IMPACT INDUCED FIRES & FUEL LEAKAGE: STATISTICAL ANALYSIS OF FARS AND STATE DATA FILES (1978-2001)

FINAL REPORT

VOLUME I: RESEARCH

PREPARED FOR
MOTOR VEHICLE FIRE RESEARCH INSTITUTE

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VOLUME I: RESEARCH

ORGANIZATION OF THIS REPORT

The final report, *Impact Induced Fires & Fuel Leakage: Statistical Analysis Of FARS And State Data Files (1978-2001)*, includes information from previous progress and task reports delivered to MVFRI and additionally a comprehensive analysis of the findings, implications for data collection and future research. There are three volumes to this final report: Volume I includes the full report of all research tasks in the project. Volume II includes the Appendices with full description of national and international data sources. Volume III includes all papers, reports (hardcopy and electronic format) and annotated bibliography referred to in this project (Volume III is available from MVFRI). All references in electronic format have been copied on a CD in pdf form and those references that were available only in hard copy have been complied in Volume III: *Papers, Articles and Reports*. A full bibliographic reference has been included in CD format as entered into the GM Fire Bibliography

Volume I, *Research*, is organized into sections that correspond with the contract tasks in the following manner. Task I, the literature review of fire and fuel leaks in post-collision passenger vehicles is under Section I. Task 2, the evaluation of data sources of passenger vehicle post-crash fires is in Section 2. Task 3, the replication of Malliaris' methodology in the analysis of Michigan accident data and FARS is in Section 3. Task 4 the analysis of the Maryland accident files is in Section 4. Task 5, the Pennsylvania and Illinois State analyses is reported in Section 5 and 6, respectively. Task 6, identification of data requirements for improved accuracy is presented in Section 7. Finally, Section 8 concludes with overall recommendations and closing summary.

SECTION 1: THE LITERATURE REVIEW

The purpose of this literature review was to identify technical reports, journal articles, and conference presentations on post-collision fires in light passenger motor vehicles. Specifically, we were interested in research reports that addressed issues of incidence, research methods, data analysis, and evaluation of this phenomenon.

We used a combination of methods to retrieve the available literature including Department of Transportation Docket, numerous on-line literature databases, University of California Government Publications Library, University of California Libraries Melvyn System, National Technical Information System, Society of Automotive Engineers, and the Motor Vehicle Fire Research Institute. The subject keywords used to search the literature databases are listed as column headings in Table 1.1. Because our purpose was to identify a narrow range of publications within the broad area of motor vehicle fires, we eliminated those articles that related specifically to the testing of flammability and development of basic compounds for fuel tank and vehicle interiors. Additionally, papers that were only related to the development and testing of experimental vehicle designs, fuel systems, and fuel tanks were excluded.

The specific electronic literature websites used to identify articles, papers, proceedings and reports are reported in Table 1.1. All available years on electronic file were searched and other non-electronic sources were reviewed to cover the years from 1950s to present. The earliest article identified was published in the year 1951.

Search of Literature Databases

The electronic databases employed represent national, private and public sites, government publications, and international sources. Many of these sites overlap in the literature sources that they access, so the numbers found on certain search criteria represent a great deal of overlap. The international sites produced on a small percentage of documents with most of those being found in Great Britain and Australia. Some of those documents found on non-US databases had a significant proportion of US based literature and duplicated what had already been identified in the other databases. The most comprehensive electronic databases that included both national and international sources were COMPENDEX, INSPEC, ITRD, PASCAL, TRIS ON-LINE, LRC Online, and FIREDOCS. The United States Fire Administration (USFA) and the Building Fire Research Laboratory have electronic databases and although these sources include all types of fire, there was some attention to fire in motor vehicles including both non-crash and crash incidences. Government publications on the DOT/GM Settlement were directly accessed through the DOT Docket site with the exception of two documents (Ray & Lau, 1996; GESAC, 1994) that were acquired through MVFRI.

It should be noted that although a number of articles may be identified with the subject headings as indicated in Table 1.1 that only a small number of these articles were relevant to the focus of this review and many represent duplication of papers listed in other sources. The final number of papers that were included in the literature review was 78. Each of these documents was recorded in Endnote6 (software for literature catalogue system, www.niles.com) and GM ACCESS Bibliography. Endnote6 has the advantage of linking directly to a text document with the full information on the citation and was used to create the reference list in this literature review. Both Endnote and ACCESS have information on each reference including author, title, source, report numbers, and abstract

Table 1.1 Sources and Yield in Literature

	Descriptors and Yield																
SOURCE CHECKED	**fire**	**fire & accident**	**leak**	**fire & fuel**	**leak & fire**	**fire & fuel & vehicle**	**fire and crash**	**leak and vehicle**	**leak and fuel**	**fire and crash and vehicle**	**fire and accident and statistic**	**fire and accident and vehicle**	**leak and fire and vehicle**	**leak and fuel and vehicle**	**leak and fuel and crash and vehicle**	**leak and fuel and accident and vehicle**	**fire and vehicle**
IIHS	95	30	13	16	9	16											
Elsevier publications (includes Fire Safety Journal)	41		0														
USFA LRC Online Card Catalogue	>20000	>300	109	>300	38	10	>300	3	4	19	21	111	2				
Center for Accident Research and Road Safety Queensland Australia CARRS-Q	0		0														
Injury Research Centre - University of Western Australia	0		0														
Vicroads (Australia)	n/a 0		n/a 0														
Traffic Injury Research Foundation (Ottawa, Canada)	n/a 0		n/a 0														
Transport Canada	>300	>300	>300	6	0	0	1	13									
Danish Transport Research Insitute (Danmarks TransportForksning)	0		0														
Finnish Road Association	7	4	0	3	0	2	0	0	0								
VTT Technical Research Centre of Finland	0		0														
French National Institute for Transport and Safety Research (INRETS)	1																

Table 1.1 (cont'd) Sources and Yield in Literature

SOURCE CHECKED	fire	fire & accident	leak	fire & fuel	leak & fire	fire & fuel & vehicle	fire and crash	leak and vehicle	leak and fuel	fire and crash and vehicle	fire and accident and statistic	fire and accident and vehicle	leak and fire and vehicle	leak and fuel and vehicle	leak and fuel and crash and vehicle	leak and fuel and accident and vehicle	fire and vehicle
Columbia University Library	65	5	5	2	3	1											
IRTAD	n/a 0		n/a 0														
TRL (England)	4	0	0														
Northwestern University	6647	151	178	92	2	3	24	0	3	1	0						
University of California, Institute of Transportation Studies	0	0	0	0	0	0	0	0	0	15	0						
TRIS Online	1623	871	602	403	52	101	237	58	75	100	79	227	8	17			
International Transport Research Documentation Database (ITRD)	1814	426	164	164	12	101	103	28	26	80	67	224	3	11	2	4	
COMPENDEX	23051	2504	8115	2172	195	60	155	136	446	32	35	102	4	25	0	2	
ICONDA	15044	837	547	234	24	3	15	3	9	1	23	9	0	0	0	0	
INSPEC	11243	677	5935	594	64	14	35	94	368	3	14	25	3	12	0	0	
PASCAL	20813	904	8312	999	110	14	58	78	175	19	22	40	4	11	1	1	
Monash University	10		0														
RARU Road Accident Research Unit Adelaide University Australia	0	0	0	0	0	0	0	0	0	0	0	8					80
SAE Highway Vehicle Safety Database	>500	48	64	79	2	17	59	8	22	32							
FIREDOCS	36826	457	38	714	21		126	3	9								757

History of FMVSS 301

Because FMVSS 301 has played an important role in guiding those studies examining effectiveness of fire vehicle safety, Table 1.2 presents the chronological development of the specific features of the Standard.

Table 1.2 FMVSS 301 Revision Summary

EFFECTIVE DATE	VEHICLE TYPE	s6.1 frontal perpendicular	s6.1 frontal oblique	s6.2 rear	s6.3 side	s6.4 rollover	s6.5 any impact location with a contoured barrier at 30 mph	Requirement
January 1, 1968	passenger cars	30 mph						less than 1 oz/min for 5 min post impact
September 1, 1975	passenger cars	30 mph with dummies in front outboard positions and any other positions required by 208				static		barrier crash 1 oz until vehicle motion stops, 5 oz/5 minutes following stop; 25 minutes after that < 1 oz/minute in any 1 minute interval; rollover: 5 oz/ 5 minutes at each 90 degree increment. At each increment of 90 degrees spillage during any 1 minute interval not more than 1 oz/minute
September 1, 1976	passenger cars	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph moving barrier w/dummies in front outboard positions	20 mph with dummies in positions required by 208	static after impacts s6.1, s6.2 or s6.3		same as above
September 1, 1976	mpv, truck and bus with gvwr < 6000 lbs	30 mph with dummies in front outboard positions and any other positions required by 208		30 mph moving barrier w/dummies in front outboard positions		static after impacts s6.1, s6.2 or s6.3		same as above
September 1, 1977	mpv, truck and bus with gvwr < 6000 lbs	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph moving barrier w/dummies in front outboard positions	20 mph with dummies in positions required by 208	static after impacts s6.1, s6.2 or s6.3		same as above
September 1, 1976	mpv, truck, bus gvw >6000 and < 10000	30 mph with dummies in front outboard positions and any other positions required by 208						same as above
September 1, 1977	mpv, truck, bus gvw >6000 and < 10000	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph with dummies in front outboard positions and any other positions required by 208	30 mph moving barrier w/dummies in front outboard positions	20 mph with dummies in positions required by 208	static after impacts s6.1, s6.2 or s6.3		same as above
April 1, 1977	schoolbuses gvw > 10000						any speed up to 30 mph	barrier crash 1 oz until vehicle motion stops, 5 oz/5 minutes following stop; 25 minutes after that < 1 oz/minute in any 1 minute interval

The history of the Fuel system standards extends prior to FMVSS 301. For example, by January 1963 the American Standards Association had inspection standards and fuel system inspection requirements. By 1967 the General Services Administration (GSA) had a front, side and rear impacts (10-12-1967) crash test requirements for cars, buses, station wagons, carryalls, and trucks to 10,000 lbs. On Jan 31, 1968 the Department of Commerce had 30-mph crash test requirements for maximum leak rates, tank filler pipes and connections (Fairchild Hiller, 1967). It is noteworthy that the GSA requirement was a more comprehensive standard than the original NHTSA FMVSS 301-1968. It wasn't until September 1, 1976 that 301 was modified to reflect the GSA set of impact conditions, however, it still only applied to passenger cars despite GSAs applications to a broader range of vehicles in 1967. As indicated in Table 1.2, in September 1, 1976 National Highway Transportation and Safety Administration (NHTSA) also had requirements for MPVs, trucks and buses with GVWR less than 6000 lbs. Finally, on September 1, 1977 this group of vehicles had the same minimal test requirements as passenger cars. As Parsons (1990) commented, it is evident that even these test requirements do not address the real world impact conditions of collision related fires such as speed and impact characteristics.

It must be recognized that while the effective dates of the FMVSS 301 requirements typically will correspond to the following model year (e.g. 301 September 1, 1976 refers in effect to vehicle model years 1977 and later), due to the existence of other requirements/standards and advanced notice of proposed changes, one could expect that many vehicles prior to the 1977 model year would already have met the 1976 Standard. As a result, any evaluation of the effectiveness of 301 would have to take the historical context of the proposed changes into account when grouping model years pre- and post-standard. In the review of epidemiological evaluation studies of Standard 301, this potential grouping problem should be considered. As we will discuss later not many, if any, studies address this salient issue. Further, due to the non-representative nature of the speed and impact characteristics of the requirements, the Standard's effect may be minimal. Thus, perhaps, explaining some of the findings reported in subsequently reviewed reports.

In this review we will refer to the version of FMVSS 301 by the month and year of the effective date [301 (9/1976)]. Although it has not been observed that earlier reports reference month, it is evident from Table 1.2 that the same effective date had a different meaning dependent on vehicle type. For example, in September 1, 1976 passenger cars, light trucks and buses (GVW less than 6000 lbs.) all had to meet different crash test requirements.

Chronological and Topical Areas in the Literature

Although collision-related fires in motor vehicles do not occur in every accident, their potential for severe injury and fatality has made them a subject of scrutiny for the better half of the last half century. The estimate of the number of impact associated car fires in the United States has been reported by Malliaris (1991) as 10,000 crash related car fires per year and about 900 of these in fatal accidents. Other investigators have estimated anywhere from 1 fire per thousand police reported crashes in passenger cars (Cooley, 1974), 2 fires per thousand vehicle accidents in Michigan (Malliaris, 1991) to 2.9 fires per thousand accidents in passenger cars and light trucks (Parsons, 1990). The wide range in this estimate is, in part, reflective of the difficulty in estimating the occurrence of fire in vehicle accidents given the existing character and structure of national and state databases.

The literature reports fall into two distinct periods—pre- standard years from 1951 through 1967 and post 1967 when the original version of the Federal Motor Vehicle Safety Standards (FMVSS) 301: Fuel System Integrity was promulgated. Table 1.3 presents the technical reports, articles, and proceedings papers that were covered in detail in this review. These sources are arranged chronologically. Table 1.3 summarizes the information of each study under the headings: date, author, purpose of the study, data sources, primary variables of interest, and major findings.

Table 1.3 Chronological Listing of Literature Review

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1951	Dunn	collision death due to burns					10% of death certificates from US in 1948	All types of accidents	2550 deaths (7.9%) associated with motor vehicle collisions. Data disputed by Cooley 1974
1964	Campbell & Kihlberg	Update figures of fire in ACIR; frequency of fire-rear & front engine cars; trend of fires across car model year.				ACIR (33,250 cases to 1963)		Model Yr 1951-1962	No difference between front and rear-engine cars; 1955-1958 models were comparatively higher incidence of fire
1965	Robinson	Frequency of secondary fires, occupant burns to crash type & accident severity					156 fire incidents		Greatest incidence in frontal and rollover incidents; rear impact <50% than frontal or rollover; fire damage, fatal burn highest in rollover; rear greater than frontal or rollovers for non-fatal burns
1966	Robertson	Design of fuel system to protect spillage even with structural failure							Recommendations for tough, flexible, smooth contoured fuel tanks mated to flexible fluid lines that survive beyond human survival range in collision
1967	Fairchild Hiller	Fire & fuel system design test program		Partial data CA, CT, KY, MI, TX, VA, IL			Data from other studies that included partial data from CA CT KY MI OR TX VA IL & varying periods from 1954-1964	Buses, school buses & passenger cars: Model year, impact type: occupants injuries as a function of impact type, burns seated position & type of impact	Recommendations for data collection on fire nationwide with CA Police Reports as a model. Data will provide a base for effective fuel design.

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Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1968	Severy et al	3, 55 mph rear-end collision experiments						seat, backrest, head restraint	First published data on the initiation and propagation of fire-related, vehicle collision events
1970	Brayman	Fuel Leakage Rates					ACIR & AMA data	Experimental data program	Leaks ACIR data 7.2% & 8.9% AMA data of injury producing accidents
1970	Gatlin & Johnson	Assess damage to electrical system collision fires					200 vehicles (1000-6000 lb) in wrecking yards	probability of electrical component damage from collision	Design recommendations for electrical systems
1970	Siegel & Nahum	Examine relationship of vehicle design, human and environmental with post crash factors of injury & survival			LA city & county fire departments 1966-1969		Identification & description of 4 post-crash time periods	Response time, extrication, ejection, occupant egress, vehicle structure; & auto fire; fuel system design; materials	Fires from collision 5%; collision fires represent 12% of all reported fuel leakage; fire & fuel leakage occur in 4% of collision; vehicle collision fires <.5%
1970	Sliepcevich, Steen, et al	Escape worthiness of fire and submergence in vehicles		OK 1967-1969 (approx)		Death Certificates Dept of Health; Police reports; Newspaper microfilms	OK 105 cases; 65 vehicles with fire & 24 submergence	Surveyed state data for submergence & fire; parameters of safe egress	Not sufficient data for full analysis. Non-fatal cases had only 4 months data. Identified parameters for ease of egress; presented research plan for quantification of data.
1972	King, Abston, & Evans	Epidemiologic study of pediatric burn victims in motor vehicle accidents			Galveston shiners Burns Institute for Children (1966-1972) 3% of cases =38			Nature & origin of burns on 38 cases	Major contributing factors to vehicle fires: fuel spillage & match playing in stationary vehicles; flammability of clothing & vehicle interior; major trauma to burn victim. Recommendations for federal standards.

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1972	Sliepcevich, Steen, et al	Escape worthiness of fire and submergence in vehicles		OK 70-71 KS 70-71		Police accident reports & fire personnel reports. *National Electronic Injury Surveillance System & National Burn Information Exchange recommended for follow-up.	145 post-crash fires in OK; 66 post crash fire fatal accidents (51 from burns) in KS	Escape times from cars and buses for fire & submergence; ignition times and burning rates of interior materials	Extensive (799 entries) bibliography of fire & submergence, concluded literature inadequate; incidence of fire & burn injury cannot be established; presented a predictive model for escape time; relationship between ignition characteristics & burning rate
1973	Campbell	Freq & severity of collision fires		North Carolina Police Accident Reports			Reviewed 240k cases	Content analysis of keywords (e.g. fire, flame, burns)	Identified 100 cases through content analysis
1973	Pursell & Hoag	Escape worthiness & flammability					Experimental	Entrapment, submergence & fire; emergency egress from school & city buses; flammability of materials	Development of methodology for measuring escape worthiness using human subjects. Suggestions for vehicle design.
1974	Austin & Wagner	Examine fuel-leakage, post-crash fire, extrication, submergence, & emergency care		Utah 1-year 5 county region			Supplemental data sheets for police agencies	Details on type of fire, driver demographics, accident type & severity; climatic conditions; extrication by vehicle type & year	Post-crash variables of interest occur in 8% of vehicle accidents (.22% chance of post-crash fire; <.22% chance of additional injuries)
1974	Cooley	Freq of fires, fatalities, types of crashes, fuel leakage				HSRI	traffic, medical & death records		Recommendations for FMVSS 301. Predicted that 180-260 fatalities could be prevented with new standard
1974	Severy, Blaisdell, & Kerkhoff	Determine factors that contribute to fuel system failure modes & collision fires					73 collision fire case studies	8 exp'tal collisions: impact speeds, nature of injuries, climatic conditions	Design concepts for limiting fuel spillages, ignition sources, & thermal stress to occupants

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1975	Austin, Wagner, Hogan, & Bryner	Examine post-crash factors, fire, submergence, fuel leakage, and extrication-evacuation in automobile collisions.		Utah Aug 1972-Sept 1973			43 incidents, 29 collision fires	Fuel fed 23 of the 29 cases, tire fires (2), electrical fires (2), trailer carrying fuel (1)	Fire departments & police investigators of incidents seen as more reliable source of data than newspaper accounts & wrecker yards
1975	Environment & Man	Method for evaluating FMVSS 301	Yes	NC TX NY			Fire dept Police Death Certif.		Recommendations for standard on smoke emission, toxicity of combustion, ignition sources, burn rate of materials
1979	Flora, Bleitler, Bromberg, Goldstein & O'Day	Evaluation of FMVSS 301	Yes		Yes			aging NOT accounted for	25% less of pre-standard; 13% "76 to original standard; 16% original to pre-standard
1981	Cooley	Non-collision fires		Fire department responses in Michigan 1976-1977					Recommendations for standard on smoke emission, toxicity of combustion, ignition sources, burn rate of materials
1981	Flora & O'Day	Journal report of 1982 NHTSA final report							see Flora & O'Day 1982
1981	Reinfurt	Evaluate FMVSS 301(1967)		NC mid 1971-1978		NCSS	109 cases from NCSS	Nat'l: car weight, impact site, object struck, type of collision, driver injury. NC: speed, impact site, vehicle age	Initial standard did not have the desired effect of reduction of post-crash fires & showed and increase in fires of model years after Standard
1982	Flora & O'Day	Effect of FMVSS 301 (1975-1977)		IL 1975 - 1980 MI 1978-1980 PA 1977-79				Cars & light trucks. Crash type, severity, & vehicle age	No effects for 1968 Standard for recent model years with age & crash severity controlled; incidence of fire < for angle, rear, & rollover impacts.
1982	Reinfurt	Evaluate FMVSS 301(1976)		NC 1971-1981 MD 1977-1980			NC Police narratives	Compared model years 1969-1975 to 1976-1981	FMVSS (1976) marginally effective with decreases in NC, but not in MD

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1983	Parsons	Evaluate FMVSS 301 (1975 upgrade)		MI (1978-1980) IL (1977-1980), NC (1971-1981), MD (1971-1981), PA (1977-1979)				Passenger cars pre & post 1976 model year ; impact speed, direction, type & fuel leakage in MI	Significant reduction on car fires, fewer fatalities,& injuries; with low & moderate crash severity only frontal impact were statistically significant; fuel leakage reduced in MI
1983	Warner, James, & Woolley	Review the injury & fatality rates of fuel fed fires							Recommend trained investigators for fires in collisions to augment police reports before any further safety improvements.
1985	Cole (2nd edition)	Method for investigating collision & non-collision vehicle fires							Detailed description of forensic evaluation of collision & non-collision fires (one of several books/manuals by Cole)
1985	Fire Research Station	Increased incidence of car fires in England						Car fires have doubled with only 25% increase in cars on road (England)	Concludes that increased electronic complexity in cars has increased incidence of fires
1988	Steilen	Examine the current risk of fuel tank-related fires.	FARS		NFIRS			Describes the FARS & NFIRS database	Of 6 data sources only 3 had fire information: NFIRS, GM studies, SAE #850092 Fuel tank fires account for 31% of total collision fires.
1989	Whitaker	Interpretation of vehicle fire statistics in UK				UK Fire Statistics 1977- 1987		Type of vehicle; cause of fires; types of fires; sources of ignition	Clarification of statistical data interpretation in regard to collision related vs. non collision related fires. Recommendation for a taskforce for data collection on fires.

