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AN ESTIMATE OF THE EFFECT OF FMVSS 301—FUEL SYSTEM INTEGRITY†

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Abstract—Federal Motor Safety Standard No. 301—Fuel System Integrity—was first promulgated, effective 1 January 1968. Its purpose was to reduce the fatalities, injuries and damage caused by fires occurring in automobile crashes. It was subsequently strengthened (1 September 1975 and again 1 September 1976) and extended to all four wheel vehicles of Gross Vehicle Weight less than 10,000 pounds (1 September 1976). This paper uses existing police accident and fire department data from a total of 10 states to estimate the effects of FMVSS 301 on the passenger car crash population. Only very limited information on the rates of fuel spillage were found, so the paper concentrates on the rate of fires in crashes involving passenger cars. Some information on fatalities from the Fatal Accident Reporting System (FARS) is also used. Post-crash passenger car fires are rare. Reported rates ranged from less than one per thousand crashes up to nearly five per thousand crashes. Rates averaged about two fires per thousand police reported crashes or about three fires per thousand towaway crashes. Fatalities are also quite rare. In 1976, 814 persons were killed in 683 vehicles that caught fire after a crash. In 1977, 982 persons died in 858 such vehicles. Fire department data proved only of supplemental use, because a car fire could not be identified with a crash. Police accident data showed smaller post-crash fire rates with newer model year cars. While this is consistent with a beneficial effect of FMVSS 301, it could also be caused by an increasing likelihood of fire in a crash for older cars. A linear trend in age for car fire rates was statistically significant only in the Illinois data. Combining the data from 6 states showed a 16% reduction in post-crash passenger car fire rates coincident with the first promulgation of the FMVSS 301 in 1968. An additional 14% reduction occurred coincidently with the later versions starting with the 1976 model year. A total reduction of 25% was estimated comparing pre-standard models with the current standard. These reductions were all statistically significant. While it was not possible to eliminate the possibility that aging contributed to the observed reductions, or that other factors could have influenced these reductions, it seems reasonable to conclude that some of the benefit resulted from the standard.

INTRODUCTION

Passenger car fires following a crash are rare. Cooley[1974] estimated that they occur at the rate of approximately 1 fire per thousand police reported crashes as defined by the National Safety Council. When a post-crash fire does occur, it is frequencly a spectacular and potentially lethal event. As a result, crashes resulting in fire tend to receive news coverage that makes them among the most visible of automobile crashes. Recently wide publicity has attended litigation involving damages sought from injuries and deaths resulting from post-crash fires. Federal Motor Safety Standard 301—Fuel System Integrity—was promulgated in an effort to reduce the fatalities, injuries, and damage caused by post-crash fires. The standard was first promulgated to take effect on 1 January 1968, [Federal Register, 1967]. It called for fuel systems of passengers cars to retain integrity (not leak fuel) after a crash and affected the fuel tank, filler pipe and fuel line connections. Compliance was to be judged or demonstrated by a 30 mph perpendicular frontal crash into a fixed barrier, following which fuel leakage was to be less than one ounce per minute.

The FMVSS 301 was upgraded effective with the 1976 model year of passenger cars[Federal Register, 1973], following some postponements of the initially proposed effective date. The main change in the standard was that following a 30 mph frontal barrier crash, the car should not leak more than one ounce of fuel per minute in any of four final resting positions—on its wheels, on its roof, or on either side. The current version of the standard was effective beginning with the 1977 model cars[Federal Register, 1975]. In addition to the previous requirements, the current version specifies testing in two additional modes—moving barrier rear collision and side impacts. Following any of the collision tests, the vehicle should not leak more than one ounce of fuel per minute in any of the four resting positions. (A vehicle need not withstand multiple tests.) The 1977 model year standards applied to all four wheel vehicles up

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to 10,000 pounds, including vans and multipurpose passenger vehicles. This paper restricts attention to passenger cars. Exact details of the standard in its three versions may be found in the Federal Register[1967], [1973] and [1975], respectively.

The aim of the standard was to reduce the additional risk posed by post-crash fires. The mechanism by which this was to be accomplished was to reduce the incidence of post-crash fuel spillage, thereby reducing post-crash fuel-fed fires and consequently the additional injuries and fatalities associated with the fires. Thus, the most direct effect to be expected would be a reduction in the rate of fuel leakage in accidents, while the most important result would be a reduction in fatalities and/or injuries caused by post-crash fires. These results should be demonstrated in the crash population if the standard is to be judged effective.

DATA SOURCES

Given the rarity of the event of a post-crash fire, and even more so, of fire-associated injuries or fatalities, it was evident that a large number of crashes must be available for study. This consideration resulted in the decision to restrict the data sources to statewide data files of either police-reported automobile crashes or fire department data on car fires. In order to be useful, a state police accident file must contain information identifying the vehicle by model year (and hence version of the standard under which it was manufactured) and determining whether or not there was either post-crash fuel leakage or fire. Additional information about the type or severity of the crash and resultant injuries would also be useful. Fire department data must contain the model year of the vehicle involved in a fire, and also some information that would indicate that the cause of the fire was a traffic accident. Again, additional information about the results of the fire and/or the type and severity of the crash would be very useful.

Consideration of these minimum data requirements reduced the set of states with appropriate police accident data to six: Idaho, Illinois, Michigan, New York, Oklahoma and Washington. Data reporting varied by state. Illinois, Michigan, Oklahoma and Idaho had a specific question on the accident form that asked whether a fire occurred. In Washington, fires were coded only if they were noted in the narrative, while New York included fire as one of several possible second hazardous events. Oklahoma recorded age with a single digit, resulting in loss of information about older models. In addition to these six states, some data were available from a six month study by the California Highway Patrol, and preliminary data from the National Crash Severity Study (NCSS) were used.

Fire Department data from six states were used in an attempt to see whether fire department data would identify more car fires from a wider population than police accident data. However, it proved impossible to determine which car fires reported in fire department data were associated with traffic accidents. Most car fires reported in fire department data are not related to crashes. It is possible that the standard, while aimed at preventing crash fires, might reduce the incidence of all car fires by improving the integrity of the fuel system. Thus, even though the fire department data cannot be related to crashes directly, an observed reduction in car fires generally might by a serendipitious benefit of the standard.

