	0.063	0.022*

*Significant at $\alpha = 0.01$
†Not significant at $\alpha = 0.05$

impact site (β_2, β_3, and β_4) and speed (β_5) are significant while Standard status (β_1) is not significant (at $\alpha = 0.05$). Here, however, age (β_6) is significant indicating that fire rates are not constant over the entire age range (0-13 years) with the rates increasing with vehicle age.

As with the case for the restricted vehicle age range (4-9), the effectiveness estimate is given by

$$\hat{E} \doteq 1 - \exp(0.267) = -0.31$$

with corresponding approximate 95% confidence bounds given by

$$(-0.66, -0.03) = (1 - \exp[\hat{\beta}_1 + 1.645\, s_1],\ 1 - \exp[\hat{\beta}_1 - 1.645\, s_1])$$

where

$$\hat{\beta}_1 = 0.267$$

$$s_1 = 0.146 \qquad \text{(from Table 4-9)}$$

and

$$t_{0.05,\infty} = 1.645$$

Again, the Standard did <u>not</u> reduce the likelihood of post-crash fires as anticipated even for this less appropriate comparison (p-value < 0.5).

Finally, as mentioned previously, the logistic regression modeling had a considerable effect on the initial crude effectiveness estimate (-0.025). This might be expected on at least two counts. First, the variable screening intentionally subdivided the data into strata that were homogeneous with respect to post-crash fire rates. To see this effect, various progressively more complex logistic regression models were fit to the data. As additional variables were added to the model, the effectiveness estimates became systematically and consistently more negative until the final model provided an effectiveness estimate of -0.28.

More specifically, the fitted models (for the 4-9 year age range) along with the derived effectiveness estimates are presented in Table 4-10. Clearly, the effectiveness estimates increase (in absolute value) as variables are added to the model. As is clear from Table 4-10, age clearly has a dampening effect on the effectiveness estimate changes.

Secondly, as the models contain additional variables, the data in the corresponding subpopulations become increasingly sparse (see Appendix C). This could well account for the apparent instability of the effectiveness estimates.

Table 4-10

FITTED LOGISTIC REGRESSION MODELS AND CORRESPONDING EFFECTIVENESS (4-9 YEAR OLD CARS)

Variables in the Model	Effect of Standard $\hat{\beta}_1$	Effectiveness Estimate $1 - \exp(\hat{\beta}_1)$
Speed x Standard	0.109	-0.11
Impact Site x Standard	0.170	-0.18
Age x Standard	-0.005	0.005
Speed x Impact Site x Standard	0.250	-0.28
Speed x Age x Standard	0.090	-0.10
Impact Site x Age x Standard	0.190	-0.21
Speed x Impact Site x Age x Standard	0.251	-0.28

Several caveats should be considered with respect to the analysis of the North Carolina narrative data. There are potential non-sampling errors arising from the following sources:

(i) Use of police accident narratives. It is likely that the magnitude of the problem of post-crash fire is underestimated either due to the police failing to mention it in the narrative or to the researcher failing to utilize all the relevant key search words. However, it is not likely that this would differentially occur for the Pre- or Post-Standard cars and thus should not affect the corresponding comparisons.

(ii) Uncontrolled confounding factors. The post-crash fire sample size precluded simultaneously controlling for more than a few confounding factors. The ones utilized were selected by variable screening but it is conceivable that other factors such as "cars with catalytic converters" might have been important to control for.

(iii) Definition of variables. With categorical data, the selection of variable levels can be important such as "speed $<$ 50 mph." An alternative definition (e.g., "speed $\leq$ 55 mph") could possibly have led to different results.

(iv) Exclusion of the oldest cars. The exclusion of pre- 1965 model cars was done to try to minimize any potential age effects. In so doing, the excluded cars were at least seven years old and, on average, much older.

Notwithstanding these caveats, it is apparent that the first version of FMVSS 301 did not have the desired effect of decreasing the post-crash fire rates in Post-Standard cars involved in crashes in North Carolina.

4.6 References for Section 4

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The tables in Appendix A represent an examination of the NCSS Master File according to whether a fire (or fuel leakage) occurred according to accident severity, investigating team, year/month, time of day, number of vehicles involved, CRASH completed, speed limit, and model year groups. They show the differential effects of weighting the observations according to the sampling plan.

In summary (as expected) post-crash fires are more likely to occur in the more serious accidents (ACC. SEVERITY = fatal or injury with hospitalization), at higher speeds (SPEED LIMIT = 50+ mph), in the more rural areas (e.g., TEAM = Indiana vs. Miami), in single vehicle accidents (NO. VEHICLES = single vehicle), during the nighttime hours (TIME OF DAY = 6:00 p.m. - 6:59 a.m.). In brief, the NCSS fire file seems totally consistent with a priori hypotheses.