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1990	Parsons	Evaluate FMVSS 301 (1975-1977 upgrades)	1975-1988	MI IL, OH, IN MD 1982-1987				Passenger vehicles; light trucks; school buses (variables similar to Parsons 1983 study)	301 reduced fires in passenger car crashes; for light trucks no reduction found; school buses too few cases. Unclear whether 301 reduces fatalities due to fire; fires in vehicles have increased due to vehicle age.
1991	Malliaris	Examine post-crash fires & fuel leakage	1975-1988	MI 1978-1985				MI variables include: impact severity, mode, car size & age.	Reported reduction in post-impact fire from 1977 forward.
1991	Radwan, Al-Deek, Garib, & Ishak	Identify best sources for fire-related information for trends and causes.		FL Fire Marshall (1988-1991); Fl Dept of Highway Safety & Motor Vehicle Data (1986-1991)		Highway Loss Data Institute non-crash fire data (HLDI: 1986-1988)		origin of fire; vehicle type & year; month of year	1st origin engine area (60%); passenger area (15%); type of crash (40%); gasoline (25%); oil leak (18%); 1979 models highest rate of fire, 2nd 1984; HLDI sports & specialty models have higher non-crash fire than 4-door sedans;& mid-size has the highest % of non-crash fires.
1993	McCarthy, Anderson, & Donelson	Examine the effects of FMVSS standard	1979-1991					1975-1977 subcompact	No difference with strengthened standard with the lightest vehicle

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1994	Tessmer	Examine fires in passenger cars, light trucks, and vans post 1978 FMVSS 301	FARS 1979-1992	Michigan PAR 1982-1991	NASS CDS 1988-1993			FARS: Model Year 1978-later cross - tabbed with PAR data on fuel leaks; burn injuries from NASS CDS on cars, light trucks, & vans; age & weight of vehicle; impact type; speed of impact	Rate of fatal 1978 or newer car crashes form 1979-1992 averages 2.42%. In Michigan from 1982-1991 the average is 4.30%.The rate of post collision fires in all 1978 or newer cars in Michigan is 0.18%. Vehicle age has a significant effect on fire. Light trucks have relatively more fires than cars & vans. Cars in fatal crashes struck in rear are 140% to 340% more likely to have a fire/MHE fire. Fires originating in fuel system rather than engine compartment result in major fires.
1994	GESAC, INC	Examination of post-collision fire incident cases to identify factors reported in reports	Yes 66 cases obtained & 28 cases used (years not specified)			NASS 1981-1993 150 cases		Passenger cars & light trucks; only cases with AIS=>2	Data base created with crash characteristics, occupant information, cause & origin of fire and fuel system design

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1996	Ray & Lau	Evaluate the comprehensive nature of state & national traffic accident data, fire incident report data & published data analysis from a variety of sources related to collision & noncollision vehicle fires.	Characteristics & history of database	Detailed examination of AK, AL, FL, MA, MI, NY, NC, PA, TX	Yes	CDS & GES of NASS National Fire Protection Ass'n (NFPA)		Literature review of studies that identified sources of statistical data related to vehicle fire.	Detailed description of state & national databases & recommendations re: reliability of databases on fire variables
1997	Griffin	Reliability of FARS for fires in passenger cars and light trucks	1987-1989			MCOD (Nat'l Center for Health Statistics)	46 PARs from TX	Passenger cars & light trucks	Rank ordering of states for vehicle fires shows great variability that suggests lack of consistency in coding; under-reporting of fire in FARS based on N-codes; unreliability of MHE coded as fire or crash
1998	Ohlemiller & Cleary	Determine the flammable characteristics of motor vehicle fluids.					Experimental	significant threat of fire hazard with flammable liquid spills in motor vehicles.	Preliminary data on the fire point of gasoline/vehicle fluid mixes, estimates of fire size from gasoline leak rates, and approximate heat flux exposure time to ignite the surface of typical vehicle plastic components are analyzed
1998	Lavelle, Kononen, & Nelander	Examine the comprehensive nature of national & state databases with respect to motor vehicle fires.	Yes	Yes	YES	NASS-GES NASS-CDS NFPA Survey		Interested in vehicle type & age; driver age & gender, crash mode & severity sequential crash-relat3d events; leakage; source of ignition; & injury consequences.	Recommendations: link MCOD to FARS records for better classification of fire related fatalities; states to add common crash-related fire variables; implementation of field investigation programs with trained fire investigators; linkage of police reports & fire personnel incidents.

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
1998	NHTSA	Proposed rulemaking to upgrade FMVSS 301						Criteria for fuel system components; crash test procedures for existing Standard; role of environmental & aging factors on fuel system	More stringent rear impact text procedure; replace lateral impact test with Standard No 214 side impact test.
1998	Ragland	Determine whether death was caused by fire or blunt trauma	1990-1993 214 cases with 292 fatalities				Case studies of FARS selected cases	Type & speed of impact;	65 fatalities from burn; 46% rear impact; 23% frontal; 15% side; 11% rollover in 1995;Ave speed 54mph (71% overlap); Estimating nationally between 94-191 rear impact fire related fatalities
1998	Shields (SAE presentation)	Case studies of motor vehicle collision fires						Viewgraph presentation of preliminary work	
1998	Shields, Scheibe & Angelos	Examine collision fires in detail				Source of cases not identified.	13 case studies with photographs, inspection results, witness & investigators statements	Fire propagation & paths, injuries	Recommendation of methods for data collection & analysis
1999	Scheibe, Shields & Angelos	Identify factors related to collision fires					21 field investigations w/ autos, pickups, vans, sports utility vehicle. 3 chosen for report.		Complex set of factors contribute to fires; all liquid fuels potential fire source; damage to electrical system ignition source; frontal impacts did not involve leakage
2000	NHTSA	Proposal to amend the rear & side impact tests of FMVSS 301							More stringent offset test using a lighter deformable barrier at 80km/hr. Replacement of the side test with the FMVSS 214 (side impact protection) test. No changes are proposed for the frontal barrier crash test for 301.

Year	Author	Purpose	FARS	State	NFIRS	Other	Field	Variables	Findings
			Data Sources						
2001	Griffin	Comparison of fatalities with & without fires	1994-1996					Passenger cars, light trucks, vans, utility vehicles; impact severity, driver, & environmental factors	Most severe crashes with male driver between 10 pm-4 am; striking vehicles more likely to have fires; single-vehicle crashes hitting trees >likely to have fires; vehicles overturning have less likelihood of fires.
2001	Griffin & Flowers	Examine fire-related injuries & fatalities		NC 1991-1996			172 cases from NC	Includes passenger cars, SUV & light pickups; TAD scale for single & multi-vehicle crashes; used statistical modeling analyses	Concluded that drivers were 4.29 times as likely to die as drivers involved in comparable crashes without fire
2001	Shields, Scheibe, Angelos, & Mann (final report of Shields 1998 SAE paper)	Case studies of motor vehicle collision fires				Interviews with police, fire personnel & witnesses; field inspections	35 incidents from 367 (3 non-collision; 21 frontal impact; 4 rear impact; 5 rollover)	Created ACCESS database with case information	Concluded that windshields, hood openings, open doors and deformed metal openings led to propagation of fire to interior.
2002	Davies & Griffin	Examine fatalities related to fire & context of event; clinical evaluation	Yes from NC and TX	TX 1990-92 NC 1995-96		PARS & Medical Examiner Reports	206 cases examined cause of death; police accident reports and medical examiners	Fatalities in post-collision fires	High percentage of fatalities were not related to fire; 21% of deaths due to fire & 79% from mechanical trauma of those crashes with fires.
2002	Griffin, Davies, & Flowers	Examine reliability of the FARS & state databases in relation to fire-related incidents & injury.	FARS 1987-1989; 1994-1996		NFIRS 1994	MCOD CODES (WI, UT)		ICD injury codes; passenger vehicles (light trucks, cars) fire injury; AK injuries	Large inconsistencies in states' reporting of vehicle fires & most harmful events & fatally related cause of death; inconsistencies within states in reporting of fires; more fire injuries than reported in FARS; unreliability of NFIRS opportunistic data.

Prior to FMVSS 301, there were a number of papers that assessed the prevalence, injury and fatality characteristics of occupants and post-crash events of fire-related collisions. These studies provided a documentation of the severe occupant consequences of fire-related accidents, vehicle design elements that contribute to such injury and emergency response and extrication issues that accompany vehicle fires.

After the promulgation of the original Standard (FMVSS 301 1/1968), researchers responded with numerous studies that assessed its effectiveness in reducing collision related, vehicle fires and post-crash fuel spillage. The revisions to FMVSS 301 effective 9/1975, 9/1976, and 9/1977 (see Table 1.2), also initiated a series of studies on the effectiveness of the Fuel Integrity System Standard. As researchers focused on epidemiological evidence for effects of FMVSS 301, they began to address the reliability and validity of accident reporting databases as related to vehicle fire variables. Within the pre- and post- era of FMVSS 301, there are distinct topics and methods reflected in the literature. Authors have systematically distinguished the following categories of investigation: a) collision versus non-collision events, b) fuel system design and fuel spillage, c) fire initiation and propagation, d) post-crash sequelae, and e) flammability standards for vehicle interiors.

Of these topics, this literature review focused on fires related to collision and post-crash sequelae. We did not examine basic engineering studies on fuel design or material flammability, but these issues are indirectly discussed in early studies on fire incidence and occupant injury. Of particular importance to this review, were methodological issues that surround the accuracy of databases and the multi-method approaches described to characterize motor vehicle, collision-related fires. Investigators, through the years, quickly discovered that any epidemiological examination of the incidence and character of post-collision fires must rely on existing national and state databases or the development of case study or field investigations. Problems associated with the national and state accident reporting systems has prompted considerable scrutiny and recommendations for a more comprehensive and linked data collection effort in relation to motor vehicle fires has evolved. In general, data collection issues have entailed an underreporting of the incidence of motor vehicle fires and fuel leaks in Police Report Records (PAR), lack of information on post-collision events that have involved fire, and a lack of comprehensive descriptions of the sources and propagation of fires and fuel spillage. The methodological studies that address these issues provide a critical perspective on any interpretation of data-based findings. Section 1 discusses the various issues relevant to national and state databases as reported by other authors; in Section 2 (*Evaluation of Data Sources*) we discuss our own findings relevant to this topic. Table 1.3, *Chronological Listing of Literature Review*, presents the author(s), purpose, databases analyzed, primary variables and findings of all the studies reviewed. The authors' affiliations are available in the Volume III of this report

Early Years Pre-FMVSS 301

Early reports on the character of collision-related, vehicle fires were concerned with impact type and fuel system design as they related to occupant injury and fatality. Dunn (1951) examined ten per cent of the death certificates in the United States and determined that 2550 deaths were resulted from burns in vehicle fires. In 1964 Campbell and Kihlberg (Campbell & Kihlberg, 1964) used the data from the Automotive Crash and Injury Research (ACIR; Cornell University) to update his figures on the frequency of fire in rear and front engine cars as well as the trend of fires across car model year. They examined model years 1951 (or earlier) through 1962 and found no difference in frequency of fire between engine position, but did find that model years 1955-1958 had a greater frequency of fires than the preceding or succeeding model years examined. No explanation was offered to explain this unusual increase.

In 1965, Robinson (1965) determined the frequency of secondary fires and occupant burns as related to crash type and accident severity by examining 156 fire incidents from the ACIR database, 1951 and earlier to 1962 (same database used by Campbell & Kihlberg, 1964). He used field investigation methods and found that the greatest incidence of fire was in frontal and rollover events with rear impacts less than 50 per cent of these latter two configurations. He also concluded that fire incidence and damage, and fatal burns were highest in rollover. However, rear impact events resulted in greater non-fatal burns than frontal or rollover accidents.

During the period just prior and immediately after the establishment of the original Standard 301, the design of fuel systems as related to post-collision environments was of interest to several authors including Robertson (1966), and Fairchild Hiller (1967). Robertson was concerned with the protection of fuel systems even under vehicle structural failure. He recommended tough, flexible, smoothly contoured fuel tanks with flexible fluid lines that would survive beyond human survival range in collisions. The Fairchild Hiller team used partial data from 8 states (CA, CT, KY, MI, OR, TX, VA, IL) from 1954-1964 to examine buses, school buses & passenger car fuel systems and fires. They considered the influence of model year, impact type, and occupant injury as a function of resultant burns, seated position, and impact type. They concluded that a nationwide effort should be mounted to collect information on the details of motor vehicle fuel systems and tests should be devised to examine the integrity of these systems under rollover and impact conditions. They thought any test standards should include the entire dynamic system not just individual components.

Severy, Brink, Harrison and Baird (1968) did three, 55 mph rear-end collision experiments to examine the seat, backrest and head restraint systems as related to the initiation and propagation of fire-related collision events. This was reported as the first published study that detailed the sequencing and location of fire propagation events. These design recommendations based on collision studies performed in 1967 were sufficient to provide crash protection from fuel spillage for delta V to about 48 km/h (30 mph). In a later study, they (Severy, Blaisdell, & Kerkhoff, 1974) made recommendations sufficient to prevent significant fuel spillage and post crash fires for all accidents that are otherwise survivable. They based their conclusions on eight full-scale collision experiments and 73 collision fire case studies that were investigated to provide data relating to fuel system failure modes and susceptibility of fuel system designs to collision fires.

Prior to the promulgation of original FMVSS 301 Standard, researchers focused on field investigations that made recommendations on fuel system design, propagation of motor-vehicle fires, and the initial steps in identifying variables related to fire that would assist in the evaluation of the Standard in real-world conditions.

Post-FMVSS 301 Years

With the advent of a FMVSS Standard related to fuel spillage and collision-related fires, a number of studies (Flora, Bleitler, Bromberg, Goldstein, & O'Day, 1979; J. D. Flora & O'Day, 1982; J. D. J. Flora & O'Day, 1981; Malliaris, 1991; McCarthy, Anderson, & Donelson, 1993; Parsons, 1983, 1990; Reinfurt, 1982; Tessmer, 1994) were funded to test the effectiveness

of the standard on passenger cars of Model Year 1968 and beyond. The Standard was revised sequentially for the 1976 and 1977 model year passenger cars and the 1977 and 1978 model year light trucks and vans to increase individual performance requirements, and to extend the requirements to other classes of vehicles (see Table 1.2). The large majority of these studies evaluated the revised FMVSS 301-1976 and 1977 standards. As each of these revisions was implemented studies ensued to test the effectiveness of the revision on reducing collision-related fires.
Prior to the revisions of the Standard, investigators were making significant recommendations to augment its strength and breadth. Gatlin and Johnson (1970) were particularly concerned with the involvement of electrical systems in conjunction with collision fires. They examined 200 vehicles (1000-6000 lb curb weight) in dealer lots and wrecking yards to assess the probability of damage to electrical system components. They made specific design recommendations for improvement in electrical systems to avoid fire ignition. Brayman (1970) engaged in an experimental barrier crash program to test fuel leakage and did statistical analyses of fuel leakage using the ACIR and AMA files. The ACIR data indicated that 7.3% of crashes have fuel leakage and the AMA files indicated 8.9% leakage. The ACIR data also showed that a fuel system leakage can occur with a strike on any part of the car but that a rear collision is over 7.5 times as likely to produce a leak than is a frontal impact. However, frontal impacts occur in almost 70% of all accidents and hence produce nearly as many leaks as rear impacts. The rollover produces a special hazard because it is more likely that the occupants will be trapped due to roof deformation. In his consideration of fuel design, Brayman concluded that any improvement on tank location must come from a total consideration of the fuel system-fuel lines, electrical system, exhaust routing, and structural configuration.

Consequent to these efforts was evident frustration in the availability of reliable, valid and comprehensive information regarding automobile fires on national and state databases. A series of studies have continued from the early 1970s through to the present to identify the inadequacies in the databases and to build alternative methods for data collection (Campbell, 1973; Center for the Environment and Man, 1977; Griffin, 1997; Griffin, Davies, & Flowers, 2002; Lavelle, Kononen, & Nelander, 1998; Radwan, Al-Deek, Garib, & Ishak, 1993; Ray & Lau, 1996; Warner, James, & Woolley, 1985; Whitaker, 1989). The development of alternative methods of data collection have ranged from intensive case study analysis using multiple data sources (Campbell, 1973; Ragland & Hsia, 1998; Shields, 1998; Shields, Scheibe, & Angelos, 1998; Shields, Scheibe, Angelos, & Mann, 2001) to Cole's (1982, 1985) series of books on automobile fire investigative methods to Griffin and associates (Griffin, 1997, 2001; Griffin et al., 2002) work on scrutiny of discrepancies in existing databases. Researchers were also interested in the occupant injury characteristics that emerged from post-standard vehicles as well as the role that post-crash sequelae might play burn injuries and fatalities. The subject of escape worthiness and extrication from burning vehicles received considerable attention in the 1970s (Austin & Wagner, 1974; Austin, Wagner, Hogan, & Bryner, 1975; Purswell, Hoag, & Krenek, 1973; Siegel & Nahum, 1970; Sliepcevich et al., 1972b; Sliepcevich, Steen, Purswell, Ice, & Welker, 1970). Methods employed by these investigators to collect the details of post-crash events are of particular interest in this review.

Tests of FMVSS 301

Seven of these studies (J. D. Flora et al., 1979; J. D. Flora & O'Day, 1982; Parsons, 1983, 1990; Reinfurt, 1981, 1982; Tessmer, 1994) were funded by NHTSA in an effort to evaluate the FMVSS 301 standard as it has evolved through the years from 1968 to 1977 (see Table 1.2).

In Flora and associates (1979) first effort to evaluate FMVSS 301, they assessed several data bases as sources of fire and fuel leakage information. In the examination of state data they concluded that those states that used the narrative in PARs were less reliable in reporting fire than those that had a check-box for fire. The NFIRS files were considered as a potential source, however, they largely reported non-crash fires. Additionally, the National Crash Severity Study was found to contain too few fires for useful analysis and appeared to under-report leaks. FARS only represented those accidents with fatalities, thus representing a special subset of the fire and fuel leakage occurrence incidents. Ultimately, they decided that the databases created by large population states with a checkbox for the fire variable were the most reliable.

