FINAL REPORT
FURTHER EVALUATION OF FMVSS 301--FUEL SYSTEM INTEGRITY--USING POLICE ACCIDENT DATA

For:
DEPARTMENT OF TRANSPORTATION
National Highway Traffic Safety Administration

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16. Abstract
Police accident data from Illinois (for six years) and from Michigan (for three years) were used to estimate the effect of FMVSS 301 in real crashes. The effect to be observed was a change in crash fire or fuel leakage rates associated with model years of cars or light trucks subject to the current version of FMVSS 301. Leakage data were only available in Michigan.

Fire rates were found to be quite low for current models. Passenger car crash fire rates were estimated to be about 1.5 fires per thousand crashes and light truck fire rates were about 2.4 per thousand crashes. Missing data rates could not be estimated in Michigan, but in Illinois, were much larger than fire rates, ranging from 17 percent to 30 percent over the six years.

Significant reductions in passenger car crash fire rates corresponding to the 1976 version of FMVSS 301 were observed in both data sets, after adjusting for crash type, severity, and vehicle age. Leakage rates appear more directly related to other changes in models than to the standard. However, even after estimating other effects, significant reductions in leakage rates corresponding to the standard were observed. Average reductions ranged from 12 percent to 27 percent. Light truck data showed no effect in fire rates, but some reduction in leakage rates corresponding to the standard.

While it cannot be proven that the standard caused these reductions, many other possible explanations were ruled out. General changes in car design in response to litigation may have contributed to the observed reductions, particularly in leak rates.

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Crash fires, Fuel systems, Fuel leakage, Safety standards, Passenger car crashes, Light truck Crashes

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EXECUTIVE SUMMARY

This is the final report of a project titled "Evaluation of the Effectiveness of FMVSS 301--Fuel System Integrity." The project was sponsored by the National Highway Traffic Safety Administration under Contract Number DOT-HS-7-01755 to the Highway Safety Research Institute of The University of Michigan. The project used data from Illinois and Michigan police-reported accidents. These data sets were selected as the result of an earlier effort that investigated the utility of various data sources in estimating reductions in crash fire and fuel leakage rates that might be associated with the implementation of FMVSS 301.

In the earlier effort (Flora et al., 1979), several data sources were investigated. Several states assign the code "fire" from interpretation of the narrative description of the crash. While this results in many of the conflagrations being included, the reported fire rates in these states are much smaller than those observed in jurisdictions that include a check box on the accident report form for occurrence of fire. Fire department data collected on statewide basis in the National Fire Incident Reporting System were considered. They were found to lack identification of a car fire with a crash; most of the vehicle fires reported there were clearly non-crash fires. In addition, model year information was sketchy and no crash details were available even if a report appeared to be a crash fire. The data from the National Crash Severity Study were found to contain too few fires for useful analysis and appeared to under-report leaks. Data from the Fatal Accident Reporting System suffer from the fact that they represent a selection of accidents in which someone was killed, resulting in a special set of data with many factors that interact with occurrence of fires or fuel leakage and prevent evaluation of the standard. Consequently, data from large states that report occurrence of fire as a variable to be answered on each accident report provide the best data for this evaluation.

The FMVSS 301 is a series of standards that specify a performance requirement that passenger cars and light trucks must meet in crash tests. The standard requires that, after a crash of a specified type, the vehicle should not leak more than one ounce of fuel per minute. The standard first applied to passenger cars in 1968 and was modified in 1976 and in 1977. It applied to light trucks in 1977, with modification in 1978. Details of the standards are summarized in Table 1 in the report. The sequential modifications generally extended the class of vehicles that the standard applied to and increased the variety of crash tests that must be used.

The standard applies to fuel leakage. Its aim is to prevent or reduce post-crash fires and associated injuries and deaths by reducing or eliminating the fuel leakage. In Michigan, separate estimates of fuel leakage and occurrence of fire are available, but in Illinois only occurrence of fire is reported. The overall fire rates in Michigan and Illinois are comparable. Post-crash fires are relatively rare events, occurring slightly less often than two fires per thousand police-reported crashes for passenger cars, and somewhat more often--about 2.5 fires per thousand crashes--for light trucks. Fuel leakage is more common, occurring in about 12 out of a thousand passenger car crashes and in about 17 out of a thousand light truck crashes. Table A summarizes the crash fire rates and fuel leakage rates for passenger cars by model year groupings that correspond to various versions of FMVSS 301, while Table B summarizes these rates for light trucks. The data are presented separately by state and year of crash. The appendix of this report gives the raw data for fires and crashes by model year and state.

The crash fire rates for passenger cars in Illinois are displayed in Figure A. In the figure, the effect of different model years can be viewed by looking at the abscissa. Within each model year, from one to six years of data are plotted. These crash years are identified by the last digit of the year. They represent up to six different ages of the model year in question, so effects of age can be viewed vertically at each model year. (All the figures in this summary also appear in the report and are discussed in more detail there.)

TABLE A

Passenger Cars
Fire Rates Per Thousand Crashes

Year	Pre-301	68-75	1976	1977+
ILLINOIS				
1975	2.241	1.570	2.097 (?)	--
1976	2.581	2.238	1.852	1.502 (?)
1977	2.076	1.813	1.446	1.217
1978	2.213	1.764	1.550	1.495
1979	1.276	1.725	1.626	1.480
1980	2.642	1.912	1.495	1.700
MICHIGAN				
1978	3.209	2.252	1.718	1.810
1979	3.010	2.584	1.881	1.169
1980	3.237	2.797	1.774	1.624
Passenger Cars Fuel Leakage Rates Per Thousand Crashes				
MICHIGAN				
1978	27.371	15.916	7.921	7.786
1979	27.144	15.462	8.816	6.589
1980	25.614	15.570	8.539	6.763

Figure B displays the crash fire rates for passenger cars in Michigan. The rates are plotted the same way as those from Illinois were. It is noteworthy in these data that the highest crash fire rate for models 1976 and later (that were subject to the revised version of FMVSS 301) is lower than the lowest crash fire rate for earlier models.

In the Michigan data, information on fuel leaks is also available. The fuel leakage rates are plotted in Figure C, with the same conventions as used before. There is a very definite trend in fuel leak rates related to model year. The rates appear nearly constant and quite low for model years 1976 and later, but show a strong increasing trend for earlier models. Some of this trend may be related to aging of the

TABLE B

Pickup Trucks
Fire Rates Per Thousand Crashes

Year	Pre-77	1977	1978+	Total
ILLINOIS				
1975	2.273	--	--	2.273
1976	2.758	4.31(?)	--	2.771
1977	1.937	3.482	0.0(?)	2.125
1978	2.770	2.039	3.142	2.698
1979	2.349	2.089	1.903	2.189
1980	2.325	1.974	2.045	2.178
MICHIGAN				
1978	2.549	2.036	2.121	2.394
1979	2.880	2.773	2.045	2.534
1980	2.906	1.891	1.533	2.250
Pickup Trucks Fuel Leakage Rates Per Thousand Crashes				
MICHIGAN				
1978	21.796	13.377	10.781	18.651
1979	21.669	9.412	8.259	16.986
1980	22.161	15.839	9.197	16.408

cars, but it may also be related to gradual changes in the average size, style, or more general model year differences.

Fire and leakage rates were found to vary by a variety of factors. Different crash configurations and crash severities affect those rates strongly--more so than do differences in model years. In Section 4 of the report, mathematical models are used to model the effects of crash severity and type in order to control for these factors before estimating the changes in fire or leak rates that may be associated with the standard.

The data do not indicate any significant differences between the 1976 and 1977 versions of FMVSS 301. In part this may be due to the fact that only a single model year is involved and that a substantial

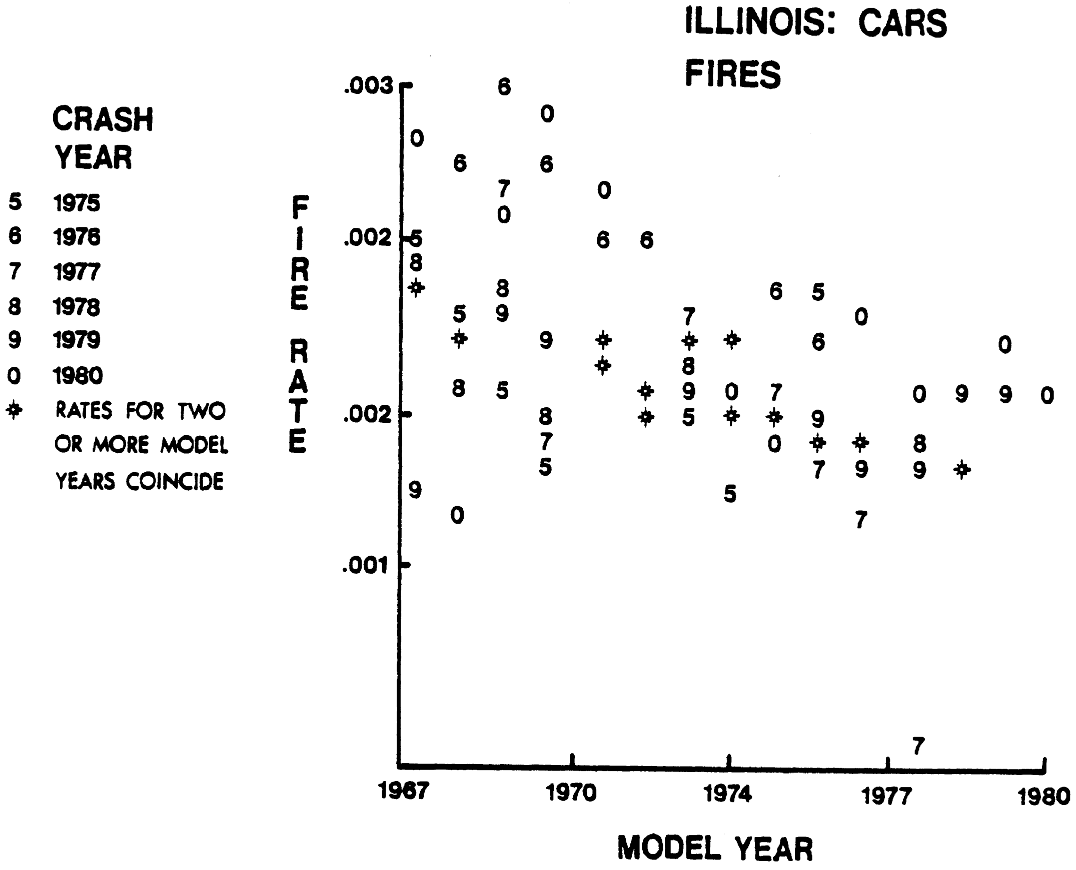

FIGURE A
Passenger Car Fire Rates by Model Year in Illinois
(Also shown as Figure 1)

amount of data is needed to detect differences. Another possibility is that some manufacturers changed cars to meet the 1977 standard in 1976, while others waited until the 1977 models. Because of the amount of data needed, it does not seem likely that differences in effectiveness between the 1976 and 1977 versions of the standard will ever be definitely identified using crash data.

The 1968 version of FMVSS 301 applied to passenger cars. The data relevant to evaluation of this version are somewhat limited, since the earliest data are crashes that occurred in 1975, when pre-standard cars were already at least seven years old. Data for pre-standard cars are therefore somewhat scarce. In the Illinois data, the 1968 standard was associated with a 6.5 percent reduction in crash fire rates. This did not reach statistical significance at the five percent level.

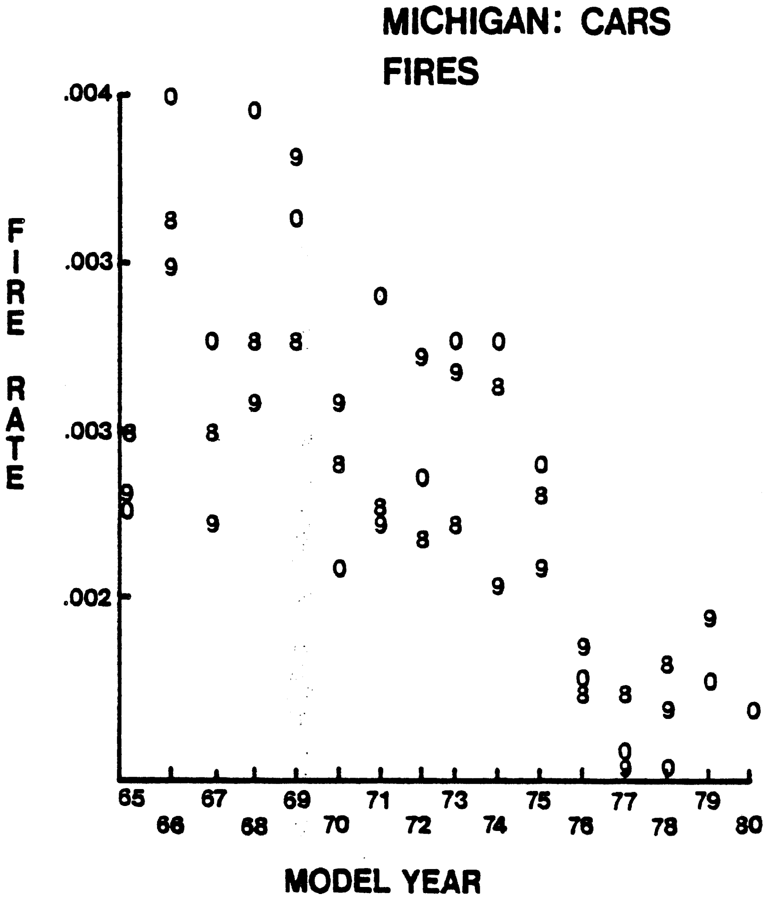

FIGURE B
Passenger Car Fire Rates in Michigan
(Also shown as Figure 8)

Similarly, in the Michigan data, the 1968 version was associated with a reduction of about eight percent in the crash fire rates, again not significant at the five percent level. Further, if attention is restricted to frontal crashes, changes associated with the 1968 model year again were not statistically significant. Thus, the crash fire data do not provide conclusive evidence of an effect of the 1968 standard on crash fire rates larger than that attributable to random variation. For leakage data in Michigan, a 35 percent reduction was observed with the 1968 models and a 38 percent reduction in leak rates in frontal crashes. However, after controlling for crash severity, these reductions disappear at all crash severity levels except the next to highest level. The other levels actually show higher leakage rates after controlling for severity and age. Thus the leakage data do not

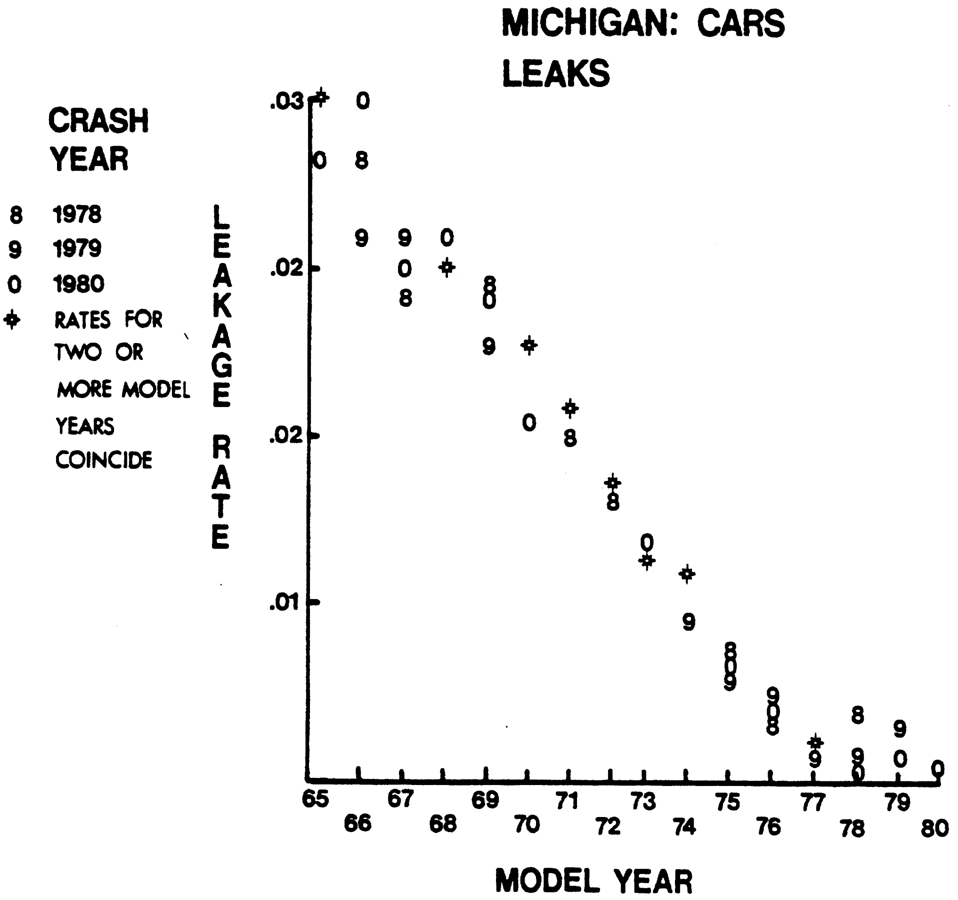

FIGURE C
Passenger Car Fuel Leak Rates in Michigan
(Also shown as Figure 9)

show any evidence of a beneficial effect of the 1968 version of FMVSS 301 that is not explained by crash severity differences.

The data for light trucks are not as substantial as those for passenger cars. In Michigan, the number of truck crashes was only about one-fifth that of passenger car crashes. In Illinois, the number was only about one-tenth that of car crashes. This difference between the states is caused by the difference in the vehicle classification scheme used in the two data sets. In addition to the smaller number of cases, there is some uncertainty about the actual vehicle types that are included in the light truck group.

In the Illinois data on passenger cars, significant reductions in crash fire rates were observed that coincided with the 1976-77 effective dates of FMVSS 301. The largest reductions--on the order of 50 percent--were observed for rollover crashes. Large significant reductions were also observed for angle impacts (24 percent) and for rear impacts (15 percent). Other crash types showed reductions of smaller magnitude that did not reach statistical significance at the five percent level. Aging as an alternative explanation was controlled for, so that these reductions cannot be reasonably identified with age of vehicle. While there could be alternative explanations, none could be identified that explained the reductions. It seems reasonable to conclude that, while these data cannot show causation, reductions occurred which may most reasonably be ascribed to the 1976-77 version of FMVSS 301.

The light truck data in Illinois do not show much evidence for an effect of FMVSS 301. The fire rates by model year for light trucks are consistent with a constant rate, subject to some random variation. There appears to be a reduction that occurs with the 1976 model years. This is one year in advance of the applicable date of the FMVSS 301, so it is not clear that it is related to the standard.

The passenger car fire rates in Michigan were modeled controlling for age and damage severity. The age variable was not found to be significant. The best model estimated separate mean levels and standard effects at each of seven crash severity levels. The estimated reductions ranged from about 9 percent to 50 percent. Fire rates for the lowest three crash severities are very low and probably represent a residual crash fire rate that is unlikely to be reduced any further. For the levels four through six, reductions of about 40 percent associated with the 1976 version of the standard were observed. The highest crash severity (seven) is an open-ended category that includes truly catastrophic crashes where no standard is likely to have much effect. Again, while these data cannot prove causality, alternative explanations such as age of vehicle, damage severity, crash type, etc. have been controlled for and it seems reasonable to conclude that the significant reductions in crash fire rates observed are associated with the models subject to the 1976 version of FMVSS 301. It should be noted that no difference between the 1976 and 1977 versions of FMVSS 301 can be found in these data. It is possible, of course, that any changes made to improve the fire rates were motivated by the much publicized law suits beginning in 1972 (Dowie, 1977) involving crash fires in addition to the impetus provided by the FMVSS 301.

Turning to light truck fire rates in Michigan, again crash severity was controlled for, as was the age of the vehicle. Since the FMVSS 301 applied to light trucks first in the 1977 models, there is less information about how the vehicles subject to the standard will do when they are older. However, after including the damage severity in the model, a reduction of 0.8 fires per thousand crashes was associated with the 1977 standard and an additional reduction of about one fire per thousand crashes was associated with the 1978 standard. The levels vary with TAD level, but using TAD 4 as an example, these correspond to crash fire rates of 2.78 per thousand reduced to 1.98 fires per thousand with the 1977 standard and further reduced to 1.01 fires per thousand with the 1978 standard. Both of these reductions were statistically significant. While again, causality should not be imputed from these data, in the absence of alternative explanations, it seems reasonable to conclude that these are the result of the standard.

In the Michigan data, the proportion of vehicles with fuel leakage after a crash could also be calculated. Leakage rates appear to have a much stronger relation to the age of the vehicle that do the fire rates. After including variables for age and age squared, for crash severity and crash type in the models, significant reductions in leakage rates were observed in the passenger car data. Because of the many other factors involved it is not possible to describe the effects simply. However, referring to Figure C, it can be seen that the leakage rates are quite low and apparently nearly constant for the models later than 1976. While this effect is consistent with a beneficial effect of FMVSS 301, the leakage rates appear to be related to gradual changes over the model years and so may be less identified with the standard than with other, gradual changes over the model years.

For leakage rates in the light truck data, interactions in standard effects and crash severity were found. After including these, significant reductions associated with the 1977 and 1978 model years were found in all crash severities but the most severe. These interactions mean that substantially different effects were observed for the different crash severities, so no concise description of the estimated effect is possible. However, significant reductions were observed that coincide with the dates of the standard. Since only few model years of data are available, it is not possible to definitely rule out age or other general model year effects. There is evidence that leakage rates in light trucks have been reduced in models subject to FMVSS 301. However, the evidence for reduction in crash fire rates is inconclusive, with one state's data indicating a reduction and the other showing no difference.

1.0 INTRODUCTION

This is the final report detailing the findings and results from a project entitled "Evaluation of the Effectiveness of Federal Motor Vehicle Safety Standard Number 301--Fuel System Integrity." The project was sponsored by the National Highway Traffic Safety Administration (NHTSA) under Contract Number DOT-HS-7-01755 to the Highway Safety Research Institute of The University of Michigan (UM Account Number 015937). The project estimates the effects of FMVSS 301 by examining post-crash fire rates and post-crash fuel spillage rates in police-reported accident data. An earlier effort (Flora et al., 1979) examined possible data sources and determined their utility in this type of evaluation.

Fires following a crash are rare events. They are estimated to occur in approximately 1.5 to 2.3 crashes per thousand police-reported crashes of passenger cars and slightly more often--from 2.2 to 2.8 crashes per thousand--in pickup trucks and general purpose vehicles with gross vehicle weight rating (GVWR) less than 10,000 pounds. Fuel leakage is more common than fire, but still relatively infrequent, ranging from about 11 to 14 cases per thousand passenger car crashes and from 16 to 19 cases per thousand crashes of pickups or vehicles with GVWT less than 10,000 pounds. These rates can differ much more for specific types of crashes, and are higher in more severe crashes.

When post-crash fires occur, they tend to be spectacular events and often receive considerable news coverage. In addition, crashes as early as 1972 resulted in numerous court cases involving car fires that received much media attention. The purpose of this report is to estimate any differences in post-crash fire and/or leakage rates corresponding to models affected by the various versions of the FMVSS 301 standard. Other variables are associated with crash fires. Some of these are the age of the car, the type of the crash, and the speed of impact or severity of the crash. To the extent possible with the data, the effects of these variables were estimated and controlled for in estimating the effect of FMVSS 301. Passenger cars and other vehicles subject to the FMVSS 301 standard were considered separately. However, the data sets contain vehicle types that do not exactly match the types identified in the standard. Vehicles are identified as vans, pickups, etc., and these categories are taken to represent the vehicles of GVWR less than 10,000 pounds referred to in the standard. To the extent extent that these identifications do not exactly match the definition in FMVSS 301, this latter analysis is somewhat approximate. These vehicles will generally be referred to as "light trucks."

Most of the analysis in this report uses data from two sources: State police accident files from the states of Illinois and Michigan. Both of these states have a specific question on the accident reporting form that must be checked yes or no for whether a fire occurred. Copies of the accident report forms are in Appendix A. The data from Illinois contain this variable beginning with the 1975 calendar year, while data from Michigan contain this variable beginning with 1978. Data from years 1975 through 1980 from Illinois and from 1978 through 1980 from Michigan have been used. Data from North Carolina have been used in a similar effort (Reinfurt, 1981), but there fires were identified from police-reported narratives, rather than from a variable required on all accident reports.

Federal Motor Vehicle Safety Standard Number 301 aims to reduce fatalities and injuries resulting from post-crash fires by reducing the incidence and/or amount of fuel spilled during and immediately following the crash. The standard was first applied to passenger cars beginning January 1, 1968. To comply with that first version of the standard, passenger cars were not to leak more than one ounce of fuel per minute following a frontal perpendicular impact into a fixed barrier at any speed up to and including 30 mph. The standard was amended applying to passenger cars manufactured after September 1, 1975, by requiring them to meet the additional condition of not leaking more than one ounce of fuel a minute in a static rollover test following a frontal impact. That is, following impact, excessive leakage should not occur whether a car was resting on its wheels, either side, or its roof. Beginning with cars manufactured September 1, 1976 and later, passenger cars were also required to meet the fuel leakage limitations following a rear impact at 30 mph with a moving barrier or a lateral impact with a moving barrier at 20 mph. The frontal impact was changed to be perpendicular or within 30 degrees of either side of perpendicular. The static rollover test was applied following any of these impacts. Exact details of the standard are in 32 FR 2416, February 3, 1967, 38 FR 22397, August 20, 1973, and 40 FR 48352, October 15, 1975.

The standard was also extended to cover vehicles up to 6000 pounds GVWR beginning on September 1, 1976. These vehicles were to meet the frontal perpendicular impact and the static rollover test as well as the rear impact test. Beginning in 1977 vehicles of GVWT from 6000 to 10,000 pounds were to meet the frontal perpendicular barrier crash requirements and in 1978 these vehicles were to meet all the requirements of the passenger car tests except the side impact. The standard also applied to school buses, but these are not considered in this report.

A number of other changes in vehicles have occurred during this period that might affect the fire and/or fuel leakage rates. The environmental protection standards added a fuel evaporation canister with additional fuel line connections to control air pollution beginning with the 1971 models. Further attempts to reduce air pollution have resulted in addition of catalytic converters to the exhaust systems of most gasoline-powered cars. The model year that these were added varies with the car make--cars sold in California generally had them earlier than other cars. Most of these appear to have been added to the 1974-1975 models for domestic manufactured cars. This converter operates at a higher temperature than conventional exhaust systems and essentially burns unburned hydrocarbons in the exhaust. It poses an additional possible source of ignition for spilled fuel. Although a few makes of cars have offered diesel-powered cars for some time, there has been a considerable increase in the number of diesel-powered cars sold in recent years, particularly since 1978. While the proportion of diesel-powered cars in these data is quite small and the differences over these years is probably negligible, to the extent that diesel fuel may be less likely to ignite than gasoline, this could affect fire rates in the future. One of the most noticeable changes in cars has been the reduction in size and weight of the cars in recent years to improve fuel economy. Smaller cars are generally more subject to damage in a crash than are larger cars, particularly in collisions involving other, larger cars. Consequently, these smaller cars may be more likely to suffer damage resulting in fuel leakage in a crash. This downsizing has taken place on two levels. Individual models have been reduced in size and weight, and purchasing patterns have changed toward buying of smaller models. Thus, while the newer models are subject to more stringent testing requirements, they may also be smaller, and more subject to damage in a crash, which may dilute the benefits of the standard. Again, this effect is probably quite small in the current data but could become increasingly important in the future.

Table 1 lists the FMVSS 301 standards and other events that may affect fuel leakage rates and/or fire rates following a crash. This includes not only the FMVSS 301, but also some other standards changes that have been identified. Other changes that affect these rates may exist, but are unknown. Changes in speed or type of crashes could certainly also affect the rates.

TABLE 1

Applicability of Standards and Other Events Influencing Fuel Leakage or Fire by Model Year

Model Year	Requirements	Vehicles Affected
Pre-1968	None	None
1968	Front barrier crash (30 mph) limited leakage from fuel tank, filler pipes, and connections during (1 oz.) and after impact (1 oz. per minute) Effective January 1, 1968	Passenger Cars
1971	In response to air pollution control legislation, evaporative emission-control systems were installed, previous fuel system components	Passenger Cars
1975-75	In response to air pollution legislation, many car models added catalytic converters to exhaust systems, increasing temperature and possible ignition source	Passenger Cars
1976	Static rollover test following frontal barrier crash (September 1, 1975)	Passenger Cars
1977	Rear moving barrier (30 mph) and Lateral barrier (20 mph) crashes added September 1, 1975	Passenger Cars
1977	Frontal perpendicular barrier crash, Rear moving barrier crash (30 mph), Static rollover test (September 1, 1976)	Gross Vehicle Weight <6000 pounds
1977	Frontal perpendicular barrier crash (30 mph) (September 1, 1976)	GVWR of 6000 to 10,000 pounds

Table 1 (Continued)

Model Year	Requirements	Vehicles Affected
1978	Frontal barrier crash within 30° of perpendicular at 30 mph. Static rollover test, 4-90° increments. Rear moving barrier crash (30 mph), Lateral moving barrier crash (20 mph)	All vehicles up to 10,000 pounds GVWR

2.0 DATA SOURCES

In this section we discuss the criteria for selection of data sources to be used in this evaluation, review the data sets evaluated in the earlier report (Flora et al., 1979), and discuss in detail the characteristics of the data sets used in the current effort.