Fire department data on a state-wide basis are assembled by the National Fire Incident Reporting System (NFIRS) of the National Fire Administration, (now a component of the Federal Emergency Management Agency). The number of states reporting to this system is increasing yearly. Data from six states were used in this study: Michigan, Missouri, New York, Ohio, Maryland and Oregon. The reported car fires from the first four were related to police reported crashes by model year of the vehicle involved, while for the last two, reported car fires were related to registration data because crash data by model year were not available.

RESULTS

Post-crash fuel leakage

Only two data sources were found that had information on fuel spillage in crashes. These were data from the NCSS, reported by O'Day[1979], and the data from the Michigan police accident records in 1978. The NCSS data on fuel leakage appear to be somewhat incomplete. NCSS investigators did not visit the scene of the crash. The vehicle involved was inspected, usually after it had been removed to a storage facility prior to repair or junking. Fuel leakage was determined by the inspection of the vehicle for punctured fuel tanks, broken fuel lines, etc.

Damage that would result in large fuel spillage would be noted in this way, but small leaks would likely be missed. There is also the possibility that additional damage during towing or during extrication of passengers might lead to fuel leaks not part of the crash damage. In general it seems likely that fuel leakage is under-reported in the NCSS and would be under-reported whenever the crash site is not observed.

Beginning in 1978, the Michigan state accident reporting form included questions relating to post-crash fires and fuel leakage. The investigating officer checks a "yes" or "no" box for each variable: fire and fuel leakage. The data are then coded into a four level variable corresponding to the four combinations of answers. If the item is omitted on the form, it is coded as a "no". There is no provision for missing data. Table 1 gives the estimated fuel leakage rates for model years corresponding to each version of the standard. Two different rates are given from the Michigan data. The larger includes cases where both fire and fuel spillage were noted, while the smaller includes only cases of fuel spillage without fire. The rates from the Michigan data show large differences among the different versions of the standard. The rates estimated from the NCSS are much lower than those from the Michigan data except for the most recent models, and do not show much difference by version of the standard. If the leakage rates from the Michigan data are related to the individual model years of the vehicle, a strong increasing trend with age is noted. It is thus not certain whether the differences in fuel leakage rates are related to the standard or merely to the age of the vehicle. At present, the alternative explanation that fuel systems tend to become more likely to leak fuel in a crash as the car ages seems at least as good an explanation of the data as the assumption that the FMVSS 301 resulted in decreased fuel leakage rates. However, the paucity of data precludes any firm conclusions. The extant data do not contradict a beneficial effect of the standard, but they are not convincing of one.

Post-crash fires—police accident data

A variety of data files were found that contained useful information on the occurence of post-crash fires. The estimated crash fire rates from each source for each version of the standard are summarized in Table 2, where post-crash fire rates and standard errors are presented in rates per thousand crashes. The actual number of post-crash fires is presented in parenthesis. Most of the data are from state-wide police reported accidents. This includes data from Idaho, Illinois, Michigan, New York, Oklahoma and Washington. The data from California are from a special six-month study by the California Highway Patrol and were only freeway and highway accidents. The data from NCSS include only towaway crashes, which are somewhat more severe crashes than the other data sets. The data from Oklahoma included information on the age of the vehicle only for the 6 most recent years—earlier model years were combined in their coding system. As a result, the data on cars of model years 1971 and earlier are combined. This means that the early fire rate includes some vehicles that were subject to the 1968 standard.

Most of the rates decrease for the later versions of the standard, which is consistent with a beneficial effect of the standard. The level of the crash fires can be seen to vary widely among the different data sources. While some of this may be due to different rates of occurrance of

Table 1. Fuel leakage rates per thousand crashes. Standard errors in parenthesis

	Standard		
Data Source	pre-301	301-68	301-76
Michigan (1978)	27.17	15.18	6.92
Leaks including fire			
	(1.046)	(0.234)	(0.208)
Leaks, no fire			
	25.86	14.34	6.39
	(1.019)	(0.228)	(0.200)
NCSS			
Leaks, no fire			
	5.40	2.82	5.96
	(0.926)	(0.328)	(0.930)

Table 2. Crash fire rates (per 1000 crashes)—police accident data

Data Set	Pre-301	301-68	301-76
California[1] (1976)	1.93 ± 0.275 (50)	1.62 ± 0.158 (105)	1.31 ± 0.416 (10)
Idaho (1976-77)	1.00 ± 0.213 (22)	0.90 ± 0.137 (62)	0.86 ± 0.422 (11)
Illinois (1976-77)	4.71 ± 0.227 (513)	4.42 ± 0.088 (2486)	3.36 ± 0.204 (419)
Michigan (1978)	3.14 ± 0.268 (81)	2.51 ± 0.095 (740)	1.80 ± 0.106 (288)
New York (1976-77)	0.37 ± 0.051 (49)	0.28 ± 0.018 (249)	0.29 ± 0.044 (44)
NCSS[2] (towaways 1977)	3.81 ± 0.794 (25)	3.09 ± 0.345 (81)	3.65 ± 0.741 (26)
Oklahoma[3] (1977)	0.49 ± 0.109 (20)	0.70 ± 0.140 (25)	0.41 ± 0.151 (7)
Washington (1976-77)	0.44 ± 0.071 (58)	0.33 ± 0.041 (66)	0.51 ± 0.133 (15)

1. Data from a six month study of highway and freeway accidents by the California Highway Patrol.

2. Data from NCCS include only those vehicles damaged enough to require towing.

3. The model year range for Oklahoma is pre-1972, 1972-1975, post-1975.

fires in crashes among the different states, the largest component contributing to this difference appears to be differences in reporting criteria and methods. Each state has a code which is entered for the "second hazardous event". In Washington, there is no specific variable for fire on the reporting form. The investigating officer's narrative is read when the data are coded at the state level and if a fire is reported in the narrative, it may be coded as one of several "additional adverse factors in the accident" variables. It seems likely that the Washington data would miss many of the fires, particularly the minor ones. However, the cases of conflagrations involving the entire vehicle would probably be included. The Washington data probably represent only the most serious fires and so differ from the other data (except for New York, which may be similar), which report all of the fires.