Flora and 0'Day (1982) examined fire and fuel variables from cars and light truck state data from Illinois (no fuel leakage information available), 1975-1980 and from Michigan, 1978-1980. They accounted for model year, crash severity, and vehicle age. They employed a linear model approach to categorical data. There general conclusions were that there was no support for a beneficial effect for the 1968 version of the standard for either fire or fuel leaks. However, there were lower crash fire rates for recent model years when age and crash severity was taken into account. For angle, rear and rollover crash types there was a 20 to 50 per cent reduction in fire rates. The data on fuel leakage was scarce and incomplete; therefore findings were focused on post-crash fires. They found a total of 25% less post-collision fires from pre-standard period (i.e. pre 1967) to the 1976 Standard. The improvement for pre-standard to first version (1967) was 16 per cent and additional 13% less fire from the original to the 1977 revised standard. Reinfurt (1981, 1982) completed two studies that assessed the effectiveness of the 1976 version of FMVSS 301. The first study included a comparison of fire incidence in passenger cars built before 1968 to those built after the original standard was implemented. This study used 109 post-crash fire cases available from the National Crash Severity Study (NCSS) file to create a descriptive analysis. There were 189 fuel leakage cases, but these were unsuitable for analysis. Factors reported were car weight, impact site, object struck, type of collision, and driver injury. Additionally, North Carolina state data from mid-1971 to 1978 was used for logistic regression analysis to control for speed, impact site and vehicle age.

> The final model provided a negative estimate (-0.28, standard error of 0.143) of the effectiveness of FMVSS 301 …post-crash fire rates for the post-standard cars (i.e. 1969-1975 model year vehicles). (Reinfurt, 1981, p. iii).

Thus, regardless of these efforts to minimize the effects of confounding variables, they found that the original standard did not have the desired effect of reduction of post-crash fires and showed an increase of fires in model years after 1967.

The primary objective of the Reinfurt's 1982 study was to assess the effectiveness of the changes in FMVSS 301 for the 1976 model year vehicles; he may have intended to study the 301 9/76 effects which as pointed out by McCarthy (1993) would have been applicable to the 1977 model year vehicles. The study data consists of police narratives from North Carolina crashes occurring in the years 1971-1981 (N=402) plus crash data from Maryland from 1977-1980 (N=159). Logistic regression models were utilized and the factors identified in the Reinfurt (1981) study were included: car age, impact site, speed, and calendar year in North Carolina and car age, impact site and vehicle damage severity for Maryland. Fire rates in model-year vehicles in 1969-1975 were compared to fire rates in 1976-1981 vehicles. The author concluded from the North Carolina data that the 1976 revision to FMVSS 301 was at least marginally effective (effect size 0.26), however, these effects were not replicated in Maryland (noteworthy is there were less than half as many cases available in Maryland). It is not known whether the observations by Ray and Lau (1996) with regard to possible miss-keying errors in the early North Carolina data would have affected the Reinfurt results. Ray and Lau concluded this possibility after reviewing 30 North Carolina police reports corresponding to an indication of fire in the computerized file and finding that only 37% of the cases actually involved fire.

The next year, 1983, Parsons reported the first of two studies he completed on an overall evaluation of the FMVSS 301. He used state databases including Michigan (1978-1980), Illinois (1977-1980), North Carolina (1971-1981), Maryland (1977-1981), and Pennsylvania (1977-79) to examine incidence of post-collision fires, the consumer cost of the Standard, and the cost-effectiveness of the standard. He looked at passenger cars pre- and post- the 1976 standard in terms of age and model year, vehicle type and size; fuel system location and design relative to impact area. His crash variables included impact speed, direction, and type. Fuel leakage information was available only from Michigan. Vehicles were grouped by model years 1972 through 1975 and 1976-1980. This grouping combines the two standard upgrades to 301 rather than look at the effects of a single upgrade. It restricts the pre-standard group to four years to create a more balanced and homogeneous sample with regard to reporting, age, and model changes. The results from this initial study indicated that there was a significant reduction in car fires, fewer fatalities and serious injuries post-Standard. Fuel leakage was also significantly reduced (from Michigan data only). The greatest reductions are observed at higher crash severities across three impact types—rear, rollover, and frontal (insufficient data to analyze side impacts). However, with low and moderate crash severity only frontal impacts were statistically significantly different. Age of the vehicle had a significant effect only with fuel leakage and not with fire.

In the second study, Parsons (1990) re-examined FMVSS 301 using state data from Michigan, Illinois, Ohio, Indiana, and Maryland from 1982-1987 and FARS data from 1975-1988. He included passenger cars, pick-ups, and school buses in the analyses, although due to the small numbers of school buses he was not able to look at all variables of interest. He concluded that there was a reduction of fires in passenger cars, no reduction in pick-up trucks, and an increase of fire incidence with age of vehicle. There was insufficient data to analyze the effectiveness with school buses. There was no significant difference in the reduction of fatalities in fire crashes. In fact, the incidence of fire in passenger car fatality crashes has increased from 20 per 1,000 in 1975 to 28 per 1,000 in 1988. He attributed the increase to vehicle age and not to size of the vehicle. Although his earlier study (Parsons, 1983) had found a fatality effect, he explained this contradiction from the limited data available in 1983 (i.e. only 3 years of data from one State). The direction of impact analyses indicated that frontal impact account for 60-70 per cent of the crash fires in both passenger cars and light trucks (includes fatal and non-fatal crashes). Rear impacts are three times as likely to have occurred in passenger car fatalities (not in light trucks), however, for non-fatal collisions there is no over-representation of rear-impact fires. Although the Standard was seen as reducing the incidence of crash fires by 14%, Parsons suggested that the speed of the FMVSS 301 standard should be raised because the most severe crashes with fatalities and ensuing fire occur at speeds in excess of the 20-30 mph existing threshold.

In a comprehensive investigation of post-collision fire and fuel leakage variables, Malliaris (1991) used the FARS database (1975-1987) and the State of Michigan data (1978-1984) to examine fuel leaks and post-collision fire rates. Michigan variables—damage severity, impact mode, car size (only passenger cars were considered) and age were included in his analyses. He reported that his findings were comparable to Reinfurt (1982), Flora and O'Day (1982), and Parsons (1983). He found significant reduction in post-collision fire from 1977 forward. He referred to analyses in other states including Illinois, Ohio, Texas, Maryland, Pennsylvania, and Washington as being consistent with particular factors of his findings. However, there is some uncertainty regarding the details of his statistical approach. For example, the report is not clear as to the significance level or the basis of the error rates in particular analyses. Additionally, Malliaris indicates a unique approach to characterizing rate reductions by computing the rate reduction over a range of years and dividing by the mean rate of the period of years of interest. Further discussion of the Malliaris' methodological approach appears in Task 3 report of this project.

McCarthy et al. (1993) evaluated FMVSS 301 revisions for 1975 and 1977. The FARS database from 1979-1991 was chosen to take advantage of the "most harmful event" code begun in 1979. He examined the rates of rear-impact collisions of subcompact cars for the model years 1975-1977. McCarthy claims that there is a decreased risk of fire with increasing size and mass, therefore his argument is that the smallest group of cars will represent the maximum risk of fire and hence the greatest engineering challenge. Consequently he apparently reasoned that if the effects of the standard were going to be apparent they would be show up in this group. It can be argued that smaller vehicles would have been more likely to have incorporated protection of fuel systems precisely because they were small prior to the implementation of the revisions to FMVSS 301. This in conjunction with the low speeds at which the revisions actually applied makes it less likely to see an effect of these revisions in the first place.

Additionally, McCarthy et al.'s (1993) use of registered vehicle years is not a valid exposure measure for vehicles over a broad range of calendar years. It is well known that the number of miles driven by vehicles declines over its lifetime and hence the exposure to accidents is reduced over time due to fewer miles being driven as the vehicle gets older. As a result McCarthy's use of the FARS data for select model years and for a subset of available vehicles even within a class of vehicles with small numbers of occurrences can easily mask any effects. He found no differences between original and strengthened standard for the lightest of vehicles.

GESAC, Inc (1994) studied 150 hardcopy cases of post-collision fire incidents from the NASS database (1981-1993). The cases were related to fires in passenger cars or light trucks in which there was at least moderately severe injury (AIS=>2). Each case consisted of the standard forms and photographs from the NASS investigating team. Additionally, 66 hardcopies of cases from FARS (years not specified) were obtained and 28 cases had sufficient information for the analysis. A database was created that described the following: damage severity, fire severity, crash severity, role of age or vehicle corrosion, suggested simulation procedures, occupant information (alcohol, drugs, restraints, ejection, entrapment, blunt and burn injuries), compartment integrity, estimation of approach speeds, event when fire started, event when fuel started leaking, cause and origin of fire, description of fire damage, and fuel system description (minimal). These variables were entered into a database to determine frequency of events.

Finally, Tessmer (1994) assessed fires in passenger cars, light trucks, and vans in the post-1978 environment. He discusses the analysis of historical data related to the occurrence of fire in fatal and less serious vehicle collisions as related to crash, vehicle, and driver factors. Model years included 1979-1992 of FARS database and 1982-1991 of the State of

Michigan database. Finally, the NASS-CDS for burn injuries from 1988-1993 was analyzed. Tessmer concluded that vehicle age has a significant effect on fire, light trucks have relatively more fires than cars and vans, and cars in fatal rear impact collisions are 140-340 percent more likely to have a fire/MHE fire. His analyses indicated that fires originating in fuel system, rather than engine compartment, are more likely to be major fires.

Limitations of National and State Databases

Prior to the promulgation of the revisions to FMVSS 301 in 1976, Center for the Environment and Man (1977) was contracted to examine various methods for evaluating FMVSS 301 reliably. They examined the FARS database and the state databases of North Carolina, Texas, and New York. The report outlines the final design and implementation plan for evaluating the effectiveness of FMVSS 301. It considers measurability criteria, alternative statistical techniques, data availability/collectability, resource requirements, work schedule, and other factors. Because of the small population of vehicle fires (2 to 3 per cent of auto accident fatalities) a multi-method approach to data collection is described: a) newly collected data on fuel system rupture in tow away accidents; b) historical data from fire departments on automobile fires and cross-indexing these data with police accident files; and c) information from vital statistics on deaths due to fire in automobile crashes and information from data files on fatal accidents. They recommend that standards be established for smoke emission, toxicity of combustion, ignition sources and burn rate of materials in motor vehicle materials and components. Similar recommendations had been made by Cooley (1974; 1981). Although not the focus of this review, it should be noted here that a number a studies were contracted from 1966 to 2002 to examine fire initiation and propagation on collision and non-collision motor vehicle fires (Jensen & Santrock, 1998, 2002; Johnson & Sanderson, 1975; Santrock, 2002a, 2002b). Ohlemiller and Cleary (1998) looked specifically at flash and fire points, leak rates, heating fuel tank and heat transfer to solid surfaces in a laboratory study.

In 1983, Warner, James, and Woolley (1983) recommended that trained investigators for post-crash motor vehicle fires be used to augment police report data prior to any further safety improvements be made. Interestingly, Whitaker (1989) in his efforts to interpret the vehicle fire statistics in the United Kingdom concluded that clarification of statistical databases should be addressed through the establishment of a task force consisting of fire personnel, police, and manufacturers.

Radwan, Al-Deek, Garib, and Ishak (1993) set out to identify the best sources for information on the trends and causes of motor vehicle fires. They used Florida data from the Fire Marshall reports (1988-1991) and the Florida Department of Highway Safety and Motor Vehicle Data (HSMVD;1986-1991), and at a national level, the Highway Loss Data Institute non crash fire data (HLDI: 1986-1988). They were interested in examining the origin of fire, vehicle type and year, and month of the year in which the fire occurred. Their findings from the State of Florida data (source was the Florida Fire Marshal and Department of Highway Safety) indicated that 75 per cent of total motor vehicle fire incidents were in automobiles. The engine area was responsible for 60% of the total incidents followed by the passenger compartment (15%). Approximately 40 per cent of vehicle fires were attributable to crash conditions. Gasoline was most involved fluid type of ignited materials (nearly 25%) whereas 18% of motor vehicle fires were ascribed to partial failure or leak of oil. During the analysis period, 1976-1991 vehicles of model year 1979 had the highest fire rate followed by vehicle make year 1984. They found no correlation between crash fire incidents and vehicle age. High temperature weather conditions did not have a distinct effect on the incidence of vehicle fires in the Florida data. Thus, there was no support for previous findings in the literature that climate temperature has a direct correlation with fire accidents (Appleby & Bintz, 1980). The National data gathered from the Insurance Institute of Highway Loss indicated that sports and specialty models have higher NONCRASH fire than 4-door sedans, and mid-size vehicles have the highest per cent of NONCRASH fires.

Because FARS and State databases have been heavily relied on to test the effectiveness of FMVSS 301 and to establish the frequency and type of post-crash fires, various difficulties with the coding variables and the reliability of the coding itself have been raised among investigators. Ray and Lau (1996) did a comprehensive review of specific sources of statistical data related to vehicle fires. They described the characteristics and historical development of FARS and did a detailed examination of state databases including Arkansas, Alabama, Florida, Maryland, Michigan, New York, North Carolina, Pennsylvania, and Texas. The NASS-CDS and GES, and the National Fire Protection Agency (NFPA) files were also examined. A series of recommendations related to the reliability of these data sources were made. State-level databases vary widely in consistency and accuracy in reporting fire accidents. These variations appear to be largely attributable to PAR (Police Accident Report) forms and the systems used to encode the field information. All of the databases lack detailed information on those factors that describe the initiation, propagation paths, and post-crash events of a fire. For example, fire origin, type of fire, source of ignition can only be determined by examining the original field reports. FARS has the advantage of providing accurate information for the identification of fire in fatal motor vehicle accidents, however, it remains difficult to isolate the causes of vehicle fire and the contribution of environmental and operator factors. The NASS-CDS(Crashworthy Data System) files do provide detailed information on traffic accidents in which fire occurred. Because of the relatively small size of the database in addition to the low rate of vehicle fire, the usefulness of the data is diminished in statistical analyses. The GES(General Estimate System) of NASS(National Accident Sampling System) files are a representative sample of US police-reported traffic accidents and provide a useful overview of vehicle fires as a check against the state databases. Unfortunately, the original accident reports from the NASS databases are not available publicly. In spite of these limitations on the richness and consistency of data regarding vehicle fires, they concluded that FMVSS 301 could be evaluated with those databases that provide adequate identification of vehicle type and model year and a sufficient number of years to analyze historical trends of fire incidence. They recommend the use of FARS and the State databases of Michigan, Pennsylvania, Florida, Alabama, and Maryland (note that Michigan data cannot be used for vehicle specific comparisons after 1991 because VIN is no longer recorded after December 31, 1991). The use of Matched Pair Analyses, in which vehicle models are essentially the same, except for the change to fuel system design as related to FMVSS 301 would be the most powerful approach to testing the Standard. Further, they recommend separate analyses for each database and that the results then are examined through meta-analysis techniques.

National databases came under further scrutiny by Lavelle, Kononen, and Nelander (1998). The purpose of this study was to 1) to evaluate possible causes and effects of vehicle fires; 2) to examine the reliability and validity of FARS, state files, National Fire Incident Reporting System (NFIRS), NASS-GES, NASS-CDS, and National Fire Protection Agency (NFPA) survey data with respect to vehicle fires; and 3) to make recommendations for improving the existing data files to enhance motor vehicle fire studies.

They present the purpose and source of information of each data base and in table form present a useful summary of their strengths and weaknesses. Their findings indicated that the existing data bases are insufficient to enable a comprehensive understanding of causality in vehicle fires. Thus, they recommended that links be made between MCOD and FARS records for better classification of fire-related fatalities; to add common crash-related fire variables to state reports; to implement field investigation programs with trained fire personnel and to link Police and fire personnel incident reports.

Griffin and his associates did a series of studies from 1997 through 2002 that cross-checked FARS and selected state databases with other police and fire personnel reports (Griffin 1997; Griffin & Flowers, 2001; Griffin, 2001; Davies & Griffin, 2002; Griffin, Davies et al., 2002). They were interested in cross referencing existing large databases with other sources of aggregate data and field case investigations in relation to fire variables and injury. In the first study, Griffin (1997) assessed the reliability of passenger cars and light trucks in FARS from 1987-1989 in relation to fire by using MCOD data from the National Center for Health Statistics. He rank ordered states by incidence of reported vehicle fires in FARS and concluded that there was considerable variability across states. Additionally, 46 Police Accident Reports from Texas were chosen to examine the "questionable coding" of the MCOD files. Consequently, he concluded that there was a lack of consistency in coding, under-reporting of fire in FARS based on N-codes and unreliability of MHE coded as fire or other injury.

Griffin and Flowers (2001) examined the relation between driver injury and post-crash fires. They were interested in the crash circumstances of passenger vehicles that did and did not have post-crash fires. The Traffic Accident Data (TAD) scale for single and multi-vehicles crashes were used to document impact location and severity. In North Carolina, between 1991 and 1996, there were 172 passenger vehicle drivers who died in post-crash fire incidents. Their analyses revealed that 23 per cent of the 172 drivers would not have died if there had been no fire. In other words,

> "(one is) 4.29 times as likely to die as drivers involved in comparable crashes [as defined by TAD1 (impact location) and TADSEV1 (impact severity)], but whose vehicles did not experience post-crash fires" (Griffin & Flowers, 2001, p. 20)

An examination of fatalities related to fire and the details of the surrounding events was also undertaken by Davies and Griffin (2002). They did a clinical evaluation of the FARS data for the State of Texas (1990-1992) and North Carolina (1995-1996) data. Two hundred and six cases were examined for cause of death in post-collision fires by cross-referencing FARS with police accident and medical examiners reports. The purpose of the study was to review a sample of fatalities that were thought to have succumbed to fire-related injuries and to describe the circumstances surrounding the deaths of the 206 decedents. Although it must be noted that in the State of Texas Medical Examiners are not required to be MDs, they concluded that a high number of the fatalities were not related to fire. Compared to the Griffin and Flowers (2001) results, they found 21 per cent of the deaths in passenger vehicles that experience post-crash fires result from fire and 79 per cent from mechanical trauma. Note that they also used North Carolina data, but included drivers and passengers involved in crashes in 1995-1996 and not just drivers as in the Griffin and Flowers (2001) study. Also the methods of analyses were different with the Davies and Griffin study that used clinical evaluation, whereas Griffin and Flowers used statistical modeling. Comparatively, Davies and Griffin also examined Texas cases (between 1990-1992) of 104 drivers and passengers in post-crash fires. They determined that 42 per cent succumbed to fire-related causes and 58 per cent to other causes. They explained the marked differences in results in the two studies partially due to "under correcting" of the non-fire-related differences between post-crash fires and non-fire crashes.

In this same year, Griffin (2001) reported a study that compared crash and fire-involved passenger vehicles (passenger cars, light trucks, vans and utility vehicles) with one or more fatalities to crash and no fire-related fatalities. Their purpose was to uncover the specific circumstances and conditions surrounding vehicles that experienced fires in a collision and those who did not. They used data from FARS years 1994-1996. They provided a detailed analyses and discussion of impact severity, driver, and environmental factors in fire and non-fire related crashes. In general, they concluded that

> "The overall impression that might be gained from the data (in Table 8) is that vehicles that experience fires are involved in somewhat more severe crashes, e.g. they are more often driven by males, occur after dark, and between the hours of 10 pm and 4 am.
>
> In single-vehicle crashes, passenger vehicles that collide with trees are much more likely to experience fires than those that do not. Passenger vehicles that overturn are relatively less likely to experience fires." (Griffin, 2001, p. 28).