To be useful in this evaluation, a data source must contain certain information. It must identify vehicles--passenger cars or other vehicles subject to FMVSS 301--by model year, crash involvement, and occurrence of fire or fuel leakage. Additional information such as the type of crash, its severity, etc. would also be useful but is not crucial. In addition, the data set must be relatively large. Crash fire rates are generally estimated to be on the order of from one fire per thousand crashes (Cooley, 1974). Given this rarity, and the approximate Poisson nature of the number of fires, a relatively large number of fires must be present in order for the variability of the fire counts to be small enough relative to the number of fires so that differences could be detected. If Poisson variation in the fire counts is assumed, about 100 crash fires are needed for the variation to be on the order of 10%. If variability on the order of 20% of the level is accepted, then about 25 fires per group are needed. With this as a basis, one would expect perhaps 100 crash fires per year in a data set with about 100,000 passenger car crashes. Since comparisons are to be made on the basis of individual model years, or groups of model years of cars that correspond to the different versions of FMVSS 301, each subgroup should contain enough crashes so that the calculated fire rate is stable enough to allow comparisons. This requirement means that one must concentrate on statewide data files from fairly large states.

2.1 Review of Evaluation of Data Sources

The previous report (Flora et al., 1979) considered several data sources and evaluated their usefulness for the evaluation of FMVSS 301. Two general types of data files were considered: state police accident files and state fire department files. Fire department data from the National Fire Incident Reporting System (NFIRS) were found to be of limited use. Most of the vehicle fires identified in fire department data were not crash fires. There was essentially no positive way to identify a vehicle fire with a crash. Many of the vehicle fires did not have model year information, so they could not be identified with a version of FMVSS 301. Thus, fire department data were not sufficiently well identified with crashes and with model years of vehicles to be very useful.

Data from the National Crash Severity Study (NCSS) were considered for use. However, there were only 109 cars that caught fire and had the detailed information available. Even with the sample weighting this amounted to only 139 car fires in the data file. Such a small number results in large variation, particularly when the car fires are used to calculate fire rates by model year or other subgroups. While the NCSS data ostensibly also contain data on fuel leakage, only slightly more vehicles were reported as having leaked fuel than caught fire. It appears that it was difficult to determine fuel leakage except when there was an obvious rupture of the fuel tank. Even some of those cases were suspect, since that damage could have occurred during removal from the scene of the crash or during extrication of occupants. As a result, while the NCSS data were analyzed in the previous report, there seems to be too few fire cases for further analysis. The leakage data seem particularly suspect. Since the crash scene was not visited, only very large leaks would be noticed.

Data from the Fatal Accident Reporting System (FARS) were also considered. A major problem arises when trying to use FARS data for evaluation. The major problem is the self-selection of the fatal crashes. Since at least one person was killed, the crashes are generally quite severe. This implies that there could be numerous interactions that make the use of these data for evaluation difficult, if not impossible. For example, it might be that newer cars are generally safer and that fatalities only occur in crashes that are more severe. An extreme (unrealistic) case would be if fatalities in some models of cars only occurred if the cars caught fire. If that were the case, then, while those models would be safer overall, their fire rate in the FARS data would be the highest. This sort of interaction because of the selection of cases by fatality operates to generally preclude the use of FARS alone in evaluation of safety standards, because in order for a case to exist in FARS, by definition, the safety features must have broken down so that a person was killed.

State accident data from the forty-eight contiguous states were considered for possible use. Most state data do not include variables to identify post-crash fires. Often a "fire" code is present in the data, but applies only to a fire as a first harmful event. In some states, fire is coded as a second or subsequent harmful event, but this coding is done at the state level from a review of the police narrative describing the crash. A number of states have fire coded from the police narrative. Washington, North Carolina, and Pennsylvania are examples of states with this kind of data. Washington State data had very few fires. Further analysis of them did not seem warranted. A recent study (Reinfurt, 1981) used the North Carolina data in an evaluation of FMVSS 301. This latter study concluded that only the comparison between no standard (model years 1965-1967) and the first version of FMVSS 301 (model years 1969-1975) could be reasonably done with the North Carolina data. The 1968 model year was split between versions of the standard and so eliminated in their analysis.

The state police data from Idaho and from Oklahoma contain a variable that notes whether the car caught fire after the crash. Unfortunately, the model year information in Oklahoma was entered as a one digit code for the age of the car. This resulted in model year identification for the seven most recent model years, with earlier models lumped. As a result, two versions of the standard were mixed. The mixing changes from year to year. Neither the Oklahoma data nor the Idaho data contain enough crashes to have very many crash fires. As a result, neither is a very useful data source for further evaluation. The data from the State of New York report fire as a second harmful event. It appears that this results in very few fires being reported. The reported fire rates are similar to those in Washington, and only about a tenth of the crash fire rates reported from states where the fire variable is a check box on the accident report form. The very low reported fire incidence in New York limits its utility. The primary analysis in this report will be on data from the states of Michigan and Illinois. Illinois has reported crash fires on their accident reporting form since 1975. Michigan has included a variable to report crash fires and crash fuel leakage since 1978. These two data sets are discussed more fully in Sections 2.2 and 2.3, respectively. Some use is made of the data from the State of Pennsylvania. The characteristics of this data set are discussed in Section 2.4.

2.2 State of Illinois Data

These data came from the Illinois Department of Transportation and consist of all police reported accidents in the State of Illinois. There are two levels of reporting. Accidents that occur on state roads (or federal highways) were always to be reported to the state. In addition, most local police jurisdictions report crashes to the state. Accidents that occurred in Chicago or were investigated by city of Chicago police were not reported to the state file until 1980. For the purposes of this study, to keep a consistent population, crashes from Chicago have been filtered out of the 1980 data.

As is usual, there is a reporting threshold for accidents. The reporting criteria are the following: accidents must be reported if there was any personal injury or if damage to any one person's property exceeded $250. Possibly the data may contain some accidents of a more minor nature that were voluntarily reported and miss some that should have been included, but the above may be taken as the threshold. One concern with police-reported data has been to ensure that the fires are post-crash fires rather than incidents in which the car caught fire and which were investigated by police and subsequently reported. In the Illinois data set an additional variable of "type of crash" has been used. The code values for this variable indicate the type of accident, such as head-on, rollover, etc. One value is "non-collision" and this presumably contains any fire cases that were not associated with a crash. Use of this variable in conjunction with the fire and model year variables would seem to ensure that the fires being analyzed are, indeed, post-crash or at least associated with a crash.

In Illinois two data forms (reproduced in Appendix A), must be filed on reportable accidents. One is completed and forwarded by the investigating officer. In addition, each driver must complete and forward a driver's accident report. Each of these forms has a check box to report whether or not a fire occurred. Both forms are forwarded to the Illinois Department of Transportation in Springfield, Illinois, where the data are computerized. In coding the data, the fire variable was coded fire if either the police or the driver's report reported the occurrence of a crash fire. If either or both reported that no fire occurred and neither reported a fire, the variable was coded as no fire. Finally, if both reports were blank on the fire variable, a missing data code was entered into the computer.

Even with this dual reporting system, there remains a substantial amount of missing data. The first year of the new form, fire data were missing on 39 percent of the crashes. The missing data rate has declined steadily, but still remains substantial, being 18 percent in the 1980 data. Table 2 gives the missing data rate by year of the crash. It is evident that all of these years have missing data rates that far exceed the crash fire rates. As a result, some assumptions about the missing data must be made in order to proceed with the analysis. One possibility is to calculate fire rates based only on cases with data on the fire variable present. (This definition of crash fire rates was used in an earlier report by Flora et al., in 1979.) A difficulty with this approach is that the reduction in missing data rates over the years may result in quite different overall fire rates. If, in fact, the missing data result from the fire variable being overlooked when there is no fire, then missing data would be all non-fire cases. Basing the fire rates on the cases with data present would then bias the rates. Conversations with the data management personnel at the Illinois Department of Transportation suggest that this is probably the case: missing data most likely contain no fires. As a result, the fire rates have been calculated as number of fires divided by all crashes for the same subgroup.

TABLE 2

Missing Data Rates From Illinois

Year:	1975	1976	1977	1978	1979	1980
Missing Data Rate	38.8%	32.7%	21.6%	20.1%	18.5%	17.8%

2.3 Data from Michigan

The data from Michigan consist of accidents reported to the Michigan Department of State Police from all police jurisdictions. Beginning in 1978, the police accident reporting form (reproduced in Appendix 2) contained two new variables to be answered yes or no. One variable asks "Did fire occur?" and the other asks "Did vehicle leak fuel?" When these data are coded at the state level, four code values are used. One code value indicates that the fire variable was coded yes, fuel leakage coded no. A second value indicates that fuel spillage was coded yes, fire coded no. A third value is used to indicate that both fire and fuel spillage variables were coded yes. Finally, a fourth code value is used for all other cases. Thus, the fourth value indicates that neither fire nor fuel spillage was coded yes. This includes cases with either fire or fuel spillage or both left blank. The presumption made in coding the data on the state level is that missing data correspond to no fire or fuel spillage. Because of this coding scheme, one cannot tell what missing data rate occurs. Thus, perforce, fire and leakage rates in Michigan will treat missing data as non-fires or non-leaks.

The criteria for reporting an accident to police in Michigan is any personal injury or damage to any one person's property in excess of $200. While accidents involving no injury and less damage or questionable amount of damage may be reported to police, many jurisdictions have a separate form, an incident as opposed to an accident form, for reporting such occurrences. These more minor crashes are then not reported to the state police. Of course it is also possible that some eligible accidents were not reported. The Michigan data also contain a variable for collision type and one for damage severity. These were used to exclude reports coded "non-collision" or zero damage. The result should be to ensure that the fires and leaks are really post-crash or at least correspond to a crash.

In calculating and reporting fire and leakage rates, the various code values must be considered. For example, if a crash is coded fire, yes, leak, no, should it be considered a fuel fire? In discussions with police as to how they would fill out a form and with coders, the concensus was that such cases were generally fuel fires. Some officers reported that they had used that when the entire car burned up and they could not tell whether fuel had leaked. Consequently, the following conventions have been established. All cases with fire coded yes were considered to be post-crash fuel-fed fires. In addition, all crashes coded yes for fire or yes for fuel leakage were considered to be cases involving fuel leakage. Thus, fire rates have been calculated with numerators consisting of cases coded either fire only or fire and leak, and denominators consisting of all crashes. Similarly, leak rates have been calculated with numerators consisting of all cases coded fire, leak, or both, and denominators based on all crashes.

2.4 Data from Pennsylvania

The state of Pennsylvania maintains computerized reports of traffic crashes in a convenient form. Three years of such data (1977-1979) were made available to this project for analysis. The criteria for reporting accidents in Pennsylvania changed on June 30, 1977, and this change is reflected in the size of the 1977 data set as compared with those of later years. Prior to June 30, 1977, all local jurisdictions were not required to report accidents to the state, although accidents which were reported included fatal and injury accidents plus crashes with property damage greater then $200. Since June 30, 1977, all towaway crashes must be reported from all jurisdictions. This change in the minimum reporting criterion (from a dollar amount to a towaway) reduced the total number of cases reported, but increased the average severity of a reported crash.

The occurrence of a fire is not reported as a check on the Pennsylvania accident report form, but it is a possible code assigned by persons in the state Department of Transportation office who are responsible for reviewing and entering the case data into the computer. From a combination of the coded and descriptive material in the written report, the coder may assign up to three "events" in sequence for each crash-involved vehicle. These events are intended to be sequential, and include "struck another vehicle," "struck a guardrail," "fire," etc. In a number of cases the code "fire" has been entered without any subsequent entries, and this has been assumed to represent a non-crash fire.

We have analyzed these entries, and have recoded the fire data into two categories--a fire for which there was also reported crash damage (listed as a "crash" fire), and a fire with no other damage reported (listed as a "non-crash" fire). The reported fire rates in Pennsylvania may be compared with reported rates in states which have a direct fire entry on the police report form. Differences in reporting threshold should be kept in mind, of course. Pennsylvania has reported about 360,000 passenger cars in accidents in 1979, with a total of 458 (272 crash + 186 non-crash) fires reported. This leads to a total fire rate of about 1.3 fires per 1000 towaway cars, a crash fire rate of 0.75 per 1000, and a non-crash fire rate of about 0.5 per 1000.

These rates can be compared to those reported in other states with a similar system for noting fires, New York, Washington, and North Carolina. The crash fire rate in New York for 1976 and 1977 data was about 0.29 fires per thousand crashes, while that in Washington was about 0.55 crash fires per thousand crashes (Flora et al., 1979). Reinfurt reported a similar rate of 0.558 crash fires per thousand crashes in North Carolina (Reinfurt, 1981). This might be compared with the reporting rate in Michigan of 4.6 fires per 1000 towaways (1980) (obtained by restricting the Michigan data to vehicles "towed from scene."), a rate of 2.2 fires per thousand towaways in NCSS, or of 1.8 fires per thousand police-reported crashes in Illinois (1980).

Aggregating the data over several calendar years provides enough cases to compare fire rates for the various FMVSS #301 standard periods.

3.0 ANALYTICAL METHODS

The analysis of possible effects of the FMVSS 301 is complicated by the fact that the standard took effect with a particular model year (for each version), while the crash data come from calendar years that were somewhat later than the effective date of the standard. Thus, for example, the earliest data from Michigan come from 1978, while the most recent versions of FMVSS 301 applied to the 1976 and 1977 model years of passenger cars. This means that the pre-standard cars were older at the time of the crash than the post-standard cars. As an example, the 1975 models were three years old in 1978, and five years old in 1980, while the 1977 models ranged in age from one year old to three years old. Thus, the age of the car is confounded with the possible effects of the standard. Any other changes in the car or accident population over time are also confounded with the standard. Such changes cannot be separated from possible standard effects.

To some extent it may be possible to disentangle the confounding of the age and the standard. Since there are six years of data from Illinois, cars built under each version of the standard can be investigated at six different ages. Likewise in Michigan, each group of model years corresponding to the versions of FMVSS 301 have data for three different years of age. Consequently, the effects of aging over six years (in Illinois) or over three years (in Michigan) can be estimated separately for each model year. There is still some confounding in that these periods are at different times in the cars' ages, e.g., from three to nine years old for 1975 models as opposed to one to six years old for 1977 models. This difference is most marked for pre-1968 cars, of course.

While the inclusion of several years' of data allows one to estimate an aging effect separate from a model year effect, there may still be other model year effects that are confounded with the FMVSS 301 standard. For example, in recent years there has been a trend toward smaller cars. This occurs on two levels. The mix of vehicles purchased has shifted toward more sales of small cars and fewer of large cars. In addition, several manufacturers have reduced the size and weight of several models. The full-sized General Motors cars were reduced in size beginning with the 1977 models, for example. As a result, the different model years have different car sizes. To the extent that car size may influence fire or leakage rates, this variable would interact or be confounded with the introduction of the standard. The Illinois data have no information on car size. The Michigan data include a variable that groups cars into four size categories. However, downsizing of recent models results in inconsistent sizes for different model years. In addition, this variable is subject to relatively large reporting errors. Consequently, it was not used. Probably for the time period of these data (1975-1980) changes in car size mixtures were relatively small. However, this factor could become more important in the future if the trend toward smaller cars continues.

There are a large number of other possible changes in the model years of these cars. There has been a recent increase in the number of diesel powered cars sold. While this would not seem likely to affect the leakage rates, if diesel fuel is less likely to ignite when spilled, it could reduce the observed fire rates. Other changes in the cars have been introduced. There is a trend toward more front-wheel drive cars. This results in quite different construction. For example, there is no differential housing near the rear fuel tank in a front-wheel-drive car. Also, the rear axle is quite different. These structural changes may affect the chance of puncture or rupture of the fuel tank in a crash and so affect the leak rate. Most of these changes would be present as gradual changes over the model years rather than the presumed step change associated with the standard. Both of these effects should be quite small for the data years under consideration, but could become increasingly important in the future.

There are a large number of crash variables that strongly affect the chance of a leak or a fire. Any crash severity variable seems to affect these rates, with higher rates in more severe crashes. In the Michigan data, the TAD scale is a measure of crash severity or damage to the car. The type of crash affects these rates. Whether the crash is a single or multiple vehicle crash also influences fire and leakage rates. Day or night is associated with fire and leakage rates, although as noted later, the effect is taken primarily as a surrogate for crash severity in that the day-night effect is nearly eliminated if rates are adjusted for TAD.

3.1 Modeling Rates

In order to consider the possible effects of the confounding and interacting variables mentioned above, rates were analyzed using a linear models approach to categorical data. The methodology is described in Grizzel, Starmer, and Koch (1969). A number of forms of these models have been used and are described in the results section. Basically, the model may be written as

$$r = B_o + \sum_{i=1}^{k} B_i X_i ,$$

where the X_i are variables such as severity, aging within model year, or standard effect dummy variables. The B_i are coefficients to be estimated and B_o represents an intercept or overall mean. We have used the weighted least squares method (equivalent to minimizing the modified chi-square) to estimate the coefficients. A program to implement this is GENCAT described by Landis et al. (1976). An alternative method of performing the calculations using standard regression programs was described by Flora et al. (1980), and was used for most of the modeling. Either method results in identical estimates for the coefficients, a statistic used to test for lack of fit of the model, and chi-square statistics used to test whether the coefficients are significantly different from zero. The coefficients can be tested individually, or as sets. Also, relations among the coefficients can be investigated.

Most of the models investigated have included a variable for aging, representing the six or three different ages of a given model year of car available in the data (Illinois or Michigan). In addition, dummy or indicator variables for the groups of model years that correspond to the different versions of FMVSS 301 are included. A linear or other smooth trend in model year is considered. In addition, indicator variables for crash types or TAD severity levels have been included. The coefficients for these variables were estimated, tested for significance, and reduced models constructed that generally fit the data adequately and included only control variables that had coefficients estimated to be significantly different from zero. In some cases variables of particular interest were left in the model to demonstrate their effect, even if it appeared not to be important.

Several methods were used to investigate age. Some consisted of looking at differences in rates for given models in different crash years. Others used indicator variables for crash years or a linear trend in age. The only significant differences that were found were in the Illinois data and suggested differences in overall rates by data year. These were not in any monotone order as would be suspected if aging were the factor. With no obvious pattern to the differences, it seems more likely that the year-by-year differences reflect reporting differences than that they reflect an age effect.

The small fire and leakage rates limit the amount of modeling that can be done. Not all variables of interest are present in all data sets. In addition, even for the variables that are present, it may not be practical to include all of them in a single analysis, because the resulting multiway table of rates would include many rates based on very few crashes. Such rates may be too unstable to analyze. With an overall crash fire rate of about two per thousand or a leakage rate of about 12 per thousand, estimating rates based on fewer than a hundred crashes is not reasonable. Even with statewide data from three or six years from fairly large states, some collapsing of the data must be done to estimate effects and fit these models.

In some cases models with interactions were needed. When this was the case, the choice was to model the interactions as main effects of one variable within the levels of the other. Suppose that X_{1i} is the set of indicator variables for factor 1 and X_{2j} is the set of indicator variables for factor 2_i with both of these being all means models. The interaction is X_{1j} times X_{2j}. That is, the effect of factor 2 within levels of factor 1 is zero for all but the particular level of factor 1.

For that level, variable 2 takes its usual value according to levels of factor 2.

3.2 Alternative Statistical Procedures

The linear models approach to categorical data described above is not the only applicable one. Rather than modeling the fire rates or leakage rates themselves, a logistic model could be used. (Other similar transformations such as the probit also exist but are quite similar.) If this were done, the fire rate would be assumed to depend on a type of tolerance distribution that is itself a linear function of the relevant crash or model year variables. Such a model would have the form

$$r = [1. + \exp(B_o + \sum_{i=1}^{k} B_i X_i)]^{-1}.$$

In this model the X_i are variables as before, and the B_i are again coefficients to be estimated. Here, however, the fire rate is assumed to be a logistic function of the linear combination of the severity and standard effects variables. The coefficients again can be estimated by weighted least squares. While this model has the advantage that the estimated rates are automatically forced to lie between zero and one, this was not found to be a problem with the linear models.

Alternative methods of estimation can also be used. The most common and best developed is maximum likelihood. This method is particularly appropriate with the logistic model (or a similar probit model). It can be achieved by iterating the weighted least squares estimation procedure. This method was used by Reinfurt (1981). One primary advantage is that such a method could be used with a continuous variable such as delta-V or crash speed without the need to categorize the data to obtain rates based on large numbers of crashes. In the data sets at hand, however, we did not have any such continuous variables.

While the maximum likelihood logistic models represent an attractive alternative method of analysis, the linear models employed appeared to fit the data adequately. The linear models have the advantage of being somewhat simpler to interpret and explain as well as being somewhat cheaper from the computational standpoint. They have been used throughout. Logistic models were considered in the earlier effort and found not to improve the fit or the explanatory power of the models.

4.0 RESULTS

The results are presented separately by the data source. The combined results are presented in Section 5, Conclusions, as well as being summarized in the Executive Summary.

4.1. Data from Illinois

The characteristics of the data file from Illinois have been discussed in Section 2.2. These data do not contain any information on leakage rates and thus refer to crash fire rates only. The data are analyzed separately for crashes involving passenger cars and then for crashes involving light trucks. The data for passenger cars are summarized in Table 3, where a question mark indicates a rate based on very few crashes.

4.1.1 Passenger Car Fire Rates in the Illinois Data

Six years of crash data were available from the State of Illinois. These were from the calendar years 1975 through 1980. Crashes involving cars of model years previous to 1968 (the year the first version of FMVSS 301 was effective) were somewhat scarce, particularly for the later crash years. Figure 1 plots the crash fire rates for passenger cars in the Illinois data by model year with crash years identified by their final digit. For this figure, model years 1960 through 1967 were pooled and were plotted at the 1967 point. Visual inspection of Figure 1 suggests that a trend toward reduced rates for more recent models may be present. A suggestion of larger variability in earlier model years can also be seen. Table 3 summarizes observed crash fire rates by crash year and model year groupings corresponding to versions of FMVSS 301.

To estimate the effects of FMVSS 301 in these data a variety of models were employed. The aim was to estimate separately effects corresponding to the various versions of FMVSS 301, and effects of confounding variables such as aging effects over the six calendar years of data for the same model years. Mathematical models that included

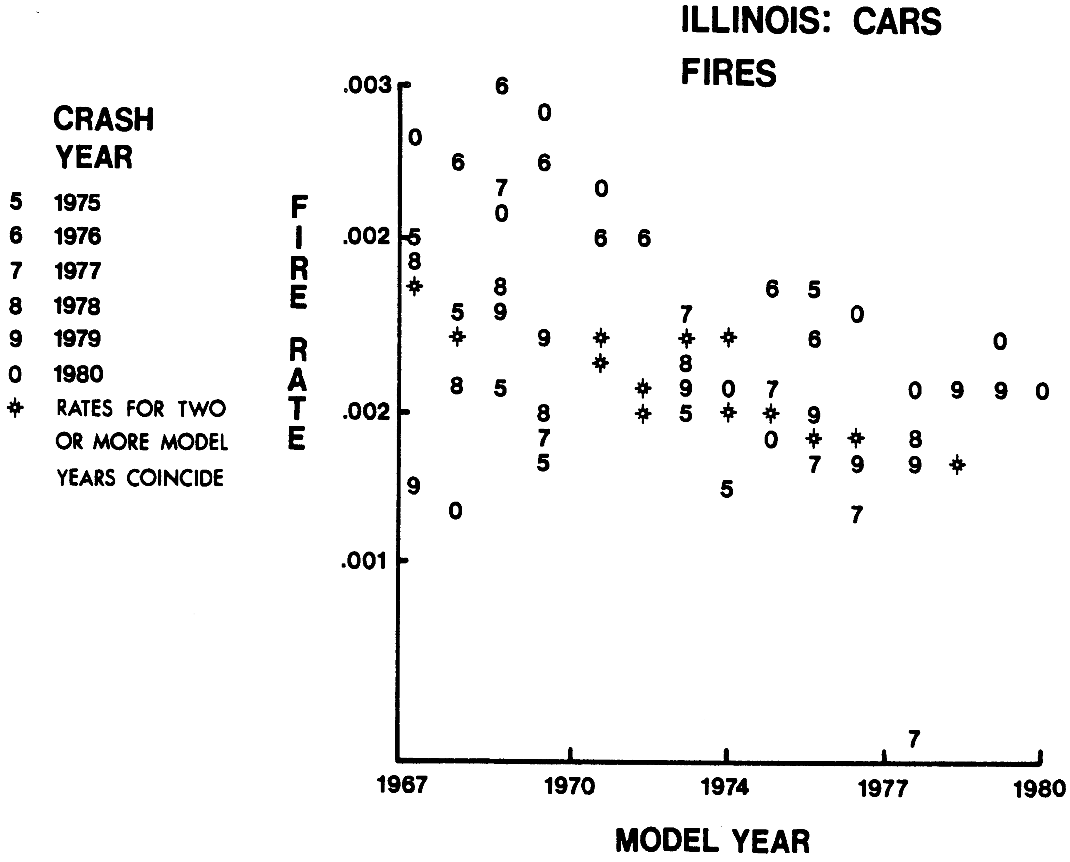

Figure 1. Passenger Car Fire Rates by Model Year in Illinois

TABLE 3

Passenger Cars, Fire Rates Per Thousand Crashes, Illinois

Year	1960-67	1968-75	1976	1977+	Total	Unknown
1975	2.241	1.570	2.097 (?)	-----	1.656	38.8%
1976	2.581	2.238	1.852	1.502 (?)	2.213	32.7%
1977	2.076	1.813	1.446	1.217	1.714	21.6%
1978	2.213	1.764	1.550	1.495	1.670	20.1%
1979	1.276	1.725	1.626	1.480	1.571	18.5%
1980	2.642	1.912	1.495	1.700	1.771	17.8%

standard effects, aging effects, and linear trends in model years were fit to these data. All models exhibited some lack of fit. The best fitting had a chi-square of 146.90 with 71 degrees of freedom for testing lack of fit. Several models resulted in similar lack of fit statistics, leaving no clear choice among them. The best fitting model was:

$$r = 1.715 + 0.034(\text{age}) - 0.129(\text{std68}) - 0.143(\text{std76}).$$

In the above equation, r stands for the fire rate per thousand crashes, age is the age of the car at the time of crash, and thus represents a linear trend in model years, while "std68" and "std76" represent indicator variables for introduction of the 1968 and 1976 versions, respectively, of FMVSS 301. The coefficient for age is clearly significantly different from zero, indicating a tendency for the fire rate to increase with the age of the vehicle. The other two coefficients are both negative, estimating reductions in fire rates coincident with the 1968 and 1976 versions of the standard, but they are only marginally statistically significant (chi-square = 5.86 with 2 degrees of freedom). The lack of fit also limits the interpretation of this model. The 1976 and 1977 versions of the standard are nearly indistinguishable in these data. An effect at 1977 could be substituted with little change. If an additional effect at 1977 is included in the model, the resulting equation becomes:

$$r = 1.721 + 0.033(\text{age}) - 0.132(\text{std68}) - 0.115(\text{std76}) - 0.044(\text{std77}).$$

While the estimated effect is also negative, indicating a slight further reduction, the associated chi-square for this additional parameter estimate is only 0.24 with one degree of freedom, indicating a clear lack of significance.

The best model that incorporates aging--rather than the linear trend in model years--was:

$$r = 2.060 + 0.007(\text{aging}) - 0.291(\text{std68}) - 0.223(\text{std76}) - 0.071(\text{std77}).$$

The associated lack of fit chi-square statistic was 156.27 with 70 degrees of freedom. The aging variable (over the six calendar years within the model years) was not significantly different from zero. For the three standard effects, the chi-square statistic was 51.37 with 3 degrees of freedom. This is highly significant, but must be interpreted with some caution because of the lack of fit of the overall model. There was again, little difference between the 1976 and 1977 versions of the standard that could be observed in the data. In this model the variable "aging" takes the values from one to six, with six corresponding to crashes in 1980.

A model with three mean fire rates fit almost as well. This model was:

$$r = 2.077 - 0.287(\text{post}67) - 0.270(\text{post}75).$$

The lack of fit was 157.23 with 72 degrees of freedom. Similarly, a model with a linear trend for age of vehicle at the time of the crash, estimated as:

$$r = 1.455 + 0.053(\text{age}).$$

had a lack of fit statistic of 152.76 with 73 degrees of freedom. While both of these models show significant lack of fit, it is also clear that in the former the three mean fire rates corresponding to pre-standard cars, first version cars, and post-76 version cars differ significantly, with the lower rates corresponding to models built under the more recent standards. Further, it is clear that the age coefficient in the latter model is significantly different from zero, showing that older model cars had higher fire rates. In the total data it was thus not possible to separate the possible effect of the standard from a possible age or other general model year effect.

Two reasons for the significant lack of fit were identified. First, the six model years did not exhibit an increasing trend in fire rates within most model years. In fact, fitting a linear age effect within model years did not produce a significant coefficient in any model years. The six calendar years of data showed evidence of differing in overall fire rates, perhaps related to their difference in missing data rates, but this difference was not related to any obvious trend. A second reason for lack of fit may be the fact that fire rates differ very dramatically by type of crash. This source of variation may act together with the differences in data years to increase variability over what would be expected otherwise.

To allow for the possibility of increased variability caused by the difference in fire rates for different crash types two approaches were used. The first concentrated on specific types of crashes that would be associated with the various versions of the standard and investigated changes in fire rates within the specific crash types. That is, the first version of FMVSS 301 addressed frontal crashes, the second added rollovers, and the third primarily added rear impacts. These three main crash types are analyzed separately in the following paragraphs. After that, the data are analyzed using ten different crash types as additional control variables.

Analysis of Fire Rates by Crash Type and Standard Version.