TABLE A-1

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY ACCIDENT SEVERITY

Accident Severity	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
Fatal	33 (6.2)* [33.3]**	501 (93.8) [5.3]	33 (6.2) [19.6]	501 (93.8) [1.1]
Injury-Hospital	51 (1.5) [51.5]	3357 (98.5) [35.4]	51 (1.5) [30.4]	3357 (98.5) [7.2]
Injury-Transported	11 (0.4) [11.1]	2531 (99.6) [26.7]	44 (0.4) [26.2]	10124 (99.6) [21.8]
No Transport	4 (0.1) [4.0]	3097 (99.9) [32.6]	40 (0.1) [23.8]	32360 (99.9) [69.8]
Total	99 (1.0)*	9486 (99.0)	168 (0.4)	46342 (99.6)

* Row % **Column %

Table A-2

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY INVESTIGATING TEAM

Team	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
Calspan	6 (0.4)* [6.1]**	1366 (99.6) [14.4]	18 (0.3) [10.7]	6337 (99.7) [13.7]
HSRI	14 (1.4) [14.1]	981 (98.6) [10.3]	14 (0.3) [8.3]	4566 (99.7) [9.9]
Indiana	23 (1.8) [23.2]	1276 (98.2) [13.5]	35 (0.7) [20.8]	4642 (99.3) [10.0]
Kentucky	12 (1.0) [12.1]	1222 (99.0) [12.9]	24 (0.4) [14.3]	5578 (99.6) [12.0]
Miami	9 (0.5) [9.1]	1747 (99.5) [18.4]	12 (0.1) [7.1]	9661 (99.9) [20.8]
SwRI	27 (1.3) [27.3]	2047 (98.7) [21.6]	33 (0.3) [19.6]	10817 (99.7) [23.3]
DSi	8 (0.9) [8.1]	847 (99.1) [8.9]	32 (0.7) [19.0]	4741 (99.3) [10.2]
Total	99 (1.0)	9486 (99.0)	168 (0.4)	46342 (99.6)

*Row %   **Column %

Table A-3

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY YEAR/MONTH

Year/Month	Accidents: Unweighted File: Fire	Accidents: Unweighted File: No Fire	Accidents: Weighted File: Fire	Accidents: Weighted File: No Fire
1977				
January	2 [2.0]*	380 [4.0]	2 [1.2]	2081 [4.5]
February	0 [0.0]	378 [4.0]	0 [0.0]	2001 [4.3]
March	2 [2.0]	429 [4.5]	2 [1.2]	2064 [4.5]
April	5 [5.1]	402 [4.2]	8 [4.8]	1956 [4.2]
May	7 [7.1]	447 [4.7]	13 [7.7]	2124 [4.6]
June	6 [6.1]	387 [4.1]	21 [12.5]	1959 [4.2]
July	6 [6.1]	421 [4.4]	15 [8.9]	1852 [4.0]
August	3 [3.0]	414 [4.4]	6 [3.6]	2118 [4.6]
September	7 [7.1]	422 [4.4]	10 [6.0]	1838 [4.0]
October	7 [7.1]	467 [4.9]	13 [7.7]	2054 [4.4]
November	7 [7.1]	437 [4.6]	19 [11.3]	2078 [4.5]
December	4 [4.0]	438 [4.6]	4 [2.4]	2064 [4.5]
1978				
January	0 [0.0]	341 [3.6]	0 [0.0]	1826 [3.9]
February	1 [1.0]	347 [3.7]	1 [0.6]	1958 [4.2]
March	1 [1.0]	397 [4.2]	1 [0.6]	1894 [4.1]

*Column %

Table A-3 (Con't)

Year/Month	Accidents: Unweighted File: Fire	Accidents: Unweighted File: No Fire	Accidents: Weighted File: Fire	Accidents: Weighted File: No Fire
1978				
April**	10 [10.1]*	282 [3.0]	10 [6.0]	1236 [2.7]
May	5 [5.1]	325 [3.4]	5 [3.0]	1705 [3.7]
June	2 [2.0]	304 [3.2]	2 [1.2]	1363 [2.9]
July	2 [2.0]	304 [3.2]	2 [1.2]	1354 [2.9]
August	4 [4.0]	363 [3.8]	16 [9.5]	1777 [3.8]
September	3 [3.0]	315 [3.3]	3 [1.8]	1533 [3.3]
October	5 [5.1]	344 [3.6]	5 [3.0]	1708 [3.7]
November	1 [1.0]	324 [3.4]	1 [0.6]	1636 [3.5]
December	6 [6.1]	357 [3.8]	6 [3.6]	1819 [3.9]
1979				
January	1 [1.0]	195 [2.1]	1 [0.6]	936 [2.0]
February	0 [0.0]	120 [1.3]	0 [0.0]	702 [1.5]
March	2 [2.0]	146 [1.5]	2 [1.2]	706 [1.5]
Total	99 (1.0)***	9486 (99.0)	168 (0.4)	46342 (99.6)