In 2002, Griffin, Davies, and Flowers wrote up a reliability study of the FARS database, years 1987-1989 and 1994-1996. They accessed National Fire Incidents Reports (NFIRS) and the MCOD codes for Wisconsin and Utah. They compared the International Classification of Diseases (ICD) coding for fire injury reported in passenger vehicles (light trucks and cars) and AK injuries. Similar to their earlier study (Griffin & Flowers, 2001), they found large inconsistencies across states' approach to coding fire variables. Additionally, they reported inconsistencies in states' reporting of vehicle fires and most harmful events, and cause of death for fatalities. Using MCOD's it was shown that more fatalities with fire injuries occur than could be determined using any indication of fire in FARS 1987-1989. Due to the under-reporting of fatalities in NFIRS vehicle fires in Michigan in 1994, as compared to those reported in FARS, they concluded that NFIRS was not a more reliable data source for fire fatalities because its collection of data was more opportunistic rather than systematic with respect to motor vehicle fires.

Field Case Studies

In the early 1970s, researchers continued the use of intensive case-by-case studies to uncover the actual sequence of post-crash, fire phenomenon. Campbell (1973) looked at the frequency and severity of collision vehicle fires by reviewing 100 cases of the North Carolina Police Accident Reports. He did a content analysis of these reports using the keywords fire, flame and burns. In a epidemiological study of pediatric burn victims in motor vehicle accidents King, Abston, and Evans (1972) found that three per cent of the burn victims at the Galveston Shiners' Burn Institute for Children from 1966-1972 were involved in vehicle fires. From the resultant 38 cases the major contributing factors were fuel spillage and match playing in stationary vehicles, flammability of clothing and vehicle interior, and major trauma to the burn victim. In this study, twelve children were burned as a result of a moving motor vehicle accident (6 rear end collisions, 3 rollover, 1 head-on, 1 from a car radiator scald, and 1 collision with a high tension wire pole). Non-moving motor vehicle accident fires included 26 children (17 left unattended in a stationary vehicle). The initiation of the fire was reportedly from playing with matches, gas spillage during vehicle repair, smoking, and volatile fumes. In these early years based on police and hospital records these authors were making recommendations for national standards to prevent a conflagration given that a fire had started.

Ragland and Hsia (1998) used 214 cases from FARS 1990 through 1993 that had 293 fatalities. They solicited the crash records from seven states—Illinois, Florida, Colorado, Arizona, Ohio, Delaware, and West Virginia. Crash records included: photographs, PARs, witness statements, and medical records. Their purpose was to depict the cause of the fire, crash conditions and severity. They found that 65 of the fatalities were from burns—46% rear impact collisions with 71 per cent overlap and an average speed of 54 mph, 23% from frontal impacts, 15% from side, and 11% from rollover crashes. He estimated from this case data that nationally in 1995 fatalities were 22% or 309 fatalities would have resulted from burn traumas. Ragland describes the crash test simulation description that best replicates the typical scenario.

> The impact speed is normalized to a 3000 pound moving deformable barrier (MDB), striking the rear of the stationary subject car….Therefore it appears that a 70% overlap 3000 lb rear moving deformable barrier at 50-55 mph may provide a reasonable crash simulation of real world rear impact fatal burn cases. (Ragland & Hsia, 1998, p. 849)

Shields and his associates over the last five years have conducted case study investigations for General Motors (in relation to GM's settlement of a legal suit with NHTSA). During this period they examined 35 collision-related fires in detail and wrote 3 reports (Scheibe, Shields, & Angelos, 1999; Shields et al., 1998; Shields et al., 2001). The first study (Shields et al., 1998) reported on 13 fire collision cases and collected photographs, inspection results, witness and investigator statements to document fire initiation, propagation and occupant injuries. From these field investigations they made a number of recommendations for methods of data collection and analyses in fire-related, motor vehicle incidents. Some of these included detailed data collection forms and instructions for field investigators, event selection criteria, and establishment of a network of field contacts to facilitate timely notification of incidents.

Scheibe et al. (1999) presented the results of case studies in their preliminary findings of their on-going investigation of incidents involving automobiles, pick-up trucks, vans, and sports utility vehicles. They selected 3 incidents to demonstrate the methodology of comprehensively chronicling factors related to collision-related fires. Their descriptions revealed what they described as the complexity of factors that result in fire. From these three cases, they concluded that coolant, oil, and gasoline were all liquid fuels with the potential to initiate fire, that damage to the electrical system can provide the ignition source, and that a large percentage of frontal impacts do not initially involve gasoline leakage. They make a strong case for field investigation methodologies that consider the detailed events in a collision that propagate fire.

In 2001 Shields et al. completed the final report on "Case Studies of Motor Vehicle Fires". The cases sampled were expanded to 35 incidents from a pool of 367 for which 3 were non-collision, 21 were frontal impact, 4 were rear impact and 4 were rollover. These 35 fire incidents involved 59 occupants, 12 whom sustained burn injuries. Seven of the incidents included at least one fatality. They detailed the methods to collect information on the actual fuels involved in ignition, ignition sources, propagation paths and times, and injury mechanisms. In tracing propagation events, they observed that windshields, hood openings, open doors and deformed metal openings contributed to conflagration.

Post-Collision Sequelae

From the early 70s there has been interest in the relation between vehicle design, escape-worthiness, and extrication. These factors are particularly relevant in relation to fire and submergence where minutes can make a difference between relatively minor injuries and death. Our review of these studies begins with Siegel and Nahum (1970) who used Los Angeles city and county fire department reports from 1966-1969 to identify response time of emergency vehicles, extrication, ejection, occupant egress, vehicle structure, fuel system design, and flammability of materials in propagation of the fire. They found that fires from collision events represented five per cent of the total number of fires reported. They describe a nine cell matrix that includes factors related to human, vehicle, and environmental conditions of pre-crash, crash and post-crash phases.

Sliepcevich and associates (Purswell, Hoag, & Krenek, 1973; Sliepcevich et al., 1972a; Sliepcevich et al., 1970) completed three studies on escape worthiness of vehicles in conditions of fire and submergence. In the 1970 study, they used Oklahoma data from 1967-1969. They chose 105 cases with 65 vehicles with fire involvement and 24 with submergence incidents. Although they surveyed State data and death certificates, police reports, and newspaper microfilms, they found that there was insufficient data for a full analysis. They identified a set of parameters for ease of egress in these incidents and presented a research plan for quantification of the data.

Their next study, (Sliepcevich et al., 1972a), used Oklahoma (1970-1971) and Kansas (1970-1971) data including police and fire personnel reports. They attempted to access National Burn Information Exchange and National Electronic Injury Surveillance System data, but were unsuccessful. Although they reviewed state data and concluded that 19 states had submergence and/or fire codes, they ultimately used a sample of 145 post-crash fires in Oklahoma and 66 in Kansas. An extensive bibliography of fire and submergence related issues (799 entries) was detailed, but considered inadequate in determining the actual incidence of injuries resulting from fire. They presented a predictive model for escape time, relationship between ignition characteristics and burning rates of materials.

Purswell, Hoag and Krenek (1973) followed Sliepcevich's work on entrapment in submergence and fire conditions. They examined flammability of materials and emergency egress in school and city buses. Based on their findings, they developed a methodology for measuring escape worthiness using human subjects and relevant vehicle design modifications.

Austin and associates (Austin & Wagner, 1974; Austin et al., 1975) completed two studies that detailed post-crash phenomenon that were related to injuries incurred but not related to the cause of impact-induced injuries. These events included fires, extrication, submergence, emergency medical care and fuel leakage.

In the first study, they described a one year effort to collect data in a five county area of Utah from local police personnel. Their results were compared to State of Utah and National (not specified) statistics for representation of incidence rates, occurrence mechanisms and consequences of post-crash fires. The 1975 report (Austin et al., 1975) is a detailed and more extensive follow-up on the initial pilot findings (Austin & Wagner, 1974). During the criterion period, late August 1972 to September 1, 1973, 43 incidents of vehicle fires were reported; 29 of these were collision-induced. Fuel-fed fires were the most numerous types of collision-induced fires (23 of 29) and 50 per cent of these fire cases were self-extinguished or were extinguished by persons on the scene. There were two fatalities among the 29 cases and both were considered a result of the collision. Of the 43 cases 14 were non-collision fires; 8 of the 14 were ignited in the engine compartment. The authors suggested that the sources of information regarding vehicle fire post-crash phenomenon are only reliably available from police reports and fire departments. The follow-up in wreckage yards and newspaper reports proved inadequate and there were no cases uniquely discovered with these methods.

Conclusions

The issues that become readily apparent in this review of post-collision fires can be divided into the following broad categories: 1) reliability and validity of existing national and state databases in relation to fire variables; 2) assumptions regarding vehicle design changes in relation to FMVSS 301; 3) use of statistical techniques to overcome lack of consistency in reporting fire variables.

Issues regarding the reliability and validity of existing national and state databases in relation to post-crash fires and fuel leaks have been established undeniably in the last 20 years as researchers have been faced with evaluating the effects of FMVSS 301. The databases used most readily by the researchers in this review include: FARS and State data files. These databases have been augmented for validity reasons by other national and state databases including: NASS-CDS; NASS-GES; MCOD; NFIRS. Additionally, investigators have resorted to descriptive data from PAR's and Fire Personnel reports as well as engaging in labor intensive field investigations of local police and fire activities, examination of vehicles in wrecking yards, and combing newspaper reports of motor vehicle fires. Any detailed cross-referencing of the various databases (Griffin, 1997; Griffin, Davies et al., 2002) has resulted in large number of false negatives in the recording of the existence of fire in post-crash events. Our information on fuel leaks is even more dismal with only a few states providing direct or indirect information in their databases at any time over the past 30 years. Consequently, it is clear that FARS and the state data bases have woefully neglected the issue of post-crash fire factors. Further, there has been no integration of FARS with other fire rich databases such as NFIRS or MCODs. In spite of the fact that as early as 1988 (Steilen, 1988) there has been repeated calls for more comprehensive treatment of the recording and coding of fire variables from a long list of researchers—Radwan, et al. (1991), Tessmer (1994), Ray and Lau (1996), Griffin (1997, Lavelle et al. (1998), and Griffin, Davies, et al., (2002) who have specifically recommended these linkages be made. There appears to be a lack of commitment to collecting information on a national basis, either through a fully implemented NASS system or the enhancement of existing data collection systems, or integration of multiple system in CODES (related to outcomes). Consequently, researchers find themselves in the predicament of trying to evaluate the fuel system standard without a comprehensive and trustworthy database, a situation lamented by Cooley as early as 1974. Many studies begin and often end with the examination of the reliability of their data, rather than the confidence that the tests of the FMVSS 301 will be based on accurate information. The epidemiological research studies are still asking for simple fire information—Did fire occur? Did a fuel spillage or leakage occur? This information is found to be most reliably reported when it is an option to "check" on a PAR. Although fire incidence and fuel leakage information has been found in narrative areas of the PAR, it is found to be most unreliably reported in that context. As we belabor getting the simplest of information on fires, we also have observed that the post-crash sequelae, such as ignition source, propagation paths, emergency response time, egress, extrication and rescue events, are only available in field investigations or case study examinations. Sliepcevich and his associates (Sliepcevich et al., 1970, 1972) along with other researchers (Austin & Warner, 1974; Austin et al., 1975; Purswell Hoag, & Krenek, 1973; Siegel & Nahum, 1970; Shields, 1998; Shields et al., 2001) have completed labor intensive experimental and field investigations on these factors. To date the richness of this type of data is not available to assist in understanding the relationship between fuel system design and injury and fatality associated with post-crash fires.

The issues of vehicle factors that may influence the overall collision-related fires have been studied throughout the history of FMVSS 301 evaluations (Flora et al., 1979; Flora & O'Day, 1982; Malliaris, 1981; McCarthy et al., 1993; Parsons, 1983, 1990; Reinfurt, 1981, 1982; Tessmer, 1994). These factors have included in part vehicle age, vehicle size, and compliance with FMVSS. In particular, analyses utilizing FMVSS as a potential indicator of change have not taken into account the effect of design changes previously incorporated. More importantly, we did not find during the past 25 years of work any matched pair analyses or analyses considering comparison of specific fuel system design approaches or changes-although it certainly has been suggested.

Of particular interest has been the influence of vehicle age on fuel spillage and subsequent fire in post-collision incidents. Virtually all researches appear to agree that vehicle age is related to the incidence of fires. There has not been any definitive study as to why this is the case. Taken alone the question appears to suggest at least two potential answers: 1) the fuel systems decline over time either through poor maintenance, decay or other reasons, or 2) the structural protection provided by the vehicle declines over time. Taken in the context of other studies suggesting that risk of fatality increases with vehicle age, and considering fatigue and rusting issues, it would seem that both factors are likely to play a role in increased fire risk given the findings of other studies that suggest risk of fatality increases with vehicle age and that structural elements will also be effected by fatigue and corrosion. The implications for real world practice are that requiring comprehensive ongoing safety inspections would have an impact; assessing whether states with safety inspections have differing experiences than those without such inspections would be interesting to consider in this light. With the exception of New Jersey, are there any states that still require yearly safety inspections?

Evaluations of 301 have the problem that researchers have grouped all vehicles in the fleet based on the year in which the FMVSS 301 Standard and/or revision was effective. This grouping of vehicles based on model year is convenient, but does not account for actual design differences in vehicle models and years. A manufacturer in anticipation of the upcoming FMVSS Standard 301 may make design modifications prior to the model year to which the Standard is required. Nor does it account for manufacturer’s response to product liability suits that lead to design changes. A highly visible example of the latter was the product liability suits related to the Pinto’s high incidence of fire in rear impacts.

The use of statistical techniques to overcome the lack of consistency in the database information we do have in relation to fire variables is not exhausted.

Inferential techniques have not been used to identify the best states for fire information and then apply the results to the remaining states. This is similar to the application of missing data techniques where we treat states with poor information in effect as having missing or unreliable data to make national estimates. Additionally, although it has been suggested as a possible technique (Ray & Lau, 1996), to date no one has reported evaluation of design techniques using specific vehicle design approach comparisons, for example, matched pairs or other types of one on one or grouped analyses.

In summation, it is clear that the quality of the fire information available must be considered in selecting accident files for use as well as in the interpretation of previously obtained results. In reality, the effects of specific vehicle fuel system design approaches on the incidence of collision related fires have not been analyzed utilizing large scale databases in the past 30 years. For example, identification of those vehicles with and without cutoff switches for electric fuel pumps would allow analysis of whether the effects of such design differences can be observed in the accident data. Many examples of fuel system design approaches, flammable fluid locations, and ignition source protection systems can be identified. To analyze effectively design change effects on fire incidence, it is clear that linking a variety of data together to enhance the quality of the information available for analysis is desirable. A concerted effort to accomplish these goals can be expected to produce significant enhancements in determining the effects of vehicle design factors on the incidence of fires in collisions.

SECTION 2: EVALUATION OF DATA SOURCES OF PASSENGER VEHICLE POST-CRASH FIRES

Our purpose in Task 2 was to characterize the data sources available that could be utilized to analyze fires in motor vehicles. Ultimately, it was our goal to identify two or three States that would enable an extension of the Malliaris (1991) methodology. Although Ray and Lau (1996) had reported in some detail the characteristics of nine State files, it was necessary for us to first investigate all states and characterize the availability of fire-related data and the variables used in the Malliaris' analyses. Our initial review included the determination of: a) the current availability of the data sources; b) the accessibility of the data for further analyses; c) the historical and current coding methods for fire-related variables; d) the coding of other identifying variables of an accident that can be used to augment fire reporting codes; and e) the continuous or discontinuous coding schemes used by each State.

Our investigation revealed numerous challenges in the existing State files that impeded straightforward and highly reliable analyses of fire-related characteristics of motor vehicle accidents. In this report, we have described in detail these challenges as they relate to PAR coding variations, missing databases, discontinuous data and other confounding sources of misinformation. In spite of these inadequacies in the State files we identified three states that best met the purposes of our analyses for Tasks 4 and 5 of this project. In this section, we describe our methods for collecting database information from State accident files and other national and international files; the characteristics of the identified potential data sources, and the procedures for choosing the best state files for use in Task 4 and 5. Section 2 is divided into two parts. Part I presents the method, procedures, findings, and conclusion in relation to the State accident files. Part II provides information on the national and international data sources investigated and identifies those that might be useful in subsequent studies.

Part I: State Accident Files

The complexity and variability of fire-related variables across states is great and requires a careful explanation. Table 2.1 lists agencies in the United States that collect and store data on fires. Previous reports have documented the difficulty in extracting fire-related data that is reliable, accessible, and continuous across years (see Section 1: Literature Review). Our purpose was to identify 2 or 3 states that had the most useful databases in regard to fire and fuel leaks in motor vehicles. To accomplish this task a careful examination of each state's police report forms, coding manual, and database characteristics was necessary.

Table 2.1 Organizations for Fire Accident Data

United States Agencies
U.S. Fire Administration
North Carolina Highway Safety Research Center
University of Michigan Transportation Research Institute
National Interagency Fire Center
National Fire Information Council
National Archives
National Fire Data Center
LSC & Associates
Insurance Institute for Highway Safety (IIHS)
Highway Loss Data Institute
National Fire Protection Association (NFPA)*
California Fire Marshals Office
Florida Fire Marshals Office
Dade County Fire Marshals Office

*Note. Some States have incorporated the NFIRS reporting systems into State reporting systems, so that, for example, there is a CFIRS – California Fire Incident Reporting System

Procedures

Sources were identified for potential use through a literature search and personal knowledge of the research area. From the potential sources of accident data, research was conducted to identify the actual location of the accident data. In the case of state accident data, each state was contacted directly to determine the department responsible for the accident database. The department contacts were made and information on additional contacts was gathered. These contacts were initiated to obtain specific coding information and the years of data availability. In some cases, other organizations were identified to determine the availability of old data files (e.g. pre-1989). U.S. databases, other than State, were reviewed for existence of specific variables and time frames in which these variables were available.

State Data Source Findings

We found that the 1975-1988 state accident files that had been at National Highway Traffic Safety Administration (NHTSA) had disappeared. Apparently, the files were on tapes and were scheduled to be transferred to the National Archives; however, most of the tapes have not been located. We understand that NHTSA is investigating their whereabouts. It remains unclear where the data may have been stored, if at all. We did discover that at least one set of tapes (those for Illinois) made it to the National Archives for the relevant time frame; (1977-1993) and that there WERE some tapes available from 1985 in HSIS-FHWA. Unfortunately, the 1978-1984 Michigan data was located in raw form outside of NHTSA, but not in a form that NHTSA would have held it. Thus, there are virtually no accident files for 50 states from 1975-1988 in the NHTSA files .