Frontal crashes. The first version of FMVSS 301 required testing of passenger cars by crashing them frontally into a fixed barrier. As a result, crashes involving frontal impacts may be most relevant in investigating the effect of this version of the standard. In the Illinois data, frontal impacts are most closely associated with crash types coded as "head-on" and "hit fixed object." These two crash types were analyzed separately, using also the model year variable. The most prominent finding was that these two types of crashes differed substantially in their fire rates. Overall, the fire rate for head-on crashes was 5.52 fires per thousand crashes, while that for fixed objects was 6.09 fires per thousand crashes. An indicator variable for this difference was the only variable that had a coefficient estimate that was significantly different from zero. A full model with a constant, an aging effect, a separate model year effect, and three standard effects had the following estimated coefficients.

$$r = 4.59 + 0.68(\text{std68}) + 0.60(\text{std76}) - 0.72(\text{std77})$$

$$- 1.67(\text{type}) + 0.05(\text{modyr}) - 0.003(\text{aging}) \text{ fires/1000 crashes.}$$

Here, the type variable indicates the difference between the crash types, "modyr" estimates a linear effect in age or model year, and "aging" estimates a linear effect in age within model years. The other variables estimate effects of the standards. The lack of fit chi-square was 210.54 with 215 degrees of freedom, indicating a satisfactory fit. Only the type variable was significantly different from zero. A reduced model with only this variable was:

r = 5.43 - 1.64(type) fires/1000 crashes.

The associated lack of fit chi-square was 213.21 with 220 degrees of freedom, indicating a satisfactory fit. In fact all of the other variables together only account for a difference of 2.71 in the lack of fit chi-square--an amount that would not be significant even if it had only one degree of freedom. The model that includes only an overall mean was estimated as

r = 5.158 fires per thousand crashes.

The associated lack of fit chi-square was 230.01 with 221 degrees of freedom. This is a non-significant lack of fit, but, as noted, the model that fits separate means for head-on crashes and fixed object crashes does fit significantly better (chi-square=17.80 with 1 degree of freedom). A model incorporating an estimated effect at the 1968 standard was estimated as:

r = 4.86 + 0.34(post67) fires/1000 crashes.

The lack of fit chi-square was 229.47 with 220 degrees of freedom. The chi-square for testing the significance of the standard effect was 0.53 with one degree of freedom--not significant. (In fact, slight increases were estimated for standards in 1968 and 1976, with a slight decrease estimated coincident with 1977, but all were clearly non-significant, with chi-squares less than one.) The fire rates for frontal crashes are plotted in Figures 2 and 3.

Thus, the frontal crashes do not provide any evidence of a standard effect at any of the three effective dates. One possible reason for this is that these crashes are generally very severe. The severity of head-on crashes and fixed object crashes as a group may be so high that the FMVSS 301 standard requirements did not result in any changes that were effective at these high severity crashes.

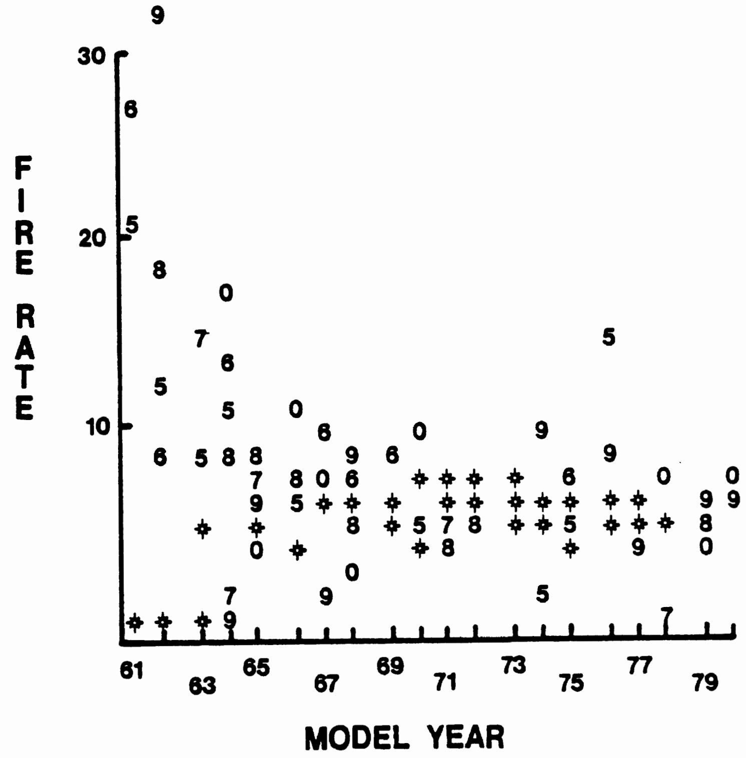

Figure 2
Passenger Car Fire Rates in Illinois Head-on Crashes

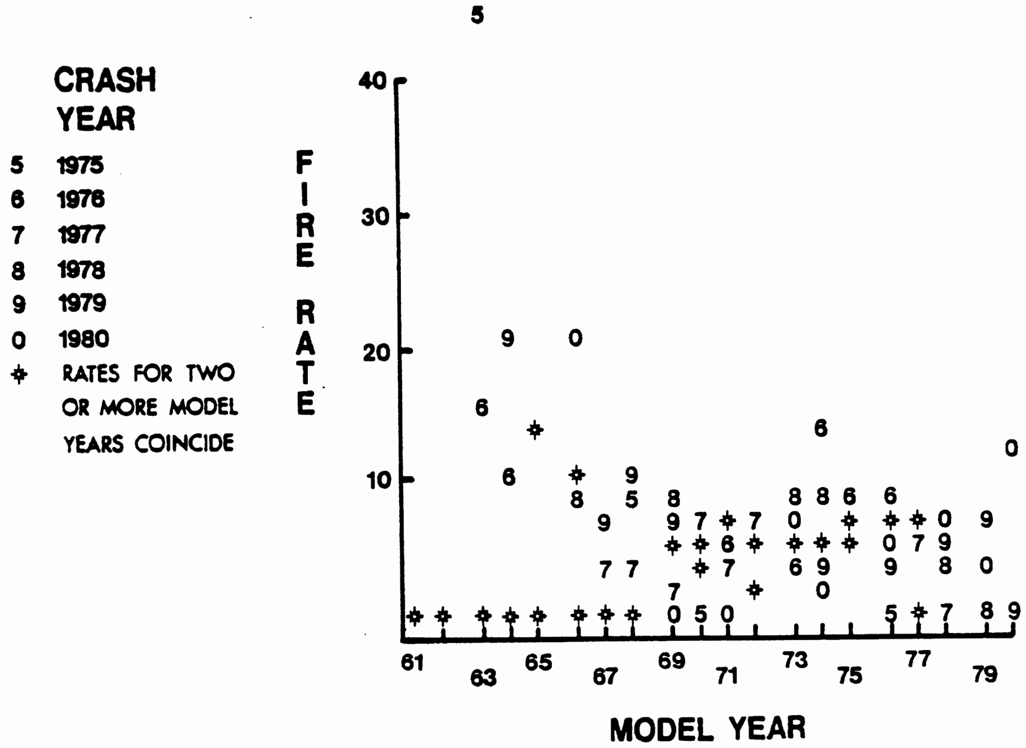

Figure 3
Passenger Car Fire Rates in Illinois Fixed-Object Crashes

Rollovers. The 1976 version of FMVSS 301 addressed rollovers in its testing requirements. Rollover fire rates are plotted in Figure 4. Crashes coded "overturn" in the Illinois data were used to investigate the possible effects of the 1976 version of the standard. These crashes have a high fire rate. Overall, there were 9.065 fires per thousand crashes in which a car rolled over. A model that estimated a standard effect at 1976 and an aging effect had estimated coefficients of:

$$r = 5.73 - 2.32(\text{std}76) + 0.12(\text{age}) \text{ fires/1000 crashes.}$$

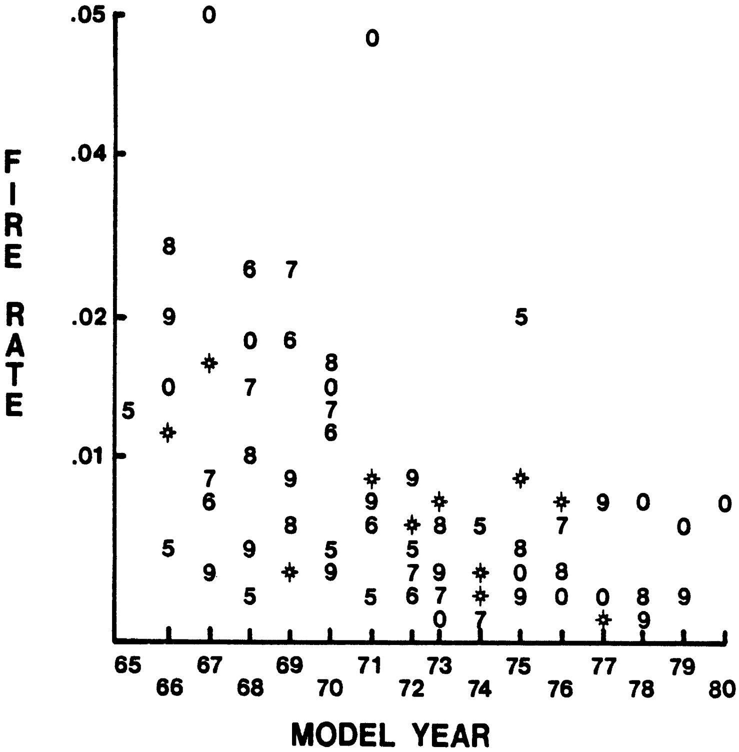

Figure 4
Passenger Car Fires in Illinois Rollover Crashes

The lack of fit chi-square was 86.12 with 73 degrees of freedom. The aging variable was not significantly different from zero. If it is deleted, the model becomes:

r = 6.05 - 2.47(std76) fires/1000 crashes.

Here the lack of fit statistic is 87.43 with 72 degrees of freedom. The chi-square statistic for testing the effect of the standard variable is 6.17 with one degree of freedom. An even more noticeable effect is observed if the 1977 model year is used. The model is estimated as:

r = 6.07 - 3.05(std77) fires/1000 crashes.

The lack of fit chi-square is 84.96 with 74 degrees of freedom and the chi-square statistic for the standard effect is 8.64 with one degree of freedom. However, an even better fit can be obtained by using a linear trend in the age of the vehicles (or, equivalently, in model years). This model is estimated as:

r = 2.47 + 0.74(per year) fires/1000 crashes.

The lack of fit chi-square is 75.13 with 74 degrees of freedom, while the chi-square for testing the significance of the age trend is 18.48 with one degree of freedom. If this linear trend is incorporated, neither the effect at 1976 nor one at 1977 is significantly different from zero. Thus, the rollover crashes are consistent with a significant reduction in fire rates coincident with either the 1976 or 1977 versions of FMVSS 301, but a linear trend in age is even more significant. Thus, age cannot be ruled out as a possible explanation for the apparent effect. If the effect were to be identified with the standard, it would appear to result in approximately a 41% reduction (1976 standard) or a 50% reduction (1977 standard) in the fire rates following rollover crashes.

Rear Impacts. The 1977 version of FMVSS 301 addressed rear impacts in its testing mode. The Illinois data have two crash type codes for rear impacts, one where both cars are moving and a second one where one car is stopped. These two crash types were used in analyzing possible effects from FMVSS 301 on rear impact crashes. These would presumably be the type most likely to be affected by the 1977 version of the standard. Fire rates for rear impacts with one car stopped are plotted in Figure 5; while the rates for both cars moving are plotted in Figure 6.

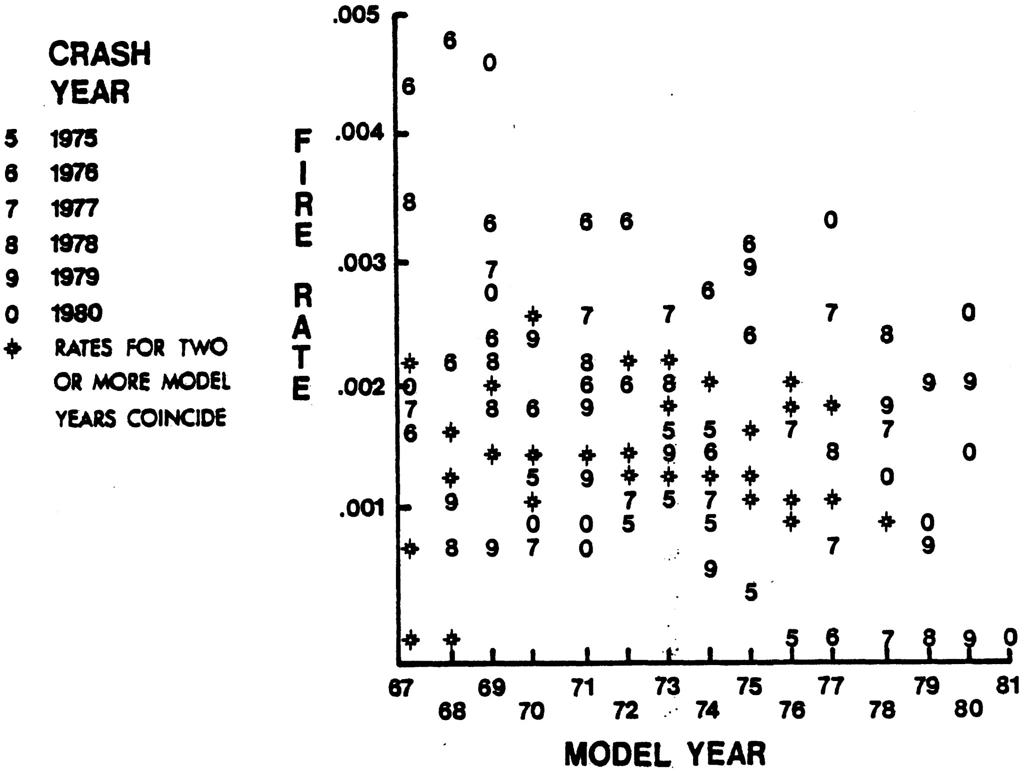

Figure 5
Passenger Car Fire Rates in Illinois Rear-End Crashes
(Stopped)

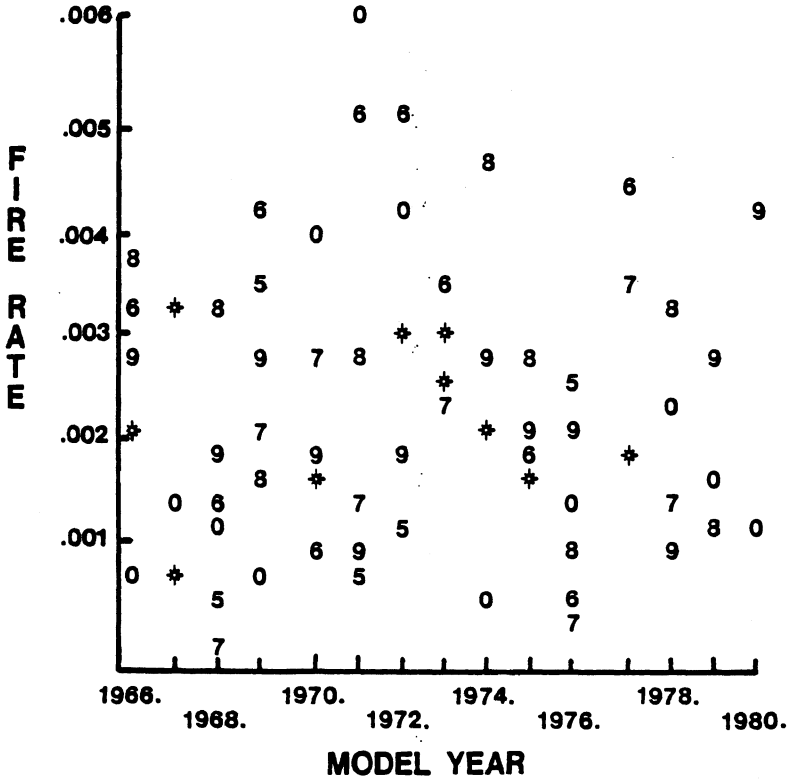

Figure 6
Passenger Car Fire Rates in Illinois Rear-End Crashes
(Moving)

Overall, the crash fire rate was 1.468 fires per thousand crashes among rear end crashes where one car was stopped and the rate was 1.851 among rear end crashes with both cars moving. A model assuming a constant fire rate for all model years and crash years and the two types of rear end collisions estimated the mean crash fire rate as 1.306 fires per thousand crashes with a lack of fit chi-square statistic of 245.36 with 220 degrees of freedom. Adding an indicator variable for the 1977 version of FMVSS 301 reduced the lack of fit chi-square statistic to 242.01 with 219 degrees of freedom. Thus, the chi-square statistic for testing the significance of the coefficient of the standard indicator variable is 3.35 with 1 degree of freedom. This model estimates a mean fire rate of 1.343 fires per thousand crashes for pre-1977 model cars and a mean fire rate of 1.164 fires per thousand crashes for the post standard models, a 13 percent reduction in fires in rear impacts. However, the coefficient is not statistically significantly different from zero at the 5 percent level.

Incorporating an indicator variable for the type of rear impact and a variable for aging gives the model:

$$r = 1.339 - 0.205(\text{std77}) + 0.156(\text{moving}) - 0.015(\text{aging}) \text{ fires/1000 crashes.}$$

The estimated effect of the standard is a reduction of about 0.2 fires per thousand crashes. The model estimates that rear end crashes with both cars moving have about 0.16 more fires per thousand crashes. The aging variable is clearly non-significant $(P>0.5)$. The lack of fit chi-square was 238.30 with 217 degrees of freedom not significant. Both the standard and the crash type variables were marginally significant $(.05 < p<.10)$. The associated chi-square statistics were 3.61 for standard and 3.28 for crash type, each with one degree of freedom, for a significance level between five percent and 10 percent in both cases.

A model with age or aging always indicated non-significance for the age or aging variables with the significance level greater than 0.5. If the model with two indicator variables is used, one for standard and one for crash type, the lack of fit chi-square is 238.63 with 218 degrees of freedom. This model estimates four means depending on type of crash and whether or not the model was subject to the 1977 version of FMVSS 301.

The four mean fire rates per 1000 estimated by the model are: pre-77 cars, 1.452, 1.295 for both moving, then one car stopped; post standard cars, 1.274, 1.116 for both moving, then one car stopped.

Since little difference in the accident data has been observed for the 1976 and 1977 versions of the standard, the 1976 version was also considered with these rear impacts. Fitting a mean with an indicator variable for the 1976 and later models gave the model:

$$r = 1.354 - 0.160(\text{std76}) \text{ fires/1000 crashes.}$$

The lack of fit chi-square was 241.92 with 219 degrees of freedom, and the chi-square for testing the standard effect was 3.44 with 1 degree of freedom, again corresponding to significance at between the five percent and 10% levels. There is virtually no difference in this model and the one that estimates the standard coincident with the 1977 model years. Incorporating an effect for the type of rear end crash gave the model:

$$r = 1.306 - 0.159(\text{std76}) + 0.157(\text{if moving}) \text{ fires/1000 crashes.}$$

The lack of fit was 238.58 with 218 degrees of freedom. The chi-squares for testing the coefficients were 3.70 for the standard and 3.65 for the crash type. Again, both significance levels were between five percent and 10%. As before, incorporating variables for age or aging did not result in any significant coefficients. In each case, the significance level for the age or aging coefficient exceeded 0.5.

A final model incorporating crash type and both standard effects was fit. The estimated coefficients were:

$$r = 1.306 - 0.092(\text{std76}) - 0.097(\text{std77}) + 0.157(\text{moving}) \text{ fires/1000 crashes.}$$

In this model the effect seems to be nearly evenly split between the 1976 and 1977 standard variables. The chi-square for these two is only 3.76 with two degrees of freedom. However, as noted, either alone accounts for most of this.

Although many fires occur in rear end crashes (a total of 1254 in the Illinois data) the fire rates per thousand crashes are relatively low: on the order of 1.5 per thousand. These data show a reduction of about 13 percent in the fire rates in rear impact crashes occurred coincident with either the 1976 or 1977 version of FMVSS 301, but that this reduction was only marginally statistically significant (.05<P<0.1). Neither aging within model years nor age of the car at time of crash was significant or appears a reasonable alternative explanation. Thus, the data on rear impacts are consistent with a beneficial effect of FMVSS 301, but do not clearly show one.

Illinois Crash Fire Rates by Crash Type. Considering crash fire rates by crash types results in large differences in crash fire rates. These range from a low of 1.039 in turning crashes to a high of 9.065 fires per thousand crashes in rollovers. Table 4 details these crash fire rates for ten crash types. Very rare crash types such as collision with railroad trains were excluded as were crashes involving pedestrians, etc. The crash types are those as reported on the Illinois accident form by the investigating officer. They may not exactly correspond to the direction of impact for the case vehicle, but are the best information available in police accident data.

TABLE 4

Crash Fire Rates by Crash Type, Illinois

Crash Type	Fire Rate Per Thousand	Total Fires
Turning	1.039	864
Angle	1.152	536
Rear End-Both Moving	1.851	442
Rear End-One Stopped	1.468	812
Head On	5.517	176
Fixed Object	6.090	1238
Rollover	9.065	207
Parked Car	1.126	448
Sideswipe-Same Direction	1.122	382
Sideswipe-Opposite Direction	1.812	212

Incorporating crash types, standard effects, and crash year effects in a model for the Illinois passenger car fire rates still resulted in a significant lack of fit (chi-square of 276.26 with 193 degrees of freedom). In order to obtain a satisfactory fit of the model, it was necessary to include interactions of standard effect variables with crash type. These were modeled as standard effects within crash types. One type of crash--angle impacts--still produced a significant lack of fit. For this type of crash fire rates by model year and crash year were more variable than binomial variation of the crash rates would account for. In order to fit the data with this type of crash included, these crash rates must essentially be fit as individual parameters. The fire rates for this type of crash are relatively low (about 1 per 1000) and the total number of fires was 536, or about 10 percent of all the fires. Rather than fit these individually, angle impacts were excluded. Table 5 gives some summary measures of the overall model which consists of three means within each crash type. Included in the table are the estimated crash fire rates for each crash type and for each of three versions of the standard: pre-standard, 1968-1975, and 1976 and later. Since the accident data do not indicate significant differences between the 1976 and 1977 standards, these have been pooled and are estimated as an effort at 1976. Also presented in the table is the estimated percent reduction in fire rates by crash type that occurred with the 1976 version of the standard. Two crash types, head-on and sideswipe same direction, showed slight increases, which are indicated by negative signs with the percent reductions. In both cases, these increases were very small, less than one percent, and are clearly non-significant. A column of chi-square statistics, each with two degrees of freedom, is presented. These can be used for testing whether the standard effects within each crash type are significant. Only those for rear impact, one car stopped or parked, rollovers, and angle impacts were significant.

Two crash types--rear impacts moving and stopped--showed lack of fit when just the standard effect variables were fit. For these two types of crashes it was necessary to also include a crash year within crash type effect. This was similar to fitting an aging effect, but the ages did not show a linear or even a monotone trend. The estimated fire rates for the rear end crashes are presented, after incorporating the

TABLE 5

Fire Rates by Standard and Crash Type

Crash Type	Pre-67	1968-75	1976+	X^2	% Reduction Current
Turning	1.215	0.989	0.975	3.21	1.4%
Angle*	0.857	1.221	0.919	10.37	24.7%
Rear-Moving	2.249	1.814	1.630	3.10	10.1%
Rear-Stopped*	1.577	1.497	1.266	6.88	15.4%
Head On	4.477	5.323	5.544	0.62	-0.04%
Fixed Object	6.609	6.076	5.531	3.25	7.9%
Rollover*	12.717	9.293	4.315	24.89	53.6%
Parked Car	1.188	1.120	0.700	3.90	19.6%
Sideswipe (Same)	1.022	1.052	1.061	0.03	-0.8%
Sideswipe (Opposite)	1.532	1.726	1.314	2.72	23.9%

crash year effects but assuming the mean crash year effect of zero. For the entire model, the chi-square for standard effects within crash types is 45.69 with 18 degrees of freedom, highly significant. However, much of this is due to the estimated very large effect in reducing fire rates in rollover crashes. While rollover crashes had the highest crash fire rates and so are a reasonable target for reduction, such crashes were relatively rare, and in fact only accounted for about four percent of the fires (see Table 4). The lack of fit chi-square for the complete model (excluding angle impacts) was 172.93 with 152 degrees of freedom (P>0.1). In addition to the parameters presented in Table 5, crash year effects for rear end moving and for rear end stopped crashes were included. These additional parameter estimates are given in Table 6. All parameters are presented in terms of fire rates per thousand crashes.

The conclusions from this analysis of the passenger car crashes in Illinois are that some significant reductions in crash fire rates have occurred coincident with the effective dates of FMVSS 301 1968 and 1976.

TABLE 6

Crash Year Effects for Rear Impacts

Crash Year	Rear-Moving	Rear-Stopped
1975	-0.602	-0.130
1976	+0.723	+0.499
1977	+0.381	-0.298
1978	-0.207	+0.154
1979	-0.048	-0.269
1980	-0.247	+0.044

The reductions are largest for rollover crashes, where they are estimated at about 50 percent. Large reductions are also observed for rear impacts (10 percent if moving, 15 percent if stopped) and for crashes into parked cars (which may also be largely rear impacts to the parked car) of 20 percent, and for sideswipes in the opposite direction of 24 percent A moderate reduction of about eight percent was estimated for crashes involving fixed objects. Aging of vehicles (at least over a six year period) seems to have been ruled out as an alternative explanation for the reduction. Thus, in the absence of other explanations, it seems reasonable to conclude that the FMVSS 301 standard may have effected most of the observed reductions. The fact that the largest reductions were estimated for rollovers and rear impacts, which would appear to be the types of crashes most directly addressed by the recent standard, lends support to this possibility. Sideswipes in the opposite direction were also estimated to show a large reduction. This could relate to the side impact testing requirements of FMVSS 301.

4.1.2 Light Truck Fire Rates in the Illinois Data

The crash fire rates for light trucks in the Illinois Data are plotted in Figure 7. Few, if any, trends are apparent visually. Older models appear to have some increased variability or possibly increased fire rates. In addition, the fire rate for 1981 model year trucks appears quite high. This rate is based on so few crashes that it is unreliable. The fire crash rates for models earlier than 1965 or so are also based on few crashes. The visual impression is that of random scatter.

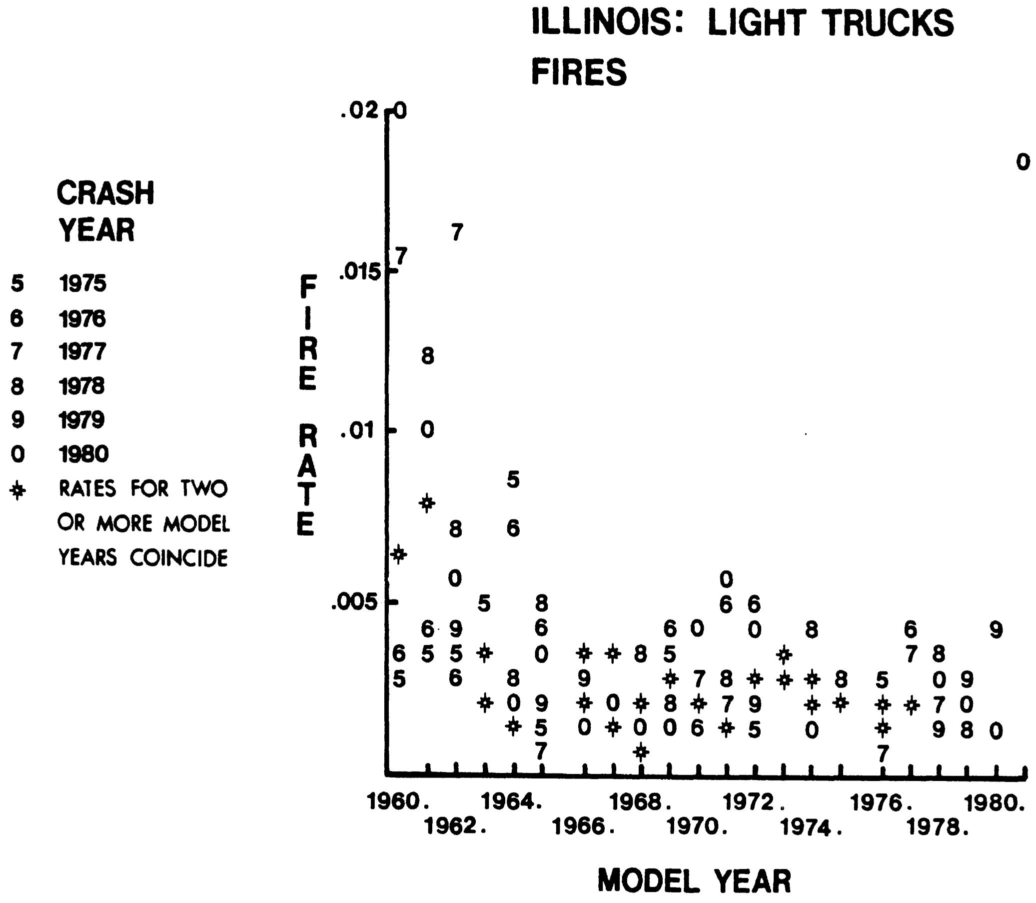

Figure 7
Light Truck Fire Rates in Illinois

Fire rates for various model year groupings are presented in Tables 7 and 8. The first table presents the fire rates for light trucks grouped by model years that correspond to the years when FMVSS 301 first applied to light trucks. Separate rates are presented for each year of data. The missing data rate for the fire variable is also presented. While this missing data rate decreased substantially in the more recent years, it is still over 10 percent. However, the overall fire rates for the different data years are reasonably consistent, suggesting that the missing data was essentially all non-fires and that it did not affect the fire rates much. Table 8 presents the fire rates grouped by the model years corresponding to the passenger car groupings by FMVSS 301 versions. In both tables question marks indicate rates based on sample sizes so small as to make the rates subject to large variability.