Fire department data

Data from fire departments proved to be of limited use. Most of the fire department data involving car fires involved non-crash fires. It was not possible to identify car fires with crashes. The variable "source of ignition" could possibly be used for this purpose. It has some code values 41-(fuel spilled, released accidently), 51-(part failure, leak or break), 53-(manual control failure), 61-(design deficiency), and 71-(collision, overturn, knockdown), which could indicate a crash. However, these are also often used for non-crash events, while others are also used in the cases of some crashes. The difficulty is that this variable aims at what actually ignited the fire, not at whether a crash was the situation that led to the fire. There is no variable that specifically identifies a crash or traffic involvement.

Attempts were made to develop a surrogate for crash involvement—a combination of several variables such as ignition factor, substance involved and location—that would identify the crash fires. A sample of three months of data was used and hard copies were reviewed to determine from narrative or other non-computerized information whether a car fire was associated with a crash. The best that could be done was to find only about 47% of the car fires that actually involved crashes, while about 50% of the cases found by the surrogate were in fact not crash fires. Details of this may be found in Flora, Beitler, Bromberg *et al.*[1979]. The rates reported in Table 3 are based on a judgement of the best codes to use as crash related car fires in each of the six states. In Michigan, the crash surrogate was used. In other states, car fires

Table 3. Fires to crashes ratio (per 1,000 crashes)—fire department data

Data Set	pre-301	301-68	301-76
	Standard		
Michigan (1976-77)	0.82	0.37	0.11
Missouri (1977)	7.92	3.74	1.20
New York (1977)	4.91	2.29	0.88
Ohio (1977)	2.17	0.84	0.23
	(Fires per Registered Vehicle)		
Maryland (1977)	0.41	0.17	0.12
Oregon (1977)	0.77	0.57	0.29

that resulted from arson or suspected arson were eliminated, and only those with ignition codes 41 or 71 were included. However, none of these is very well associated with crash fires. Even after attempts to make the data as consistant as possible, large differences in the fire to crash ratios remain. These ratios should probably be interpreted as reductions in car fire rates, not necessarily associated with crashes. In the Maryland and Oregon data, registered vehicles were used as the denominator, since crash data by model year were not available. These rates are approximately one-tenth the rates if crashes were used instead of registrations.

The fire department ratios show generally lower values corresponding to the newer cars. While this is consistent with a beneficial effect of the standard, there are other, alternative explanations. The fire rates generally increase steadily with the age of the vehicle, suggesting that age may be a more important factor than the design changes that occured with the introduction of the standard. On the other hand, design changes could have been more year-by-year than all at once to coincide with the standard. While the fire department data are consistent with a beneficial effect of the standard, given the difficulty of identification with a crash and the alterative explanations, they are best regarded as only supplemental evidence. Figure 1 shows the typical pattern of the data from fire departments. It presents the data from New York. While the fire department data are consistant with a beneficial effect of the standard, given the difficulty of identification with a crash and the alternative explanations they are best regarded as only supplemental evidence. All of the fire department data showed highly significant age effects, with little or no additional effects coincident with the introduction of the standard.

Analysis of police accident data

Most of the evidence about the effect of FMVSS 301 is from the police accident data. It is not possible to completely separate age from version of the standard since the standard was

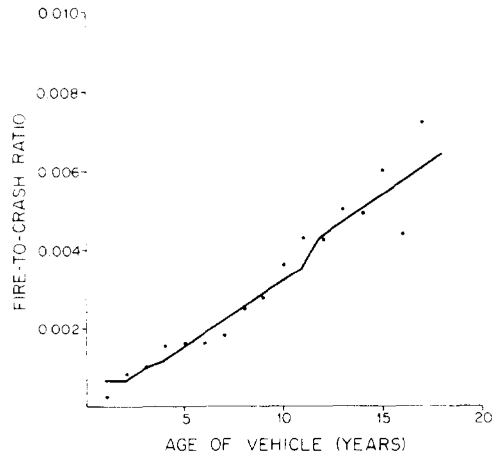

Fig. 1. New York crash fire ratios (1977) (Fire Department Data).

introduced at a specific point in time and the data about the post-crash fires come from a one or two year period of accidents. Thus, cars built when different versions of the standard were in force are inherently of different ages at the time of their crashes. However, since each version of the standard, except for the transitionary 1976 standard, has several model years of cars, trends in age may be investigated within versions of the standard. If no such trends are found or if standard effects are found after adjusting for such trends, then the evidence in favor of an effect of the standard would be more convincing.

Age was treated as a covariate in a linear model to try to separate possible effects of age from those of the standard on the crash-fire rates. The model was

$$E(r_i) = B_0 + B_1X_1 + B_2X_2 + B_3X_3, \qquad (1)$$

where $E(r_i)$ is predicted crash fire rate for model year of age i, X_1 is the age at the time of crash, X_2 and X_3 are dummy variables that indicate the presence of the first version of the standard and the second version of the standard, and B_0, B_1, B_2 and B_3 are parameters to be estimated. The variable X_2 took the value zero for models prior to 1968 and one for models for 1968 and later. The variable X_3 took the value zero for model prior to 1976 and one for model years 1976 and later. Thus, the coefficients B_2 and B_3 represent estimates of the effects of the introduction of the standard in 1968 and 1976 and later after the effect of age has been included.

A model of the form (1) was fit by the method of weighted least squares to each of the data sets of police accident data. (The method of weighted least squates was described by Landis *et al.*[1976] and an alternative formulation was presented by Flora *et al.*[1980]). Figure 2 shows a typical result with the model (line) compared to the observed data (represented by "·"). The figure presents data from Michigan, 1978. Although a decreasing trend appears, the coefficient for age was not statistically significantly different from zero. Detailed results can be found in Flora *et al.*[1979]. In all of the data sets but one, the age effect was not significant. The one exception was Illinois, which exhibited a significant trend in age, primarily in the 1968–74 models, little trend in the rates was found for older or newer models. If a linear trend for age was included in the model, none of the standard effects was significant.