We were able to gain permission to utilize requested state databases without too much difficulty, however, it was found that some states (e.g. Texas) deleted data when it was 10 years old. Others did it more frequently or were no longer able to access data after they changed database systems. Fortunately we found that the data was archived in a different location within their State records system, and that these locations could be identified with considerable effort

Table 2.2 State Coding Variables Related to Fire in Motor Vehicles
Note: yellow=fire variable; orange= potential problem; red=problem

STATE	DATA YEARS	FIRE VARIABLE	LEAK VARIABLE	VEHICLE			VEHICLE DAMAGE AREA	VEHICLE DAMAGE EXTENT OR CRASH SEVERITY	IMPACT CONFIGURATION F,S,R, ROLL	BODYTYPE: CAR, VAN, SUV,PICKUP	VIN	VEHICLE WEIGHT, WB, OR SIZE
				MAKE	MODEL	YEAR						
Alabama	1993-2001	YES	NO (Fuel system)	YES	NO	YES	YES	YES	YES	YES	NO	NO
Alaska	1979-2001	YES	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO
Arizona	1991-2001	first harmful event; subsequent harmful event	NO	NO	NO	NO	YES	YES	YES (Collision manner)	YES	NO	NO
Arkansas	1997-2001	YES	NO	YES	TEXT (99-01- Pick List)	NO	YES	YES	YES	YES	NO	NO
	1987-1996	YES	NO	YES	TEXT (87-98 -4 letters)	no/ yes*	YES	YES	YES	YES	YES	NO
Florida	1986-1992	First harmful event; subsequent harmful event	NO	NO	NO	YES	YES	YES	YES	YES	NO	NO
	1993-2001	first harmful event; subsequent harmful event	NO	NO	NO	YES	YES	YES	YES	YES	YES	NO
Georgia	93-98	YES	NO	un-known	un-known	un-known	YES	YES	YES	YES	Un-known	NO
Hawaii	1986-2000	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	YES
Idaho	1994-2001	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO

Table 2.2 (cont'd): State Coding Variables Related to Fire in Motor Vehicles

STATE	DATA YEARS	FIRE VARIABLE	LEAK VARIABLE	VEHICLE			VEHICLE DAMAGE AREA	VEHICLE DAMAGE EXTENT OR CRASH SEVERITY	IMPACT CONFIGURATION F,S,R, ROLL	BODYTYPE: CAR, VAN, SUV,PICKUP	VIN	VEHICLE WEIGHT, WB, OR SIZE
				MAKE	MODEL	YEAR						
Illinois	1977-2000	Fire occurred; first harmful event (non-collision)	NO (Fuel system)	NO	NO	YES	YES	YES	YES	YES	YES	NO
Indiana	1990-2000	Fire Occurred.	NO	TEXT	TEXT	TEXT	YES	YES	YES	YES	NO	NO
Iowa	1990-2000	YES	NO	NO	NO	YES	NO	YES	YES	YES	NO	NO
Kansas	1990-2002	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO
Maine	1985-2000	YES	NO	NO	NO	NO	NO	NO	NO	YES	NO	NO
	1989-1994	YES	NO	NO	NO	NO	YES	NO	NO	YES	NO	NO
	1995-2001	YES	NO	YES	YES	YES	YES	NO	NO	YES	NO	NO
Maryland	1994-2000	YES	NO	YES	TEXT	?	YES	YES	YES	YES	YES	NO
Massachusetts	1990-2000	YES	NO	YES	YES	YES	YES	NO	YES	NO	NO	NO
Minnesota	1985-2001 (HSIS)	YES	NO	1990' onward	1997' onward	85-91	YES	YES	YES	YES	YES NO*	YES
Mississippi	1985-2001	YES	NO						YES	YES		

Table 2.2 (cont'd): State Coding Variables Related to Fire in Motor Vehicles

STATE	DATA YEARS	FIRE VARIABLE	LEAK VARIABLE	VEHICLE			VEHICLE DAMAGE AREA	VEHICLE DAMAGE EXTENT OR CRASH SEVERITY	IMPACT CONFIGURATION F,S,R, ROLL	BODYTYPE: CAR, VAN, SUV,PICKUP	VIN	VEHICLE WEIGHT, WB, OR SIZE
				MAKE	MODEL	YEAR						
Missouri	1984-2001	YES	NO	YES	NO	YES	YES	YES	YES	YES	YES (12 bytes)	NO
Montana	1992-2001	YES	NO (Contributing factor - Fuel system)	YES	YES	YES	NO	YES	YES	YES	96' onwards	NO
New Hampshire	Unable to contact	YES										
North Carolina	1991-1999	YES	NO	TEXT (7 charcters)	NO	YES	YES	YES	YES	YES	YES	NO
North Dakota	1995-2001	YES	NO				YES	YES	YES	YES		
New Jersey	1997-2000	YES	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO
New Mexico	1977/79?-2000	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES (87' onwards	NO
New York	1974-2001	fire explosion; sequence of events (1-2 events)	NO	YES	NO	YES	1974-83	1974-83	1974-83	YES	YES	NO
Ohio	1988-2002	YES	NO	YES	NO	YES	YES	YES	YES	YES	NO	NO
Oklahoma	1992-2000	YES	NO	YES	NO	YES	YES	NO	NO	YES	NO	NO
Oregon	1985-2000	YES	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO

Table 2.2 (cont'd): State Coding Variables Related to Fire in Motor Vehicles

STATE	DATA YEARS	FIRE VARIABLE	LEAK VARIABLE	VEHICLE			VEHICLE DAMAGE AREA	VEHICLE DAMAGE EXTENT OR CRASH SEVERITY	IMPACT CONFIGURATION F,S,R, ROLL	BODYTYPE: CAR, VAN, SUV,PICKUP	VIN	VEHICLE WEIGHT, WB, OR SIZE
				MAKE	MODEL	YEAR						
Pennsylvania	1980-2001	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	WB
South Carolina	1985-2000	YES	NO	YES	NO	YES	94'	94'	YES	YES	NO	NO
South Dakota	1983-2001	YES	NO (Contributing factor - Fuel system)	NO	NO	NO	NO	YES	YES	YES	NO	NO
Texas	1991-2000	YES	NO	YES	YES	YES	YES	YES	YES	YES	NO	NO
Utah	1987-2001(Combination of HSIS and state data)	YES	NO	NO	NO	YES	YES	YES	YES	YES	86-96	NO
Vermont	1992-2000	98-00	NO	YES	YES	YES	YES	98-2000	92-2000	YES	98-00	NO
Washington	1977-2001	79'-96	79-96	77-96	77-96	77-96	YES	YES	YES	77-96	NO	NO
West Virginia	?	YES										
Wisconsin	1994-2001	YES	NO	TEXT (10)	NO	YES	YES	YES	YES	YES	NO	NO
Wyoming	1991-2001	YES	NO	YES	YES	YES	YES	YES	YES	YES	YES	NO

The specific characteristics of fire and fuel leak-related coding variables for each State are documented in Table 2.2. As can be seen in the data, almost 40 states collect information on the occurrence of fires. Two states (Michigan to 1991 and Washington) had information explicitly related to fuel leaks. However, there are a number of states that have hazardous spill information that could pick up fuel leaks by virtue of the hazardous materials cleanup activities. Unfortunately, this approach to identifying fuel leaks was not fruitful upon detailed examination.

We found that state databases that used a narrative template for fire occurrence (thus requiring coding analysts to determine whether a fire had occurred) identified the incidence of fires less often than states in which the PAR had an unambiguous box to check for the occurrence of fire. As an alternative to both the narrative and the checkbox, the use of vehicle based event sequences that include a fire code has been deemed effective (Lavelle et al., 1998; Parsons, 1990; Ray & Lau, 1996).

Another critical coding issue is whether fire is coded to describe an occurrence of a fire *in an accident* or is it coded as related to *a specific vehicle* in the accident (in other words is the fire descriptive of the accident or is it descriptive of a particular vehicle in the accident). If it is the former, then the fire rates are not useful in the determination of fire rates in vehicles. For example, 70% of accidents are vehicle-to-vehicle collisions, however, even if we know a fire occurred in an accident we don’t know whether one or both vehicles were involved in the fire. Thus, to compute the number of fires in vehicles involved in collisions, variations in coding of fire at the accident level versus the vehicle level must be specified. Accident level coding will provide inherently less reliable metrics than vehicle level coding of fire.

Table 2.3 Fire and Fuel-Leak Coding Schemas for States

STATE	YEARS	1st Harmfull Event				Most Harmfull Event		Subsequent Event	Fire Occurred			Sequence of Events (1-4)		
		Non-Collision		Fire	Fire/ Explosion	Non-collision	Fire/ Explosion	Fire	Y/N	Pre-Crash	Post-Crash	Fire / Explosion	Fire	Non-Collison
		Fire / Explosion	Fire			Fire/ Explosion								Fire/ Explosion
South Dakota (Pop 754,844)	83-01								X	X	X			
Arkansas (Pop 2,573,400)	87-01		X				X (Fire)		X					
Kansas (Pop 2,688,418)	90-02								X					
Oregon (Pop 3,421,399)	85-00	X							X					
Oklahoma (Pop 3,450,654)	92-00								X					
Alabama (Pop 4,447,100)	93-01				X		X							
Minnesota (Pop 4,919,479)	85-01								X			X		
Maryland (5,296,486)	94-00													
Wisconsin (Pop 5,363,675)	94-01	X							X					
Washington (Pop 5,894,121)	79-96								X			X		
Indiana (Pop 6,080,485)	90-00								X					
Massachusetts (Pop 6,349,097)	90-00								X					
North Carolina (Pop 8,049, 313)	91-99										X			
Michigan (Pop 9,938,444)	78-91								X					
Ohio (Pop 11,353,140)	88-01								Fire due crash ; other fire					
Pennsylvania (Pop 12, 281, 054)	80-01												X	
Illinois (Pop 12,419,293)	77-00	X							X					X (1-3)
Florida (Pop 15,982,378)	86-01			X				X						
New York (Pop 18,976,457)	74-01													X (1-2)
Texas (Pop 20,851,820)	91-00													

Table 2.3 (cont'd): Fire and Fuel-Leak Coding Schemas for States

STATE	Defect	Contribtuing Circumstances		Accident Type	Damage Scale		Irregular condition	Data Years Known to be Available	Fire Variable	Leak Variable	VEHICLE			Vehicle Damage Area	Vehicle Damage Extent or Crash Severity	Impact Config-uration (F,S,R Roll)
	Fire	Non collision Fire/ Explosion	Collision Fire	Fire	Collision Non	Collision Due	Caught Fire				MAKE	MODEL	YEAR			
South Dakota (Pop 754,844)								1983-2001	YES	NO (Contributing factor - Fuel system)	NO	NO	NO	NO	YES	YES
Arkansas (Pop 2,573,400)								1987-2001	YES	NO	YES	TEXT (99-01- Pick List); text (87-96) 4 letters	no ray yes	YES	YES	YES
Kansas (Pop 2,688,418)								1990-2002	YES	NO	YES	YES	YES	YES	YES	YES
Oregon (Pop 3,421,399)								1985-2000	YES	NO	NO	NO	NO	NO	NO	YES
Oklahoma (Pop 3,450,654)								1992-2000	YES	NO	YES	NO	YES	YES	NO	NO
Alabama (Pop 4,447,100)								1993-2001	YES	NO (Fuel System)	YES	NO	YES	YES	YES	YES
Minnesota (Pop 4,919,479)								1985-2001 (HSIS)	YES	NO	1990' onwards	1997' onwards	85-91	YES	YES	YES
Maryland (5,296,486)							X	1994-2000	YES	NO	YES	TEXT	?	YES	YES	YES
Wisconsin (Pop 5,363,675)								1994-2001	YES	NO	TEXT (10)	NO	YES	NO	YES	YES
Washington (Pop 5,894,121)								1977-2001	79'-96	79-96	77-96	77-96	77-96	YES	YES	YES
Indiana (Pop 6,080,485)		X (2001)						1990-2000	Fire Occurred.	NO	TEXT	TEXT	TEXT	YES	YES	YES
Massachusetts (Pop 6,349,097)								1990-2000	YES	NO	YES	YES	YES	YES	NO	YES
North Carolina (Pop 8,049, 313)								1991-1999	YES	NO	TEXT (7 charcters)	NO	YES	YES	YES	YES
Michigan (Pop 9,938,444)								1978-1999	1978-1991	1978-1991	YES		YES	YES	YES	YES
Ohio (Pop 11,353,140)								1988-01	YES, 88-99	NO	YES, 88-99	YES, 88-99	YES, 88-99			
Pennsylvania (Pop 12, 281, 054)								1980-2001	YES	NO	YES	YES	YES	YES	YES, 0-3 SCALE	YES
Illinois (Pop 12,419,293)								1977-2000	Fire occurred; first harmful event (non collision)	NO (Fuel system)	NO	NO	YES	YES	NO	YES
Florida (Pop 15,982,378)								1986-2001	First harmful event; subsequent harmful event	NO	NO	NO	YES	YES, PT OF IMPACT	YES, $$ ONLY	YES
New York (Pop 18,976,457)								1974-2001	fire explosion; sequence of events (1-2 events)	NO	YES	NO	YES	1974-83	1974-83	1974-83
Texas (Pop 20,851,820)					X	X		1991-2000	YES	NO	YES	YES	YES	YES	YES	YES

Although Table 2.2 presents a summary of information on each of the state's databases, it does not reflect the characteristics of field reports and reliability of data coded. Nonetheless, it does narrow the pool of potential state candidates by reporting the critical variables of interest for further investigation.

Table 2.3 summarizes the schemas used in those states that have fire related variables. Two additional coding factors are: a) whether or not it is the analyst or the police officer recording the data, and b) the decision-making rules for coding a fire as related to a vehicle traffic accident or independent of a traffic accident. The decision-making rules for coding control whether or not a fire in a motor vehicle can be coded independent of what else happened in the accident. For example, at the vehicle level if categorizing by the first harmful event or most harmful event and if fire didn't correspond to either of these characterizations, then the occurrence of a fire would be overlooked. One solution to this problem is the provision for an unlimited number of events that can be recorded for an accident. Thus, if the coder is trained to consider fire as a significant event, it would be entered concurrent with other accident sequelae. The weakness of this method is the reliance on the effectiveness of coder training in fire events. Unfortunately, this type of training is woefully lacking in most state level programs (Griffin, Davies, & Flowers, 2002; Environment and Man, 1975). Fire variables are listed under the first harmful event and most harmful event and then a non-collision field under which is Fire/Explosion. Examples of coding protocols for "harmful accident events" from North Dakota, Illinois, Oklahoma, and Massachusetts are presented in Table 2.4.

Table 2.4 Harmful Event Coding Schemes

North Dakota

Z. FIRST HARMFUL EVENT
(Initial Collision - Characterizes the crash type. Use one of the codes below.)

AA. SEQUENCE OF EVENTS (Use up to 3 of the codes below for each vehicle. If necessary, to describe the sequence of accident-related events following the first harmful event.)

COLLISION WITH OBJECT - NOT FIXED

01. Motor Vehicle in Transport
02. Motor vehicle in Transport in Other Rdwy
03. Pedestrian
04. Pedalcycle
05. Railway Train
06. Deer
07. Other Large Game
08. Farm Animal
09. Small Animal
10. Parked Motor Vehicle
11. Other Object (Not Fixed)

COLLISION WITH OBJECT - NOT FIXED

20. Overturn / Rollover
21. Fire / Explosion
22. Immersion
23. Jackknife
24. Downhill Runaway
25. Cargo Loss or Shift
26. Separation of Units
27. Ran off Roadway
28. Other Non-Collision

COLLISION WITH FIXED OBJECT

30. Impact Attenuator
31. Bridge / Pier / Abutment
32. Bridge Parapet End
33. Bridge Rail
34. Guardrail Face
35. Guardrail End
36. Median Barrier
37. Highway Traffic Sign Post
38. Overhead Sign Support
39. Luminaire / Light Support
40. Utility Post
41. Other Post
42. Culvert
43. Curb
44. Ditch
45. Embankment
46. Fence
47. Mail Box
48. Tree
49. Other Fixed Object

BB. MOST HARMFUL EVENT (If an event following the initial collision causes the most damage, use the codes above. One for each vehicle, if necessary, to identify this most harmful event.) LEAVE BLANK IF SAME AS "Z" ABOVE

Illinois

	Y	N
TOWED	☐	☐
FIRE	☐	☐
HAZMAT SPILL	☐*	☐
COM VEH	☐*	☐

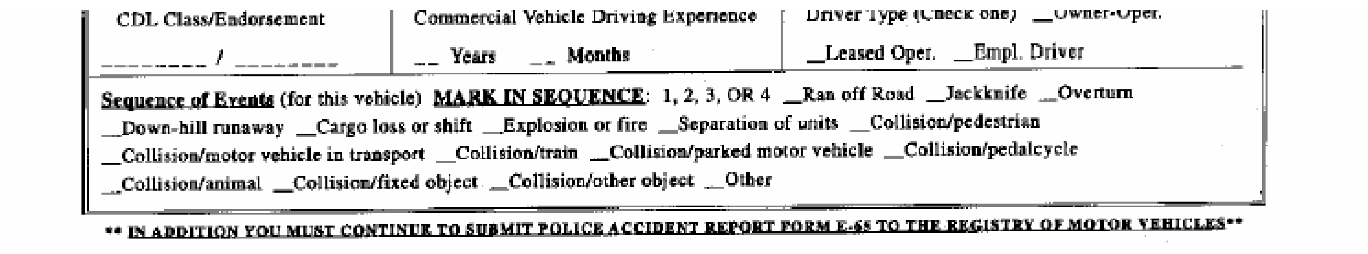
*IF YES SEE BELOW

NO. LA
ALGN
RSUR
VEHU

Oklahoma


BURNED? Y N
NUMBER

Massachusetts


CDL Class/Endorsement ________ / ________
Commercial Vehicle Driving Experience __ Years __ Months
Driver Type (Check one) __Owner-Oper. __Leased Oper. __Empl. Driver

Sequence of Events (for this vehicle) MARK IN SEQUENCE: 1, 2, 3, OR 4 __Ran off Road __Jackknife __Overturn __Down-hill runaway __Cargo loss or shift __Explosion or fire __Separation of units __Collision/pedestrian __Collision/motor vehicle in transport __Collision/train __Collision/parked motor vehicle __Collision/pedalcycle __Collision/animal __Collision/fixed object __Collision/other object __Other

** IN ADDITION YOU MUST CONTINUE TO SUBMIT POLICE ACCIDENT REPORT FORM E-65 TO THE REGISTRY OF MOTOR VEHICLES**

Because of the salience of the precise methods of coding fire in the interpretation of analyses, our initial approach was to obtain available police reports and coding manuals for each of the states. The electronic versions available for these codebooks are contained in the Appendices.   The information was reviewed and tabulated in a general way with regard to the availability of variables of interest. While some of the information later turned out to be incorrect or was of less detail than desired, the initial compilation is shown in Table 2.3.

- We gathered information on the threshold at which an accident was required to be reported and thus documented in accident data files. This strategy allowed us to characterize the potential effects on comparability of data between states. We found that. States’ reporting threshold for accident reports varies substantially and that some States change reporting threshold across years. A summary of this information is shown in Table 2.5. Colorado provided detailed information on their reporting thresholds. These details are noted below.

- Motor vehicle crashes resulting in death or personal injury, or motor vehicle crashes in which one or more of the following conditions occur:
- Leaving the scene involving damage to an attended vehicle or property (Section316.061 (1), F.S.);
- Driving while under the influence of alcoholic beverages, chemical substances, or
- controlled substances or with an unlawful blood alcohol level (Section 316.193, F.S.).
- An investigating officer may report other traffic crashes on the long-form crash report. In particular, applicable statutes specify an officer's discretion to submit a long-form report in crashes where a vehicle is rendered inoperable to the degree that a wrecker is required to remove it from traffic.
- Statutory revisions in 1983 and 1989 reduced the number of non-injury crashes required to be reported to the Department. Any presentation of historical data that includes such crashes, such as total traffic crash counts, will reflect these changes. Data on traffic crashes involving death, injury, or other criteria for law enforcement long-form reports as outlined above are not affected.

During the initial round of collecting information on police reports and codebooks, we discovered that states with adequate information for our project might not have the historical periods of interest accessible in computerized form. For example, some states claimed that they had been deleting archival data after a given period of time. NHTSA, as we have previously mentioned, had lost the accident data that they had collected. In general, we found that numerous states have various problems associated with administration and management of databases that adversely affect the utility of their data.

To identify viable candidates for this study, we examined in detail every state that had an explicit *fire* variable. As well, we looked at those states that a) did not have the explicit variable, but were recommended by Failure Analysis Associates (FAA), b) had variables of interest, and c) used sequence of events codes (see Table 2.3). *Leak* occurrence was found in only one state other than Michigan (Washington, but it was found that their data system disintegrated during an upgrade and the data hasn't been entered since 1996).

Although Malliaris used "damage severity" in his analyses, we identified potential problems in the interpretation of this variable. Some damage severity classifications indicate that a vehicle that has a fire may be recorded as totaled because of the incidence of fire and not due to damage severity from a collision. As a result the incidence of fire may automatically select the damage severity rather than the severity of the vehicle damage from events other than fire. This confounding became apparent in considering dollar based damage estimates but it may be present also in crash severity scales. Interestingly, we have received data from Alabama that suggests that the distribution of fires versus no fires in an accident is discriminated by travel speed [Parsons (1990) addressed the effect of fire occurrence with speeds exceeding the FMVSS 301 Standard test].