TABLE 7

Fire Rates Per Thousand Crashes
Pickup Trucks, Illinois

Crash Year	pre-1977	1977	1978+	Total	Unknown
1975	2.273	-----	-----	2.273	25.2%
1976	2.758	4.31 (?)	-----	2.771	22.3%
1977	1.937	3.482	0.0 (?)	2.125	16.0%
1978	2.770	2.039	3.142	2.698	14.6%
1979	2.349	2.089	1.903	2.189	13.7%
1980	2.325	1.974	2.045	2.178	12.0%

Fitting a model with a constant fire rate for all model years to these data gives an adequate fit. The estimate of a common fire rate is 1.85 fires per thousand crashes. The lack of fit test is based on a chi-square statistic of 122.48 with 116 degrees of freedom. This is clearly not significant. Thus, these fire rates are consistent with a constant fire rate of about 1.85 fires per thousand crashes for all models of light trucks.

Although the data are consistent with a constant fire rate, there is enough variation that other effects might be significant. Models have been fit to the data to estimate possible age effects, standard effects, and other differences among model years. A model with an overall mean, a variable for aging within model year, indicator variables at the 1976, 1977, and 1978 model years, and a linear trend in model years was fit to the data. The lack of fit chi-square was 100.78

TABLE 8

Fire Rates Per Thousand Crashes, Pickup Trucks, Illinois

Crash Year	1960-67	1968-75	1976	1977+	Total
1975	3.408	2.045	0.00 (?)	-----	2.273
1976	2.736	3.119	0.793	4.31 (?)	2.771
1977	2.573	2.184	0.651	3.289	2.125
1978	2.999	3.175	1.218	2.525	2.698
1979	2.108	2.407	2.276	1.965	2.189
1980	1.572	2.616	1.715	2.028	2.178

with 111 degrees of freedom, indicating a good fit. However, only the mean and the indicator variables for 1976 and 1977 models had coefficients that were significantly different from zero. The mean being non-zero merely means that the average fire rate was significantly positive. The estimated effect with 1976 models was negative, indicating a reduction in fire rates associated with 1976 and later models. However, the estimated effect for the 1977 models was positive, suggesting that the estimated reduction in 1976 was not maintained. The estimated effect for 1978 models was again negative, but not significantly so. These differences may reflect inherent variability rather than true model year differences.

Neither the aging variable nor the linear trend in model years was significantly different from zero. The aging variable refers to the fact that, since there are six calendar years of data, a given model year may have data for up to and including six different ages. This aging variable investigates possible differences by age within each model year. The linear trend in model years investigates whether there is a smooth linear trend in fire rates by model year rather than changes in level as estimated by the effect variables.

The full model was estimated as

$$r = 2.16 + 0.09(\text{aging}) - 0.05(\text{MY}) - 1.28(76) + 1.20(77) - 0.32(78) \text{ fires/1000 crashes.}$$

In this equation, r stands for the fire rate per thousand crashes. The variables are identified as aging (the six years within model year), MY (the linear trend effect in model years), and the numbers refer to the estimated changes in level at the indicated model years. While there is a slight increase with age within model year, there was a slightly decreasing trend in the model years. That is, older model years were estimated to have slightly lower fire rates. However, this is after the reductions in 1976 and 1978 have been included.

A number of other models were fit to the data. The FMVSS 301 standard applied to light trucks beginning with 1977 models, and was extended to vehicles with GVWR less than 10,000 pounds beginning with 1978 models. Consistently, however, the 1976 models were identified with low fire rates. Thus, there appears to be some reduction in crash fire rates with 1976 and subsequent models, even though this anticipates the application of FMVSS 301 to light trucks. A model incorporating this change in level and an aging effect was estimated as

$$r = 1.97 - 0.48(1976 \text{ and later}) + 0.028(\text{aging}) \text{ fires/1000 crashes.}$$

Here, r denotes the fire rate per thousand crashes as before, and the aging represents an increase per year of age. However, the aging effect is not significantly different from zero. The lack of fit chi-square is 115.78 with 114 degrees of freedom.

Many models gave essentially the same fit to the data. One of the best fitting model for these data fits separate mean fire rates in four model year groups: pre-1976, 1976, 1977, and later model years. This model had a lack of fit chi-square of 103.19 with 113 degrees of freedom. the four mean fire rates were estimated as

r = 2.06 per thousand for pre-1976 models,

r = 1.06 per thousand for 1976 models,

r = 2.26 per thousand for 1977 models, and

r = 1.91 per thousand for 1978 and later models.

The data can also be modelled as two different means, one for the pre-1976 models and one for the 1976 and subsequent models. This is probably better, owing to the high variability of the rates for the single model years 1976, 1977, 1978. If this model is used, the means are estimated as 2.06 fires per thousand crashes for pre-1976 models and 1.58 fires per thousand crashes for 1976 and more recent models. The lack of fit is 115.96 with 115 degrees of freedom. While the 1976 date corresponds to the implementation of the static rollover testing requirement for passenger cars, this is one year earlier than it was required for light trucks.

In summary, the Illinois data on light trucks show little difference in fire rates by model years. They are consistent with a constant fire rate subject to random variation among the model years. However, there is some evidence for a reduction in fire rates with more recent models. The indication is that such a reduction would coincide with the 1976 models--one year in advance of applicability of the FMVSS 301. A reduction of about 23 percent (from 2.06 to 1.58 fires per thousand) may have occurred. However, the degree to which this reduction is associated with FMVSS 301 is problematical. It evidently took place in advance of the applicable date of the standard. On the other hand, other explanations such as aging of vehicles, do not explain it.

4.2. Michigan Car Fires

Crash fire rates for passenger cars in Michigan are plotted in Figure 8. The rates are plotted by model year. The three years of data are identified by the last digit of the year (1978-1980) in which the crash occurred. In the figure, rates that are based on small numbers of crashes, such as crashes involving 1981 model cars in 1980, have been excluded.

Inspection of Figure 8 shows that fire rates are lower for the more recent model years. No consistent pattern of the three crash years at each model year is apparent. For example, the 1978 model was new in 1978, one year old in 1979, and two years old in 1980. Thus the three

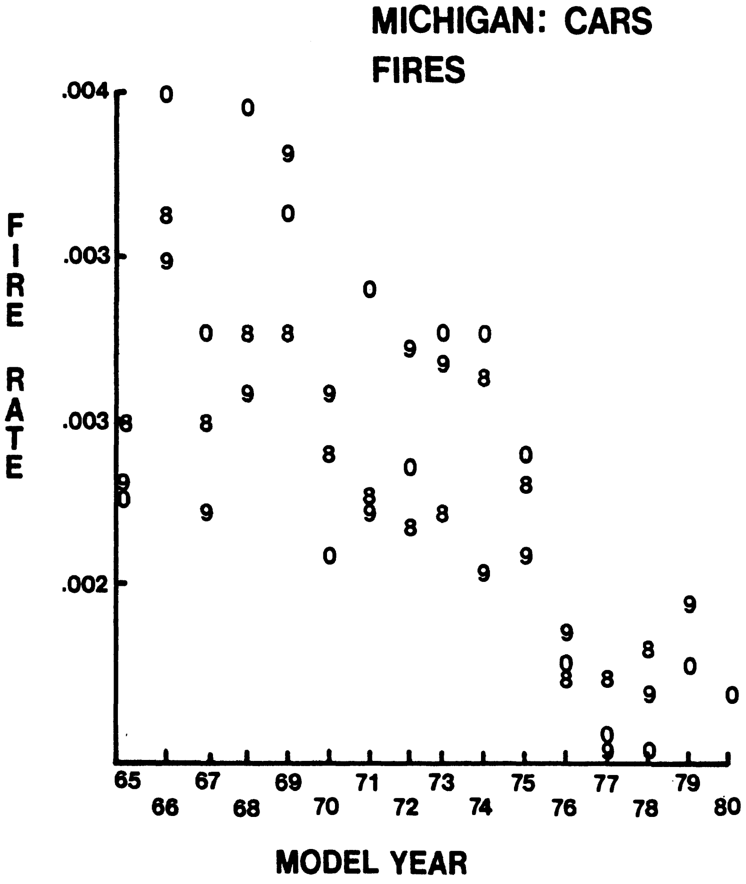

Figure 8
Passenger Car Fire Rates in Michigan

rates plotted for model year 1978 represent three different ages for this model year. The rate when these cars were new is the highest, followed by one year old, with the lowest rate in 1980, when the models were two years old. If aging strongly affected fire rates, one should see a predominance of zeroes (1980 data) as the highest value for many model years. In fact, these seem nearly uniformly distributed for the three years. Thus, aging--over this three-year period--does not seem particularly important in affecting fire rates.

The FMVSS 301 was revised in 1976 and again in 1977. It is noteworthy in Figure 8 that, while there is some variability of the fire rates, the highest rate among post 1975 model years is lower than the lowest rate for earlier model years.

In order to quantify the observations and to investigate the possible effects of FMVSS 301 analytically in these crash data, a number of statistical models were fit to the fire rates. Fitting was by the method of weighted least squares (equivalent to modified minimum chi-square). This method has been discussed by Grizzel, Starmer, and Koch (1969). A program for implementing this is GENCAT (Landis 1976). Most of the calculations were done by modifying a regression program to perform the weighted least squares calculation as described by Flora et al. (1980).

A number of analytical models were fit to the Michigan fire rates. First, a separate mean and slope for a three-level aging variable were fit within each model year. This model fit the data adequately, but none of the slope estimates was significantly different from zero.

A model including an overall mean, indicator variables for the possible effects of the 1968, 1976, and 1977 versions of FMVSS 301, and a linear trend in model years. The resulting estimates are

$$r = 2.947 + 0.023(my) - 0.387(std68) - 0.771(std76) - 0.123(std77)$$

In the equation, r denotes fire rate per thousand crashes. The lack of fit for this model was 56.03 with 58 degrees of freedom. The only coefficients that are significantly different from zero are the mean ($p = 0.0000$) and the 1976 standard effect ($p = 0.0000$), but the 68 version of the standard is nearly significant ($p = 0.105$). Deleting the aging variable still left the 1977 effect non-significant and the 1968 effect questionable. In fact, a model with an overall mean and a single change in level corresponding to the 1976 model year fit the data adequately. (Lack of fit chi-squared statistic 42.22 with 41 degrees of freedom, fit on data excluding small numbers of crashes.) A model with a change in level corresponding to the 1977 model years also fits, but not quite as well. In view of the timing of the standard and the fact that the data show a lower rate from 1976 on, the model with the 1976 effect seems clearly indicated. This model is:

$$r = 2.566 - 0.873(std76) \text{ fires/1000 crashes.}$$

The preceding models were fit on the rates excluding those based on small numbers of crashes. However, fitting the models on all the rates gives the same general conclusion and quite similar numerical results. A model with a mean and a linear effect in model year (age) has estimated coefficients of

$$r = 1.466 + 0.128(my) \text{ fires/1000 crashes.}$$

The Lack of fit chi-square is 73.24 with 61 degrees of freedom. A model fitting a change in level at the 1976 models fits substantially better.

$$r = 2.579 - 0.884(std76).$$

It has a lack of fit chi-square of 59.64 with 61 degrees of freedom. Estimating a change with the 1977 models fits substantially worse (chi-square 96.82 with 61 degrees of freedom):

$$r = 2.422 - 0.753(std77) \text{ fires/1000 crashes.}$$

The overall model with a mean, three standard effects, a linear trend in model year, and an aging variable (over the three ages for each model year) gave the estimates:

$$r = 2.199 + 0.053(MY) - 0.020(aging) - 0.044(std68) - 0.578(std76) - 0.024(std77) \text{ fires/1000 crashes.}$$

The lack of fit chi-square was 52.33 with 57 degrees of freedom. Only the mean and the std76 variables were significantly different from zero at the one percent level. However, the linear trend in model years was significant at the five percent level. While all standard effects are estimated as negative, indicating reductions in the fire rates, only that associated with the 76 models was significant.

Estimating effects at either the 1968 or 1977 models only gave substantially worse fits with significant lack of fit. The best fitting model includes a linear trend in model year and the 1976 standard effect variable:

$$r = 2.518 - 0.601(std76) + 0.054(\text{model year}) \text{ fires/1000 crashes.}$$

The lack of fit chi-square is 52.58 with 60 degrees of freedom. Each of the coefficients is significantly different from zero, with associated chi-square statistics of 163.72, 20.67, and 7.06 for the mean, 1976 standard, and age variables, respectively, each with one degree of freedom. While the 1976 standard alone fits adequately, the linear trend in model years results in a significant improvement. The estimated effect of the FMVSS 301 is significantly beneficial even after including a linear trend for age in the model.

A model with a mean and the three standard effects also fits adequately,

$$r = 2.940 - 0.385(\text{std}68) - 0.769(\text{std}76) - 0.116(\text{std}77) \text{ fires/1000 crashes.}$$

However, addition of the linear trend in model year variable reduces the lack of fit chi-square from 56.242 to 52.576, giving a chi-square of 3.78 with one degree of freedom for the age variable, nearly significant at the five percent level (five percent critical value is 3.84). In the model with the three standard effects, only the 1976 variable is significant, although the 1968 variable is nearly so (P = 0.11). If the linear trend in age is included, only the 1976 variable remains significant.

The conclusion in these data seems to be that there is a trend for older model year cars to have higher fire rates. This cannot be adequately modeled as a linear increase with age, but needs an additional step reduction at the 1976 standard. While the increase can be adequately described as a single step function drop with the 1976 models, addition of a linear trend significantly improves the model. Thus, the conclusion is that there is both a linear trend and a significant step function drop at 1976. This coincides with the revised version of FMVSS 301. While many other changes have been made in the vehicle population, it appears that these data provide evidence of an effect associated with FMVSS 301 in addition to other model year effects. No further effect is evident with the 1977 version, nor can 1977 adequately replace 1976 as the change point. In addition, while there is some evidence of a reduction coincident with the 1968 version, this effect is adequately explained with a linear trend and so is less likely to be associated with the standard. Only the 1976 version appears effective in these data, but it may in fact include an anticipation of the 1977 version, so that these two cannot be separated.

Passenger Car Fire Rates by Crash Type. While the overall fire data from Michigan show evidence of a standard effect with the 1976 change, they do not indicate such effects with either the earlier 1968 standard or the subsequent 1977 change. These three changes addressed different types of crashes, the 1968 version testing cars in a frontal crash situation, the 1976 version testing for rollovers, and the 1977 version adding rear and side impacts in the testing. It has been found that different crash types are associated with quite different values for fire rates. In addition, it has been found that severity variables such as day night or TAD severity also affect fire rates. It is possible that such other variables might be obscuring effects associated with the 1968 or 1977 version of FMVSS 301.

In order to consider this, separate files of crashes and fires were constructed for frontal (associated with 1968 FMVSS 301), rollover crashes (associated with 1976 FMVSS 301), and rear-end impacts (associated with 1977 version of FMVSS 301). Overall fire rates differed considerably for the three types of crashes, being about 1.968 fires per thousand for frontal crashes, 4.719 fires per thousand for rollovers, and 1.665 fires per thousand for rear impacts.

Frontal Impacts. Considering the frontal impacts associated with the 1968 version of FMVSS 301, a model with a mean, standard effects at the three times, a linear trend in age and an aging variable (three years within each model year) was fit to the data. The estimated model was

$$r = 2.818 - 0.249(\text{std68}) - 0.769(\text{std76}) + 0.034(\text{std77}) - 0.090(\text{aging}) - 0.039(\text{MY}) \text{ fires/1000 crashes.}$$

The lack of fit was 56.56 with 57 degrees of freedom, but only the overall intercept and the 76 standard variables were significantly different from zero. The model with these two variables was estimated as

$$r = 2.240 - 0.563(\text{std76}) \text{ fires/1000 crashes.}$$

The lack of fit was 59.94 with 61 degrees of freedom. Both coefficients were highly significant (P = 0 to four decimals). The frontal crashes were associated with the 1968 version of FMVSS 301. Fitting this point as a change in level gives the estimates:

$$r = 2.252 - 0.294(\text{std68}) \text{ fires/1000 crashes.}$$

However, the model has significant lack of fit (chi-square of 91.49 with 61 degrees of freedom) and the coefficient for the standard effect variable is not significantly different from zero. Fitting a model with a linear trend in model years (or age) gives the estimates

$$r = 1.582 + 0.059(\text{MY}) \text{ fires/1000 crashes.}$$

The lack of fit is 75.375 with 61 degrees of freedom. It is evident that there is a reduced fire rate at the more recent models. The most evident point is with 1976 models. While either a linear trend in age or a step reduction at 1977 appears significant, both also have a lack of fit. This lack of fit disappears with the 1976 model used as the effective change. Thus, analysis of frontal crashes suggests a reduction in fire rates coincident with the 1976 model year. This is significantly better as an explanation or description than either a linear trend in model years, or a step function at the 1977 models or the 1968 models. Thus, frontal crashes support an effect with the 1976 version, or 1977, but not directly an effect at 1968, nor any additional effect apparent with 1977 models over 1976 models.

Rollovers. Turning to rollovers, which were addressed by the 1976 version of FMVSS 301, the full model is estimated as

$$r = 5.432 - 0.583(\text{std68}) + 2.46(\text{std76}) - 5.03(\text{std77}) + 0.336(\text{aging}) + 0.199(\text{MY}) \text{ fires/1000 crashes.}$$

The lack of fit is 57.05 with 57 degrees of freedom, but only the 1977 standard appears significantly different from zero. Clearly, the correlation between the 1976 and 1977 effects is confounding the issue and accounts for the positive coefficient for the 1976 variable.

Fitting a model with a mean and a 1976 standard effect results in the estimates

$$r = 6.676 - 3.343(\text{std76}) \text{ fires/1000 crashes.}$$

The lack of fit is 62.82 with 61 degrees of freedom, and the chi-square for the standard effect is 10.66 with one degree of freedom. Fitting the 1977 effect gives the estimate

r = 6.841 - 3.968(std77) fires/1000 crashes.

The lack of fit is 58.08 with 61 degrees of freedom, and the chi-square statistic for the standard estimate is 15.40 with one degree of freedom. Fitting an effect at 1968 gives a significant lack of fit and a non-significant estimate for the coefficient. If a liner trend in the age of the vehicle at the time of the crash is included, the model becomes

r = 1.943 + 0.488 (age) fires/1000 crashes.

The associated lack of fit is 62.32 with 61 degrees of freedom, about the same as for the 1976 standard effect, but not quite as good as the 1977 version. If age and the 1976 or 1977 variables are both in the model, the model for 1976 becomes

r = 3.931 - 1.567(std 1976) + 0.298(age) fires/1000 crashes.

The lack of fit is 61.66 with 10 degrees of freedom, but neither of the coefficients is significantly different from zero. Including the 1977 version instead of the 1976 version gives

r = 6.335 - 3.640(std77) + 0.058(per year age) fires/1000 crashes.

The lack of fit is 58.03 with 60 degrees of freedom. Thus, there is evidence that the 1977 standard improved the rollover fire rates even if an age trend is included. (Chi-square of 4.3 with one degree of freedom.) (The age trend is non-significant in the above model.) The apparent effect of a reduction in rollover fire rates appears most closely associated with the 1977 versions of the FMVSS 301 rather than with the 1976 version. Some reduction occurred with the 1976, but apparently more occurred with the 1977 and these data indicate that the most closely associated time point for a reduction was the 1977 version.

Rear impacts were addressed by the testing procedure required with the 1977 version of FMVSS 301. Fitting the full model as before gave the estimates

r = -0.59 + 1.73(std68) - 0.45(std76) + 0.32(std77) - 0.08(aging) + 0.12(age) fires/1000 crashes.

The associated lack of fit was 35.16 with 57 degrees of freedom, but only the 1968 standard, the age, and the 1976 standard apparently significantly different from zero. Fitting reduced models gave a number of possible models.

If the 1977 model year is used to estimate a standard effect, the model is estimated as

$$r = 1.894 - 0.538(\text{std77}) \text{ fires/1000 crashes.}$$

The lack of fit is 60.82 with 61 degrees of freedom, and the chi-square for the 1977 standard effect is 13.56 with one degree of freedom. Essentially a similar result is obtained if the effect is fitted at 1976:

$$r = 1.072 - 0.735(\text{std76}) \text{ fires/1000 crashes.}$$

The lack of fit is only 48.76 with 61 degrees of freedom, while the chi-square for the standard effect is 25.61. Thus, this model appears to fit better. If a linear trend in age is fit, the model results in

$$r = 1.141 + 0.088(\text{MY}) \text{ fires/1000 crashes.}$$

The lack of fit is 57.39 with 61 degrees of freedom, and the chi-square for the age coefficient is 16.98, leaving relatively little to choose among these models.

Fitting age and a standard effect at 1976 results in the model

$$r = 2.072 - 0.745(\text{std76}) + 0.00006(\text{MY}) \text{ fires/1000 crashes.}$$

The lack of fit is 48.76 with 60 degrees of freedom, the chi-square for the standard is 8.63, but that for age is 0.04, clearly non-significant. However, if MY and the 1977 standard are both included in a model, the result is

$$r = 1.357 - 0.201(\text{std77}) + 0.066(\text{MY}) \text{ fires/1000 crashes.}$$

Here, the lack of fit is 56.55 with 60 degrees of freedom. The chi-square statistics for age and the standard effect are 4.27 and 0.84, respectively, each with one degree of freedom. Thus, in this model, MY is significant, while the standard is non-significant, but still estimated to reduce the fire rates.

For these rear impacts, it appears that the strongest evidence is that the 1976 version of FMVSS 301 resulted in a reduction in the fire rates. This appears to be more supported than either a linear trend in the model years or than an effect at 1977. Aging over the three data years was not significant.

Thus, considering the data separately by crash type results in the conclusion that a significant reduction occurred coincident with the 1976 version of FMVSS 301. The 1976 and 1977 versions cannot be clearly separated, but it seems clear that a significant reduction in crash fire rates is associated with either models 1976 or 1977 or both. Neither aging over three years, nor a linear trend in model year (or age at time of crash) is an adequate alternative explanation for the observed reductions. While for some crash types, there are additional model year differences, it seems clear that a reduction most reasonably associated with the model years fires affected by the strengthened version of FMVSS 301 in 1976 or 1977 occurred.

Passenger Car Crash Fires by TAD. The Michigan data include a Michigan Crash Severity Variable or TAD scale (undated). This variable is coded by police. It consists of a seven-level vehicle variable indicating increasing amounts of damage. Officers code the amount of damage by comparing the vehicle to representative pictures of levels 2, 4, or 6 and interpolating or extrapolating to get the full seven point scale. The TAD variable was introduced to control for crash severity. Table 9 gives fire rates by levels of TAD. Higher levels of this variable reflect more severe crashes. It may be observed that the fire rates are nearly constant up through TAD level 3 and then increase rapidly.

A number of analytical models were fit to the fire data with the TAD variable included as a crash severity control variable. As usual, in addition to the TAD variable, the three-year aging variable, the linear trend in model year, standard effects variables modeled as changes in levels at the 1968, 1976, and 1977 model years, and an overall mean were considered as candidate variables. The three-year aging variable was never found to be significantly different from zero. This suggests that aging, as distinct from model year differences, does

TABLE 9

Fire Rates by TAD

TAD	Fires/crashes
0	0.0015
1	0.0014
2	0.0014
3	0.0016
4	0.0021
5	0.0035
6	0.0063
7	0.0300

not play a very important role in explaining the variation in fire rates. Of course, it may be that the effect of age over three years is not large enough to be identified.

As is suggested by the data in Table 9, the fire rates do not change much for TAD levels 1 to 5. Most of the models indicated that no differences in fire rates among these TAD levels were significant. This was reflected in estimates of TAD effects that were not significantly different from zero for levels 1 to 4 or 5. Incorporating only variables for the TAD levels leaves some lack of fit, although this model explains a great deal of the variability. Fitting a model with main effects for TAD and the 1976 standard and TAD by 1976 standard interactions modeled as main effects within TAD levels gave the following model:

TAD Level	Mean	STD 76	X^2 (STD)	Signif.
1	0.881	-0.187	<1	NS
2	1.223	-0.248	4.71	<.05
3	1.367	-0.358	9.39	<.01
4	1.301	-0.111	<1	NS
5	1.898	-0.656	11.61	<.01
6	3.397	-1.723	26.65	<.01
7	6.349	-3.032	20.12	<.01
8	26.261	-3.925	4.11	<.05

This model fits a separate mean and 1976 standard effect for each TAD level. The chi-squares associated with standard effects are listed and most were significant at the five percent level. The overall lack of fit of this model was 434.45 with 488 degrees of freedom, not significant. If a linear trend for age is added to the model in each TAD level, the resulting chi-square for the main effect of age (model year differences) and age by TAD interactions in excess of the standard and TAD effects is 30.67 with eight degrees of freedom. If the variables are added in the other order--age first, then the 1976 standard effect--the standard and standard by TAD interactions in excess of the linear trend have a chi-square of 63.80 with eight degrees of freedom. Thus, there is some evidence of both a linear trend and an effect at 1976, but the 1976 effect seems more important. Also, some of the apparent linear trend could be due to a change with 1976 models. Notice that in the model presented above, the larger TAD levels also have larger estimated reductions associated with the standard variable. While the relation of the TAD scale to the speed at impact used in the testing requirements of FMVSS 301 is not exactly known, this may indicate that some benefit occurs even at impacts higher than the testing requirements. The highest TAD level is an open ended one and contains crashes which are quite severe. While the estimated reduction is large in this category, nearly four fires per thousand from a mean of 26 fires per thousand, the significance of the reduction was just at the five percent level (chi-square of 4.11 compared to the five percent critical value of 3.84). In addition, as a percentage of the mean, the reduction is only about 15 percent, while at other levels the reduction is proportionally much larger, ranging from 25 percent to 50 percent. This may indicate that the highest TAD category contains some crashes so severe that no effect is possible. There are relatively few crashes in this category.

A model that included main effects for all three standard effects, as well as the mean and the five highest TAD variables was fit, with the estimated coefficients:

(2) r = 1.000 + .323(68) - 0.257(76) - 0.166(77) + 0.113(T3) + 0.445(T4) + 1.300(T5) + .300(T6) + 23.557(T7) fires/1000 crashes.

This model had a lack of fit chi-square of 478.15 with 495 degrees of freedom. Individually, only the 1976 standard was significant at the five percent level. However, the sum of the 1976 and 1977 variables, which represents the effect of the current standard as compared to the 1968-1975 version, has a chi-square of 40.16 with one degree of freedom, highly significant. Notice that the estimated effect at the 1968 model year is positive, indicating a larger fire rate for models 1968-1975 than for the pre-1968 models, after the crash severity is controlled by TAD. This contrasts with estimated effects found when crash severity is not controlled by TAD. There are several possible explanations. One is that this may reflect partially a selection bias for older cars that are still operating. That is, the pre-1968 models were at least 10 to 13 years old and ranged up to 18-20 years old. Cars that are still in use after this much time may have been exceptionally trouble free, or may have had extensive repairs and maintenance. Also, sample sizes are quite small for these early model years. In addition, it is likely that these cars have different uses than the more recent models, particularly those since 1976. These early models have particularly sparse data in the highest TAD levels.

<u>Fuel Leakage Rates in Michigan Passenger Cars</u>. The leakage rate is plotted by model year and crash year in Figure 9. In the Figure, the crash year is identified by the last digit: 0 indicates 1980, 9 indicates 1979, and 8 indicates 1978. It is evident that there is a very definite trend for leak rates to be higher in the older model year cars. This trend is very strong and appears approximately linear from 1966 to 1977 models or so. Some flattening of the trend may be present in the 1977 to 1980 models. To some extent this may be due to the fact that the rates cannot be negative. It may be that the trend includes the gradual changes in car size mix, changes to front wheel drive, and other model changes as well as differences due to age. However, trends toward smaller cars would generally operate to increased leak rates, while the effect of front wheel drive is uncertain. The aging effect

within each model year would be represented by the positions of the three points representing three different years of age at each model year. No consistent patterns are evident. Generally the three points for a given model year show about the same spread as between one or two model years. This suggests that differences among model years may reflect differences other than the age differences, although age differences cannot be excluded.