Since the age effect was generally non-significant, the simpler model with just different means in the different standard groups was used. This model can be represented as

$$E(r_i) = B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 \qquad (2)$$

where r_1 is the crash fire rate for year i; X_1 is one for model years prior to 1968, zero otherwise; X_2 is one for model years 1968 through 1975, zero otherwise; and X_3 is one for model year 1976, zero, otherwise; and X_4 is one for model years 1977 and later, zero otherwise. The coefficients B_1, B_2, B_3 and B_4 are parameters to be estimated and represented the mean fire rate within each version of the standard. This model fit the data adequately in most states. The most important exception was Illinois, where the lack of fit chi-squated statistic was 25.96 with 13 degrees of freedom ($P = 0.017$). With the large numbers of crashes in Illinois, this lack of fit might merely

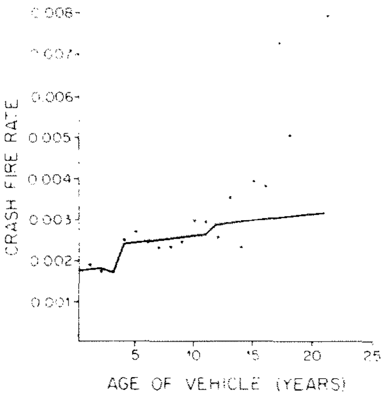

Fig. 2. Michigan crash fire rates (1978) (Police Accident Data).

be reflecting the known fact that the model is an approximation. However, inclusion of a linear trend in age during the 1968–75 model years improved the fit substantially, giving a chi-squared statistic for lack of fit of 13.26 with 13 degrees of freedom, ($P > 0.4$). A somewhat marginal fit of the means model was also found in the Idaho data, with $X^2 = 12.44$ with 8 degrees of freedom ($P = 0.13$). Inclusion of a linear term in age improved this somewhat ($X^2 = 8.47$, 7 degrees of freedom, $P = 0.29$). In other states' data, the all means models fit well, with all of the significances of the lack of fit tests greater than 0.3.

The 1976 and later versions were subsequently combined for several reasons. Relatively few cases of crashes were available for the later model years. The 1976 standard covered only one model year and hence will always be subject to data limitations, considering the rarity of the event. The current version of the standard was to have begun in 1976 but was delayed one year. No significant differences were found between the 1976 and later versions of the standard. Thus, combining the 1976 and later models was thought advisable to enhance the comparison with earlier (1968–75) version of the standard.

Table 4 gives the parameters estimated from the all means models and their standard errors for the statewide data sets. Note that these are slightly different from the means obtained by combining data in Table 2. The data from Oklahoma have been excluded because of the inability to distinguish between the pre-standard cars and the first version of the standard.

Most of the data in Table 4 show reductions of the fire rates coinciding with later versions of FMVSS 301. However, most of the differences are not sighificantly different from zero. As a result, results from any one of the data sets would be inconclusive in terms of whether or not there was a change in the fire rate at the time of the change in the standard FMVSS 301.

Table 4. Estimated parameters and standard errors for the all means models

	Standard Version		
Data Source	Pre-301	301-68	301-76+
Idaho	1.00	0.90	.86
	0.213	0.125	0.289
Illinois	5.02	4.35	4.14
	2.286	0.875	2.026
Michigan	2.91	2.50	1.77
	0.335	0.092	0.105
New York	0.37	0.28	0.28
	.051	0.018	0.043
Washington	0.44	0.33	0.51
	.071	0.041	0.133

COMBINED ESTIMATES OF EFFECT OF FMVSS 301 ON POST-CRASH FIRES

None of the individual data sets contained enough data to show significant effects associated with the standard versions on the rate of occurence of post-crash fires. However, most data sets did indicate that what differences there were, were in the anticipated direction, namely, reduction on the post-crash fire rates with the more stringent versions of the standard. It is desirable to combine the information from the data sets in some fashion to try to provide a more definite answer to the question of what effect FMVSS 301 may have had in the accident population.

The data from the different sources are based on different operational definitions of a crash fire. Even more so, they are based on different definitions of what constitutes a crash. As a result, the rates from different data sources are not directly comparable, nor should they be combined. In order to make these data comparable and to be able to combine them, the crash-fire rates were converted to percentage changes from one version to the standard to another. Table 5 presents these estimated percentage changes, together with their estimated standard errors. The 1976 and later versions of the standard were treated as one. The estimated standard errors were calculated by using a Taylor series approximation to the function of the

Table 5. Percent changes in fire rates associated with changes in FMVSS 301

Source	Pre-301 Compared to 301-68		301-68 Compared to 301-76		301-76 Compared to Pre-301	
	Pct. Chage	Std. Error	Pct. Chage	Std. Error	Pct. Charge	Std. Error
Illinois	-14.7	4.14	-5.0	4.32	19.0	5.33
Washington	-23.4	15.61	+55.4	43.98	+17.6	35.92
New York	-19.0	12.76	+2.32	15.88	16.9	17.26
California (spec.study)	-16.7	14.31	18.9	26.32	32.5	25.39
Idaho	+8.05	26.81	3.19	3.67	+4.59	38.62
Oklahoma	+48.2	44.45	-44.74	23.62	-18.1	35.05
Michigan	-18.1	8.17	-24.17	4.35	38.3	6.54
NCSS	-22.3	17.79	+22.4	27.59	-4.9	22.65
Combined	-15.6	3.27	13.9	2.91	25.0	3.86

difference of two rates, divided by the earlier rate. In the table, negative signs indicate reductions in the crash-fire rate, while positive signs indicate increases.