Table 2.5 State Reporting Threshold of Accidents

STATE	REPORTING THRESHOLD (Property Damage, Injury and/or Fatality) to a single person.												
	$0	$150	$250	$300	$400	$500	$600	$700	$750	$1,000	$2,000	$3,000	NOTES
ALABAMA						82-02							
ALASKA						X					96-02		
ARIZONA										X			
ARKANSAS						X							
CALIFORNIA						X							
COLORADO	X												A law enforcement officer must submit a long-form crash report when investigating:*
CONNECTICUT	X												Visible damage, fatality or injury
DELAWARE						88-95				96-99			In 2000 = $1400, 2001 = $1500, 2002 = $1600
FLORIDA	X												Vehicle Wrecked (Towing required), DUI, Injury, hit and run
GEORGIA						X							
HAWAII												X	
IDAHO									X				
ILLINOIS			Pre 92'			92-03							
INDIANA									X				
IOWA										X			
KANSAS						X							
KENTUCKY						X							
LOUISIANA						X							
MAINE										X			
MARYLAND	X												Tow Away, Hit and Run, Fatality, Injury
MASSACHUSETTS										X			
MICHIGAN					98-02								
MINNESOTA						81-94				94-02			
MISSISSIPPI			X										
MISSOURI						X							
MONTANA						X							
NORTH CAROLINA						84-96				96-02			
NORTH DAKOTA										94-02			
NEBRASKA						X							
NEW HAMPSHIRE						Pre 91'				91-02			
NEW JERSEY						X							
NEW MEXICO						X							
NEW YORK					78-85		86-90			91-02			
NEVADA						X							
OHIO		Pre 00'			00'								
OKLAHOMA				Pre 98'		98-02							
OREGON						Pre 97				97-02			Changed on 8/31/97
PENNSYLVANIA						X							
RHODE ISLAND						X							
SOUTH CAROLINA					Pre 96'					96-02			
SOUTH DAKOTA						Pre 00'				00-02			
TENNESSEE					X								
TEXAS			78-90			90-02							
UTAH										X			This Varies from area to area, have to call each area to find out - this is for Salt Lake City
VERMONT													There is NO Statute requiring the police in Vermont to report on crashes.**
VIRGINIA										X			
WASHINGTON				80-87		87-00		00-02					
WEST VIRGINIA						X							
WISCONSIN						Pre 96				96-02			
WYOMING										X			Combined Total.

*Note: Details on the Colorado reporting thresholds are found in the text.

**Note: The State Police have a policy of investigating (then reporting) those crashes of property damage of $4000+. They always report on fatal and incapacitating injury crashes. The local Police Departments follow somewhat the same procedures

To choose the best states that would be consistent with the Malliaris (1991) analysis methodology we engaged in a selective criteria procedure. To narrow the pool of potential states we used the following inclusion and exclusion criteria. To produce analyses consistent with Malliaris the following variables were needed (aside from leaks):

1. Fire occurrence
2. Damage area (front, side, rear, rollover)
3. Damage severity
4. Vehicle size (requires make/model/vin or other method available) (vehicle size was not found to be significant by Malliaris)
5. Vehicle type (car, SUV, van, pickup; Malliaris only considered cars)
6. Vehicle model year (to determine vehicle age)

Controlling roughly for information in these categories we ultimately found a subset of states that appeared to have the principal components of this information. We then further investigated the details of these states. In many cases we found information that made a state less desirable for complete analyses than we had anticipated based on preliminary data.

Investigation of the Top Twenty State Candidates

Based on this initial screening of the State databases, there remained a total of 20 states, which included some states that didn't have an explicit fire variable but did potentially have event codes that could contain a fire event. Additionally, some states that would have been excluded by us, we retained because Failure Analysis Associates (FAA; Ray and Lau, 1996) had recommended or considered them potential candidates. Each of these remaining States (shown in Table 2.3) was investigated in great detail to determine the character and reliability of the inclusion criteria variables

Further investigation of the top twenty candidates for inclusion in our analyses uncovered numerous obstacles in the collection and analysis of the variable coding information. These have included the finding that many states have changed their data collection, reporting procedures, and systems during the last three decades. In specific, many states have not actually put all the data collected into the computer databases, past coding information is not readily available, knowledgeable parties are difficult to find, reach, or get responses from, documents are not available, and many states have deleted their files and/or coding manual documentation except for recent years. Thus, despite the presence of variables, there are coding and accessibility problems in their utility. Consequently, our determination of the best states for fire-related analyses has involved a significant uncovering of a great deal of information that has been very difficult and time-consuming to extract from the State agencies.

Summary of Top Twenty Candidate States

We identified the populations in the top 20 candidate states and sorted them accordingly. Next we chose 15 of the largest states and identified particular problems that would limit the utility of the data. Finally, we chose our three best candidates for data analysis from the list below.

Texas the incidence of fire is recorded into the damage area variable in such a way that it will obscure what the damage area is. So when a fire occurs, the direction of impact and damage severity will be unknown. In addition, the information is not coded at the scene but determined from the narrative by an analyst.

New York the incidence of fire can be included in an analyst-coded sequence of events field based on the police report narrative. A sampling of 8 FARS reported fires found only 2 showed up in the state database as having a fire in the sequence of events fields. It has been reported that only about 200 fires are reported in the state database annually.

Florida's fire variable would only distinguish fires at the accident level, not at the vehicle level.

Illinois does not contain damage severity and is reported to have significantly underreported fires (Parsons, 1990) during the 1980's; whether their new data forms have corrected the problems is unknown. The data is available from 1977 to 1991 (national archives) and 1989-1999 (NHTSA) and 1996-2001 (Illinois). However the 1996-1999 data has some problems in that some portions of the state were omitted.

Indiana is reported to under report fires (Parsons, 1990) and damage severity is not available except as a dollar estimate. Interestingly it does have police response times. The data is available at least from 1989 to 2000 from Indiana.

Ohio only coded VIN information up until 1999 (although they are considering putting it back on the file in 2003) and has not been putting the damage area onto the computerized file even though it is on the police form. The data is available at least from 1988 to 2001.

Maryland has a damage extent variable that is described as no damage, superficial, functional, disabling, destroyed, other, unknown. The fire variable is associated to the variables N/A, no damage, superficial, functional, disabling, destroyed, other, and unknown. The data is at least available from 1989-1991 from NHTSA and 1992-2001 from Maryland.

Michigan does not have the model year or VIN available after 1991 and hence there is no way to code for vehicle age. The leak variable was also eliminated after 1991. The data is available up through at least 1999. In Michigan the continuing analysis would not allow an indication of the age of the vehicle as the information on make, model, model year, and vin were not included after 1991. There is only a rudimentary characterization of vehicle type and no indication of vehicle weight category. Further, the fire/leak variable was eliminated although the fire information could be captured in an event-based variable. Vehicle size in Michigan is by weight categories that are used once and were found not to be significantly different. Vehicle type in Michigan for our purposes is limited to car and truck.

Minnesota has data from 1991 to date. However, the cost of purchasing the data is $20,000.

Pennsylvania uses analysts to determine the occurrence of fires. VIN information has to be specially requested. The fire information from the narrative is coded into event sequence information for the vehicle. Damage area is the initial impact area. The data is available from 1980 to 2000 from Pennsylvania and they may have older data.

North Carolina has had coding/key punching errors that have resulted in problems in their database system in particular with respect to the coding of fires. As a result their coding manual indicates not to use their fire variable at least for the period 1992-1999. Others have indicated problems prior to this time period as well.

Massachusetts does not have crash severity coded on the police form and hence does not meet the methodology requirements.

Washington does not have computerized files after 1996. The data is backlogged and they may never be computerized. The problem occurred during a transition in their accident database system.

Wisconsin while there is a damage area box on the police report form it has not made its way into the computerized file.

Alabama has fire information available but only as a first harmful event or most harmful event for the accident, as opposed to the same information for each vehicle. Thus one cannot determine which vehicle had the fire in this database.

Best States for Analysis

It appeared that given the goals of the study that ***Maryland, Minnesota and Pennsylvania*** were the best candidates for the analysis of fire-related variables in impact conditions. ***Illinois*** (1996-2001) data was obtained for use in the event that problems arose in the chosen states.

Part II: National and International Data Sources

Table 2.6 illustrates the results for the national database search. The columns indicate the gross variables of interest and an "X" or date range (e.g. 1991-1999) indicates the general availability of the category information or the range of years for which the variable information was available. In the cells where no information is provided it indicates that the variable was not available. If a determination was not made, then the notation ND (not determined) is included. Detailed information on each of these sources of data is provided in Volume II: *Appendices* of this report.

Of the national databases, NASS-CDS has the most variables available in one file related to fire and fuel leaks in motor vehicle accidents. One private database was found that was focused solely on motor vehicle fires but the number of cases contained in it is small.

CODES was found to be an expansion of the injury detail associated with state accident files, created through linkage of injury files (like hospital outcomes) and the state accident files. It doesn't expand the crash related variables associated with the state accident files.

The National Fire Incident Reporting System (NFIRS) was identified as a file with comprehensive information related to fire response and situations; however, it was found that its focus was much more detailed with respect to structure and consumer product fires, as compared to vehicles. However, it is clear that substantial information could be made available if the forms used for vehicle fires was made as detailed as the forms used for describing structure fires. Even in its current state the data could provide significant expansion of information regarding response times, for example, and probably fuel leaks if coupled with other data files on motor vehicle accident and injuries such as is done through CODES. To be fully effective the forms that firefighters are filling out with regard to motor vehicle fires would have to be overhauled to be more relevant to the vehicle related aspects of the fires and fuel leaks [e.g. fuel leak source: 0) none, 1) fuel line, 2) filler neck, 3) fuel tank, 4) fuel rails on engine, 5) fuel filter, etc; fuel system failure mechanism: 0) none, 1) impact damaged fuel line, 2) impact damaged fuel tank, 3) impact damaged fuel filter, 4) leaking fuel line pre impact, etc; fire initiation: 1) pre impact, 2) from impact. 3) post impact etc.]

Table 2.6 National Sources of Data

	NATIONAL									
		ACCIDENT YEARS VARIABLES ARE AVAILABLE								
DEPARTMENT	**DATABASE**	**FIRE VARIABLE**	**LEAK VARIABLE**	**YEARS VEHICLE MAKE/MODEL AND MODEL YEAR**	**VEHICLE DAMAGE AREA**	**VEHICLE DAMAGE EXTENT OR CRASH SEVERITY**	**IMPACT CONFIGURATION (F,S,R, ROLL)**	**BODYTYPE (CAR, VAN, SUV,PICKUP)**	**VIN**	**VEHICLE WEIGHT, WB, OR SIZE**
DOT-NHTSA	National Accident Sampling System-Crashworthiness Data System (NASS-CDS)	1979-2000	1991-2000	1979-2000	1979-2000	1979-2000	1979-2000	1979-2000	1979-2000	1979-2000
DOT-NHTSA	National Accident Sampling System-General Estimates Systems (NASS-GES)	1988-2000		1988-2000	1988-2000	1988-2000	1988-2000	1988-2000		
DOT-NHTSA	Fatal Accident Reporting System (FARS)	1975-2000		1975-2000	1975-2000	1975-2000	1975-2000	1975-2000	1975-2000	

Table 2.6 (cont'd): National Sources of Data

		ACCIDENT YEARS VARIABLES ARE AVAILABLE								
DEPARTMENT	**DATABASE**	**FIRE VARIABLE**	**LEAK VARIABLE**	**YEARS VEHICLE MAKE/MODEL AND MODEL YEAR**	**VEHICLE DAMAGE AREA**	**VEHICLE DAMAGE EXTENT OR CRASH SEVERITY**	**IMPACT CONFIGURATION (F,S,R, ROLL)**	**BODYTYPE (CAR, VAN, SUV,PICKUP)**	**VIN**	**VEHICLE WEIGHT, WB, OR SIZE**
DOT-FHWA	HIGHWAY SAFETY INFORMATION SYSTEM (HSIS)	Dependent on state		X						
LSC-ASSOCIATES	VEHICLE FIRE DATABASE									
US Fire Administration	NATIONAL FIRE INCIDENT REPORTING SYSTEM (NFIRS)	X							X	

A study to demonstrate the feasibility and utility of merging the NFIRS and State accident data is recommended. It is expected that firefighter response times, fuel leak information, fire fighting time, extent of fire damage to the vehicle would be able to be added to the state data. The NFIRS data from 1990 to 1998 is available at the present time in computerized form from NTIS. However, it is known that it has been collected at least as early as 1980. If related injury rates were desired then the available supplemental information on injuries through CODES could be incorporated.

Alternatively, coupling of state fire marshal offices (for fires) or hazardous spill responsible offices (for leaks; e.g. Connecticut) with the state accident data would provide more detailed information than presently provided for in the accident data alone.

Availability of National Data Sources

In general, the national data sources identified are available across the years of interest. The reliability of the NASS-CDS data was relatively good and potentially useful for exploratory analyses. Since 1988 information on approximately 5000-7000 vehicles per year has been obtained based on a stratified sampling scheme with a focus on light passenger vehicles 5 years old or less. The data collected can be statistically evaluated. The variables collected should be of interest to MVFRI for their research. The information gathered could then be applied to evaluate specific designs for which more data is available, but for which additional detail is needed. Thus, for example, if it was found that design approach “x” appeared to have substantially better performance than others, the experience of that design approach in larger groups of data could be evaluated through use of the state files.

Supplementing the state files with the NFIRS data should be explored to determine the reliability and completeness of the information in the database. For example, it could be that the information is filled in so rarely as to make the data useless for research purposes at hand. However, if the data is present and reliable it has the potential to expand the range of questions that can be addressed. In any event, the source certainly has the potential to be expanded to be of greater usefulness in this area.

International

Information on international databases was sought through personal contacts as well as Internet search methods. The international sources were tracked down to determine their existence, availability and magnitude. A selection of countries and organizations found to have accident data or information are presented in Table 2.7. The only file in Europe that appeared to have substantial data of interest was the Cooperative Crash Injury Study (CCIS; see Volume II: *Appendices* for a detailed reference to this source) overseen by the Commission of the European Communities. The CCIS file was found to contain relevant variables with regard to vehicle design and fuel system integrity, fire, and fuel leak outcome. While it has some sampling biases it does not appear that these would lead to substantial interpretive problems associated with the effects of design practice on fuel leak and fire outcomes. The number of cases sampled is about 1500 per year and thus it is small compared to the NASS file. However, a cursory analysis of the file from recent years indicates about 10% of the vehicles has fuel system damage, 5% have fuel leaks and 1% have fires.

There are conflicting messages about the availability of the CCIS data and the costs involved. The reliability of the data is likely to be good from a vehicle design practice viewpoint and outcome viewpoint. The data is highly relevant. The utility from a statistical viewpoint has some problems but not in our view such that the data should not be analyzed to determine what it is saying. Its suggestions can then be used like those from NASS to examine on a larger scale whether the expectations would be upheld for the vehicles with various design practices observed. These results from the second stage work would then be more convincing; however since the state files do not have good control over crash severity and impact conditions, depending on what the analyses suggested there may be limitations in the ability to apply the results if they depend on variables not present in the larger state files.

The overall aim of the STAIRS (Standardization of Accident and injury Registration System) project (Final Report, February 1999) was to define the fundamental requirements for a Pan-European in-depth accident and injury database. There are five primary goals for the database, two are related to research and three related to dissemination of information. The research goals are: a) to establish a common set of variables and their coding protocols across all European countries; and b) to link the STAIRS database with each country's national databases. STAIRS appears to be a promising project with the opportunity to cull detailed variables from multiple country sources. Recent communication (TNO, Delft, NL, September 23, 2003) indicated that the database was implemented in mid-September, 2003.

Table 2.7 International Data Sources*

International
Multiple Country Databases
International Transport Research Documentation (ITRD)
Standardization of Accident and injury Registration System (STAIRS)-European Community
Cooperative Crash Injury Study, Commission of the European Communities (CCIS)
British Databases
Transportation Research Laboratory (TRL).England
London Accident Analysis Unit
STAT-19 England
French Databases
Centre Européen de sécurité et d'analyse des risques.
Organization for Economic Co-operation and Development,
French National Institute for Transport & Safety Research (INRETS)
Australian Databases
Center for Accident Research and Road Safety Queensland, Australia
Injury Research Centre, University of Western Australia
Vic Roads
Road Accident Research Unit, Adelaide University, RARU
Accident Research Foundation, Monash University
Other Countries
Traffic Injury research Foundation (Ottawa, Canada)
Danish Transport Research Institute (Danmarks Transport Forksning)
Finnish road Association
Swedish National Road Administration (VV) Accident Data Base (VITS).
SAE India
German Insurance Accident Data

*Note: For a full description of these sources see Volume II: *Appendices*

SECTION 3: VERIFICATION OF STATISTICAL METHODS

The purpose of Task 3 was to verify the statistical methods that were used by Malliaris (1991) to determine the occurrence of fire and fuel leaks in passenger vehicles. The first statistical analysis tested the results generated previously by Malliaris as defined by the graphically illustrated results in his paper. The purpose of this approach was twofold:

1. It provided a clear demonstration of appropriate statistical methods for applicability to more current and expanded databases.
2. The work of Malliaris is highly regarded in the technical literature, however, his methods and the details of his previous analysis of impact-induced car fires are no longer available.

Data from FARS and the State of Michigan were used to generate the results for years 1978-1984. Analysis was performed to investigate the following areas of interest.

1. Impact fire rates vs. model year
2. Fuel leak hazard
3. Incidence of fire and leaks at high impact severity
4. Impact type
5. Vehicle type

Methods

In preparing to identify fire risk trends for a number of states and over a number of periods, we approached the problem starting with ensuring that the analysis methods used by earlier researchers were understood. The methodology described by Malliaris was defined in the contract as the methodology to be used.

Michigan Accident Data

The Michigan accident data files for the years 1978-1984 were used. The vehicle level records were used.

Vehicle Type

The records classified as “passenger vehicles” using the Traffic Unit Type variable (Var00102=1) were selected for use. Vehicle weight categories were found to be defined in a variable called vehicle type (Var00104). The vehicle weight categories available were: 1) passenger car – Under 1500 lbs., 2) passenger car - 1500 to 2499 lbs, 3) passenger car - 2500 to 3500 lbs,

4) passenger car – over 3500 lbs, 5) station wagon, carryall, etc,, 6) jeep type, 7) pickup or panel truck, 8) stake or dump truck, step van, motor home, etc., 9) truck-tractor (semi) or road tractor), and 10) Other or unknown or not a motor vehicle.

Fire and Leak Variable

The occurrence of fire was determined utilizing Var00119. This variable has four values. The definition of the value of 2 for Var00119 is fire. The definition of 3 for Var00119 is leak and fire occurred; 4=no vehicle fuel leak or fire. For the present purposes when Var00119 was 2 or 3 we would indicate a fire. The definition of the value of 1 for Var00119 is that there was a fuel leak. Thus a (0=no fire,1=fire) fire variable and (0=no leak,1=leak) leak variable were created using the coding scheme shown below:

Fire	Var00119
0	1,4
1	2,3

Leak	Var00119
0	2,3,4
1	1

Statistical Analysis Software

The Statistical Analysis System (SAS; SAS Institute, Cary, N.C., Version 8) was used for all processing. The calculation of standard errors for the means was accomplished using PROC MEANS or PROC SUMMARY in SAS.

Vehicle Age

Malliaris found that vehicles 0-4 years old had similar fire rates while older vehicles had higher fire rates. Arguing that older vehicles might have higher fire rates due to maintenance issues, he considered only vehicles 0-4 years old. The definition we used to establish the vehicle age was simply accident year minus model year (Var000004 - Var00106). Because the next model year can occur in the present calendar year, a negative 1 age can be produced, but the number of these vehicles was small and they were included. Because analyses involving design changes or the effects of regulatory changes were not being conducted, the regulatory change years had already occurred, and the number of cases would be small the cases were not eliminated. However, it could be argued that for purity the -1 vehicle age vehicles should be excluded. Thus, for calendar year 1978, model years 1979, 1978,1977,1976,1975,1974 would be included as vehicle ages between 0-4 years old.