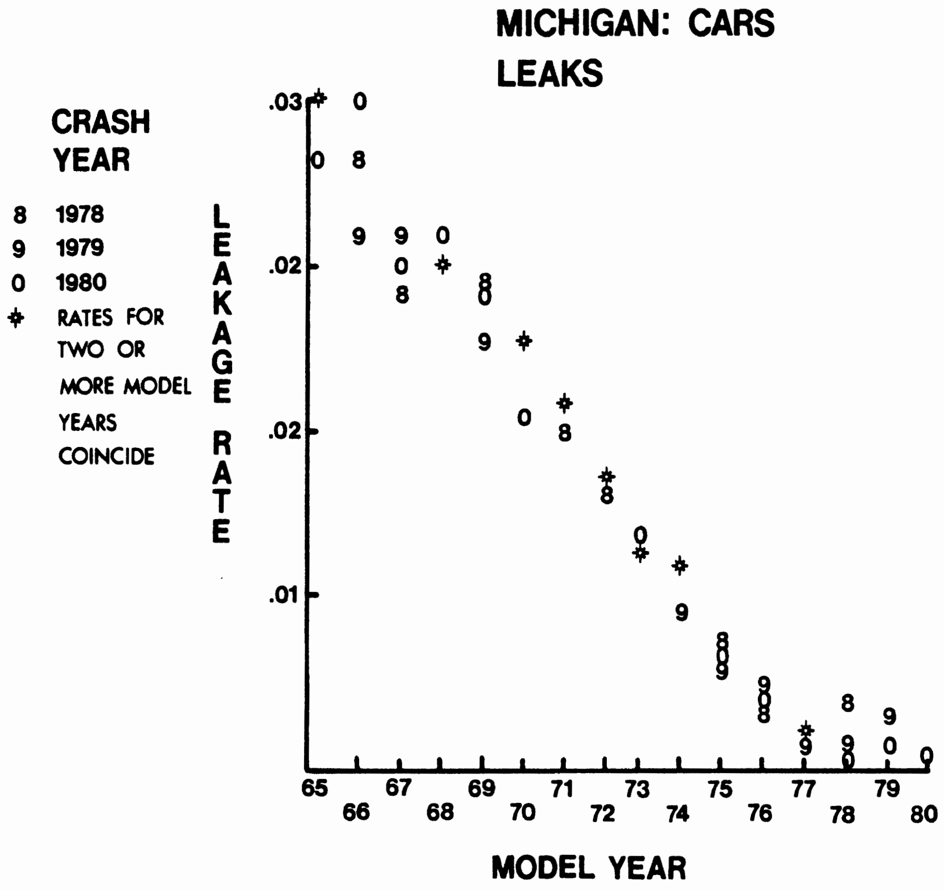

Figure 9
Passenger Car Fuel Leak Rates in Michigan

Modeling the leak rates including variables for each version of the standard, a mean, an aging effect, and a linear trend in model years resulted in the following estimated model:

$$r = 6.487 - 2.341(std68) - 1.786(std76) + 1.239(std77) - 0.018(aging) + 0.645(MY) \text{ leaks/1000 crashes.}$$

The coefficient for aging was non-significant (P=0.9), while all others were significantly different from zero at the five percent level. The positive estimate for the 1977 standard indicates that models later than 1976 had slightly higher leak rates than the 1976 models. Models 1976 and later, however, had lower rates than the earlier models. Thus, it appears that 1976 models had lower leak rates relative to the trend line than either the preceding or following models. As throughout, it is difficult to distinguish between the 1976 and 1977 versions of the standard in the crash data. One possible explanation for the higher leak rates (relative to the model year trend) with the 1977 models is that this was the first year of downsizing of full-sized GM cars, and these cars sold well in 1977 and 1978.

There remains some lack of fit (chi-square of 102.45 with 57 degrees of freedom) in the model. Eliminating the non-significant aging variable results in very small changes in the model (coefficients change only in the last digit if at all).

The relation of leak rate to TAD is very strong. Table 10 shows the leak rates by TAD level. The leak rates approximately double from one TAD level to the next. Since this relation is so strong, models including TAD were fit to the leak rates separately by model year, crash year, and TAD. In addition to the previous variables, a linear TAD variable and an exponential TAD variable were included. The best fitting model that resulted was

$$r = 1.357 + 0.00785\exp(TAD) - 0.173(TAD) - 0.127(aging) + 0.510(std68) - 0.476(std76) \text{ leaks/1000 crashes.}$$

However, this model still exhibited some lack of fit (chi-square of 857.37 with 498 degrees of freedom). All the coefficients were significantly different from zero. The estimated effect for the 1977 standard was also negative, but non-significant. The estimate for 1968 was positive, indicating that after adjusting for TAD, the 1968-1975 models had a higher rate than the pre-1968 or post-1976 models. The post-1976 models had a lower rate than the pre-1967. Two forms of the

TAD variable were included. One was a linear effect and the other an exponential one. With these two, the linear had a negative coefficient, but the exponential variable was positive and accounted for much of the TAD effect. Both a linear and quadratic variable in model year were included, but both were non-significant. Somewhat surprisingly, the three-year aging variable was significant, but its coefficient was negative, indicating that the older cars within each model year tended to have lower leak rates than the younger ones after TAD was accounted for.

TABLE 10
Leakage Rates by TAD (Michigan)

TAD	Leakage Rate Per Thousand	N
0	2.167	43,834
1	3.079	339,091
2	4.952	349,348
3	8.712	268,021
4	16.418	170,176
5	32.016	89,737
6	62.192	41,886
7	131.454	26,838

In considering leakage rates separately for three types of crashes: frontal impacts, rear-end impacts, and rollovers, the three-year aging variable was never found to be significant. Leakage rates differ substantially for the three different types of crashes. For frontal impacts, the average leakage rate was estimated to be 7.50 leaks per thousand crashes. For rollover crashes, the average leakage rate was estimated to be 80.84 leaks per thousand crashes, while for rear-impact crashes, the average leakage rate was estimated to be 13.07 leaks per thousand crashes. Although rollovers are a relatively infrequent type of crash, they apparently present much more opportunity for leakage to occur. Rear-impact crashes are generally less severe than frontal impacts. However, presumably because of the location of most fuel tanks in the rear of the car, leakage rates are higher in rear impacts even though generally the severity of the impact is less than in frontal crashes. This is in some contrast to fire rates, which were higher for frontal crashes than for rear-impact crashes.

Frontal Impacts. Restricting attention to the set of frontal crashes, the average leak rates were 16.33 for pre-1968 models, 9.62 for 1968 through 1975 models, 5.59 for 1976 models, and 5.08 for 1977 and later models. All of these rates are per one thousand crashes. Changes in leakage rates by age of car over the three years were not significant. However, there were clearly more differences among model years than could be explained by the four groups. There appears to be a strong linear trend for the leak rates to increase with the age of the car at the time of the crash (as distinct from the three different ages within a given model year). However, even with this linear trend and effects corresponding to the different standards included, there was still substantial additional variability among rates for different model years. The version of the standard dealing with frontal impacts was the 1968 version. A model estimating the effect of this together with the age trend was

$$r = 5.10 - 1.94x(68std) + 0.74(MY) \text{ leaks/1000 crashes.}$$

If an effect of the later version of the standard is also included, the model becomes

$$r = 6.49 - 2.34x(68std) - 1.79x(76std) + 0.65(MY) \text{ leaks/1000 crashes.}$$

In both cases, r stands for the leak rate per thousand crashes and the standard effects are indicator variables that take the value 0 or 1 depending on whether the model was not or was subject to the indicated standard. The MY variable is the age of the model in years at the time of the crash, with a value of one for a crash in the same year as the model year of the car. The 1977 version of the standard could be substituted for the 1976 version; they are not distinguishable in the data. However, the two indicator variables are correlated so that only one should be included in a model. All coefficients were significant at the five percent level.

Rollovers. Turning attention to rollover crashes--addressed by the 1976 version of the standard--one sees a much higher leakage rate. Again, grouping models by version of the standard, the average leakage rates per thousand crashes are estimated as: 194.8 for pre-1968 models, 135.2 for 1968 through 1975 models, 85.2 for 1976 models, and 42.3 for 1977 and later models. No effect of aging over the three years within each model was apparent, however, there was an increasing trend in leakage rates with older models. Incorporating a linear trend in age and an effect for the 1976 standard results in an estimated model of

$$r = 20.06 - 11.82(76std) + 13.22(MY) \text{ leaks/1000 crashes.}$$

As before, these rates are per thousand crashes, and the age variable is the age in years of the particular model at the time of the crash, while the standard variable is an indicator variable taking the value 1 for vehicles subject to the standard. Thus, a negative coefficient for the standard variable indicates a reduction in leakage rates estimated to coincide with models first subject to the standard. In both these cases, a significant ($p<.05$) reduction in leakage rates is estimated even after the inclusion of a linear trend for age. This would be consistent with beneficial effects of the standards.

Rear Impacts. The 1977 version of the standard addressed rear impacts. Turning attention to rear-impact crashes, the average leakage rates were estimated for model years corresponding to each version of the standard as: 35.76 for pre-1968 models, 21.33 for 1968 through 1975 models, 10.29 for 1976 models, and 8.22 for 1977 and later models. As before, there was no evidence of an aging effect for the three years of ages within a given model year of car, but there was evidence of a more general tendency for leakage rates to increase for the older models. Fitting a model with a linear effect for age of the car and a standard effect for the 1977 version gives the estimated model:

$$r = 0.07 + 2.65x(77std) + 2.90x(MY) \text{ leaks/1000 crashes.}$$

The variables are as before, except that MY now is coded as zero for a crash of a car during the same calendar year as its model year. This model estimates an increase in leakage rates coincident with the 1977 standard after the linear trend in age has been incorporated. Fitting a similar model but using the 1976 standard rather than the 1977 standard gives:

$$r = 4.22 - 1.12x(1976std) + 2.40(MY) \text{ leaks/1000 crashes.}$$

Here again, MY is taken as zero for a crash in the same calendar year as the model year of the car. In this model, the effect of the 1976 standard is estimated to be negative, corresponding to a reduction in leakage rates. One interpretation could be that a reduction occurred with the 1976 models and no further reduction occurred with the 1977 models. That is, although the 1976 version of the standard did not specifically address rear impacts in its testing requirements, this may have been anticipated and the 1976 and 1977 standards may have been implemented at essentially the same time.

Thus, as was seen in the overall data, there appears to be a slight increase in the leak rates relative to model year trend with the 1977 models as opposed to the 1976 models. Apparently, this is most apparent in the rear impact crashes.

All of the models for leak rates that have been discussed so far have had significant lack of fit. While the effects of the standard or other variables have been apparent, there remains some variation that is unexplained and may be associated with other factors. A model that fit an overall mean, main effects and effect by TAD interaction for age, age squared, aging, and three standard effects fit the data adequately (chi-square for lack of fit 480.86 with 448 degrees of freedom). This was accomplished by fitting main effects separately within each TAD level. The result indicated that most variables were not significant, particularly in the lower TAD levels.

A variable selection procedure was used within each TAD level to obtain a more parsimonious model. The overall model that resulted had a lack of fit chi-square 503.75 with 480 degrees of freedom. The model contains interactions and these were modeled as main effects of the other variables within each TAD level. The model that resulted is presented by TAD:

TAD 0

$r = 0.851$

TAD 1

$r = 0.331(\text{MY}) - 0.018(\text{MY squared})$

TAD 2

$r = 0.0070(\text{MY squared}) + 1.058(\text{std68})$

TAD 3

$r = 1.636 - 0.382(\text{std77})$

TAD 4

$r = 2.293 - 0.332(\text{Age}) - 0.793(\text{std77})$

TAD 5

$r = 6.265 - 0.489(\text{Age}) - 0.891(\text{MY}) + 0.0385(\text{MY squared}) + 3.312(\text{std68}) - 4.142(\text{std76})$

TAD 6

$r = 1.166(\text{Aging}) + 2.110(\text{MY}) - 0.111(\text{MY squared}) - 4.888(\text{std76}) + 2.943(\text{std77})$

TAD 7

$r = 60.711 - 2.016(\text{MY}) - 19.809(\text{std76})$ leaks/1000 crashes.

Standard effects were non-significant for TAD levels zero and one. At TAD 2, a detrimental effect was estimated coincident with the 1968 standard. At higher levels, benefits (reductions) were estimated for some version of the standard. However, at TAD 5, the 1968 standard was estimated as an increase while the 1976 standard was estimated as a reduction. Similarly, at level 6 the 1977 version was estimated as an increase while the 1976 version was estimated as a decrease. Combined, at level 6, there is still an estimated reduction for the 76 and later models.

Because of the complexity of this model incorporating different variables and interactions with each TAD level, an alternative model with interactions was fit. Again, the interactions were modeled as main effects of the other variables fit within each TAD level. The overall mean and the 1968 and 1976 standard effect variables were forced in the model, then the others were selected only if significantly different from zero. The overall lack of fit chi-square for this model was 500.28 with 468 degrees of freedom. This is a non-significant lack of fit, but clearly there could be other variables that might still significantly influence the leak rates. The estimated coefficients for this model are presented below, again by TAD level. All coefficients are to be interpreted in terms of leaks per thousand vehicles.

TAD 0

$r = 0.620 + 0.331(\text{std68}) - 0.215(\text{std76})$

TAD 1

$r = 0.798 + 0.671(\text{std68}) - 0.341(\text{std76})$

TAD 2

$r = 0.401 + 0.619(\text{std68}) + 0.093(\text{std76}) + 0.00678(\text{MY squared})$
TAD 3
$r = 1.469 + 0.169(\text{std68}) - 0.305(\text{std76})$
TAD 4
$r = 4.508 + 0.704(\text{std68}) - 0.373(\text{std76}) - 1.394(\text{std77}) - 0.364(\text{Aging}) - 0.575(\text{MY}) + 0.027(\text{MY squared})$
TAD 5
$r = 6.254 + 3.312(\text{std68}) - 4.142(\text{std76}) - 0.489(\text{Age}) - 0.841(\text{MY}) + 0.038(\text{MY squared})$
TAD 6
$r = 3.030 - 1.313(\text{std68}) - 4.030(\text{std76}) + 3.930(\text{std77}) + 1.384(\text{Age}) + 2.933(\text{MY}) - 0.148(\text{MY squared})$
TAD 7
$r = 24.04 + 16.723(\text{std68}) - 8.822(\text{std76})$ leaks/1000 crashes.

The conclusion seems to be that leak rates are related to many factors. However, after accounting for many of these--TAD, age, etc.,--there appears to be generally a significant reduction in leak rates that coincides with the 1976 and later model year of cars. The estimates of the 1968 standard are that after adjusting for severity, model year trends, and are rates were higher. However, the interactions between age and other variables, mean one should not interpret this as meaning that the 1968 version of FMVSS 301 was detrimental. There is clearly a strong relationship between leak rate and model year of the cars with newer models, particularly those 1976 and later, having low leak rates. However, causes cannot be ascribed, and alternative explanations to FMVSS 301 cannot be ruled out.

4.2.2. Michigan Light Truck Fires

The fire rates by model year for light trucks (pickups and vans) in the Michigan data are plotted in Figure 10. In that figure, separate rates are plotted for each of three calendar years of data. These years are 1978, 1979, and 1980, and are identified on the figure by the digit corresponding to the last digit in the year. A visual inspection of the figure suggests that the fire rates are fairly small, and that they may be lower for more recent model years.

In order to investigate the relationship of these rates to various factors, analytical models were used. The FMVSS 301 first applied to light trucks with the 1977 models, and then with more stringent requirements, to the 1978 and subsequent models. In addition to these

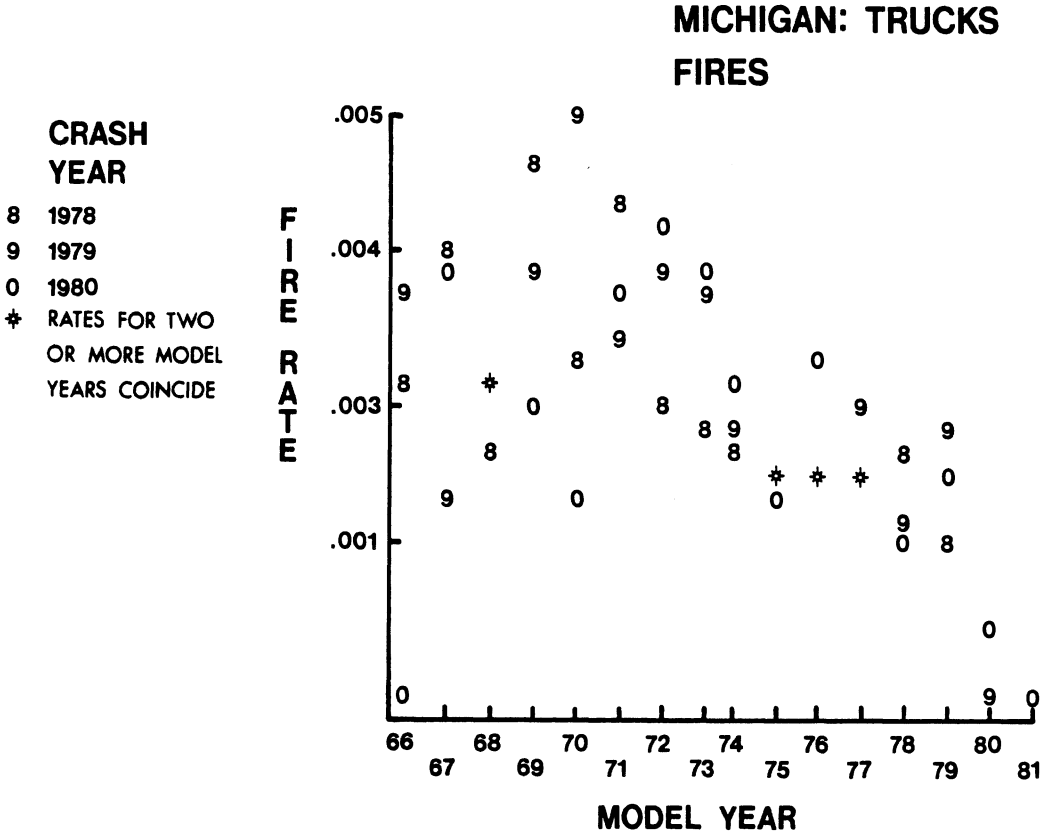

Figure 10
Light Truck Fire Rates in Michigan

possible standard effects, there could be an aging effect over the three different years, or a more general model year effect. A model with two standard effects, an aging effect (over the three data years within model years) and a linear effect in model year was fit to the data. The model was estimated as

$$r = 2.067 - 0.144(\text{std77}) - 0.375(\text{std78}) - 0.060(\text{aging}) + 0.050(\text{MY})$$
fires/1000 crashes.

In this, all coefficients are in terms of fires per thousand vehicles in crashes. The lack of fit statistic was 47.73 with 58 degrees of freedom, not statistically significant. However, except for the overall mean, none of the individual coefficients was significantly different from zero at the five percent level. Various reduced models were fit to the data. In none of them was the aging (over the three data years within model years) variable significantly different from zero. A model with a mean and a linear effect for model year (or age at time of crash) had the estimated coefficients:

$$r = 1.583 + 0.101(MY) \text{ fires/1000 crashes.}$$

The lack of fit was 51.08 with 61 degrees of freedom. Both the mean and the MY coefficient were significantly different from zero ($P<0.001$). A model with both the 1977 and 1978 effects had the estimated coefficients

$$r = 2.481 - 0.350(std77) - 0.483(std78) \text{ fires/1000 crashes.}$$

The lack of fit for this model was 49.25 with 60 degrees of freedom. The two standard effects had a chi-square of 15.19 with two degrees of freedom, highly significant. However, because of the high correlation between the two effects, the individual chi-squares were only 1.48 and 2.55, respectively, for the 1977 and 1978 standard coefficients estimates. Either the model year 1977 or 1978 may be estimated as the effect of the standard. If 1977 is taken as the point, then the estimated model is:

$$r = 2.48 - 0.682(std77) \text{ fires/1000 crashes.}$$

The lack of fit chi-square is 51.8 with 61 degrees of freedom, not significant. This model fits nearly as well as the model with a linear effect estimated in age of model year (lack of fit of that model was 51.08 with 61 degrees of freedom). Thus, at this point, there is clearly a tendency for lower fire rates associated with more recent models of light trucks, but these could be due either to a standard effect or to a linear trend in the age of the truck at the time of the crash. No aging was demonstrated over the three calendar years within each model year.

The model with two effects for the standard fit slightly better than the model with a linear age effect. This model estimates the crash fire rates for light trucks in Michigan as 2.481 per thousand prior to the standard, 2.130 per thousand for 1977 models and 1.647 per thousand for the 1978 and later models. This corresponds to a 16 percent reduction with the 1977 model, an additional 23 percent reduction with the 1978 models, or a 34 percent reduction from pre-standard to current standard. However, the possibility of a linear trend in age cannot be eliminated as a possible alternative explanation of the observed effect.

The TAD damage scale was also used as a control variable. When light truck crashes were tabulated by model year, crash year, and TAD level, many of the model years showed zero fire rates. That is, the data were too thinly spread. Fire rates are relatively constant for TAD levels 1-4, then increase with levels 5 and 6. The most pronounced jump occurs at TAD level 7, which has a much larger fire rate than any other TAD level. While it might be possible to combine TAD into three or four levels and possibly pool across data years for fire rates, this pattern was not the same for leak rates. As can be seen in Table 11, leak rates increased with each TAD level. Consequently, TAD levels were not pooled for fire rates. Rather, model years have been pooled by standard, but the crash years were kept separate. This allows investigation of an aging effect (over three years), but ignores possible trends in model years in favor of estimating possible standard effects.

The crash fire and leak rates for each TAD level, data year, and model year grouping are presented in Table 11. The rates are per thousand vehicles. The corresponding frequencies are presented in Table 12.

A model that included a mean, the two standard effects, an aging variable, and dummy variables for the TAD levels was fit to these data. The aging coefficient was non-significant ($P>0.5$); the coefficient estimated an increase of 0.058 fires per thousand with each year of age. A reduced model eliminating the aging variable was fit with the following coefficient estimates in fires per thousand:

$$\begin{aligned} r = {} & 6.939 - 0.797(\mathrm{Std77}) - 0.972(\mathrm{Std78}) - 5.342(\mathrm{TAD1}) - \\ & 5.513(\mathrm{TAD2}) - 4.789(\mathrm{TAD3}) - 4.160(\mathrm{TAD4}) - 4.132(\mathrm{TAD5}) - \\ & 1.403(\mathrm{TAD6}) + 25{,}339(\mathrm{TAD7}). \end{aligned}$$

The lack of fit chi-square for this model was 46.56 with 54 degrees of freedom. The chi-square for the two standard effects was 33.80 with two degrees of freedom. Each of the two effects was also significantly different from zero, indicating reductions in the crash fire rates. The

TABLE 11

Fire and Leakage Rates for Light Trucks
(Fires per thousand crashed vehicles)

TAD	Fire Rates			Leak Rates		
	Pre-77	1977	Post-1977	Pre-77	1977	Post-1977
1978						
1	1.399	0.908	0.270	5.215	2.498	2.701
2	1.190	0.831	0.702	10.946	4.712	5.965
3	3.118	0.934	2.245	20.386	11.671	7.295
4	2.418	1.021	3.633	31.431	17.365	17.257
5	4.386	3.145	3.521	82.237	51.887	31.690
6	5.818	0 (1.397) *	6.536	104.727	53.073	49.020
7	30.303	52.846	24.390	204.545	191.057	121.951
1979						
1	1.696	1.093	1.211	4.703	4.917	2.018
2	1.152	1.020	1.190	8.258	6.120	5.268
3	1.854	0.527	1.856	21.398	5.802	10.074
4	2.964	4.378	1.419	36.314	28.897	13.245
5	4.138	5.505	0 (0.457) *	60.230	51.376	31.050
6	6.233	7.117	6.944	112.199	64.057	59.028
7	37.736	43.269	28.646	194.229	163.462	106.771
1980						
1	1.965	1.083	0.538	5.896	3.970	2.016
2	1.403	0.980	0.330	8.838	6.369	3.794
3	2.629	0.746	1.318	18.002	15.660	7.382
4	2.852	2.532	2.231	37.072	29.114	17.403
5	4.920	2.299	1.696	70.111	41.379	32.231
6	5.814	13.333	5.190	96.512	111.111	44.983
7	27.108	28.777	32.099	185.241	151.079	101.235

*Observed rate was 0. Number in parentheses is the midpoint of a 95 percent confidence interval for the rate.

TAD variables were also highly significant, with a chi-square of 158.61 with six degrees of freedom. The TAD levels 1 through 5 were significantly negative, TAD level 6 was slightly negative, while TAD level 7 had a very much larger fire rate than any of the others. (The

TABLE 12

Fire and Leak Frequencies for Michigan Light Trucks

TAD	1970-76			1977			1978 On		
	Fire	Leak	Total	Fire	Leak	Total	Fire	Leak	Total
Crash Year: 1978									
1	22	82	15,715	4	11	4403	1	10	3703
2	15	138	12,607	3	17	3608	2	17	2850
3	26	170	8339	2	25	2142	4	13	1782
4	10	130	4136	1	17	979	4	19	1101
5	12	225	2736	2	33	636	2	18	568
6	8	144	1375	0	19	358	2	15	306
7	32	216	1056	13	47	246	5	25	205
Crash Year: 1979									
1	22	61	12,971	4	18	3661	9	15	7433
2	12	86	10,414	3	18	2941	7	31	5884
3	13	150	7016	1	11	1896	7	38	3772
4	12	147	4048	5	33	1142	3	28	2114
5	9	131	2175	3	28	545	0	34	1095
6	7	126	1123	2	18	281	4	34	576
7	34	175	901	9	34	208	11	41	384
Crash Year: 1980									
1	18	54	9159	3	11	2771	4	15	7441
2	10	63	7128	2	13	2041	2	23	6062
3	13	89	4944	1	21	1341	5	28	3793
4	9	117	3156	2	23	790	5	39	2241
5	8	114	1626	1	18	435	2	38	1179
6	5	83	860	3	25	225	3	26	578
7	18	123	664	4	21	139	13	41	405

variables for TAD were modeled as effects from the mean implying that the sum of the TAD values must be zero.)

Thus, incorporating TAD as a control variable also results in an estimated standard effect. The 1977 version of FMVSS 301 is associated with an estimated reduction of about 0.8 fires per thousand crashes and the 1978 version is associated with an estimated additional reduction of nearly one fire per thousand crashes of light trucks.

Fuel Leakage Rates in Michigan Light Trucks. The fuel leak rates per thousand are plotted by model year and crash year in Figure 11. Again, the data years are indicated by the last digit of the year. A very strong trend for older models years to have higher leak rates is evident. Also increased variability in the older model years can be noted.

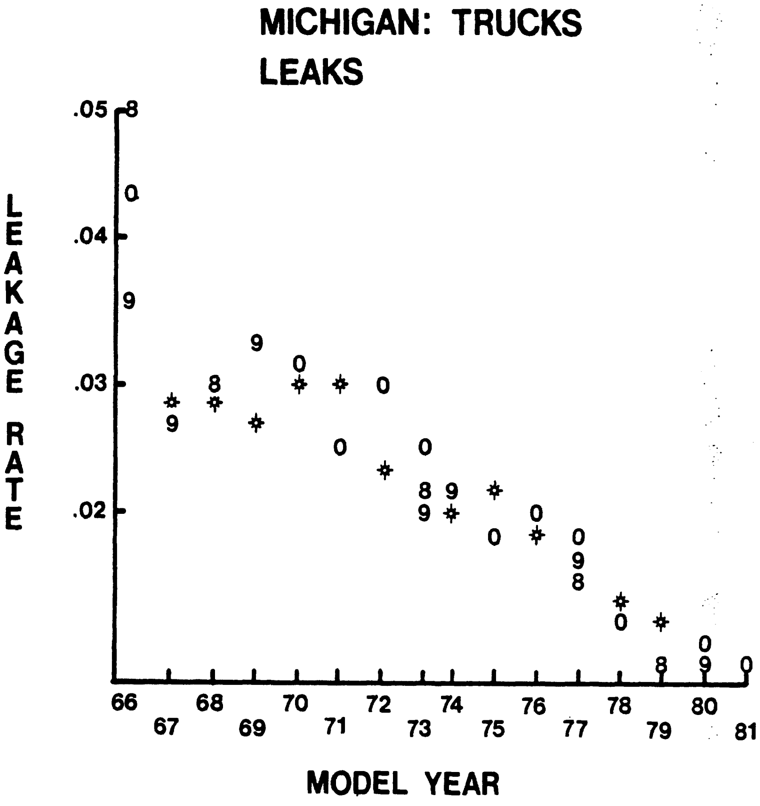

Figure 11
Light Truck Fuel Leak Rates

To quantify these effects, a model was fitted to these rates. The model included variables for a linear trend in model years, an aging effect over the three data years, standard effects at 1977 and 1978 as well as an overall mean. While only the mean, a linear model year effect and a standard effect at 1977 appeared statistically significant, this model exhibited a significant lack of fit (chi-square of 137.26 with 60 degrees of freedom). Two sources of this lack of fit were identified. The lack of fit could be attributed to the data from 1978, the first year of the new data form. Alternatively, eliminating the data points based on small numbers of crashes (early model years, model year 1981 in crash year 1980, etc.) also eliminates the lack of fit.

Considering a reduced data set with 45 leak rates, and fitting a model with a mean, standard effects at model years 1977 and 1978, an aging effect (over three years) and a linear trend in model years fit satisfactorily (chi-square of 37.39 with 40 degrees of freedom).

The three-year aging effect was clearly not significantly different from zero. Neither was the estimated effect at model year 1977. Reducing the model by deleting the three-year aging effect still leaves a non-significant effect for the 1977 version of the standard. Eliminating that variable gives the estimated model.

r = 8.000 + 1.604(Age) - 2.294(std78) leaks/1000 crashes.

Here "MY" is a linear trend in model years at time of crash. The lack of fit chi-square is 38.10 with 42 degrees of freedom. All three coefficients are significantly different from zero with associated chi-squares of 78.37, 158.84, and 9.40, for the intercept, age, and standard variables, respectively, each with one degree of freedom.

The linear model year effect cannot be deleted without introducing significant lack of fit. If a variable to estimate an effect of the 1977 version of FMVSS 301 is substituted for the 1978 version, the estimated model becomes

r = 7.479 + 1.685(MY) - 1.414(std77) leaks/1000 crashes.

However, the standard coefficient is not significantly different from zero at the five percent level (chi-square of 2.65 with one degree of freedom).

If both standard variables are included, the model is estimated as

$r = 8.473 + 1.554(MY) - 0.500(std77) - 2.143(std78)$ leaks/1000 crashes.

The associated lack of fit is 37.83 with 41 degrees of freedom. The 78 standard variable is significant ($P<0.01$), but the 77 standard is not ($P>0.5$), although both are estimated as negative, indicating estimated associated reductions. These data seem to indicate a significant reduction in fuel leak rates in crashes, primarily associated with the 1978 version of FMVSS 301 as it applied to light trucks. This reduction is in addition to the linear trend in age or model year.