The individual estimated percent changes were combined into an overall estimate of the percent change by using a weighted mean. The weights were inversely proportional to the variances of the individual percent changes. The combined estimate is that there was a 15.6% reduction in crash fire rates associated with the 1968–75 models as compared with the pre-1968 (pre-standard) models. The estimated standard error for this change is 3.27%. A further reduction of 13.9% was estimated from the first version of the standard (1968–75 models) to the current (1976 and later). Its associated estimated standard error is 2.91%. Finally, comparing the current standard version (1976 and later) to the pre-standard models, gives an estimated reduction of 25.0% associated with this change. Its estimated standard error is 3.86%.

The combined data estimate reductions in the crash-fire rate associated with each version of the standard. These reductions are significantly different from zero, being more than four times their estimated standard errors in all three cases. It should be clearly noted that the limitations of the data prevent the exclusion of other factors as possible causes for the observed reductions in post-crash fire rates. One may only say that the reductions occurred and were associated with the car models produced under different versions of the standard. While the age of the vehicle was significant only for the Illinois data, age is confounded with the standard so that its influence cannot be completely ruled out.

It is also possible that these reductions were subject to large but unknown biases. Although the combined estimate is based on data from six states (plus a special study in California and preliminary data from the NCSS), the combined result is most heavily influenced by data from the states with the smallest estimated variances for the differences. The data from two of the states—Illinois and Michigan—influence the combined estimate strongly. Both states have substantial numbers of crashes and crash-associated fires. Although many crashes occurred in New York, very few fires were reported, leading to fairly large variances for the percent changes. The states such as Idaho, Oklahoma and Washington were simply too small to add very much to the combined estimates. If there were regional differences in the effect of FMVSS 301 of crash-fire rates, the results reported will be biased toward the effect in the upper Midwest.

OTHER FACTORS AFFECTING FIRE RATES

Several other factors about the crash were found to influence the crash-fire rate. However, the data from different states differed so much in the variables included and the definitions of these variables, that no common set of factors could be used in combination with the combined data. Cooley[1974] found differences in the proportion of accidents with fuel leakage and fire associated with several accident variables. The data used by Cooley were mostly from The Collision Performance and Injury Reporting File (CPIR) maintained by the University of Michigan's Highway Safety Research Institute. This file consists of detailed reports on vehicles involved in rather serious crashes. The data are not representative of any particular population. Some of the variables Cooley found to be important were accident type, part of car damaged, and collision force.

Relation of fire rates to type of crash

The present study also found marked differences in the crash-fire rates with several accident variables. For example, Table 6 gives the crash fire rates by type of crash from the Illinois data and the Washington data. Note that the Washington data contain only four crash types, while there are thirteen types reported in the Illinois data. It is evident that "angle impact" in Washington includes many more types of crashes than in Illinois. Even the crash types with the same names are not defined in the same way from state to state.

The fire rates are largest for crash types associated with more severe types of accidents, for example, striking fixed objects, rollovers and head-ons. However, because of the frequency of the crash types, more fires actually occur in rear impacts. Rear impacts are usually less severe crashes, so that the chance of a fire is less in these types of crash than in some others.

Relation of fire rates to speed

The speed of the car prior to the crash is an important variable affecting the probability of a post-crash fire occurring. The higher the speed, the more severe the crash and the greater the chance of a fire. It is difficult to determine speed in a crash. In Washington, the posted speed limit is listed and serves as a surrogate for speed prior to crash. In Oklahoma, the officers estimated a speed prior to the crash. This is used, although the accuracy of the estimation is subject to question. Table 7 presents the crash fire rates by speed and standard for the Washington and Oklahoma data. Note that the model year ranges for Oklahoma are not exactly those of the versions of the standard, since the coding of vehicle age in Oklahoma combined all models prior to 1972. The rates for different versions of the standard, adjusted for the speed distribution are presented at the bottom of the table, together with their standard errors. Although there is a definite trend for the fire rates to increase with speed, speed distributions among the different model years were quite similar, and the adjustment has had little effect.

Table 6. Fire rates by type of crash—Illinois and Washington

	Illinois		Washington	
Type of Crash	Number of Crashes	Rate per 1,000	Number of Crashes	Rate per 1,000
Overturn (roll over)	7,894	9.75	5,755	3.13
Rear Impact	110,440	4.56	59,619	0.10
Head on	3,793	15.29	—	—
Sideswipe	56,659	3.81	—	—
Angle Impact	53,592	3.51	72,850	0.14
Turning	96,549	3.25	—	—
Parked Car	55,181	3.06	—	—
Pedestrian	5,433	1.47	—	—
Railroad Train	865	10.40	—	—
Pedal Cyclist	4,633	1.08	—	—
Animal Struck	3,000	2.67	—	—
Fixed Object Struck	47,621	8.36	34,533	1.65
Other (included non-collision)	13,432	14.67	—	—

Table 7. Crash fire rates by speed* and standard—Washington and Oklahoma

	Washington				Oklahoma			
Speed	Pre-1968	1968-1975	1976+	All	Pre-1972	1972-1975	1976+	All
0-30	0.34	0.25	0.12	0.26	0.07	0.09	0.38	0.13
31-45	0.58	0.48	0.70	0.53	0.11	0.06	0.00	0.07
46+	1.61	1.10	2.06	1.33	1.90	2.95	1.25	2.16
Crude Rate	0.64	0.49	0.72		0.49	0.70	0.40	
Adjusted Rate	0.66	0.49	0.68		0.54	0.79	0.45	
Std. Error	0.110	0.055	0.197		0.121	0.157	0.183	

*In Washington "Speed" is the posted speed limit. In Oklahoma "Speed" is the officer's estimate of speed prior to crash.

This was found to be the case for most variables. Since the definitions of variables affecting fire rates differed so much among the states, and since adjustments had insignificant effects, adjustments were not used in combining the data.