Crash Condition Control

Malliaris argued the importance of controlling for damage severity and impact mode between model year groupings in the event that one model year range might experience a different accident mix compared to others or that the accident mix might change over time. The damage severity variable was Var00118 and has the values 1-9 corresponding to 1) no damage, 2) little damage, 3) , 4) , 5), 6), 7), 8) Maximum damage, 9) unknown. Two categories of damage severity were created with a low group for 1-5 and a high group for 6-8. To control for these effects, the probability of being in any given cell for a model year group was either used as is or adjusted to be consistent with the other model year groups. The later was called "controlled" and the former "usual". Computation of standard errors for the means for these "controlled" and "usual" analyses was determined using the SAS PROC MEANS procedure. However, the correct treatment for combining the rates to form a fire rate for any given group or overall is subject to discussion. In this case the overall standard error of the model year group sample was used.

Impact mode was defined using Var00117 with front, side, rear and rollover defined as groups. These groups corresponded to values in this variable of (1,2,8), (3,7), (4,5,6) and (10) respectively.

The calculation of standardizations corresponding to controlling for variations in accident circumstances was accomplished by creating cells from damage severity, impact area and model year groups. There were 4 model year groups (74-75,76-78,79-81,82-84).

Fire and Leak Rate Reductions

A series analyses were done to compute the fire and leak rate reductions under various conditions as had been done by Malliaris. These analyses generally looked at the effects of controlling for vehicle age, controlling for crash conditions (impact mode and severity) by model year, controlling for specific impact conditions, and finally for vehicle size. The specific methods for each table are described herein.

The percentage reduction in fire and leak rates by model year controlling for vehicle age was computed for Table 3.1. In this analysis vehicles were grouped by age. Within a given age group the percent change in rates were computed from the previous model year and a mean percent change per model year was computed. The standard error of the mean percent reduction was computed and used as an error term.

During the project a comparison method was applied to the analysis of vehicles grouped by age (see Table 3.1a). The percent change in fire rates controlled for vehicle model year was computed by regressing the natural log of the fire rates by model year onto the model year. The resulting parameter estimate for the time component represents the percent change in rates across time. The standard error for this parameter estimate was reported as the standard error for the estimate of percent change in rates. Vehicles were limited to ages between 0 and 4 years. In this analysis results were computed for both passenger cars and trucks (the latter determined to be primarily pickup trucks).

The percentage reduction in fire and leak rates by model year controlling for vehicle age was computed for Table 3.2. In this analysis, vehicles were grouped by age. Within a given age group the percent change in rates were computed from the previous model year and a mean percent change per model year was computed. The standard error of the mean percent reduction was computed and used as an error term.

Cells were computed to control for crash severity and impact mode across model years and for the overall probabilities for falling into a given crash severity and impact mode (see Table 3.3). The overall probabilities were applied to the model year groups of interest to compute a "controlled" rate (fire or leak as appropriate). The data is for passenger cars 0-4 years old. While there is discussion with regard to the appropriate method for calculating the standard error, in this case the standard errors associated with the respective cells were combined in accordance with their respective probabilities to characterize the standard error for the model year group. The 'usual' mean rates and standard error were calculated from the same groups, using the vehicle counts within cell as weights. Table 3.3a contains a comparison with the Malliaris results.

Table 3.4, contains results for passenger car fire and leak rates by model years, controlled for vehicle age (0-4 years old) under the "high" severity impact conditions, and the "rear and rollover" impact modes. The data in the table excludes cases in the "other non-collision or unknown impact type" contained in Var00030. The percent reductions were computed by subtracting the previous model year rate from the next model year rate and then averaging over the period.

Table 3.5, examines the fire and leak rate variations by vehicle size by model year grouping controlling for vehicle age (0-4 years old). The percent reductions are computed simply by subtracting the previous model year rate from the next model year rate and then averaging over the period. The correct treatment for determining the standard error for the rate reductions is subject to discussion.

Fatal Accident Reporting System (FARS) Analyses

Data from FARS for the accident years 1975-2000 were used. The number of registered vehicle years (provided by Dr. Paul Bedewi and George Washington University) was determined using the National Vehicle Population Profile (NVPP). Four vehicle categories were created, one for passenger cars and three for light trucks, consisting of pickups, vans, and SUV's. Fire rates were computed using registered vehicle years as the denominator. Vehicles 0-4 years old were determined in the manner described previously to determine the number of fires. For these analyses the fires corresponding to vehicles with a minus age were moved into the next accident year even though the year model information in the NVPP contains the next model year information (that would correspond to the minus 1 vehicle age). The number of fires occurring in a given accident year in a particular vehicle group were divided by the corresponding number of registered vehicle years.

The presence of fire in a vehicle in a fatal accident was determined using the variable FIRE_EXP with a value of 1. In the analysis, fires in any vehicle involved in a fatal accident were included.

In addition to determining the fire rates across all impact modes in FARS, an analysis for the rollover and rear impacts was made selecting the cases with fires where either the variable Rollover was coded as greater than 0 or principal damage area (Impact2) was coded as (5,6,7).

Impact Induced Fires and Leaks

In the Michigan data Var00119 defines fuel leakage and/or fire associated with the accident vehicle. The principal values available are 1) fuel leaked from vehicle, 2) vehicle or cargo caught fire, 3) fuel leaked from vehicle and there was a fire, 4) no vehicle fuel leak or fire occurred. A fire was considered to have occurred if this variable was coded as a 2 or 3. A leak was considered to have occurred if the variable had a value of 1. The number of cases coded as “fuel leaked from vehicle and there was a fire” was smaller than the “fuel leaked” or “vehicle or cargo caught fire” coded situations.

Most of the cases in the file corresponded to clearly definable impacts; however, accident type (var00030) defined “other non-collision or not known” cases. Investigation of these cases indicated that a substantial portion have total traffic units (var00046)=1, traffic unit number (var00101)=1 , traffic unit object hit (var00115)=1 (no object impacted). These cases also have a fire rate about 50 times higher than the other accident types presented and if included or excluded have the ability to affect the results. Thus further work is needed to substantiate the actual characteristics of these cases. Hardcopy records could be obtained and examined to resolve whether the cases should be included in this analysis or not. The current analyses do not exclude these cases.

In Michigan, for the accident files considered here, if a vehicle was driving down the road and had a fire, pulled off to the side and stopped and the vehicle burned up, it would be considered an accident for purposes of the accident file. If the vehicle was driving down the road, pulled over to the side and parked and then caught fire, it would not be considered a traffic unit for purposes of the file.

In Michigan, a parked car is not a traffic unit but an object; information about parked cars that are impacted by another vehicle is not put into the file. It appears that most of the fires in this category are associated with what is described as some other non-collision accident or unknown type of accident other than at an intersection. About 15% of the accidents classified this way have fires associated with them.

Findings

Impact Fire Rates vs. Model Year

A comparison of the fire rates reported by Malliaris (1991) and those determined with the data we received showed that the fire rates by model year are very similar as can be seen below.

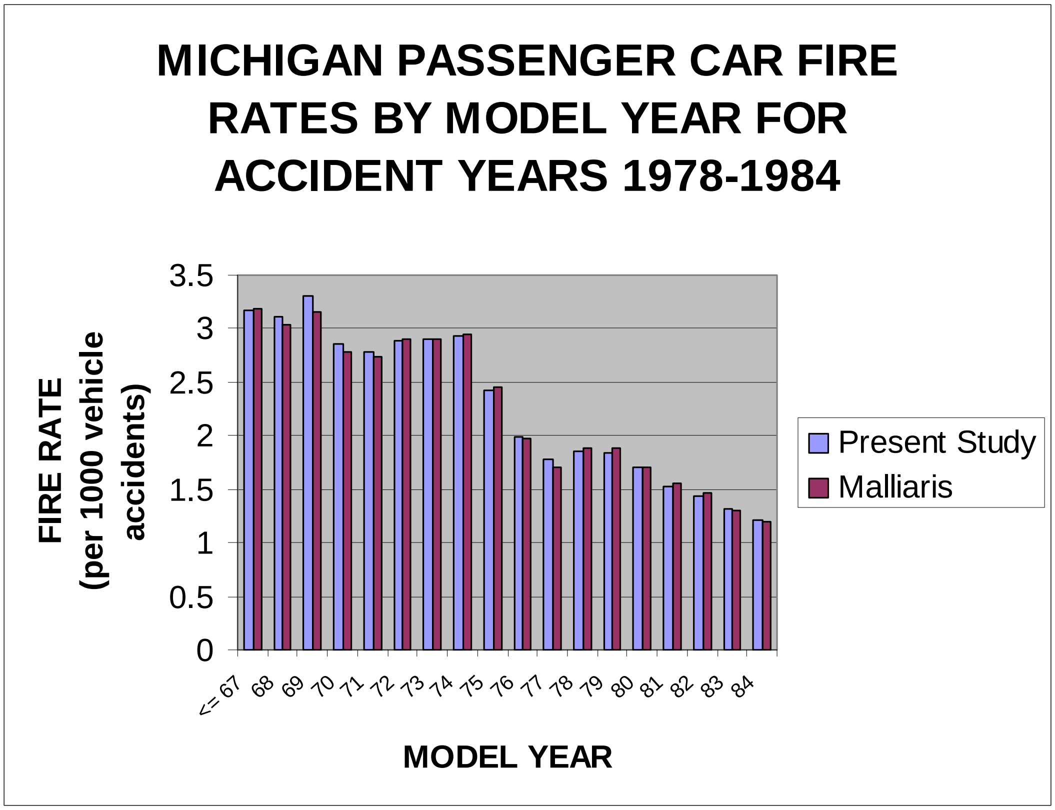


Figure 3.1 Michigan Passenger Car Fire Rates by Model Year for Accident Years 1978-1984

However, in conducting this analysis we found 2,951,975 passenger cars (var00102) with a known model year (var00106). Malliaris reported 2,280,500 cases for the same analysis. Hence, we clearly have far more cases in our analysis. The closeness of the fire rate results with such a large discrepancy in the number of cases suggested that a random elimination of cases would have to have occurred. We explored the potential for controlling known values for other variables. We concluded that controlling for other variables (i.e. eliminating cases that had missing values for important variables) did not explain the discrepancy. For example, controlling for known values in variable 104 vehicle type, 106 impact areas, 117 impact code, and 118 damage severity still resulted in 2,833,593 cases. It appeared that the best explanation was that cases were accidentally lost during the transport from Michigan to Malliaris or during the subsequent processing.

Fuel Leak Hazard vs. Model Year

Analysis to produce the results related to leak rates depicted in Malliaris' (1991) Figure 2 was conducted. The results again are similar, but not exactly the same, as can be seen in Figure 3.2. Again, the magnitude of the differences in the number of cases considered was thought to be the explanation.

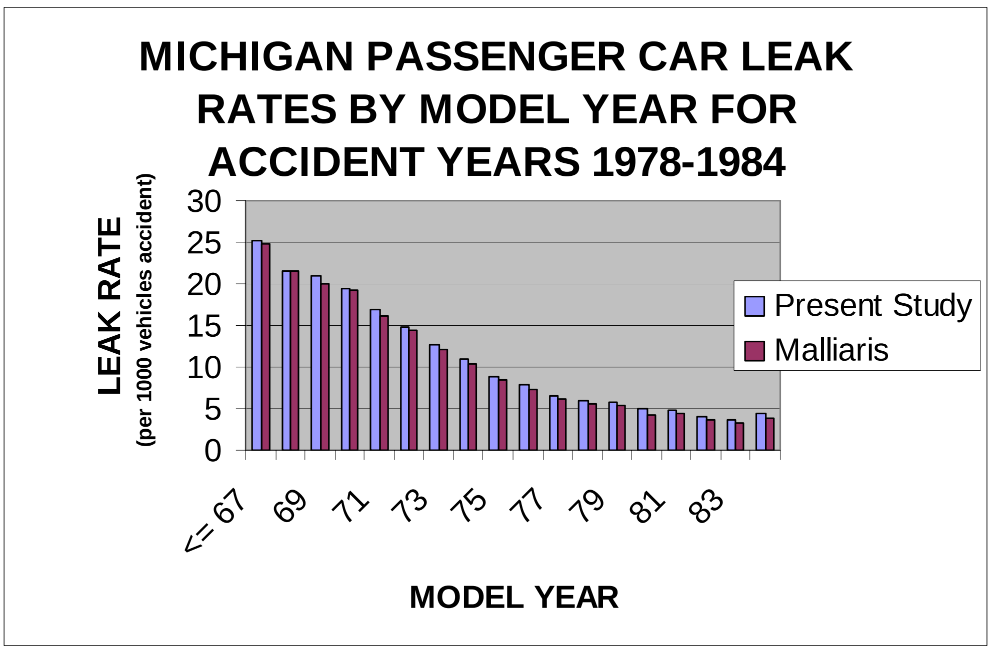


Figure 3.2 Michigan Passenger Car Leak Rates by Model Year for Accident Years 1978-1984

Vehicle Type Considerations

Consideration was given to the effect of car size based on the curb weight categorization that had been incorporated into the Michigan dataset. The results, without control, and including all impacts classified as "other non-collision accident or unknown accident type," showed results similar to Malliaris (see Figures 3.3 for fire rates and Figure 3.4 for leak rates).

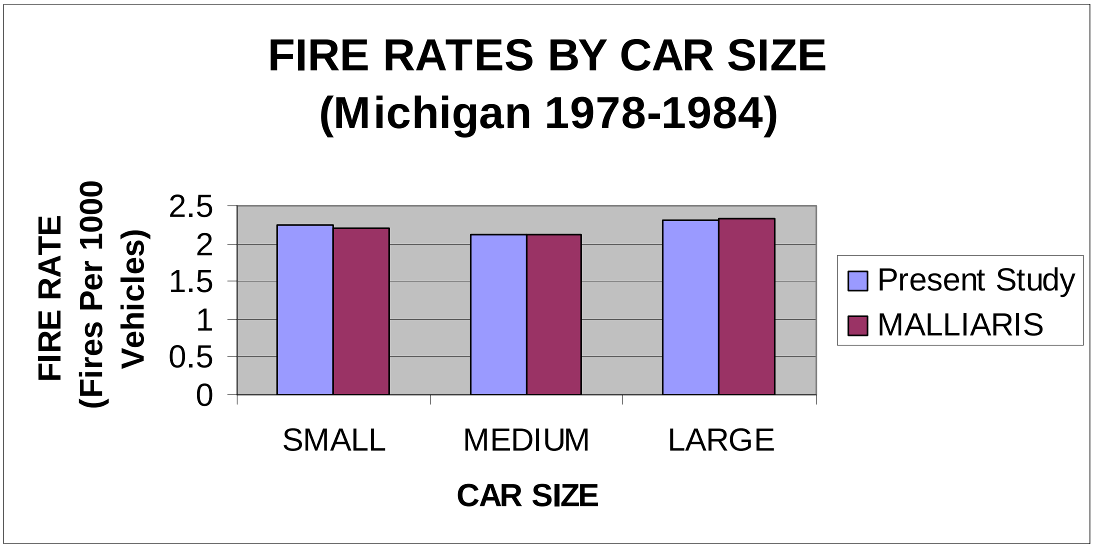


Figure 3.3 Fire Rates by Car Size (Michigan 1978-1984)

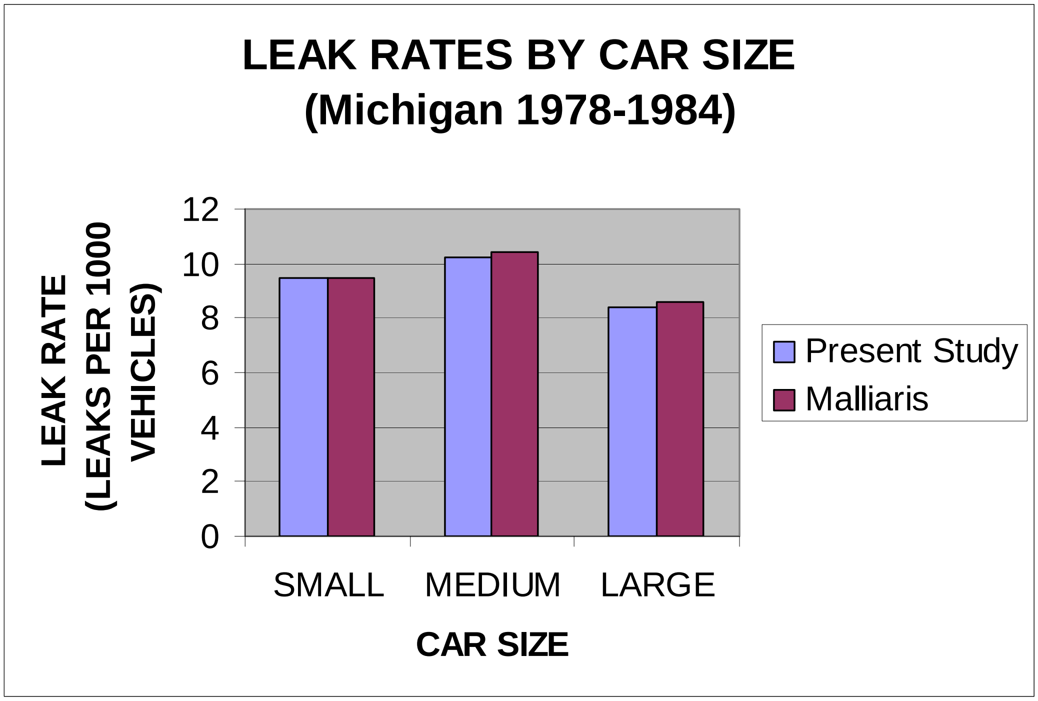


Figure 3.4 Leak Rates by Car Size (Michigan 1978-1984

In an exploratory analysis of trucks it was found that vehicles coded as trucks were primarily pickups. An illustration of the fire rates found is shown in Figure 3.5.

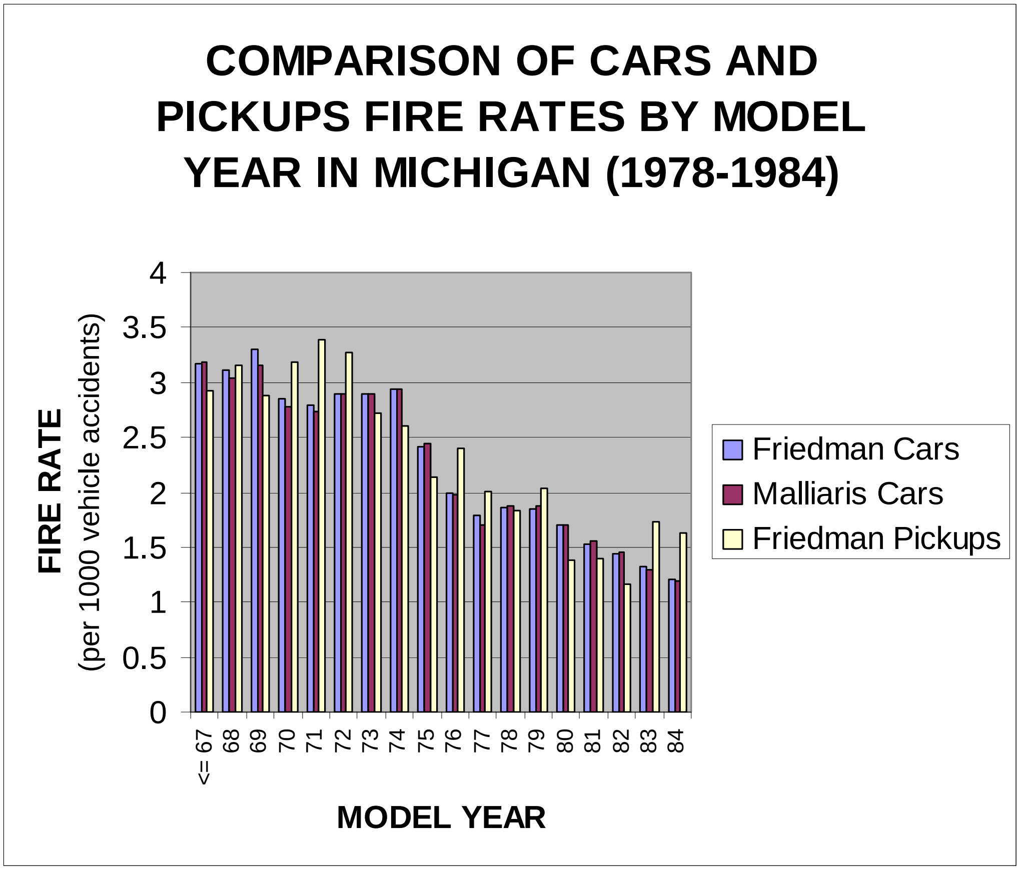


Figure 3.5 Comparison of Cars and Pickups Fire Rates by Model Year in Michigan (1978-1984)

Fire and Leak Rates by Calendar Year

The overall trend of fire and leak rates for passenger car vehicles 0 to 10 years old by calendar year is shown in Figure 3.6. The decline in the leak rates observed is likely related to the disproportionately higher leak rates found in earlier model years as illustrated in Figure 3.2. As the calendar years move forward we eliminate the earlier model years with higher leak rates.