*Column %   **Start with new fire supplement   ***Row %

TABLE A-4

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED)
WITH VS. WITHOUT POST-CRASH FIRES BY <u>TIME OF DAY</u>

Time of Day	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
Midnight - 6:59 a.m.	43 (1.9)* [43.4]**	2202 (98.1) [23.3]	73 (0.8) [43.5]	9103 (99.2) [19.7]
7:00 a.m. - 8:59 a.m.	4 (0.5) [4.0]	730 (99.5) [7.7]	7 (0.2) [4.2]	4204 (99.8) [9.1]
9:00 a.m. - 2:59 p.m.	13 (0.6) [13.1]	2116 (99.4) [22.4]	22 (0.2) [13.1]	11089 (99.8) [24.0]
3:00 p.m. - 5:59 p.m.	10 (0.6) [10.1]	1710 (99.4) [18.1]	13 (0.1) [7.7]	9165 (99.9) [19.8]
6:00 p.m. - 8:59 p.m.	14 (1.0) [14.1]	1361 (99.0) [14.4]	35 (0.5) [20.8]	6635 (99.5) [14.4]
9:00 p.m. - 11:59 p.m.	15 (1.1) [15.2]	1333 (98.9) [14.1]	18 (0.3) [10.7]	5989 (99.7) [13.0]
Total	99 (1.0)	9452*** (99.0)	168 (0.4)	46185 (99.6)

*Row % **Column % ***Unknown time for 34 non-fire cases

TABLE A-5

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY NUMBER OF VEHICLES INVOLVED

# Vehicles Involved	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
1	45 (1.3)* [45.5]**	3471 (98.7) [36.6]	87 (0.6) [51.8]	14502 (99.4) [31.3]
2	49 (0.9) [49.5]	5112 (99.1) [53.9]	70 (0.3) [41.7]	27295 (99.7) [58.9]
3	2 (0.3) [2.0]	745 (99.7) [7.9]	5 (0.1) [3.0]	3793 (99.9) [8.2]
≥4	3 (1.9) [3.0]	158 (98.1) [1.7]	6 (0.8) [3.6]	752 (99.2) [1.6]
Total	99 (1.0)	9486 (99.0)	168 (0.4)	46342 (99.6)

*Row % **Column %

TABLE A-6

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY CRASH RECONSTRUCTION COMPLETED

Crash Reconstruction	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
Completed: Dam. & Traj.	11 (1.1)* [11.1]**	1024 (98.9) [10.8]	20 (0.5) [11.9]	3843 (99.5) [8.3]
Damage Only	49 (1.4) [49.5]	3538 (98.6) [37.3]	82 (0.5) [48.8]	16343 (99.5) [35.3]
Other (including not completed)	39 (0.8) [39.4]	4924 (99.2) [51.9]	66 (0.3) [39.3]	26156 (99.7) [56.7]
Total	99 (1.0)	9486 (99.0)	168 (0.4)	46342 (99.6)

*Row % **Column %

TABLE A-7

DISTRIBUTION OF NCSS CAR ACCIDENTS (UNWEIGHTED, WEIGHTED) WITH VS. WITHOUT POST-CRASH FIRES BY SPEED LIMIT (VEHICLE #1)