To further investigate this, the leak rates presented in Table 11 were analyzed by models similar to those used for the fire rates in the previous section. However, for leak rates, the relation with TAD level is a much stronger one, with increases noted at each TAD level. A model fitting main effects of standards, TAD, and aging in addition to a mean showed significant lack of fit (chi-square of 280.69 with 54 degrees of freedom). This model suggests that aging (over the three crash years) was not significant.

In order to obtain a satisfactory fit, interactions of standard and damage severity had to be included. This was accomplished by fitting a mean and two standard effects within each level of the TAD. Table 13 gives these estimated effects. The lack of fit test was 54.53 with 42 degrees of freedom.

All of the estimated coefficients were significantly different from zero at the one percent level except for the 1977 standard at TAD level 7. The chi-square for main effects of TAD is 2183.66 with six degrees of freedom. For main effects of standard, the chi-square is 174.69 with two degrees of freedom, and the chi-square for the TAD by standard interaction is 226.22 with twelve degrees of freedom. Both versions of the standard are estimated to be associated with significant reductions in crash leak rates at each level of TAD. Leak rates increase strongly with crash severity as measured by TAD.

TABLE 13

Interaction Model of TAD and FMVSS 301 Effects,
Michigan Light Trucks

TAD	Mean	1977 Standard	1978 Standard
1	5.17	-1.78	-3.04
2	9.37	-3.88	-4.73
3	20.07	-11.03	-11.81
4	34.56	-10.87	-19.06
5	70.71	-22.27	-39.05
6	104.82	-38.71	-54.17
7	195.88	-25.15*	-88.68

*Not significant (P>0.1). All others are highly significant (P<0.01).

4.2.3. Other Factors Influencing Fire or Fuel Leakage Rates

The possible effects of day or night as the time of the crash were investigated. The use of lights at night could provide an additional source of ignition, and so could result in higher fire rates. In the Michigan passenger car data, the crude fire rate for daytime crashes was 1.78 fires per thousand crashes. The crude fire rate for nighttime crashes was 2.98. The corresponding rates of fuel leakage were 8.11 leaks per thousand crashes for daytime crashes and 17.06 leaks per thousand crashes for nighttime crashes. Approximately 63 percent of the Michigan crashes occurred during daytime and 37 percent during night. There are several other factors that differ for day or night crashes. Crashes that occur at night are generally more severe crashes. A higher proportion of nighttime crashes are single-vehicle crashes, more occur in rural areas, etc. In order to consider whether these other factors could account for the difference in fire and leak rates, adjusted fire and leak rates were calculated, adjusting for the TAD severity scale.

The adjusted fire rates were 2.07 fires per thousand crashes, day; and 2.31 fires per thousand crashes, night. Most of the difference in fire rates was removed by adjusting for the difference in TAD severity distributions. Similarly, adjusted leak rates were calculated. These resulted in adjusted rates of 9.36 leaks per thousand crashes, day; and 12.95 leaks per thousand crashes, night. Much of the difference has been removed by adjusting for TAD severity, but some still remains. It seems likely that the primary difference in day and night fire and leak rates represents differences in the crash populations.

The potential difference in day and night time crashes was thought to be possibly caused by the additional ignition source posed by the vehicle's lights being on at night. However, the crude ignition rates (fires per leaks) were 0.22 for daytime crashes, and 0.18 for nighttime crashes. This represents a higher chance of ignition, given fuel leakage, for daytime rather than nighttime crashes, contrary to what was expected. After adjusting for TAD, the ignition rates are virtually the same: 0.155 for days and 0.152 for nights. One might suspect that small amounts of fuel leakage might be harder to notice at night. However, this effect, if present, would tend to reduce the number of leaks in nighttime crashes and would increase the apparent ignition rate. The data do not appear to support this hypothesis. It may be that the addition of lights does not present an important additional source of ignition. Possibly most cars have at least brake lights on at the instant of impact and the possible addition of headlights does not add substantially to the chance of ignition.

As noted previously, the type of crash also influences the fire or leak rate. Table 14 gives the passenger car fire and leak rates for a number of crash configurations. Some of these were combined in considering the frontal, rollover, and rear impact crashes as identified with each version of FMVSS 301.

Another factor that affects fire and fuel leakage rate is the number of vehicles involved in the crash. Table 15 gives the observed fire and fuel spillage rates for single and multiple vehicle crashes in Michigan for the three years 1978-1980. As with the day-night variable, inclusion of TAD and/or crash type accounts for much of the variation.

TABLE 14

Fire and Leak Rates by Crash Configuration

Crash Type	Fire Rate	Leak Rate	N	Proportion of Crash
Center front	2.650	14.550	175,876	0.285
Right front	1.701	7.435	92,281	0.149
Right side	1.901	14.536	43,134	0.070
Right rear	1.507	8.027	38,495	0.062
Center rear	2.006	23.107	70,800	0.115
Left rear	1.770	11.750	37,278	0.060
Left side	1.908	13.970	44,025	0.071
Left front	1.510	6.889	96,671	0.156
Other Impact	27.094	35.674	4,429	0.007
Rollover	7.328	121.131	11,599	0.019
Front & Rear	2.370	26.963	3,375	0.005

However, if such a measure of accident severity is not available, and either day/night information or single/multiple vehicle crash information is available, either would be a potentially important control variable to use in considering fire or leakage rates.

TABLE 15

Fuel and Spillage Rates for Single and Multiple Vehicle Crashes, Michigan, 1978-80

Year	Single			Multiple		
	Fire Rate*	Leak Rate*	N	Fire Rate*	Leak Rate*	N
1978	4.181	37.367	(67,920)	1.816	10.819	(440,413)
1979	4.038	29.136	(64,387)	1.603	9.354	(408,579)
1980	3.859	23.908	(67,886)	1.511	8.392	(326,295)

*Per 1000 crashed vehicles.

4.2.4. Ignition Rates

In the Michigan data, both leak and fire data are available. The occurrence of a fire in a crash can be thought of as a two-step process. First, a leak must occur to provide a source of fuel. Following that, there must be a source of ignition to ignite the fuel and cause the fire. Preventing fuel leaks removes the source of fuel for the fire. It is also of interest to consider whether fuel ignites if it has leaked. By forming the ratio of fires to leaks in the Michigan data, one can investigate the probability of ignition given fuel leakage. These ratios have been plotted in Figure 12. As before, the leaks are plotted separately for different model years and the three different crash years.

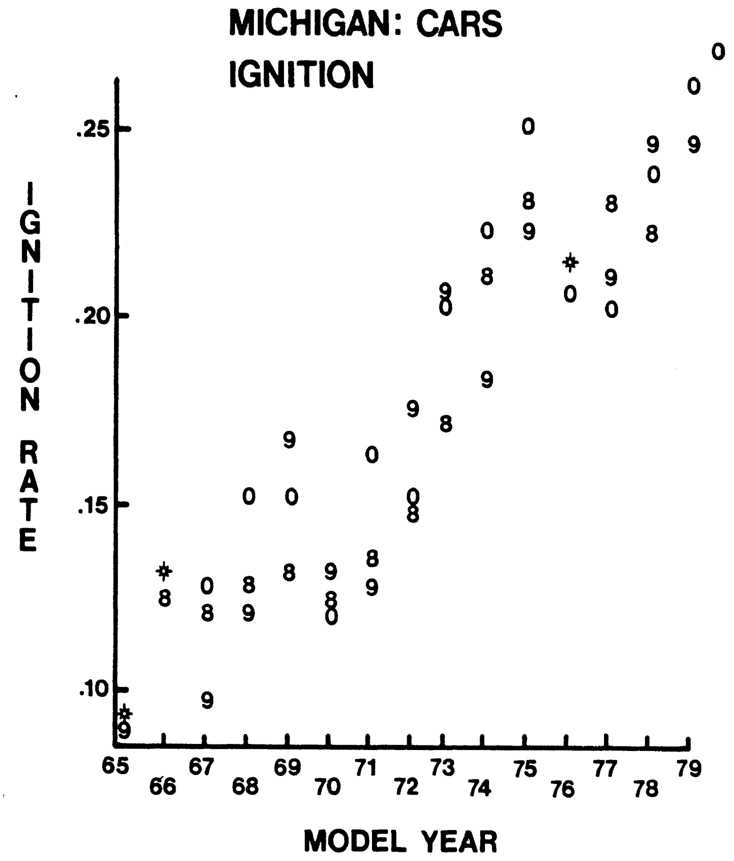

Figure 12
Ignition Rates by Model Year: Michigan Passenger Cars

It is apparent in the figure that there is an increasing trend in the ignition rates for newer models. It also appears that there are two segments to the figure. One appears to end with the 1975 models and the other to consist of the 1976 and later models. The ignition rate for the 1975 models, and to somewhat a lesser extent of the 1974 models, appears to be higher than the trend line. The reasons for this are not known. However, many car manufacturers added catalytic converters to the exhaust systems of models in 1975 to meet more stringent emission control standards (a few 1974 models also had catalytic converters). The addition of a catalytic converter would result in a higher temperature in the exhaust system. Secondly, there is an additional cannister in the exhaust system that could scrape pavement and provide sparks in a crash. Finally, if the converter itself ruptures, the catalyst would be available to react with fuel that might be spilled in a crash making it more likely to ignite. Thus, it is possible that this higher ignition rate may reflect the addition of the catalytic converter. If that is the case, then the more recent models have apparently reduced the problem somewhat as evidenced by the drop in the ignition rate with the 1976 model. This second segment--beginning with model year 1976--corresponds to the 1976 version of FMVSS 301. That standard aimed to reduce fuel leakage. If fuel leakage was substantially reduced--particularly in less severe crashes--this reduction in the denominator of the ignition rates could result in the increasing trend in ignition. This does not explain the drop in ignition rates in 1976, however.

The general upward trend in the ignition rate for newer models is not easy to explain. Fires have been reduced in newer models. However, the leaks have been reduced even more and the relationship of the leak rates to model years is much stronger than the relation of fires to model years. Thus, the much higher leak rates in older models produce lower ignition rates because the denominator of the rate is much larger while the numerator is only slightly larger. Another possible consideration is that in the newer models, leak rates in particular are very small at low severity (low TAD) crashes. Most of the leaks that do occur in the newer models occur in high TAD crashes. Such severe crashes may result in larger leaks (that is, in more fuel being spilled) and would provide more sources of ignition in terms of damage to the electrical system providing shorts, or metal on pavement sparking. Thus, the higher ignition rates in more recent models may reflect that the standard has considerably reduced small leaks and leaks in low severity crashes. If so, then when a leak does occur, it is in a high severity crash, which is much more likely to also provide ignition.

While not of primary interest, a linear model was fit to the ignition data, incorporating a mean, a linear trend in model year, and an aging effect over the three crash years within each model year. The estimated model had a lack of fit of 45.95 with 42 degrees of freedom and coefficients:

$$r = 0.263 + 0.01204(\text{per year Model year}) + 0.018(\text{per year age}).$$

The associated chi-square statistics for the three parameters were: 1454.35, 218.5, and 24.96, for the mean, model year effect, and age within model year, respectively. In this model only, these rates are presented as actual rates and are not per thousand crashes.

4.3 Pennsylvania Data

Computerized accident report files from Pennsylvania have been processed to determine the number of crash and non-crash fires by car model year for each of three calendar years. Data are shown summarized by the periods of the several versions of FMVSS #301 in Table 16.

Although the number of reported fires is small, there is a significant decrease in the fire rate (fires per 1000 crashed cars) associated with the 1976 version of the standard, when it is compared with all earlier vehicles (with a chi square value of 4.02 $p<.05$). The change associated with the 1976 version of the standard compared with the 1968 version yields a chi square value of 2.49, not quite significant at the 10 percent level. Finally, the 1968 version compared with the period prior to that (when there was no standard) also shows some improvement, with a chi square value of 3.12. The only change which does not show any improvement (in fact a slight negative result) is the 1976 to 1977 modification. Data for these two periods is sparse, in any case. The pooled fire rates (crash and non-crash) are plotted in

TABLE 16

Crash Fires and Fire Rates in Pennsylvania (1977-79)
by Version of the FMVSS #301

Model Years covered by Standard	Crash Fires	Total Vehicles In Crashes	Fires/ 1000 Crashes
(1) 1977-1980 . . .	114	173794	.66
(2) 1976	42	68383	.61
(3) 1968-1975 . . .	321	426322	.75
(4) 1967 or earlier	60	62649	.96

Partitioned chi square computations:
Total table (4 x 2), chi square = 7.26 (3 d.f.)

(1) vs. (2), chi square = 0.12 (1 d.f.)
(1,2) vs. (3), chi square = 2.49 (1 d.f.)
(1,2,3) vs. (4), chi square = 4.65 (1 d.f.)

(1) vs. (2), chi square = 0.12 (1 d.f.)
(1,2) vs. (3,4) chi square = 4.02 (1 d.f.)
(3) vs. (4) chi square = 3.12 (1 d.f.)

Figure 13 by age at time of crash. Non-crash fires seem to be about the same from new to ten year-old cars and then to show some scatter thereafter. Crash fire rates stay fairly constant in this range (the extremes in this age span are 0.57 and 0.93, but most values are closer to the mean.) The low fire rates probably result from the fact that fires are noted in the narrative rather than as a specific variable. This method generally results in underreporting of fires. However, it may be that most of the conflagrations are reported in this manner, and more of the smaller fires are missed.

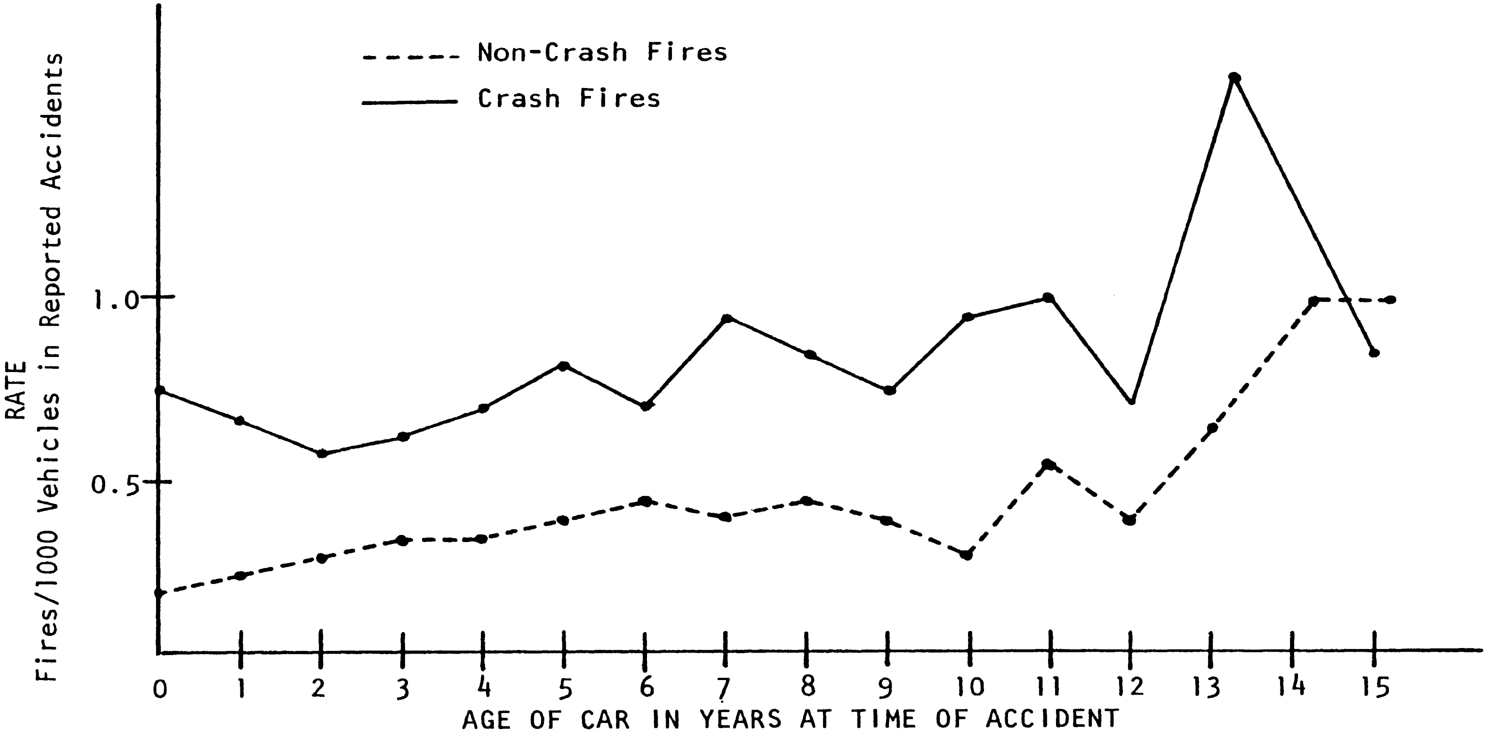

Figure 13
Passenger Car Fire Rates in Pennsylvania

5.0 CONCLUSIONS

Post-crash fires are relatively rare events. For police-reported crashes involving passenger cars in Michigan (three years) and Illinois (six years), post-crash fires occur at rates of from 1.5 to 2.3 fires per thousand crashes. If attention is restricted to a more severe set of crashes--those requiring towaway--this rate rises to about 4.6 per thousand in Michigan. Crash fire rates involving light trucks were slightly higher: from 2.2 to 2.8 per thousand police-reported crashes in the two states over the same period.

Two types of reporting of fires exist in police accident data. One type consists of a check box on the accident reporting form asking that the investigating officer check whether a fire occurred for each vehicle involved in a crash. The second type of reporting relies on the narrative description of the crash to indicate whether or not a fire occurred. The reported fire rates differ by about a factor of ten depending on which method is used, with the narrative coding being much lower than the check box reporting. It appears that relying on the narrative to report fires results in under-reporting of fires. The check box method reports a number of incidental or minor fires. This may be appropriate, since if these fires are not extinguished, some may eventually involve the entire car. In general, relying on incidental reporting of any item of interest can lead to inaccurate or misleading results. It is better to use a question specifically asking for the desired information. Thus, the data from Michigan and Illinois that include the specific fire information appear more useful than the results from other states that are based only on the anecdotal information about the crash. Data sets that include specific variables should be used when possible.

Fuel spillage is much more frequent than fire, but still relatively rare. It is estimated to occur approximately 11 to 14 times per thousand police-reported crash in three years of data from Michigan involving passenger cars. For light trucks, the spillage rate is again somewhat higher, estimated as from 16 to 19 cases per thousand police-reported crashes over a three-year period from 1978-1980.

Both fire rates and fuel spillage vary with a number of crash variables. The strongest relationship is with the accident severity, or Michigan TAD, a seven-point scale of crash severity available in Michigan but not in Illinois. These rates also vary by the type of crash, by day and night, and by the number of vehicles in the crash. Most of these other variables are related to crash severity, and their effects were not apparent in the Michigan data after accounting for TAD level.

The data do not indicate any differences between the 1976 and 1977 versions of FMVSS 301. In part this may be due to the fact that a large amount of data are needed and that a single model year will not provide a sufficient amount of data. An alternative possibility is that few differences were incorporated between the 1976 and 1977 models that would affect fuel leakage or fire rates. It does not seems likely that the 1976 and 1977 versions of the standard will ever be distinguished in the crash data.

The 1968 version applied only to passenger cars. The data relevant to this version are somewhat limited, since the earliest data come from 1975, when the pre-standard models were at least seven years old. Data for pre-standard years are scarce. In the Illinois data, overall, the 1968 version was associated with a 6.5 percent drop in crash fires--not statistically significant. In addition, addressing frontal crashes, the estimated effect of the 1968 version was also not significant. In looking at the detailed crash types, six of the 10 showed reductions ranging from five percent to 127 percent. Three of these (turning, rear impacts moving, and rollovers) were significant at the five percent level. However, four crash types showed increases coinciding with 1968. Two of these (angles and head-ons) were significant while one was marginally significant (sideswipe--opposite directions). Thus, the Illinois data show little evidence of an effect corresponding to the 1968 version of FMVSS 301.

The Michigan data on crash fires show reductions on from eight to 10 percent corresponding to the 1968 standard. However, in no case did these reach the five percent significance level, whether considered overall or by crash type. Leak rates show about a 35 percent reduction overall corresponding to 1968. A similar rate (38 percent) is observed in frontals after including age. However, when crash severity is included, all levels of TAD except TAD 6 show higher leak rates for the time covered by the 1968 standard, but only for TAD 5 was this significantly different from zero at the five percent level. It thus appears that these data do not provide evidence to support an estimate of a beneficial effect of the 1968 version of FMVSS 301. While the data limitations must be considered--there are few data for the pre-1968 cars--the conclusion seems to be that no change in either fire or leak rates was observed to correspond to the 1968 version of FMVSS 301 after other factors were accounted for.

Both the Michigan and Illinois data indicate that there are lower crash fire rates for passenger cars of more recent model years. In Michigan, the reduction was clearly better modeled as a change when the FMVSS 301 standard went into effect in 1976 or 1977 than as a smooth trend in model years. The effect so estimated was significantly different from zero after including a variable for the age effect and for the TAD severity effects. The effect in Illinois was modeled within crash types, serving as somewhat of a surrogate for crash severity control. Significant reductions coinciding with the FMVSS 301 standard were observed in angle, rollover, rear impacts, and crashes involving parked cars. The amount of reduction varied, but ranged from about 20 to 50 percent for these crash types.

The data for light trucks are not as substantial as those for passenger cars. The number of truck crashes in Michigan was about one-fifth the number of car crashes. In Illinois, there were only about a tenth as many light truck crashes as car crashes. This difference is caused by the different vehicle classifications used in the two states. In addition to the fact that the data are fewer, there is more uncertainty about the actual vehicle types that are included in light trucks.

The Illinois light truck data are consistent with a constant crash fire rate of 1.85 per thousand for all model years. There is not a significant lack of fit to this constant mean model. However, if the data are subdivided, there appears to be some reduction with 1976 and later model years. The best such model fits two means: 2.06/1000 for pre-1975 trucks and 1.58/1000 for 1976 and later trucks.

The Michigan data on crash fire rates for light trucks indicate slightly more evidence for a standard effect. There is a reduction in fire rates with newer models, but this can be equally well modeled as two reductions corresponding to the standard in 1977 and 1978 or as a linear trend in model years. This, while the Michigan light truck data show significantly lower crash fire rates for models built under the standard, general trends in model years explain the data equally well.

The leak data show more evidence of a standard effect. There is a significant reduction in leak rates corresponding to the 1977 or 1978 standard even after linear trend in model years is included. The 1977 and 1978 versions cannot be distinguished. If the crash severity variable is included, both versions of the standard appear to have significant reductions in leak rates at all severity levels except the highest. Thus, there is evidence that FMVSS 301 has reduced leak rates in light truck crashes, but evidence for a reduction in crash fire rates is inconclusive.

Leaks were much more closely related to model years than were fires, but information about this was available only for Michigan accidents. For passenger cars, there are many interacting variables affecting the leak rates. There is a strong trend for leak rates to be higher in older cars. The rates are much lower and fairly flat for model years 1976 and later. There appear to be some effects that may relate to the standard after accounting for TAD level and linear trends in model years, but this is smaller than either the TAD effect or the smooth trend in model years. It may well be that more continuously varying variables such as gradual model year changes, different car sizes in different model years, or different configurations may have played as important a role in leak rates as did the FMVSS 301 requirement at the specific 1976 and 1977 model years. Further changes in models such as the continued trend toward downsizing or the trend toward front wheel drive may continue to affect leak rates.

For light trucks, the changes in leak rates appear to be more sudden and perhaps more closely related to the standard. After adjusting for TAD, leak rates are estimated to be significantly reduced beginning with both 1977 and 1978 models. The amount of this reduction varied with TAD level, but appears to be in the 30-40 percent ranges for TAD 1-3, about 30 percent for TAD 4-6, and 13 percent for TAD 7 corresponding to the 1977 standard, while the estimated effects are in the 50 percent range for 1978.

It is reasonable to conclude that the FMVSS 301 led to a reduction in crash fire rates both for passenger cars and for light trucks, but other possible causes for this reduction exist and cannot be entirely ruled out. Aging of the vehicles, while confounded with the possible effects of the standard, generally does not seem to have been an important factor in the reduction of fire rates for newer models. Further, the estimated reductions have persisted after control for crash type and severity variables. However, it is possible that other causes could have contributed to the reduction. The large amount of publicity such as in Dowie (1977) that crash fires have received may have played a role. The liability cases and attendant adverse publicity involving car fires that automobile companies have been involved in may also have influenced any changes that led to the observed reductions.

For leaks--which are more directly addressed by the testing requirements of FMVSS 301--it is clear that many other factors have influenced the leak rates in addition to or in place of the FMVSS 301. Leak rates are related to crash type, severity, and a smooth trend in model year more strongly than to changes in levels associated with the FMVSS 301 standard. It seems likely that the gradually changing size, structure, and mix of models in model years is at least as important to leak rates as the standard. While some significant effects corresponding to the FMVSS 301 standard were found after adjusting for age, crash, type, and severity, these were present only in certain crash severities.

Ignition rates, that is, the chance of a fire if fuel leaks, show a tendency to be higher in more recent model years. The model year 1975 appears unusually high even with this trend. This coincides with the first use of catalytic converters in large numbers of passenger cars, and this may have contributed to increased ignition rates for the model years 1975 and later. Other than that possible effect, the higher ignition rates for 1976 and later models may reflect the near elimination of leaks in low severity crashes and a very low overall leak rate in these models. That is, when a leak occurs in these later models, it is associated with a very severe crash, which provides much more opportunity for ignition of the spilled fuel. Thus, one interpretation of the higher ignition rates is that it reflects primarily the reduction of the leaks. In fact, both the number of fires (the numerator) and the number of leaks (the denominator) are lower in the more recent models. However,the reduction in the denominator was larger, producing the increase in the ratio of fires to leaks. For current models of passenger cars (1977 and later), both fire and fuel leak rates are quite low. The fire rates averaged 1.47 fires per thousand crashes in Illinois and 1.53 fires per thousand crashes in Michigan for model years 1977 and later. Furthermore, most of the fires and leaks that remain occurred with quite severe crashes. Most were in TAD level 6 or 7 crashes in Michigan or in head-on or rollover crashes in Illinois. These crashes are severe enough so that they are likely to result in serious injury or fatality whether or not a fire occurs (O'Day and Flora, 1982).

Whether the observed reduction in fires and leaks should be attributed to the FMVSS 301 standard, design modifications relating to fuel economy, changes dictated by the market, or to the results of litigation cannot be definitely determined. However, after adjusting for other factors such as age and crash severity, significant reductions in fire and leak rates occurred for models first subject to the FMVSS 301. It seems reasonable to conclude that the standard contributed to these reductions.

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APPENDIX A

DATA TABLES

This appendix contains some of the raw data used in the report. Because all variables used in this report would result in a very extensive set of tables, only the tables of fire and no-fire frequencies by model year for cars and trucks for each data year from each state are included here. These data are therefore pooled over crash types, accident severities, etc.

TABLE A1

MICHIGAN CAR FIRE DATA 1978

MODEL YEAR	LEAKS	FIRES	BOTH	NONE	TOTAL	FIRERATE*	LEAKRATE*
1960.	14.	1.	3.	493.	511.	7.83	35.23
1961.	5.	1.	0.	200.	206.	4.85	29.13
1962.	17.	0.	4.	543.	564.	7.09	37.23
1963.	35.	2.	2.	1041.	1080.	3.70	36.11
1964.	59.	4.	4.	2010.	2077.	3.85	32.26
1965.	125.	9.	2.	4350.	4486.	2.45	30.32
1966.	166.	14.	9.	6520.	6709.	3.43	28.17
1967.	224.	17.	10.	10592.	10843.	2.49	23.15
1968.	380.	32.	19.	17580.	18011.	2.83	23.93
1969.	479.	40.	27.	22991.	23537.	2.85	23.20
1970.	567.	40.	32.	29153.	29792.	2.42	21.45
1971.	583.	52.	33.	36266.	36934.	2.30	18.09
1972.	680.	77.	34.	48678.	49469.	2.24	15.99
1973.	657.	91.	37.	55448.	56233.	2.28	13.96
1974.	503.	97.	36.	48025.	48661.	2.73	13.07
1975.	307.	64.	30.	38942.	39343.	2.39	10.19
1976.	313.	63.	25.	50773.	51174.	1.72	7.84
1977.	377.	75.	37.	63859.	64348.	1.74	7.60
1978.	291.	65.	20.	45547.	45923.	1.85	8.19
1979.	11.	7.	2.	2467.	2487.	3.62	8.04

*Per 1000 crashed vehicles.

MICHIGAN CAR FIRE DATA-1979

MODEL YEAR	LEAKS	FIRES	BOTH	NONE	TOTAL	FIRERATE*	LEAKRATE*
1960.	9.	2.	1.	406.	418.	7.18	28.71
1961.	2.	0.	0.	164.	166.	0.	12.05
1962.	4.	2.	1.	376.	383.	7.83	18.28
1963.	25.	2.	1.	688.	716.	4.19	39.11
1964.	45.	5.	1.	1291.	1342.	4.47	38.00
1965.	78.	3.	3.	2707.	2791.	2.15	30.10
1966.	93.	11.	3.	4183.	4290.	3.26	24.94
1967.	156.	10.	6.	6596.	6768.	2.36	25.41
1968.	245.	20.	12.	11214.	11491.	2.78	24.11
1969.	284.	39.	12.	15361.	15696.	3.25	21.34
1970.	396.	41.	19.	17356.	17812.	3.37	25.60
1971.	465.	47.	17.	27413.	27942.	2.29	18.93
1972.	542.	68.	44.	38954.	39608.	2.83	16.51
1973.	524.	112.	21.	46726.	47383.	2.81	13.87
1974.	404.	66.	22.	41785.	42277.	2.08	11.64
1975.	266.	55.	20.	34424.	34765.	2.16	9.81
1976.	307.	66.	18.	44388.	44779.	1.88	8.73
1977.	305.	58.	21.	54136.	54520.	1.45	7.04
1978.	302.	72.	29.	58632.	59035.	1.71	6.83
1979.	240.	62.	20.	40367.	40689.	2.02	7.91
1980.	2.	1.	2.	2490.	2495.	1.20	2.00
1960.	3.	2.	1.	323.	329.	9.12	18.24

*Per 1000 crashed vehicles.