Relation of fire rates to damage severity

In Michigan some information about the severity of the accident is given by the TAD scale, which scales the amount of damage to the automobile. Table 8 gives the crash-fire rates for the different versions of the standard by the TAD damage score. The adjusted rates by standard and their estimated standard errors are also presented. Again, the adjustment has had little effect on the rates. In general the fire rates increase with the TAD level. The rates are virtually the same for levels 1–3, then increase somewhat with each level from 4 to 6. A marked increase in fire rates occurs with the TAD level 7. These are, of course, the very severe crashes. Viewing the TAD-specific rates suggests that the 301-68 version of the standard may have reduced the chance of fire in crashes of TAD levels 1–4, while the 301-76 version may have further reduced the chance of fire for crashes of TAD levels 5 and 6. The highest level of TAD appears to be of crashes so severe that none of the standards is likely to have been useful.

A number of other factors could influence the crash fire rate, such as car size. Car size was only available as a grouping full size, intermediate and compact, with fourth category of sub-compact in some states. The effect of car size on fire rates was investigated in those states

Table 8. Crash fire rates (per 1,000 crashes) by amount of damage—Michigan

TAD Damage Score	pre-301	301-68	301-76	All
1	0.91	1.43	1.20	1.32
2	2.17	1.53	1.19	1.43
3	2.96	1.39	1.32	1.43
4	3.82	1.90	1.93	2.02
5	3.81	4.04	2.08	3.40
6	6.38	6.43	3.96	5.00
7	21.63	29.53	21.22	26.72
All	3.14	2.51	1.80	
Adjusted rate	2.90	2.48	1.91	
Standard Error	0.326	0.091	0.113	

where the data permitted. No consistent relationship of crash fire rates to car size was found, nor did the distribution of reported car sizes differ significantly among the model year groups identifying the standard. It should be noted that car size considerations are complicated by the downsizing of cars of recent models as well as by possible interactions between car size and type of crash.

Another complicating factor is the additional emission control equipment required in recent model years. The addition of the fuel evaporation cannister and the catalytic converter may provide an additional source of fuel leakage and an additional source of ignition, respectively. The catalytic converter was added to most U.S. cars with the 1975 model year and operates at a much higher temperature than conventional exhaust systems, providing a more likely source of ignition if fuel is spilled. This addition occured almost at the same time as the strengthened version of the standard and may partially have counteracted the beneficial effects of the standard. Inspection of the fire and fuel leakage data from the Michigan crashes in 1978 show that among cars in crashes that leaked fuel, there is a higher proportion of fires for models from 1975 on than for earlier models. The probability of fire given fuel leakage for models since 1975 is estimated as 0.0793, while for models between 1968 and 1974, it is 0.0521 and it is 0.0459 for earlier models. The chi-squared statistic for testing differences among these three rates is 16.41, with 2 degrees of freedom, highly significant. Partitioning this into a test for the difference between the rates for the 0 pre-1968 and 1969–74 models gives a chi-squared statistic of 0.42, with one degree of freedom, not significant, while the statistic testing for difference between the 1975 and later model's rate and the earlier rate is 15.99 with one degree of freedom, highly significant.

In general, higher fire rates are associated with more severe crashes. The type of crash, the speed of crash, the amount of damage all are associated with differences in the crash fire rates. However, adjustments for these factors changed the crash fire rates relatively little, indicating that the small differences observed in these data in the distributions of crashes by these factors did not seriously affect the rates. It was not feasible to consider these factors jointly, so the question of possible interactions among these factors remains open. It is also possible that other factors influence the likelihood of a post-crash fire. In these data, although fire rates were found to differ widely by other factors, adjustments proved unnecessary, and the percent changes presented in Table 5 appear to be an adequate summary of the changes observed in crash fire rates in the accident populations studied.

EFFECTS OF FMVSS-301 ON FATALITIES

The Fatal Accident Reporting System (FARS) includes data on all cars involved in fatal accidents. Included in the data is a variable that indicated whether a fire occurred in the crash. In addition, the total number of persons killed in the crash is reported. Table 9 gives data from three years (1976–78) of fatal crashes. For each model year of passenger car, the table gives the number of passenger cars in which there was a fatality and which caught on fire. The third column gives the number of passenger cars in which there was a fatality, while the fourth column gives the ratio of cars with fire to all cars with fatalities. Little difference among the fire ratios is apparent, although the differences are statistically significant. What difference there is indicates that fires were slightly more frequent among cars in fatal accidents for the more recent models. A model with a linear trend in age fit the data well, estimating an average decrease of 0.00093 per year of age in the rate. While this is not what one would expect if FMVSS 301 were effective in reducing fire-associated fatalities, it must be remembered that this is a file of cars in which someone was killed in a crash. Given the substantial design changes over the model years, it may be that newer models are less likely to produce a fatality when a crash occurs, and that fire, while a nearly constant ratio with all fatal involvements, is actually less frequent because all fatal involvements are reduced. That is, it may be that fires have been reduced, but that other design changes have reduced the involvement of cars in fatal accidents even more, resulting in a nearly constant or slightly increasing ratio of fires in fatal crashes to all fatal crashes. This cannot be tested without additional exposure data, such as vehicle miles traveled by model year of the vehicle and perhaps other variables.

If one restricts attention to rear-damaged passenger cars in fatal crashes the picture is

Table 9. Passenger cars with fatality—FARS 1976–78

Model Year	Number with Fire	Total Number	Ratio of Fires to Cars	
1978	69	2,167	0.0318	0.0354
1977	149	3,991	0.0373	
1976	194	5,273	0.0368	0.0368
1975	171	4,440	0.0385	0.0312
1974	188	5,932	0.0317	
1973	191	6,426	0.0297	
1972	188	6,212	0.0303	
1971	173	5,588	0.0310	
1970	163	5,421	0.0301	
1969	155	5,059	0.0306	
1968	129	4,422	0.0292	
1967	92	3,652	0.0253	0.0245
1966	78	3,250	0.0240	
1965	69	2,550	0.0271	
1964	31	1,730	0.0179	
1963	21	1,155	0.0182	
1962	19	685	0.0277	
1961	37	1,176	0.0315	
	2,117	69,129	0.0306	