Speed Limit (Vehicle #1)	Accidents			
	Unweighted File		Weighted File	
	Fire	No Fire	Fire	No Fire
None	0 (0.0)* [0.0]**	43 (100.0) [0.5]	0 (0.0) [0.0]	238 (100.0) [0.5]
≤ 20 mph	0 (0.0) [0.0]	81 (100.0) [0.9]	0 (0.0) [0.0]	395 (100.0) [0.9]
25 mph	1 (0.3) [1.0]	363 (99.7) [3.8]	1 (0.0) [0.6]	2052 (100.0) [4.4]
30 mph	6 (0.3) [6.1]	1961 (99.7) [20.7]	12 (0.1) [7.1]	11066 (99.9) [23.9]
35 mph	9 (0.5) [9.1]	1959 (99.5) [20.7]	21 (0.2) [12.5]	10573 (99.8) [22.8]
40 mph	5 (0.5) [5.1]	944 (99.5) [10.0]	5 (0.1) [3.0]	4869 (99.9) [10.5]
45 mph	7 (0.9) [7.1]	770 (99.1) [8.1]	7 (0.2) [4.2]	3469 (99.8) [7.5]
50 mph	3 (1.0) [3.0]	310 (99.0) [3.3]	3 (0.2) [1.8]	1376 (99.8) [3.0]
55 mph	66 (2.2) [66.7]	2937 (97.8) [31.0]	117 (1.0) [69.6]	11579 (99.0) [25.0]
Unknown	2 (1.7) [2.0]	118 (98.3) [1.2]	2 (0.3) [1.2]	725 (99.7) [1.6]
Total	99 (1.0)*	9486 (99.0)	168 (0.4)	46342 (99.6)

*Row %   **Column %

TABLE A-8

PERCENTAGE DISTRIBUTION AND FUEL LEAKAGE RATES (PER 1,000 VEHICLES) BY MODEL YEAR - UNWEIGHTED, WEIGHTED

	Unweighted			Weighted		
	Leakage	No Leakage	$\hat{\ell}$	Leakage	No Leakage	$\hat{\ell}_W$
Pre-1968 (Pre-Standard)	26 [13.8]*	2386 [14.6]	10.80	65 [17.5]	11164 [13.7]	5.79
1968 (Interim)	7 [3.7]	908 [5.6]	7.65	16 [4.3]	4613 [5.7]	3.46
1969-1975 (Post-Standard I)	117 [62.2]	9575 [58.7]	12.07	222 [59.8]	48692 [59.7]	4.54
Post-1975 (Post-Standard II)	38 [20.2]	3441 [21.1]	10.92	68 [18.3]	17043 [20.9]	3.97
Unknown	1	111		1	581	
Total	189 (1.1)	16421 (98.9)		372 (0.5)	82093 (99.5)	

*Column % (excluding "Unknown")

TABLE B-1
NORTH CAROLINA FIRE RATES (PER 1000 VEHICLES) BY MODEL YEAR

Model Year	No. of Crash-Involved Vehicles	No. of Fires	Post-Crash Fire Rate (per 1000) $\hat{r}$
1964	137,606	105	0.76
1965	68,133	44	0.65
1966	82,191	41	0.50
1967	83,711	52	0.62
1969	118,050	67	0.57
1970	111,412	58	0.52
1971	113,852	53	0.47
1972	127,158	86	0.68
1973	108,190	54	0.50
1974	71,991	36	0.50
1975	36,294	23	0.63
1976	38,033	13	0.34
1977	21,257	11	0.52
1978	6,007	1	0.17
TOTAL	1,123,885	644	0.57

TABLE B-2
NORTH CAROLINA FIRE RATES (PER 1000 VEHICLES) BY ACCIDENT YEAR

Accident Year	No. of Crash-Involved Vehicles	No. of Fires	Post-Crash Fire Rate (per 1000) $\hat{r}$
1971	78,091*	44*	0.56
1972	165,009	125	0.76
1973	155,558	85	0.55
1974	146,949	56	0.38
1975	152,037	82	0.54
1976	171,125	95	0.56
1977	179,389	123	0.69
1978	75,727*	34*	0.45
TOTAL	1,123,885	644	0.57