TABLE A1

MICHIGAN CAR FIRE DATA 1980

MODEL YEAR	LEAKS	FIRES	BOTH	NONE	TOTAL	FIRERATE*	LEAKRATE*
1961.	1.	0.	0.	96.	97.	0.	10.31
1962.	11.	1.	0.	219.	231.	4.33	51.95
1963.	5.	1.	1.	441.	448.	4.46	15.63
1964.	17.	0.	1.	861.	879.	1.14	20.48
1965.	43.	4.	0.	1614.	1661.	2.41	28.30
1966.	67.	6.	3.	2527.	2603.	3.46	29.20
1967.	83.	7.	5.	3922.	4017.	2.99	23.65
1968.	150.	16.	8.	6620.	6794.	3.53	25.61
1969.	191.	26.	6.	9346.	9569.	3.34	23.30
1970.	231.	24.	6.	13350.	13611.	2.20	19.18
1971.	303.	37.	19.	18437.	18796.	2.98	19.10
1972.	401.	51.	20.	27321.	27793.	2.55	16.98
1973.	410.	63.	39.	34859.	35371.	2.88	14.48
1974.	330.	67.	23.	31444.	31864.	2.82	13.18
1975.	210.	52.	16.	27109.	27387.	2.48	10.15
1976.	241.	45.	16.	34968.	35270.	1.73	8.56
1977.	261.	59.	7.	43092.	43419.	1.52	7.53
1978.	221.	49.	18.	45072.	45360.	1.48	6.35
1979.	235.	60.	24.	46386.	46705.	1.80	6.83
1980.	129.	35.	12.	27581.	27757.	1.69	6.34
1981.	8.	4.	0.	1201.	1213.	3.30	9.89

*Per 1000 crashed vehicles.

TABLE A2

MICHIGAN TRUCK FIRE DATA 1978

Model Year	Leaks	Fires	Both	None	Total	Firerate*	Leakrate*
1960.	1.	0.	0.	296.	297.	0.	3.37
1961.	3.	1.	0.	77.	81.	12.35	37.04
1962.	3.	0.	0.	130.	133.	0.	22.56
1963.	14.	0.	0.	211.	225.	0.	62.22
1964.	8.	0.	2.	370.	380.	5.26	26.32
1965.	23.	1.	0.	653.	677.	1.48	33.97
1966.	50.	2.	1.	1010.	1063.	2.82	47.98
1967.	33.	3.	3.	1460.	1499.	4.00	24.02
1968.	50.	3.	1.	1833.	1887.	2.12	27.03
1969.	57.	6.	7.	2692.	2762.	4.71	23.17
1970.	69.	6.	2.	2706.	2783.	2.87	25.51
1971.	81.	10.	5.	3304.	3400.	4.41	25.29
1972.	94.	6.	7.	5051.	5158.	2.52	19.58
1973.	116.	12.	4.	6791.	6923.	2.31	17.33
1974.	115.	8.	7.	6956.	7086.	2.12	17.22
1975.	114.	10.	3.	6573.	6700.	1.94	17.46
1976.	147.	16.	5.	10153.	10321.	2.03	14.73
1977.	156.	16.	12.	13571.	13755.	2.04	12.21
1978.	94.	14.	9.	10468.	10585.	2.17	9.73
1979.	4.	1.	0.	726.	731.	1.37	5.47

*Per 1000 crashed vehicles.

MICHIGAN TRUCK FIRE DATA 1979

Model Year	Leaks	Fires	Both	None	Total	Firerate*	Leakrate*
1960.	11.	0.	2.	234.	247.	8.10	52.63
1961.	3.	0.	1.	67.	71.	14.08	56.34
1962.	3.	0.	0.	88.	91.	0.	32.97
1963.	2.	0.	0.	160.	162.	0.	12.35
1964.	7.	1.	0.	300.	308.	3.25	22.73
1965.	22.	1.	0.	486.	509.	1.96	43.22
1966.	27.	2.	1.	819.	849.	3.53	32.98
1967.	27.	2.	0.	1124.	1153.	1.73	23.42
1968.	35.	2.	2.	1435.	1474.	2.71	25.10
1969.	58.	8.	0.	2067.	2133.	3.75	27.19
1970.	49.	5.	6.	2064.	2124.	5.18	25.89
1971.	70.	7.	2.	2765.	2844.	3.16	25.32
1972.	76.	9.	7.	4240.	4332.	3.69	19.16
1973.	80.	12.	8.	5640.	5740.	3.48	15.33
1974.	102.	12.	3.	5956.	6073.	2.47	17.29
1975.	96.	5.	6.	5471.	5578.	1.97	18.29
1976.	128.	10.	8.	8530.	8676.	2.07	15.68
1977.	135.	20.	9.	11446.	11610.	2.50	12.40
1978.	119.	12.	10.	13185.	13326.	1.65	9.68
1979.	62.	13.	9.	9399.	9483.	2.32	7.49
1980.	1.	0.	0.	163.	164.	0.	6.10

*Per 1000 crashes vehicles.

TABLE A2

MICHIGAN TRUCK FIRE DATA 1980

Model Year	Leaks	Fires	Both	None	Total	Firerate*	Leakrate*
1960.	9.	1.	1.	179.	190.	10.53	52.63
1961.	2.	0.	0.	28.	30.	0.	66.67
1962.	2.	0.	0.	55.	57.	0.	35.09
1963.	3.	0.	0.	118.	121.	0.	24.79
1964.	10.	0.	0.	168.	178.	0.	56.18
1965.	10.	0.	0.	315.	325.	0.	30.77
1966.	23.	0.	0.	503.	526.	0.	43.73
1967.	18.	2.	1.	756.	777.	3.86	24.45
1968.	25.	2.	1.	1023.	1051.	2.85	24.74
1969.	35.	4.	0.	1541.	1580.	2.53	22.15
1970.	44.	3.	0.	1548.	1595.	1.88	27.59
1971.	38.	6.	1.	1918.	1963.	3.57	19.87
1972.	71.	10.	3.	3002.	3086.	4.21	23.98
1973.	74.	9.	6.	3935.	4024.	3.73	19.88
1974.	61.	10.	2.	4212.	4285.	2.80	14.70
1975.	59.	5.	2.	3979.	4045.	1.73	15.08
1976.	99.	15.	4.	6327.	6445.	2.95	15.98
1977.	118.	9.	7.	8326.	8460.	1.89	14.78
1978.	78.	8.	5.	9276.	9367.	1.39	8.86
1979.	81.	16.	5.	10744.	10846.	1.94	7.93
1980.	20.	1.	1.	3098.	3120.	.64	6.73
1981.	1.	0.	0.	153.	154.	0.	6.49

*Per 1000 crashed vehicles.

TABLE A3

ILLINOIS CAR FIRES DATA 1975

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	3.	581.	326.	910.	3.29
1961.	2.	948.	376.	1326.	1.50
1962.	11.	2563.	1181.	3755.	2.93
1963.	23.	4451.	2138.	6612.	3.48
1964.	24.	7248.	3679.	10951.	2.19
1965.	43.	12905.	6652.	19600.	2.19
1966.	50.	16387.	8881.	25318.	1.97
1967.	68.	19669.	11309.	31046.	2.19
1968.	81.	25821.	15100.	41002.	1.97
1969.	76.	29522.	17401.	46999.	1.62
1970.	68.	30896.	17881.	48845.	1.39
1971.	91.	32843.	19124.	52058.	1.75
1972.	100.	39274.	24319.	63693.	1.57
1973.	114.	45171.	28421.	73706.	1.55
1974.	91.	41093.	26451.	67635.	1.34
1975.	57.	23045.	14699.	37801.	1.51
1976.	5.	1481.	898.	2384.	2.09

*Per 1000 crashed vehicles.

ILLINOIS CAR FIRES DATA 1976

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	3.	427.	183.	613.	4.89
1961.	4.	692.	263.	960.	4.17
1962.	6.	1947.	750.	2703.	2.22
1963.	13.	3428.	1253.	4694.	2.77
1964.	24.	5889.	2292.	8205.	2.92
1965.	33.	10551.	4265.	14849.	2.22
1966.	47.	14236.	5822.	20105.	2.33
1967.	73.	18400.	8057.	26530.	2.75
1968.	92.	24775.	10918.	35785.	2.57
1969.	125.	29946.	13437.	43508.	2.87
1970.	116.	31551.	13864.	45531.	2.55
1971.	115.	34487.	15204.	49806.	2.31
1972.	140.	41920.	19298.	61358.	2.28
1973.	131.	47256.	21894.	69281.	1.89
1974.	116.	43050.	20119.	63285.	1.83
1975.	110.	36016.	17566.	53692.	2.06
1976.	89.	32509.	15451.	48049.	1.85
1977.	4.	1867.	793.	2664.	1.50

*Per 1000 crashed vehicles.

TABLE A3

ILLINOIS CAR FIRES DATA 1977

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	1.	373.	80.	454.	1.10
1961.	1.	523.	126.	650.	1.54
1962.	5.	1508.	354.	1867.	2.68
1963.	6.	2774.	653.	3433.	1.75
1964.	11.	4894.	1181.	6086.	1.81
1965.	23.	9031.	2139.	11193.	2.05
1966.	38.	12848.	2976.	15862.	2.39
1967.	43.	17417.	4185.	21645.	2.03
1968.	58.	24840.	6236.	31134.	1.86
1969.	96.	31154.	8120.	39370.	2.46
1970.	67.	35918.	8909.	44894.	1.51
1971.	90.	40166.	9749.	50005.	1.80
1972.	110.	50498.	12493.	63101.	1.74
1973.	144.	57118.	14423.	71685.	2.01
1974.	104.	51392.	12863.	64359.	1.61
1975.	90.	42959.	11040.	54089.	1.66
1976.	103.	56615.	14495.	71213.	1.44
1977.	72.	46006.	11002.	57080.	1.26
1978.	1.	2372.	507.	2880.	.35

*Per 1000 crashed vehicles.

ILLINOIS CAR FIRES DATA 1978

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	251.	52.	303.	0.00
1961.	2.	349.	91.	442.	4.51
1962.	2.	996.	220.	1218.	1.64
1963.	2.	1964.	380.	2346.	.85
1964.	17.	3365.	701.	4083.	4.16
1965.	15.	6129.	1375.	7519.	1.99
1966.	24.	9121.	1939.	11084.	2.16
1967.	33.	13086.	2811.	15930.	2.07
1968.	40.	19081.	4303.	23424.	1.71
1969.	64.	25446.	5859.	31369.	2.04
1970.	60.	30875.	7100.	38035.	1.60
1971.	83.	36216.	8255.	44554.	1.86
1972.	95.	47818.	10708.	58621.	1.62
1973.	122.	54732.	12435.	67289.	1.81
1974.	114.	49590.	11006.	60710.	1.89
1975.	83.	40742.	9784.	50609.	1.64
1976.	104.	54679.	12303.	67086.	1.55
1977.	119.	63823.	14657.	78599.	1.51
1978.	83.	45701.	10530.	56314.	1.49
1979.	4.	2357.	560.	2921.	1.37

*Per 1000 crashed vehicles.

TABLE A3

ILLINOIS CAR FIRES DATA 1979

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	191.	49.	240.	0.00
1961.	.0	269.	53	322.	0.00
1962.	3.	653.	139.	795.	3.76
1963.	.0	1308.	269.	1577.	0.00
1964.	4.	2204.	421.	2629.	1.52
1965.	9.	4047.	809.	4865.	1.85
1966.	7.	6145.	1170.	7322.	.96
1967.	13.	8755.	1690.	10458.	1.24
1968.	29.	13159.	2511.	15699.	1.85
1969.	44.	18236.	3710.	21990.	2.00
1970.	55.	23822.	4971.	28848.	1.90
1971.	67.	29497.	5925.	35489.	1.89
1972.	79.	41554.	8435.	50068.	1.58
1973.	100.	48528.	10141.	58769.	1.70
1974.	88.	44663.	9185.	53936.	1.63
1975.	73.	37424.	7785.	45282.	1.61
1976.	99.	50626.	10178.	60903.	1.62
1977.	102.	58874.	12083.	71059.	1.45
1978.	107.	64091.	12900.	77098.	1.40
1979.	81.	40014.	8035.	48130.	1.68
1980.	4.	2013.	351.	2368.	1.69

*Per 1000 crashed vehicles.

ILLINOIS CAR FIRES DATA 1980

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	148.	38.	186.	0.00
1961.	.0	169.	32.	201.	0.00
1962.	1.	440.	98.	539.	1.86
1963.	3.	816.	162.	981.	3.05
1964.	9.	1442.	252.	1703.	5.28
1965.	7.	2463.	450.	2920.	2.39
1966.	14.	3691.	627.	4332.	3.23
1967.	11.	5232.	927.	6170.	1.78
1968.	11.	7761.	1451.	9223.	1.19
1969.	31.	10759.	2081.	12871.	2.41
1970.	49.	14934.	2889.	17872.	2.74
1971.	56.	19150.	3786.	22992.	2.43
1972.	57.	27800.	5608.	33465.	1.70
1973.	79.	34194.	6905.	41178.	1.92
1974.	67.	32367.	6540.	38974.	1.72
1975.	51.	27680.	5389.	33120.	1.54
1976.	66.	36952.	7121.	44139.	1.49
1977.	101.	42732.	8372.	51205.	1.97
1978.	93.	46681.	8909.	55683.	1.67
1979.	81.	48265.	9362.	57708.	1.42
1980.	57.	25750.	4897.	30704.	1.85
1981.	2.	986.	202.	1190.	1.68

*Per 1000 crashed vehicles.

TABLE A4

ILLINOIS TRUCK FIRE DATA 1975

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	140.	45.	185.	0.00
196.0	1.	111.	37.	148.	0.00
1962.	1.	200.	72.	273.	3.66
1963.	2.	294.	86.	382.	5.24
1964.	5.	407.	126.	538.	9.29
1965.	1.	578.	185.	764.	1.31
1966.	2.	694.	215.	911.	2.20
1967.	4.	903.	293.	1200.	3.33
1968.	1.	993.	352.	1346.	.74
1969.	6.	1222.	412.	1640.	3.66
1970.	3.	1245.	423.	1671.	1.80
1971.	2.	1384.	473.	1859.	1.08
1972.	4.	2091.	701.	2796.	1.43
1973.	10.	2731.	950.	3691.	2.71
1974.	10.	3238.	1141.	4389.	2.28
1975.	5.	2009.	640.	2654.	1.88
1976.	.0	139.	50.	189.	0.00

*Per 1000 crashed vehicles.

ILLINOIS TRUCK FIRE DATA 1976

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	104.	33.	137.	0.00
1961.	.0	97.	21.	118.	0.00
1962.	.0	141.	51.	192.	0.00
1962.	.0	227.	63.	289.	0.00
1964.	4.	393.	121.	518.	7.72
1965.	3.	597.	167.	767.	3.91
1966.	3.	719.	192.	914.	3.28
1967.	1.	812.	272.	1085.	.92
1968.	2.	957.	290.	1249.	1.60
1969.	7.	1271.	361.	1639.	4.27
1970.	2.	1331.	351.	1684.	1.19
1971.	9.	1399.	360.	1768.	5.09
1972.	14.	2118.	655.	2787.	5.02
1973.	13.	2860.	845.	3718.	3.50
1974.	10.	3293.	948.	4251.	2.35
1975.	8.	2868.	866.	3742.	2.14
1976.	3.	2995.	786.	3784.	.79
1977.	1.	181.	50.	232.	4.31

*Per 1000 crashed vehicles.

TABLE A4

ILLINOIS TRUCK FIRE DATA 1977

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	2.	103.	19.	124.	16.13
1961.	1.	105.	17.	123.	8.13
1962.	3.	150.	26.	179.	16.76
1963.	1.	257.	57.	315.	3.17
1964.	.0	430.	90.	520.	0.00
1965.	.0	530.	110.	640.	0.00
1966.	2.	766.	140.	908.	2.20
1967.	1.	892.	184.	1077.	.93
1968.	.0	1113.	214.	1327.	0.00
1969.	4.	1427.	263.	1694.	2.36
1970.	5.	1455.	294.	1754.	2.85
1971.	3.	1602.	303.	1908.	1.57
1972.	9.	2428.	471.	2908.	3.09
1973.	10.	3286.	641.	3937.	2.54
1974.	10.	3707.	751.	4468.	2.24
1975.	7.	3317.	657.	3981.	1.76
1976.	4.	5181.	961.	6146.	.65
1977.	17.	4157.	708.	4882.	3.48
1978.	.0	234.	52.	286.	0.00

*Per 1000 crashed vehicles.

ILLINOIS TRUCK FIRE DATA 1978

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	65.	13.	78.	0.00
1961.	1.	68.	7.	76.	13.16
1962.	1.	114.	19.	134.	7.46
1963.	.0	200.	42.	242.	0.00
1964.	1.	351.	72.	424.	2.36
1965.	3.	505.	95.	603.	4.98
1966.	3.	669.	115.	787.	3.81
1967.	1.	844.	146.	991.	1.01
1968.	4.	1006.	174.	1184.	3.38
1969.	3.	1338.	242.	1583.	1.90
1970.	3.	1375.	216.	1594.	1.88
1971.	5.	1469.	252.	1726.	2.90
1972.	8.	2175.	409.	2592.	3.09
1973.	11.	3051.	536.	3598.	3.06
1974.	19.	3510.	589.	4118.	4.61
1975.	11.	3204.	548.	3763.	2.92
1976.	7.	4931.	808.	5746.	1.22
1977.	14.	5893.	959.	6866.	2.04
1978.	17.	4295.	756.	5068.	3.35
1979.	.0	286.	56.	342.	0.00

*Per 1000 crashed vehicles.

TABLE A4

ILLINOIS TRUCK FIRE DATA 1979

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	.0	60.	16.	76.	0.00
1961.	.0	46.	13.	59.	0.00
1962.	.0	92.	16.	108.	0.00
1963.	.0	177.	37.	214.	0.00
1964.	.0	293.	39.	332.	0.00
1965.	1.	395.	73.	469.	2.13
1966.	2.	573.	98.	673.	2.97
1967.	3.	768.	144.	915.	3.28
1968.	2.	855.	128.	985.	2.03
1969.	4.	1135.	207.	1346.	2.97
1970.	3.	1183.	208.	1394.	2.15
1971.	2.	1335.	224.	1561.	1.28
1972.	5.	2084.	363.	2452.	2.04
1973.	9.	2765.	442.	3216.	2.80
1974.	11.	3293.	538.	3842.	2.86
1975.	8.	3030.	444.	3482.	2.30
1976.	12.	4524.	736.	5272.	2.28
1977.	13.	5387.	823.	6223.	2.09
1978.	9.	6281.	943.	7233.	1.24
1979.	15.	4546.	696.	5257.	2.85
1980.	.0	104.	16.	120.	0.00

*Per 1000 crashed vehicles.

ILLINOIS TRUCK FIRE DATA 1980

MODEL YEAR	FIRES	NONFIRES	MISSING	TOTAL	FIRE RATE*
1960.	1.	41.	6.	48.	20.83
1961.	.0	41.	6.	47.	0.00
1962.	.0	72.	9.	81.	0.00
1963.	.0	123.	12.	135.	0.00
1964.	.0	213.	21.	234.	0.00
1965.	1.	281.	37.	319.	3.13
1966.	.0	390.	61.	451.	0.00
1967.	1.	506.	86.	593.	1.69
1968.	1.	618.	92.	711.	1.41
1969.	1.	826.	125.	952.	1.05
1970.	4.	844.	144.	992.	4.03
1971.	6.	903.	106.	1015.	5.91
1972.	7.	1420.	207.	1634.	4.28
1973.	7.	1916.	254.	2177.	3.22
1974.	2.	2190.	309.	2501.	.80
1975.	4.	1959.	286.	2249.	1.78
1976.	6.	3062.	431.	3499.	1.71
1977.	8.	3557.	488.	4053.	1.97
1978.	12.	4306.	546.	4864.	2.47
1979.	11.	5432.	708.	6151.	1.79
1980.	3.	1877.	253.	2133.	1.41
1981.	1.	45.	7.	53.	18.87

*Per 1000 crashes vehicles.

APPENDIX B

ACCIDENT REPORT FORMS

This appendix contains copies of the police accident reporting form used in Michigan. Also included is the back page of the accident forms booklet. This page includes the description of the Michigan accident severity variable used in the analysis.

Two forms from Illinois are included--the driver report form and the police accident report form. Note that the fire variable is on the second page of these.

Place an "X" on appropriate selection

ORIGINAL

UD-10 (Rev. 1-78)

State of Michigan

OFFICIAL TRAFFIC ACCIDENT REPORT

Department Name | LEIN Number | Department Complaint No.

DO NOT USE

Accident Location

County Number | City Number | Twp. Number | Day of Week S M T W T F S | Accident Date: Mo. Da. Yr. | Time ☐ A.M. ☐ P.M.

ON Name | Route No. | Ft. Mi. N S E W | Intersection | Route Nos.

Accident Conditions

WEATHER: 1 Clear, Cloudy | 2 Fog | 3 Rain | 4 Snow

LIGHT: 1 Day | 2 Dawn, Dusk | 3 Street Lights | 4 Dark

ROAD SURFACE: 1 Dry | 2 Wet | 3 Snowy, Icy | 4 Other

TOTAL LANES

☐ Divided ☐ Limited Access

Y N Construction Zone

Y N Investigated at Scene

Total No. Vehicles

Vehicle Driver No. 1

State | Driver's License | DOB | Hazardous Action Number | Citation Charge | HBD | HN | Test | Helmet Y N

Driver's Name: First | M | Last | Address | City | State | Age | Sex | Inj.

Year | Make No. | Type | Trailer | Reg. | Yr/State | VIN Number | Removed to/by

Y N Haz. Citation | Y N Other Citation | *Y N Driver Re-exam | *Y N Vision Obstruct. | *Y N Vehicle Defect | Y N Vehicle Drivable | *Y N Fuel Leakage | *Y N Vehicle Fire | Impact | Severity | Truck Cargo | Y N Cargo Spillage | Cargo Description ________ | Class

Restraints by occupants pos. | Name | Address | Pos. | Age | Sex | Inj. | Helmet Y N

1 2 3 | Y N

4 5 6 | Y N

Total occupants | Local Use/Owner, Phone | Insurance Co. | Agency Address | Injured taken to/by

Driver No. 1

Vehicle Driver No. 2

State | Driver's License | DOB | Hazardous Action Number | Citation Charge | HBD | HN | Test | Helmet Y N

Driver's Name: First | M. | Last | Address | City | State | Age | Sex | Inj.

Year | Make No. | Type | Trailer | Reg. | Yr/State | VIN Number | Removed to/by

Y N Haz. Citation | Y N Other Citation | *Y N Driver Re-exam | *Y N Vision Obstruct. | *Y N Vehicle Defect | Y N Vehicle Drivable | *Y N Fuel Leakage | *Y N Vehicle Fire | Impact | Severity | Truck Cargo | Y N Cargo Spillage | Cargo Description ________ | Class

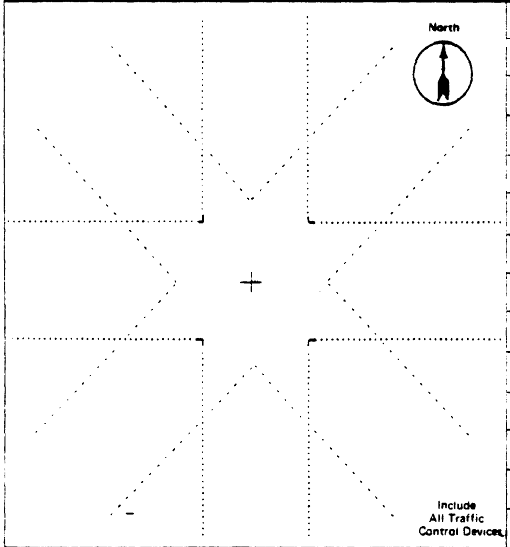
Restraints by occupants pos. | Name | Address | Pos. | Age | Sex | Inj. | Helmet Y N

1 2 3 | Y N

4 5 6 | Y N

Total occupants | Local Use/Owner, Phone | Insurance Co. | Agency Address | Injured taken to/by

Driver No. 2



ACCIDENT DESCRIPTION AND REMARKS (*Explain)

Describe all unusual conditions and circumstances

Accident Date

File Class

Department Complaint No.

Date Reported | Time A.M. P.M. | Investigators | Badge No. | Damage Property Other Than Vehicles

Photos by | Complaint Disposition ☐ Open ☐ Closed | Reviewer | Owner | Address

Ar
Pseudo
Time
No. Units
No. Inj.
No. Killed
Residence
Test
Intent
Direction
Obj. Hit
Situation
Cont. Ci
Residence
Test
Intent
Direction
Obj. Hit
Situation
Cont. C
Road A
Traffic
Road Loc.
Acc. Type
Where
How
Tags
Road Def
1 Veh. Def
1 Vision Ob
2 Veh. Def
2 Vision Ob
MALI
Coder
File

FORWARD COPY TO: **Michigan Department of State Police, Safety & Traffic Division**
7150 Harris Drive, Lansing, Michigan 48913

This form is prescribed by Director of Department of State Police pursuant to Section 257.622 of Compiled Laws of 1970, as amended.

RESTRAINT USE BY OCCUPANT POSITION

EXAMPLE:

Restraints by occupant pos.		
A 1	2	3
4	5	6
Total occupants		

The numbers 1 through 6 identify occupant positions.

When an occupant is unbelted on the lap of another, that occupant position restraint code would be "Belt Not Used" (c).

Do not code restraint information for occupants in buses, motorcycles, snowmobiles, etc.

When occupant position is unknown, use judgement as to where restraint information should be coded.

Indicate total occupants for each vehicle.

RESTRAINT CODES

Enter the appropriate ALPHA code in the occupant position box.

A. No belt(s) available.
B. Belt(s) used.
C. Belt(s) not used.
D. Air bag activiated.
E. Air bag not activated.
F. Restraint failure (bag, belt or child restraint device).
G. Unknown.

CLASS OF CARGO

1. Commercial – no cargo.
2. Commercial – flammable or explosive – no cargo.
3. Commercial – flammable or explosive – with cargo.
4. Commercial – general freight – non-bulk.
5. Commercial – general freight – bulk.
6. Non-commercial – (private use, i.e., campers, motor homes, miscellaneous articles and empty.)

Class the cargo and describe in the appropriate box.

HAZARDOUS ACTION CODE

Enter the hazardous action code number for all drivers, pedestrians, bicyclists. If any of these units, do not have a hazardous action enter a code "0".

0 No hazardous action.
1 Speed too fast.
2 Speed too slow.
3 Failed to yield right-of-way, disregard of traffic control.
4 Drove wrong way.
5 Drove left of center, improper overtaking and passing, improper lane usage.
6 Improper turn, improper or no signal.
7 Improper backing, unsafe start.
8 Following too closely, unable to stop within assured clear distance ahead, failed to use due care and caution.
9 Other or not known.

VEHICLE MAKES AND TYPES

PASSENGER CARS

MAKE

00 American Motors
01 Buick
02 Cadillac
03 Chevrolet
04 Chrysler
05 Dodge
06 Ford
07 Imperial
08 Jeep
09 Lincoln

MAKE

10 Mercury
11 Oldsmobile
12 Plymouth
13 Pontiac
14 Volkswagen
15 GMC
16 International
17 Not assigned
18 Other foreign
19 Other domestic

TYPE

0 Passenger car under 1,500 lbs.
1 Passenger car 1,500 lbs. to 2,499 lbs.
2 Passenger car 2,500 lbs. to 3,500 lbs.
3 Passenger car more then 3,500 lbs.
4 Carryall
5 Jeep type

TRUCKS

MAKE

20 Chevrolet
21 Diamond T
22 Dodge
23 Federal
24 Ford
25 GMC
26 International

MAKE

27 Mack
28 Peterbilt
29 Reo
30 White
31 Jeep
32 thru 38 not assigned
39 Other trucks

TYPE

6 Pickup, panel, or van
7 Stake truck, dump, step van, flat bed, motor home, etc.
8 Truck tractor (semi)
9 Other or not known

SPECIAL VEHICLES

MAKE

40 Motorcycle
41 School Bus
42 Commercial Bus
43 Farm Equipment
44 Road Construction Equipment
45 Fire Equipment
46 Ambulance, Hearse

MAKE

47 Police Equipment
48 Snowmobile
49 Other or Not Known
50 Off-Road Recreational Vehici
51 Go Cart
52 Moped

TYPE

0 Passenger car under 1,500 lbs.
1 Passenger car 1,500 lbs. to 2,499 lbs.
2 Passenger car 2,500 lbs. to 3,500 lbs.
3 Passenger car more then 3,500 lbs.
4 Carryall
5 Jeep type

TYPE

6 Pickup, panel, or van
7 Stake truck, dump, ste van, flat bed, motor hc etc.
8 Truck tractor (semi)
9 Other or Not Known

TRAILERS

0 None
1 All trailers, except below
2 Towed vehicles
*3 Single bottom semi
**4 Double bottom combination
5 House trailer
9 Unknown

SINGLE BOTTOM

DOUBLE BOTTOM

CODE OF INJURY

K–FATAL INJURY–Any injury which results in death.