somewhat different. Table 10 presents the data for rear-damaged vehicles from the FARS 1976–78 data. In this table, the ratios of vehicles with fire to all vehicles involved in fatal crashes can be seen to be somewhat decreasing for newer model years of vehicles. The ratio of fire involvements is 6.0% for cars from 1976 models on, while it is 7.9% for models from 1968 to 1974, and 7.7% for earlier models. This would suggest the 1976 and later versions of FMVSS 301, with additional testing requirements for rear impacts may have been effective in reducing the fires in fatal crashes where the cars were damaged in the rear. The trend was in the other direction for front damaged vehicles, side damaged vehicles, and all vehicles involved in fatal crashes, however. It is interesting to note that the rate of fire occurrence in fatal crashes differs by part of the car damaged. Fires occurred in about 7.5% of the rear damaged cars in fatal crashes, in about 1.5% of the front damaged cars, in about 1.6% of the side damaged cars, and overall, in 2.1% of all cars involved in fatal crashes. Fires occurred in 3.1% of the vehicles in which a fatality occurred, emphasizing the additional risk of fatality posed by fire.

Although the rates at which fire occurs in fatal crashes differed significantly by standard, the differences were small, the rates being 0.0238, 0.0311 and 0.0359, for the pre-301, first version and current version. As mentioned, this may be because of the self-selecting nature of fatal crashes. The distribution of vehicles involved in crashes nationwide is not known. However, the NCSS data may be taken as an estimate of the distribution of the vehicles by model year involved in towaway crashes. If this is done, it is possible to compute a ratio of fatal fire involvements to crash involvements—at least as estimated by the NCSS.

This has been done by computing the proportion of each car model year with fatal fire involvements, the proportion of each model year in the NCSS reconstructed population, and taking the ratio of these two proportions. This ratio is plotted in Fig. 3, and shows an improving trend with newer model years. The dashed line is a linear regression line. If the two proportions were the same, the ratio would be one. Model years with ratios less than one are somewhat better than average, while those with ratios greater than one are somewhat worse than average from the point of view of fire involvement.

Table 10. Rear-damaged passenger cars in fatal crashes—FARS 1976–78

Model Year	Number of Cars with fires	Number of Cars in fatal crashes	Ratio of Cars with fire to total cars	
1978	10	159	0.0629	0.0629
1977	21	334	0.0629	
1976	24	421	0.0570	0.0570
1975	24	353	0.0680	0.0789
1974	42	459	0.0915	
1973	43	527	0.0816	
1972	40	482	0.0830	
1971	39	395	0.0987	
1970	31	399	0.0777	
1969	21	391	0.0537	
1968	20	291	0.0687	
1967	14	226	0.0619	0.0768
1966	21	204	0.1029	
1965	10	132	0.0758	
1964	6	109	0.0550	
1963	6	77	0.0779	
1962	6	38	0.1579	
1961	3	73	0.0411	
	381	5,070	0.0751	

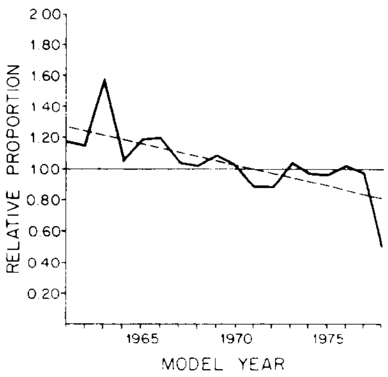

Fig. 3. Relative proportion of fatal-fire involved cars to NCSS—towaway-involved cars by model year.

If the NCSS model year distribution represents the national population well, one may infer that newer cars are less likely to involve a fire, given that they were involved in a towaway crash. Such an interpretation must be made with caution at this point, since the NCSS data may not be representative of the national population. A stronger inference should be possible once the data from the National Accident Sampling System (NASS) become available, and their combination with FARS data in a manner similar to that shown here should certainly be planned.

For eight states for which model year distributions of vehicles involved in crashes were available, the number who died in cars with fires was obtained from the FARS. Table 11 shows the rates of fatalities in crashes with fire to all crashes for these eight states for model years grouped by version of the standard. These fire-associated fatality rates are quite variable. One particularly large rate occurred in Illinois where 22 persons died in crashes with fire in cars of model years later than 1975 during 1977. (Nineteen vehicles were involved, so the large number

Table 11. Fatality rates (per 1,000 crashes) in crashes, with fire for selected states—FARS 1976 and 1977

State	Pre-301	301-68	301-76
Idaho	0.091	0.105	0.000
Illinois	0.191	0.164	0.259
Michigan	0.089	0.051	0.026
Missouri	0.125	0.072	0.062
New York	0.072	0.106	0.087
Ohio	0.097	0.123	0.098
Texas	0.085	0.097	0.114
Washington	0.069	0.127	0.103

of deaths did not result from one or two catastrophic crashes with multiple fatalities.) While some states, such as Michigan and Missouri, show reductions in the rates, others, such as Illinois and Texas, show increases. The overall pattern is unclear because of the variability of the rates, but it is evident that the reductions in crash-fire rates estimated previously were not observed in the fatal crashes—at least on the individual state level.

The number of fatalities in cars that caught on fire in the crash is given for each group of model years corresponding to versions of FMVSS 301 in Table 12. The data are from the FARS for accidents in each of the calendar years 1976 and 1977. The number of vehicles that caught fire when involved in fatal crashes is shown in parentheses in the table. There is no adequate national source for the number of cars involved in crashes during these years separately by the model year groups. In part this is caused by the different definitions of crash among the states. An alterative is to use the number of registered vehicles as denominators for these numbers of fatalities. These data are given in Table 13. However, a complication arises. The registration data are compiled annually, as of July 1 of each year indicated. The registrations are grouped by the version of the standard. No 1978 vehicles have been included, so the latest group contains only model years 1976 and 1977. The data are taken from Wards Automotive Report[1976, 1977 and 1978] and were originally compiled by R. L. Polk.