*Partial accident year

TABLE B-3
NORTH CAROLINA PASSENGER CAR CRASH INVOLVEMENT
(POST-CRASH FIRES)
BY MODEL YEAR AND ACCIDENT YEAR

Model Year	Accident Year 1971	1972	1973	1974	1975	1976	1977	1978
64	22,685 (16)	37,112 (40)	24,200 (16)	16,648 (8)	13,588 (10)	11,749 (5)	8,863 (9)	2,761 (1)
65	8,292 (5)	15,836 (13)	12,013 (3)	9,298 (6)	7,991 (8)	7,160 (7)	5,723 (0)	1,820 (2)
66	8,770 (3)	17,203 (10)	14,188 (7)	11,663 (4)	10,533 (4)	9,537 (3)	7,709 (10)	2,588 (0)
67	8,183 (5)	16,464 (10)	13,804 (8)	11,879 (7)	11,063 (10)	10,488 (4)	8,871 (5)	2,959 (3)
69	10,079 (7)	20,205 (13)	18,384 (11)	16,476 (7)	16,135 (8)	16,650 (13)	14,719 (8)	5,402 (0)
70	9,494 (3)	18,784 (11)	16,458 (10)	14,978 (7)	14,992 (3)	15,705 (12)	15,374 (9)	5,627 (3)
71	9,405 (5)	19,526 (10)	16,774 (9)	14,754 (6)	15,178 (5)	16,173 (5)	15,888 (10)	6,152 (3)
72	1,183 (0)	18,854 (18)	22,029 (14)	18,800 (3)	18,671 (12)	20,092 (13)	19,761 (21)	7,768 (5)
73	--	1,025 (0)	16,992 (6)	20,214 (6)	19,472 (12)	20,882 (9)	21,204 (16)	8,401 (5)
74	--	--	716 (1)	11,906 (2)	16,705 (8)	17,788 (11)	17,712 (13)	7,165 (1)
75	--	--	--	334 (0)	7,143 (2)	11,905 (6)	11,975 (10)	4,937 (5)
76	--	--	--	--	566 (0)	12,408 (7)	17,895 (4)	7,164 (2)
77	--	--	--	--	--	588 (0)	13,079 (8)	7,590 (3)
78	--	--	--	--	--	--	616 (0)	5,391 (1)

APPENDIX C

NORTH CAROLINA POST-CRASH FIRE AND POPULATION FREQUENCIES BY IMPACT SITE, SPEED, VEHICLE AGE (4-9 Years), AND STANDARD STATUS COMBINATIONS

TABLE C

OBSERVED NORTH CAROLINA POST-CRASH FIRE AND POPULATION FREQUENCIES BY IMPACT SITE, SPEED, VEHICLE AGE (4-9 Years), AND STANDARD STATUS COMBINATIONS

Impact Site	Speed	Vehicle Age	Standard Status	No. of Post-Crash Fires	Population (No. of Cars in Accidents)
Front	Low	4	P	0	3380
			S	8	37769
		5	P	0	10244
			S	7	29575
		6	P	1	15659
			S	6	21861
		7	P	5	16768
			S	3	14936
		8	P	2	13932
			S	1	7955
		9	P	1	12237
			S	0	2114
	High	4	P	0	796
			S	16	10767
		5	P	1	2552
			S	12	8197
		6	P	4	4454
			S	18	5802
		7	P	3	4912
			S	10	4035
		8	P	4	4470
			S	3	2096
		9	P	4	3651
			S	0	537

TABLE C (Con't)

Impact Site	Speed	Vehicle Age	Standard Status	No. of Post-Crash Fires	Population (No. of Cars in Accidents)
Side	Low	4	P	0	678
			S	2	21308
		5	P	0	2076
			S	2	16825
		6	P	1	4853
			S	1	12231
		7	P	1	6643
			S	2	8495
		8	P	0	7193
			S	2	4518
		9	P	0	6465
			S	0	1252
	High	4	P	0	175
			S	9	6509
		5	P	0	641
			S	6	4994
		6	P	1	1728
			S	4	3651
		7	P	5	2482
			S	6	2493
		8	P	5	2480
			S	3	1290
		9	P	1	2050
			S	0	351

TABLE C (Con't)

Impact Site	Speed	Vehicle Age	Standard Status	No. of Post-Crash Fires	Population (No. of Cars in Accidents)
Rear	Low	4	P	0	1739
			S	6	14608
		5	P	3	5108
			S	2	11512
		6	P	6	6961
			S	1	8544
		7	P	3	6496
			S	0	5679
		8	P	2	4529
			S	1	3136
		9	P	4	4114
			S	0	795
	High	4	P	0	250
			S	1	2132
		5	P	0	694
			S	3	1485
		6	P	0	1171
			S	1	1037
		7	P	0	1200
			S	2	699
		8	P	0	928
			S	0	342
		9	P	1	620
			S	0	98

TABLE C (Con't)

Impact Site	Speed	Vehicle Age	Standard Status	No. of Post-Crash Fires	Population (No. of Cars in Accidents)
Unspecified	Low	4	P	1	470
			S	5	2332
		5	P	2	1505
			S	4	1963
		6	P	2	1777
			S	1	1476
		7	P	2	1427
			S	1	1147
		8	P	0	665
			S	1	625
		9	P	1	714
			S	0	146
	High	4	P	4	695
			S	6	1576
		5	P	7	2414
			S	5	1252
		6	P	8	2696
			S	3	894
		7	P	8	1975
			S	1	694
		8	P	4	542
			S	0	384
		9	P	2	468
			S	0	109
		Total		264	471,903