A–INCAPACITATING INJURY–Any injury other than fatal which prevents normal activities and generally requires hospitalization.

B–NON-INCAPACITATING INJURY–Any injury not incapacitating but evident to others at the scene.

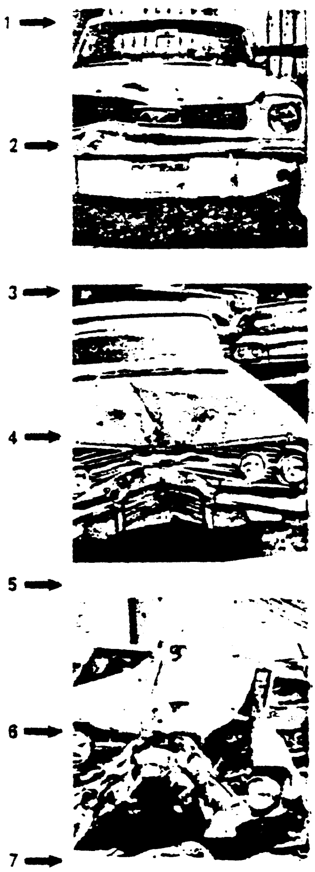
C–POSSIBLE INJURY–No visible injury but complaint of pain or momentary unconsciousness.

O–NO INJURY–No indication of injury.

(Refer to training manual for ~~injury~~ details)

VEHICLE SEVERITY

Select the degree of severity. 1 being least severe and 7 most severe, for each vehicle. If a vehicle sustained no damage a "0" (zero) rating is used.



BICYCLISTS – PEDESTRIANS – WITNESSES

B–BICYCLIST–List name and address of bicyclist in the space normally used for passengers. For example:

	Pos	Age	Sex	Inj
Joey Doe, Lansing, Mich.	B	*10*	*M*	*A*

DO NOT carry bicyclist's name in area used for driver.

P–PEDESTRIAN–List name and address of pedestrian in the space normally used for passengers. For example:

	Pos	Age	Sex	Inj
Jane Doe, Lansing, Mich.	P	*22*	*F*	*B*

DO NOT carry pedestrian's name in area used for driver.

W–WITNESSES–List name and address of witness in the space normally used for passengers. For example:

	Pos	Age	Sex	Inj
John Doe, Lansing, Mich.	W	*25*	*M*	–

SEATING POSITIONS

A. 1 through 6 identifies where passengers are sitting.
B. Position 7 to be used for passengers of motorcycles, bicycles, snowmobiles, and buses.
C. Use 9 for unknown positions.
D. When passengers are sitting on laps, use same number.
E. Indicate total occupants for each vehicle.

(Cover Revision 12-78)

DRINKING CONDITION

HBD–Had been drinking.
HN–Had not been drinking.
TEST–When chemical test is taken record the results in the test space.

For EACH Driver, Pedestrian, and Bicyclist

1. Indicate YOUR CONSIDERED OPINION as to the drinking conditions.
2. IF TESTED (breath, blood, urine, autopsy) indicate the results.

HBD	HN	Test
X		.11

3. IF NOT TESTED or results of tests (chemical–autopsy) are not known, you MUST indicate as follows:

No Test	Chemical Test, No Results	Autopsy, No Results
Test N	Test C	Test A

PARKED CARS

DO NOT put owner's name in the driver's position. Indicate owner's name and address in the LOCAL USE line. Vehicle identification shall be carried in its usual position.

DIAGRAM

1. Complete the accident diagram on the accident report even though a more detailed additional diagram is completed.
2. Use of the standard accident template is encouraged for uniformity, and include all traffic control devices.

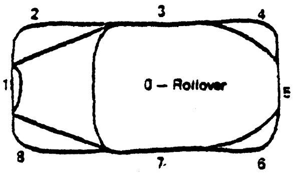
DESCRIPTION

1. Record in narrative form the investigating officer's description of the accident.
2. Record the explanation of the reported vision obstruction, vehicle defects and driver re-exam.
3. Record all unusual conditions and circumstances, excessive speed, drag racing, hood flying up, etc., which may have contributed to the cause of the accident.
4. The officer's considered opinions should be given if facts are not obtainable.

IMPACT CODE

Identify the area of damage by the position of the FIRST IMPACT ONLY for each vehicle.

CODE 0 – Used to designate a rollover impact, which means overturning on side, top, or completely over.



CODE 9 – Used for all other accidents – For Example: All "Other Non-collision Accidents" such as top damage caused by vehicles attempting to go under low underpasses, or undercarriage damage.

CODE 99 – Used for all unknowns – For Example: A hit-and-run vehicle leaving the scene and impact is unknown.

In chain reaction accidents, the vehicles in the center shall show resulting damage to both front (1) and rear (5).

7649501

______ POLICE

TRAFFIC ACCIDENT REPORT

POLICE ACCIDENT NO. INCIDENT NUMBER

Sheet ____ of ____ Sheets.

COUNTY

TOWNSHIP OR CITY

I.D.O.T. USE ONLY

ON: Number or Name of Highway or Street
1.

1 At Intersection With ______
(Number or Name of Intersecting Highway or Street)

2 If not at Intersection ____ or ____ (Circle 1) N E S W of ______
Feet Miles (Nearest Highway, Street, Bridge, or other Landmark)

2. DATE OF ACCIDENT MO / DAY / YR

TIME OF ACCIDENT : A.M. P.M.

TOTAL UNITS INVOLVED

DAY OF THE WEEK
M T W T F S S

CIRCLE ONE OR MORE **TYPE OF REPORT** CIRCLE ONE OR MORE

1. Conventional
2. Desk
3. Animal
4. Private Property
5. Hit & Run
6. Supplementary

1. Fatal
2. Injury
3. Property Damage
4. Arrest
5. Interstate/Expressway

UNIT 1

DRIVER'S NAME: Last First M.I.
3.

DATE OF BIRTH MO / DAY / YR

1. MALE
2. FEMALE

TAKEN TO:

TAKEN BY

INJ. CODE

DRIVER'S ADDRESS

CITY/STATE/ZIP/PHONE

DRIVER'S LICENSE NO.

STATE

CLASSIFICATION

RESTRICTIONS

COLOR
4.

YEAR

MODEL

MAKE

VEHICLE TYPE

Total Occ Unit 1 Including Driver

VEHICLE OWNER

VEHICLE IDENTIFICATION NO.

VEHICLE REGIST. STATE

OWNER'S ADDRESS

CITY/STATE/ZIP

TAG MO. — YEAR

VEHICLE REMOVED BY

VEHICLE REMOVED TO

1. DRIVEN AWAY
2. TOWED AWAY

F  R

CIRCLE POINT OF CONTACT

$ ______
APPROX. COST TO REPAIR OR REPLACE

SEATING IN VEHICLE

1	2	3
4	5	6

STATION WAGON

7	8	9

UNIT 2 OR PEDESTRIAN

☐ DRIVER'S NAME: Last First M.I.
5.
☐ PEDESTRIAN

DATE OF BIRTH MO / DAY / YR

1. MALE
2. FEMALE

TAKEN TO:

TAKEN BY:

INJ. CODE

DRIVER'S ADDRESS

CITY/STATE/ZIP/PHONE

DRIVER'S LICENSE NO.

STATE

CLASSIFICATION

RESTRICTIONS

COLOR
6.

YEAR

MODEL

MAKE

VEHICLE TYPE

Total Occ Unit 2 Including Driver

VEHICLE OWNER

VEHICLE IDENTIFICATION NO.

VEHICLE REGIST. STATE

OWNER'S ADDRESS

CITY/STATE/ZIP

TAG MO. — YEAR

VEHICLE REMOVED BY

VEHICLE REMOVED TO

1. DRIVEN AWAY
2. TOWED AWAY

F  R

CIRCLE POINT OF CONTACT

$ ______
APPROX. COST TO REPAIR OR REPLACE

CODE FOR INJURY
Use only most serious one in each space for injury.

K Dead Before Report Made
O No Indication of Injury
A Bleeding Wound, Distorted Member, or Had to be Carried From Scene
B Other Visible Injury, as Bruises, Abrasions, Swelling, Limping, etc.
C No Visible Injury But Momentary Unconsciousness or Complaint of Pain.

If witness place W in unit no. box

List Additional Passenger or Witness Information On a Separate Attached Sheet.

DAMAGE TO PROPERTY OTHER THAN VEHICLES

NAME OF OWNER OF PROPERTY

ADDRESS OF OWNER

NATURE OF DAMAGE

APPROX. COST TO REPAIR OR REPLACE
$ ______

TIME NOTIFIED OF ACCIDENT : A.M. P.M.

ARRIVED AT SCENE : A.M. P.M.

DATE NOTIFIED OF ACCIDENT MONTH / DAY / YEAR

DATE REPORT COMPLETED MONTH / DAY / YEAR

ARREST (NAME) Last First M.I.

SECTION NUMBER

TICKET NUMBER

ARREST (NAME) Last First M.I.

SECTION NUMBER

TICKET NUMBER

SIGNATURE OF ARRESTING OFFICER
X

I.D. NUMBER

BEAT/ZONE

COURT DATE / /

REVIEWING OFF.

PASSENGERS AND/OR WITNESSES

NAME Last First M.I.
7.

ADDRESS

CITY

STATE

1 - M 2 - F

AGE

TAKEN TO:

UNIT NO.

SEAT POS.

TAKEN BY:

INJ. CODE

NAME Last First M.I.

ADDRESS

CITY

STATE

1 - M 2 - F

AGE

TAKEN TO:

UNIT NO.

SEAT POS.

TAKEN BY:

INJ. CODE

NAME Last First M.I.

ADDRESS

CITY

STATE

1 - M 2 - F

AGE

TAKEN TO:

UNIT NO.

SEAT POS.

TAKEN BY:

INJ. CODE

NAME Last First M.I.

ADDRESS

CITY

STATE

1 - M 2 - F

AGE

TAKEN TO:

UNIT NO.

SEAT POS.

TAKEN BY:

INJ. CODE

NAME Last First M.I.

ADDRESS

CITY

STATE

1 - M 2 - F

AGE

TAKEN TO:

UNIT NO.

SEAT POS.

TAKEN BY:

INJ. CODE

(SR1733 - 500M - REV. 9-80)

INDICATE BY DIAGRAM WHAT HAPPENED

Indicate North

R ____ ____

T ____ ____

SECTION ____________

IDENTIFY STREETS AND HIGHWAYS BY NAME AND NUMBER

7649501

Describe what happened · REFER TO UNITS BY NUMBERS

8 TYPE OF ACCIDENT

1 · Pedestrian
2 Motor Vehicle in Traffic
3 · Parked Motor Vehicle
4 · Railroad Train
5 · Pedalcyclist
6 · Animal ____________
7 · Fixed Object
8 · Other Object
9 · Motorcycle
10 · Moped
11 · Other ____________

9 MANEUVER

Driver		
1	2	
1	10	Avoiding Pedestrian
2	11	Avoiding Other Vehicles
3	12	Avoiding Animal
4	13	Avoiding Previous Accid nt
5	14	Skidding Before Braking
6	15	Skidding After Braking
7	16	Crowded off Roadway
8	17	Driverless Moving Vehicle
9	18	Other ____________

10 WHAT VEH. WERE DOING

Veh		
1	2	
1	13	Going Straight Ahead
2	14	Changing Lanes
3	15	Making Right Turn
4	16	Making Left Turn
5	17	Making U Turn
6	18	Slowing or Stopped
7	19	Starting in Traffic Lane
8	20	Starting from Parked Position
9	21	Stopped in Traffic
10	22	Parked
11	23	Backing
12	24	Other ____________

11 WHAT PEDESTRIAN WAS DOING

1 · Crossing at Intersection With Signal
2 · Crossing at Intersection Against Signal
3 · Crossing at Intersection No Signal
4 · Crossing Not at Intersection
5 · Coming From Behind Parked Vehicle
6 · Walking in Roadway · With Traffic
7 · Walking in Roadway · Against Traffic
8 · Getting off or on School Bus
9 · Getting off or on Other Vehicle
10 · Playing in Roadway
11 · Hitching on Vehicle
12 · Working in Roadway
13 · Not in Roadway
14 · Other ____________

12 ALCOHOL

Driver		
1	2	
1	5	No Evidence of Drinking
2	6	Drinking · Ability Impaired
3	7	Drinking · No Evidence of Impairment
4	8	Undetermined

14 CHEM. TEST

1.	Driver No	2
	TEST OFFERED	
Yes · No		Yes · No
	TEST REFUSED	
Yes · No		Yes · No
	TEST RESULTS	
%		%

13 APP. PHY. CONDITION

Driver		
1	2	
1	12	Previous Inj·Disability
2	13	Illness · temporary
3	14	Fatigued · Asleep
4	15	Medicated
5	16	Normal
6	17	Emotionally Upset
7	18	Distract·In or Outside
8	19	Preoccupied
9	20	Age
10	21	Condition Unknown
11	22	Other ____________

15 ROAD CHARACTER

1 · Straight Level
2 · Straight · on · Grade
3 · Straight Hillcrest
4 · Curve Level
5 · Curve · on · Grade
6 · Curve · Hillcrest

16 LIGHT

1 · Daylight
2 · Dawn
3 · Dusk
4 · Darkness
5 · Darkness · Road Lighted

17 WEATHER

1 · Clear
2 · Raining
3 · Snowing
4 · Fog/Smog
5 · Sleeting
6 · Blowing Dust

18 ROAD SURFACE COND.

1 · Dry
2 · Wet
3 · Snowy/Ice
4 · Muddy
5 · Oily
6 · Other ____________

19 ROADWAY DEFECTS

1 · Shoulder Low
2 · Shoulder Soft
3 · Holes, Bumps, etc
4 · Loose Material
5 · Repair Work Barricaded
6 · Repair Work not Barricaded
7 · No Defects
8 · Other ____________

20 ROADWAY LANES

Veh		
1	2	
1	8	One Lane
2	9	Two Lanes
3	10	Three Lanes
4	11	Four Lanes
5	12	Five Lines or more
6	13	Unpaved any width
7	14	One Way

21 VISION OBSCURED

Veh		
1	2	
1	13	Not Obscured
2	14	Rain, Snow, Ice on Windshield
3	15	Trees, Crops, Bushes
4	16	Buildings
5	17	Embankment
6	18	Sign Board
7	19	Hillcrest
8	20	Parked Vehicle(s)
9	21	Moving Vehicle(s)
10	22	Blinded by Headlights
11	23	Blinded by Sunlight
12	24	Other ____________

22 TRAFFIC CONTROL

1 · Stop Signs
2 · Stop and Go Light
3 · Officer or Flagman
4 · Railroad Crossing Gates
5 · Railroad Flashing Lights
6 · None
7 · Other ____________

Traffic Control/Sign Visible
1 Yes 2 No

Controls Functioning?
1 Yes 2 No

23 MISC. INFORMATION

VEHICLE
1. 2.

SPEED LIMIT (Miles per Hour)

SPEED LIMITED POSTED?
1 Yes · No 2 Yes · No

DID FIRE OCCUR?
1 Yes · No 2 Yes · No

24 VEHICLE CONDITION

Veh		
1	2	
1	9	No Apparent Defects
2	10	Lights Defective
3	11	Brakes Defective
4	12	Steering Defective
5	13	Puncture · Blowout
6	14	Worn or Slick Tires
7	15	Motor Trouble
8	16	Other Defects ____________

25 HAZARDOUS MATERIALS

HAZARD CLASS

DID SPILL OCCUR? 1 Yes 2. No

26 SPECIAL STUDIES

7649501

MOTORIST'S REPORT OF ILLINOIS MOTOR VEHICLE ACCIDENT

I.D.O.T. USE ONLY

WHERE ACCIDENT OCCURRED

COUNTY

CITY

Road or Street on which Accident Occurred ______ (Highway Number, U.S. or State, if no highway number - identify Road by Name)

At Intersection With ______ (Number or Name of Intersecting Highway or Street)

If not at Intersection ______ Feet or ______ Miles (CIRCLE 1) N E S W of ______ (Nearest Highway, Street, Bridge, or other Landmark)

WHEN ACCIDENT OCCURRED

MONTH / DAY / YEAR

M T W T F S S

HOUR : AM PM

NUMBER OF VEHICLES INVOLVED IN ACCIDENT

DRIVER NUMBER 1 - YOURSELF

DRIVER'S NAME (LAST, FIRST, MIDDLE)

BIRTH MO DAY YR / /

DRIVER'S LICENSE NO

STATE

1 MALE 2 FEMALE

STREET ADDRESS

CITY/STATE/ZIP CODE

COUNTY

VEHICLE NUMBER 1 - YOUR VEHICLE

OWNER'S NAME

ADDRESS

VEHICLE MAKE

YEAR

MODEL & TYPE

VEHICLE LICENSE NUMBER - STATE & YEAR

IDENTIFICATION NUMBER - SERIAL

APPROX COST TO REPAIR $

WAS VEHICLE PARKED? 1 - Yes 2 - No

LEGALLY? 1-Yes 2-No

Were you driving a vehicle owned by your employer, in the course of your employment? If yes check square ☐.

DRIVER NUMBER 2 - OTHER DRIVER - OR PEDESTRIAN

☐ DRIVER'S NAME (LAST, FIRST, MIDDLE)

☐ PED

BIRTH MO DAY YR / /

DRIVER'S LICENSE NO.

STATE

1 MALE 2 FEMALE

STREET ADDRESS

CITY/STATE/ZIP CODE

COUNTY

VEHICLE NUMBER 2 - OTHER VEHICLE

OWNER'S NAME

ADDRESS

VEHICLE MAKE

YEAR

MODEL & TYPE

VEHICLE LICENSE NUMBER - STATE & YEAR

IDENTIFICATION NUMBER - SERIAL

APPROX. COST TO REPAIR $

WAS VEHICLE PARKED? 1 - Yes 2 - No

LEGALLY? 1-Yes 2-No

Was driver (owner) of Vehicle Two insured? Yes ☐ No ☐ Not Known ☐

DID POLICE OFFICER INVESTIGATE ACCIDENT? 1 - Yes 2 - No

CODES FOR COMPLETION OF INJURY INFORMATION

SEATING IN VEHICLE

USE CODE "P" IF PEDESTRIAN

1 2 3
4 5 6
STATION WAGON
7 8 9

INJURY

K - Dead before Report made
1 - Visible signs of Injury as bleeding wound or distorted member, or had to be carried from scene
2 - Other visible injury bruises, etc
3 - No visible injury but complaint of pain or momentary unconsciousness

YOUR REPORT IS CONFIDENTIAL AND CANNOT BE USED AS EVIDENCE IN ANY TRIAL PRINT OR TYPE ALL INFORMATION ON THIS FORM

LIST PERSONS KILLED OR INJURED

		AGE	SEX	VEH NO	SEATING	INJURY
NAME	ADDRESS					
DESCRIBE INJURIES						
NAME	ADDRESS					
DESCRIBE INJURIES						
NAME	ADDRESS					
DESCRIBE INJURIES						

DESCRIBE DAMAGE TO PROPERTY OTHER THAN MOTOR VEHICLES

APPROX. COST TO REPAIR

OWNER'S NAME

OWNER'S ADDRESS

SIGN HERE

SIGNATURE OF PERSON MAKING REPORT

ADDRESS

DATE

COMPLETE BOTH SIDES OF THIS FORM

Mail Report To:
Accident Report Office
Illinois Department of Transportation
Springfield Illinois 62766

Form SR-1 (Rev. 9/80)

YOUR INSURANCE

If you fail to give full information below it will be assumed that you did not have automobile liability insurance.

Have your insurance policy in front of you when you fill in this form.

Full name of your insurance company (not agency) which issued policy to cover liability for damage or injury to others.

Name and Address of Representative who sold policy.

Policy Number

Policy Period From: ______ To: ______

Name of Policy Holder

THIS SPACE FOR FLEET OPERATORS ONLY

If your vehicle operated in compliance with the Federal "Motor Carrier's Act," show the Interstate Commerce Commission docket number.

Is a Form SR-23 on file with the Department of Transportation covering your vehicle?

Has the Secretary of State issued a certificate of self-insurance covering your vehicle?

(DETACH AND KEEP)

LEGAL REQUIREMENTS

The driver of any motor vehicle involved in an accident which results in injury, death, or damage to any one person's property in excess of $250 must complete this report within 10 days after the accident.

If the driver is physically incapable of completing the report the owner or another occupant of the vehicle should do so.

YOUR REPORT IS CONFIDENTIAL AND CANNOT BE USED AS EVIDENCE IN ANY TRIAL.

PRINT OR TYPE ALL INFORMATION ON THIS FORM

INSTRUCTIONS

OBSERVE THE FOLLOWING RULES:

1. **PRINT ALL NAMES AND ADDRESSES. CIRCLE ALL ITEMS THAT IDENTIFY YOUR ACCIDENT.**
2. Answer all questions to the best of your knowledge. If unable to answer any questions, mark "NK" for "not known".
3. Under "Where Accident Occurred" give sufficient information to locate the exact scene of the accident.
4. Under "Model and Type of Vehicle" indicate the exact type (for passenger cars only) model; that is, passenger car Fairlane, passenger car with two-wheel trailer Delta 88, etc., or combinations; that is, tractor and semitrailer, truck and four-wheel trailer, motorcycle, etc.
5. The nature and extent of all damages and injuries must be clearly and completely stated. Whenever a doctor's statemen of injuries or a garage estimate of the cost of repairs is immediately available give this information, otherwise give your own careful estimate.
6. A motor bus, bicycle, or animal drawn vehicle should be recorded as a vehicle for the purpose of this report. A person on skates, coaster wagon, sled, etc. should be classed as a pedestrian. Describe the conveyance and give exact location in the street or on the roadway.
7. If the accident involved a fixed object, describe it fully and give the exact location. State whether it was protected by flags, signs and/or lights.
8. Use a second report form or a sheet of paper the same size to report additional vehicles, injured persons, witnesses, or any other information for which there is not sufficient space.
9. **SIGN THE REPORT** in the space at the bottom.

7649501

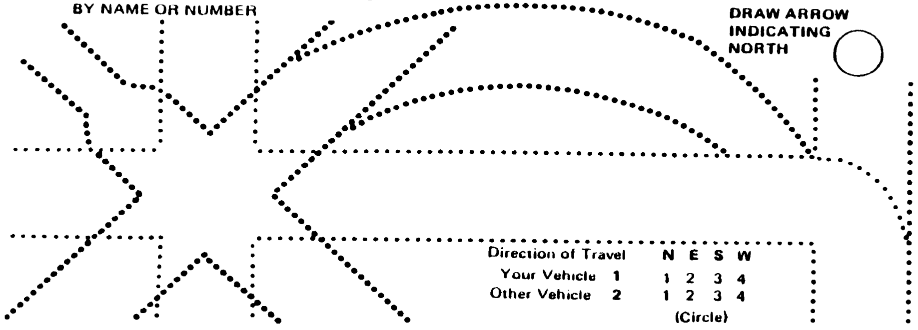
Important - this accident should also be reported to your insurance representative. Failure to report may jeopardize your automobile liability insurance

DIAGRAM WHAT HAPPENED INSTRUCTIONS

1. Follow dotted lines to draw outline of roadway at place of accident.
2. Number each vehicle and show direction of travel by arrow.
   →[1]✕[2]←
3. Use solid line to show path before accident
   ——→[2]>
   dotted line after accident
   - - - →[2]>
4. Show pedestrian by: —○
5. Show railroad by: ┼┼┼┼
6. Show utility poles by: ⌽
7. Show motorcycle by: ○○

IDENTIFY STREETS AND HIGHWAYS BY NAME OR NUMBER

DRAW ARROW INDICATING NORTH ○



Direction of Travel	N	E	S	W
Your Vehicle 1	1	2	3	4
Other Vehicle 2	1	2	3	4
	(Circle)			

DESCRIBE WHAT HAPPENED (Refer to vehicles by number):

CIRCLE NUMBER OF ITEM OR ITEMS IN EACH BOX PERTAINING TO ACCIDENT

8 TYPE OF ACCIDENT - WITH

1 - Pedestrian
2 - Motor Vehicle in Traffic
3 - Parked Motor Vehicle
4 - Railroad Train
5 - Bicyclist
6 - Animal ______
7 - Fixed Object
8 - Other Object
9 - Motorcycle
10 - Moped
11 - Other ______

9 MANEUVER

1 - Avoiding Pedestrian
2 - Avoiding Other Vehicles
3 - Avoiding Animal
4 - Avoiding Previous Accident
5 - Skidding Before Braking
6 - Skidding After Braking
7 - Crowded off Roadway
8 - Driverless Moving Vehicle
9 - Other ______

10 YOUR ACTION AT TIME OF ACCIDENT

1 - Going Straight Ahead
2 - Changing Lanes
3 - Making Right Turn
4 - Making Left Turn
5 - Making U Turn
6 - Slowing or Stopped
7 - Starting in Traffic Lane
8 - Starting from Parked Position
9 - Stopped in Traffic
10- Parked
11 - Backing
12 - Other ______

11 WHAT PEDESTRIAN WAS DOING

1 - Crossing at Intersection With Signal
2 - Crossing at Intersection Against Signal
3 - Crossing at Intersection No Signal
4 - Crossing Not at Intersection
5 - Coming From Behind Parked Vehicle
6 - Walking in Roadway - With Traffic
7 - Walking in Roadway - Against Traffic
8 - Getting off or on School Bus
9 - Getting off or on Other Vehicle
10 - Playing in Roadway
11 - Hitching on Vehicle
12 - Working in Roadway
13 - Not in Roadway
14 - Other ______

12 ROAD CHARACTER

1 - Straight Level
2 - Straight - on - Grade
3 - Straight - Hillcrest
4 - Curve-Level
5 - Curve - on - Grade
6 - Curve - Hillcrest

13 LIGHT

1 - Daylight
2 - Dawn
3 - Dusk
4 - Darkness
5 - Darkness - Road Lighted

14 WEATHER

1 - Clear
2 - Rain
3 - Snow
4 - Fog/Smog
5 - Sleet
6 - Blowing Dust

15 ROAD SURFACE CONDITION

1 - Dry
2 - Wet
3 - Snow/Icy
4 - Muddy
5 - Oily
6 - Other
______

16 ROAD DEFECTS

1 - Low Shoulder
2 - Soft Shoulder
3 - Holes, Bumps, etc.
4 - Loose Material on Roadway
5 - Construction - Barricaded
6 - Construction - Not Barricaded
7 - No Defects
8 - Other ______

17 TOTAL ROADWAY LANES

1 - One Lane
2 - Two Lanes
3 - Three Lanes
4 - Four Lanes
5 - Five or More
6 - Unpaved any Width
7 - One Way? 1-Yes 2-No

18 VISION OBSCURED

1 - Not Obscured
2 - Rain, Snow, Ice on Windshield
3 - Trees, Crops, Bushes
4 - Buildings
5 - Embankment
6 - Sign Board
7 - Hillcrest
8 - Parked Vehicle(s)
9 - Moving Vehicle(s)
10 - Blinded by Headlights
11 - Blinded by Sunlight
12 - Other ______

19 TRAFFIC CONTROL

1 - Stop Sign
2 - Stop and Go Light
3 - Officer or Flagmen
4 - Railroad Crossing Gates
5 - Railroad Flashing Lights
6 - None
7 - Other ______

1 - Was Traffic Sign Visible?
1 - Yes 2 - No
2 - Control Functioning?
1 - Yes 2 - No

20 MISCELLANEOUS INFORMATION

ODOMETER READING
☐☐☐☐☐.☐ 1/10

SPEED LIMIT
______ M.P.H.
POSTED 1 - Yes 2 - No

Were You Familiar With Road on Which Accident Occurred? 1 - Yes 2 - No

DID FIRE OCCUR?
1 - Yes 2 - No

The Safety Responsibility Law

For general information only

(See Sections 7-100 through 7-216 of the Illinois Vehicle Code for complete statute).

In certain cases drivers and owners may be required to prove financial responsibility, usually by presenting evidence of automobile liability insurance.

When any person sustains property damage in excess of $250 or personal injuries, the names of uninsured motorists are sent to the Secretary of State with a legal notice of possible security deposit. The notice names all potential property damage and bodily injury claimants, and lists the evaluated amounts of those potential claims. The evaluations are based on information shown in the reports filed by drivers or owners. It is important that reports be filed promptly and that complete and accurate descriptions of property damage and bodily injuries be shown in the spaces provided on the report form.

The accident file, which usually contains a police report and a report from each driver, will be sent to the Secretary of State. That office will review the reports to ascertain if the uninsured driver was legally at fault. If the driver was clearly not at fault the file will be closed; otherwise a Hearing will be held. If the Hearing officer concludes, after considering all written and oral evidence, that there is reasonable possibility of legal fault, the uninsured driver will have the following options: 1. Deposit security. 2. Present evidence of releases from liability (or signed agreements to pay for damages in installments) from all potential claimants named on the security deposit notice. 3. Show evidence of a final adjudication of nonliability. If the uninsured motorist fails to comply with any of the above options, his/her driver's license (if driver) and vehicle registration privileges (if owner) would be suspended.

(None of the above affects any person's right to sue to recover damages).

(Security deposits, releases, or installment agreements are to be submitted to the Secretary of State).

FOR YOUR RECORDS

We recommend that you preserve certain information for yourself or your Insurance Company.

Accident date: Month/ Day/ Year ____/____/____ County of Accident ______

Your vehicle: Name ______ Address ______
Driver: ______
Owner: ______

Other vehicle: ______
Driver: ______
Owner: ______

If you need to correspond with the Accident Report Office, attach this slip to your letter, or show the above information in your correspondence. Send the letter to:

Accident Report Office
Department of Transportation
Springfield, Illinois 62766