Because of the difference in the compilation of the fatal accident data and the registrations, it is not clear which year's registrations are best used as denominators. For example, the 1976 fatal data show a small number (56) of fatalities associated with crashes with fire for 1976 models. In part this is due to the lack of exposure of 1976 models during 1976. Most 1976 cars

Table 12. Fatalities in crashes with fire. Number of cars involved in parenthesis

	Model Year			
	Pre-1968	1968-1975	1976-On	Total
1976	171 (156)	587 (480)	56 (47)	814 (683)
1977	152 (145)	642 (555)	188 (158)	982 (858)

Table 13. Passenger cars registered in the U.S.

	Model Year		
Year	Pre-1968	1968-1975	1976-1977
1976	18,706,879	68,463,206	6,408,026
1977	17,544,626	65,624,810	16,734,158
1978	14,130,501	61,535,222	19,864,729

Table 14. Fatality and vehicle involvement rates (per 1,000 registered vehicles) in fatal accidents with fire

	Standard		
	Pre-301	301-68	301-76
Fatalities			
1976	0.0914	0.0857	0.0874
1977	0.0866	0.0978	0.1124
Vehicles			
1976	0.0834	0.0701	0.0734
1977	0.0827	0.0846	0.0944

did not have a full year's driving exposure during 1976. On the other hand, using the registrations as of 1 July 1976 excludes all 1976 models sold after that date, presumably a substantial number. The use of 1976 registration with 1976 fatalities seems best—the lower number of registrations may approximately offset the reduced exposure. Table 14 gives the fatalities in fatal accidents with fires divided by the registrations. The table also presents the proportion of vehicles involved in fatal accidents with fire to the registered vehicles for each of the two years. Inspection of these rates makes it apparent that the hoped for reduction of fatalities in crashes with fires has not been observed. While the proportions decrease in the 1976 data, they increase in the 1977 data as one moves across the table from left to right, corresponding to the earlier to later model year groups.

While there are certainly limitations in the data, it seems a reasonable conclusion that the FMVSS 301 has had no observable effect on fatalities in crashes with fires. It is possible that the other factors in the fatal accidents have changed and have covered up a possible effect of FMVSS 301. However, it is unlikely that such factors would have obliterated a beneficial effect as large as some expected[Cooley, 1974]. It also seems that the reduction in crash fires observed coincident with the standard has not translated itself over into a corresponding reduction in fatalities.

It should be noted that these fatalities are fatalities that occurred in crashes with fire. The fatalities did not necessarily result from the fire. Some would have occurred whether or not there was a fire, some may have resulted directly from the fire, and some may have been contributed to by the fire. In general, detailed autopsy results are necessary to determine whether a particular crash fatality resulted from a fire, from other injuries suffered in the crash, or from a combination of injuries from the crash and burns from the fire. Such data are not available in the FARS. Cooley[1974] compares a number of data sources on crash fire fatalities and concludes that from 50 to 60% of the fatalities in crashes with fires resulted from the fire, at least in part. That is, these fatalities might not have occurred if there had been no fire. At least some of these, however, involved life threatening injuries besides those resulting from the fire. Thus any effect that FMVSS 301 would have on fatalities in crashes accompanied by fire would presumably apply only to the 40–50% fo the fatalities that were caused in part by injuries resulting from the fire.

SUMMARY

The main purpose of FMVSS 301 was to reduce deaths and injuries resulting from fires in automobile crashes. It aimed to accomplish this by strengthening the fuel sustem to reduce the fuel spillage in a crash, thereby reducing the chance of fuel-fed fires. The data on fuel leakage in crashes are quite limited and rather mixed, but it does appear that the chance of fuel leakage in a crash is reduced for more recent model year cars. Whether this is a result of the standard or a consequence of the fact that these cars were newer when they were involved in a crash cannot be determined.

Data on occurrence of fire in a crash were more plentiful. There were large differences in definitions and consequently in the levels of fire rates among states. As a consequence the data were converted to percent changes for calculating a consensus result. A significant reduction in post-crash fire rates was observed to coincide with each of two versions of FMVSS 301. This does not appear to have been a result merely of the different ages of the cars, and adjustments for other variables such as type of crash proved to result in little change. While it is not possible to ascribe causality, it seems a reasonable conclusion that the standard resulted in significant reductions in the occurrence of post-crash fires.

Data on injuries were too limited to be of use or could not be related to fires. In order to be used such data would have to include information about the types of injuries suffered in crashes with fire, so that the injuries not resulting from the fire could be separated from the additional injuries resulting from the occurrence of a post-crash fire.

To some extent, the same is true of fatalities. Many fatalities (about half according to Cooley[1974]) in crashes with fire would have occurred even if no fire had resulted from the crash. In the other half of fatalities in crashes with fire, the injuries reported on the autopsy reports reviewed by Cooley would not necessarily have been fatal had they not been accompanied by burns or additional injuries caused by the fire. No reduction in fatalities in crashes with fire was observed. If the estimated reduction in crash fires had carried over to result in a reduction in fatalities, a reduction of fatalities in crashes with fire of from 7 to 13% would hve been expected, allowing for half of the fatalities in newer models in crashes with fire to have resulted whether or not the fire occurred. This was not observed. It may be that the variability of the fatals is too large to observe such a small change. This is suggested by the fact that a reduction in fatals in crashes with fire was seen in 1976, but an increase was observed in 1977. Another possibility is that the use of registration data (owing to the lack of national crash data) obliterated any change. It may be that the nature of crashes resulting in fatalities has changed, being more severe crashes than in the past, thus making fires more likely, but being in general such severe crashes that survival would be unlikely even without a fire.

CONCLUSIONS

FMVSS 301 appears to have been effective in reducing the incidence of post-crash fires by about 25% compared to pre-standard vehicles; by about 13% for the latest version of the standard, compared to the first version of the standard; and by about 16% for the first version of the standard compared to pre-standard vehicles. Other factors may have contributed to the reduction, but several possible factors apparently did not. While a reduction in post-crash fire rates associated with the standard seems reasonable, a similar reduction in fatalities could not be demonstrated. Thus, there is some question of the effect of the standard on its primary goal. The data on fatalities are far from conclusive and it is possible that a reduction may be evident when more data are available.

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