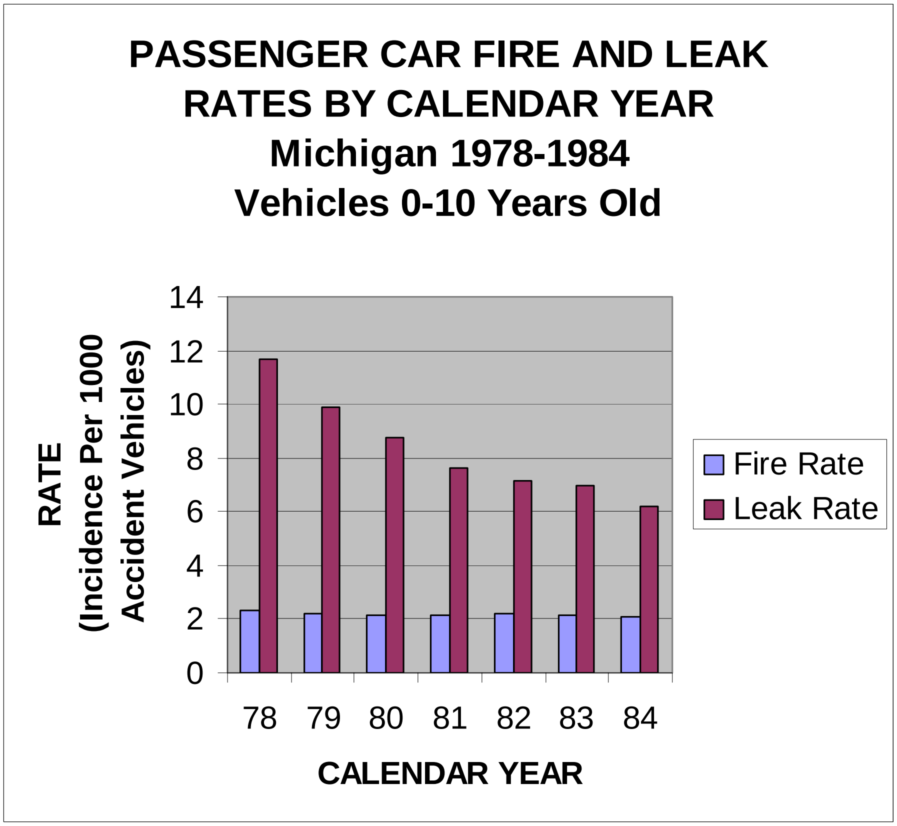


Figure 3.6 Passenger Car Fire and Leak Rates by Calendar Year Michigan 1978-1984, Vehicles 0-10 Years Old

Fire and Leak Rates Controlling for Vehicle Age 0-4 Years Old

The effect of controlling for vehicle age with comparison to the Malliaris results are shown in Figure 3.7.

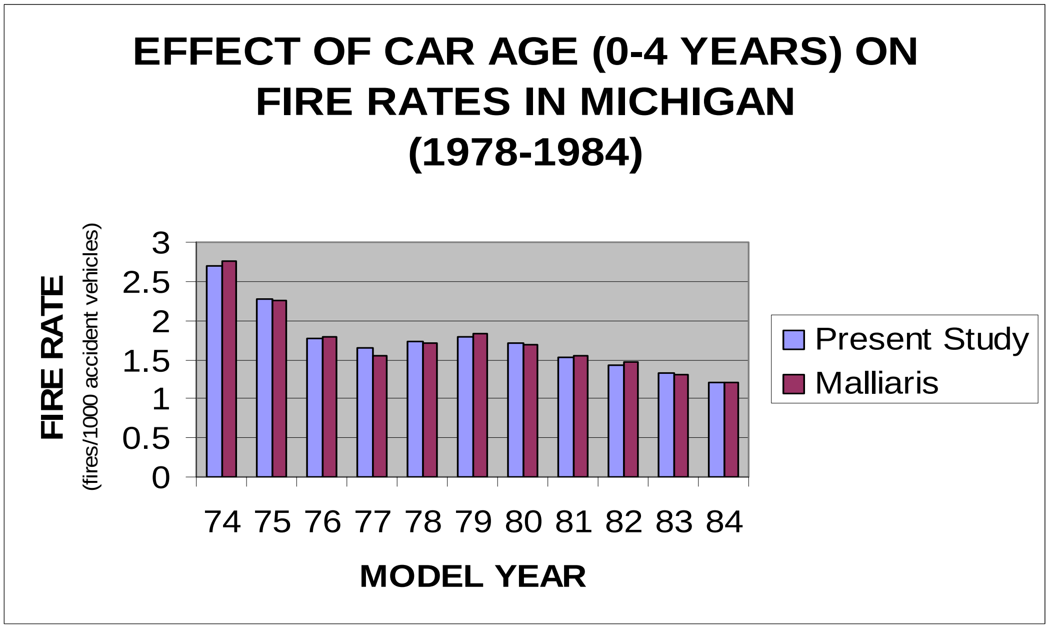


Figure 3.7 Effect of Car Age (0-4 Years) on Fire Rates in Michigan (1978-1984)

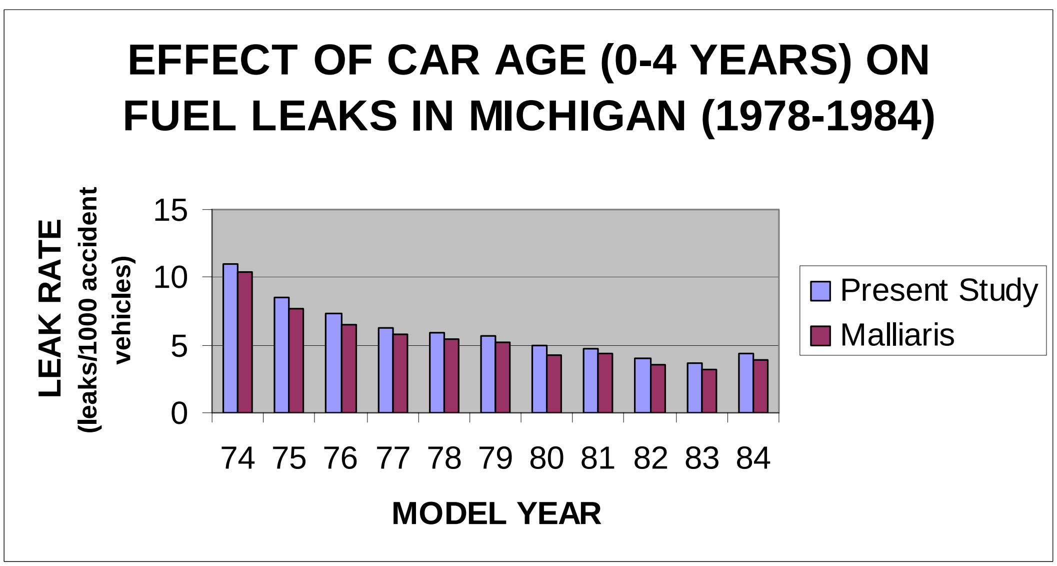


Figure 3.8 Effect of Car Age (0-4 Years) on Fuel Leaks in Michigan (1978-1984)

Impact Mode and Severity

Figure 3.9 shows the relative frequency of occurrence for damage area and severity groupings. The consistency of our results with Malliaris suggested that the groupings for low and high severity and damage area were the same ones used by Malliaris.

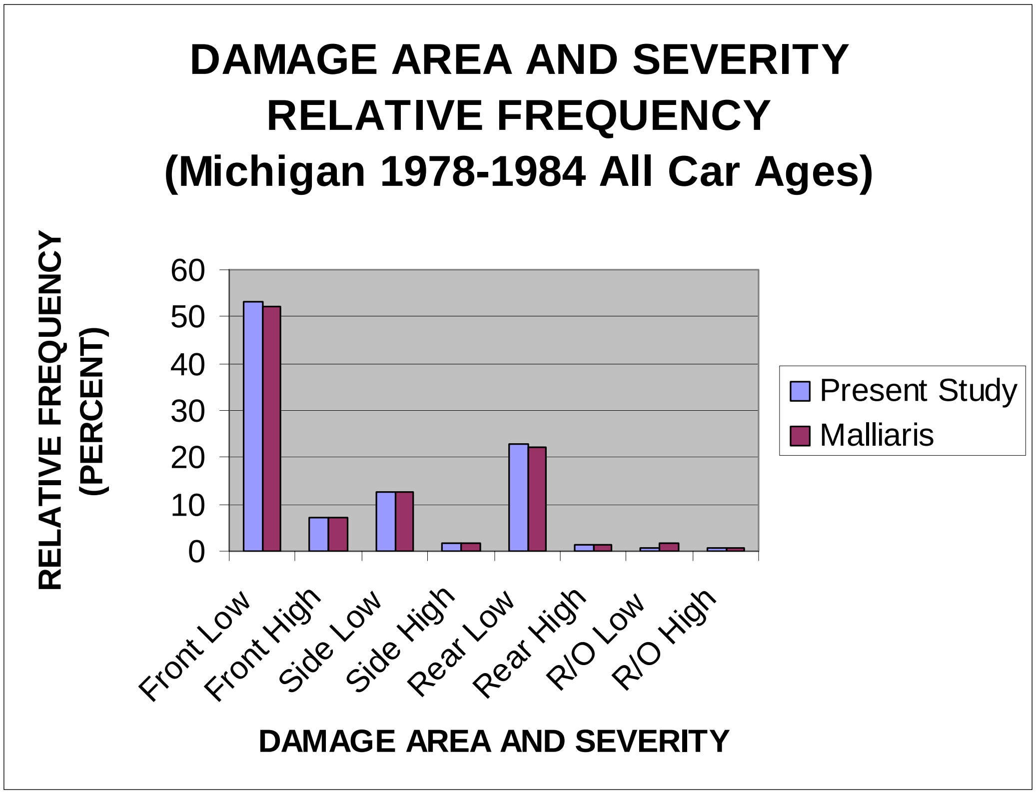


Figure 3.9: Damage Area and Severity Relative Frequency (Michigan 1978-1984 All Car Ages

The fire rates and leak rates for all vehicle ages as a function of the damage area and damage severity coding present in the Michigan files are presented in Figure 3.10 and 3.10a. There is a significant disparity between the Malliaris results and our analysis for fire rates in rollover impacts and to a lesser extent in the leak rates in the rollover category.

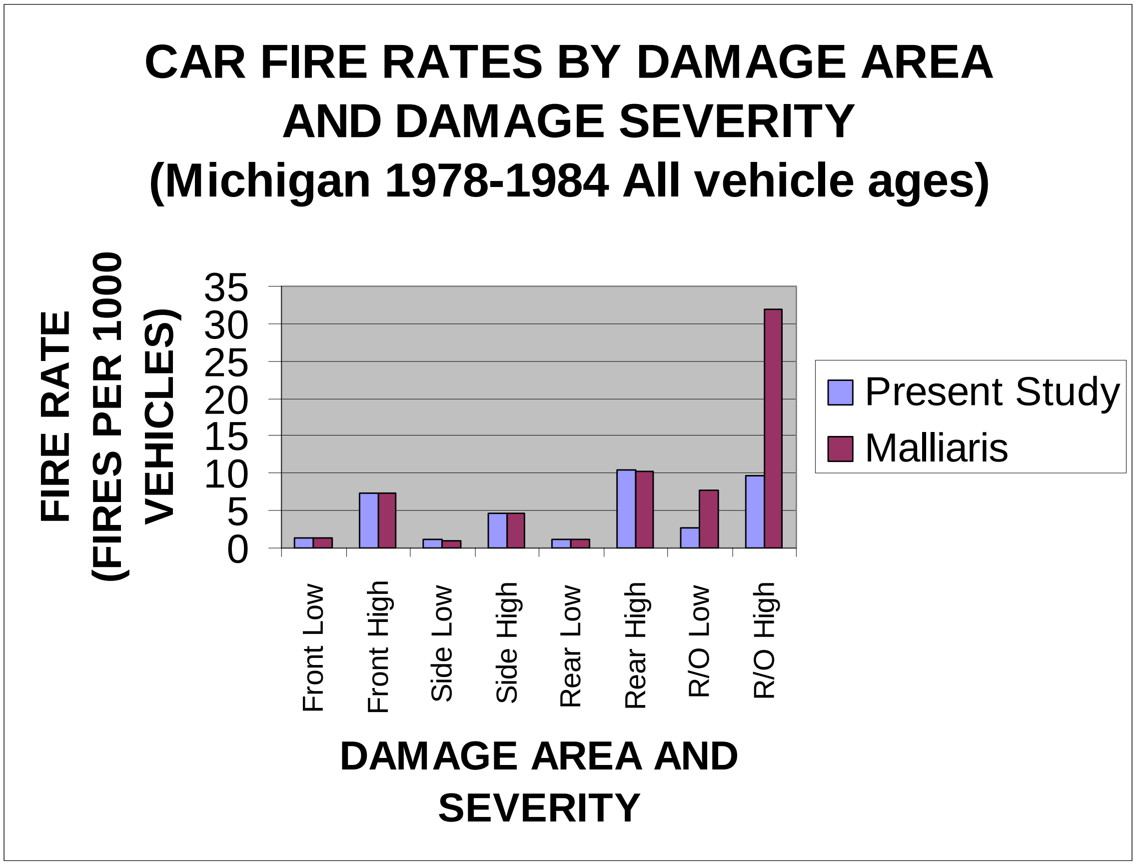


Figure 3.10: Car Fire Rates by Damage Area and Damage Severity All Vehicle Ages Michigan (1978-1984)

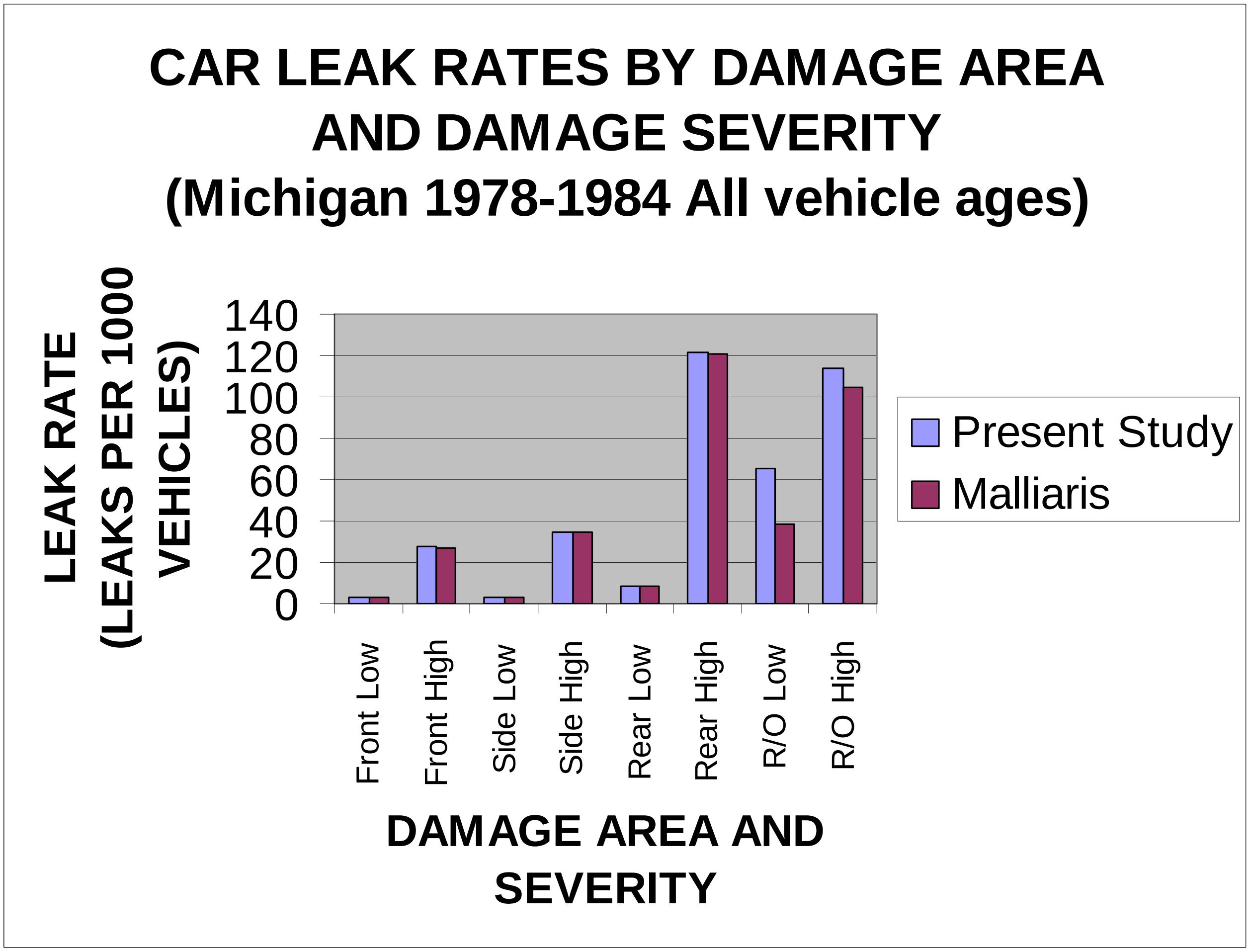


Figure 3.10a: Car Leak Rates by Damage Area and Damage Severity All Vehicle Ages Michigan (1978-1984)

Rate Reductions

Variations in fire and leak rates by vehicle size and estimates of rate reductions by model year were computed by Malliaris. The results from the present analysis and a comparison with Malliaris' results are shown in Table 3.1. Table 3.1 shows the results of the original method for computing fire and leak rates controlling for vehicle age. Passenger cars showed reasonable agreement with Malliaris' results, suggesting that we had approximated the method he had used.

Table 3.1 Passenger Car Fire and Leak Rates and Percentage Reductions by Model Year With and Without Control for Vehicle Age (Michigan 1978-1984)

Rate Type	Vehicle Age Control	Mean Rate	Malliaris Mean Rate	Mean Percent Reduction Compared to Previous Year Rate	Maliaris Rate Reduction Percentage per MY	Standard Error for Mean Percent Reduction	Maliaris Error Term
Fire	No	1.91	1.95	7.3	7.4	3	1.5
Fire	Yes	1.73	1.73	5.3	5.3	2.7	1.6
Leak	No	6.19	6.3	10.8	11.3	2.4	1.5
Leak	Yes	5.5	5.47	9.3	9.8	2.7	1.6

Table 3.1a shows the results of applying the regression of the natural log of the rates against model year to determine the percentages reductions in fire and leak rates by model year controlled for vehicle age. Table 3.1a is for both passenger cars and trucks. The results for passenger cars compared favorably with Malliaris' findings.

Table 3.1a Passenger Car and Truck Fire and Leak Rates and Percentage Reductions by Model Year With and Without Control for Vehicle Age Using Regression (Michigan 1978-1984)

Event	Vehicle Type	Vehicle Age Control	Mean Rate per 1,000 impacts	Rate reduction Percentage, per MY	Standard Error for reduction percentage	Malliaris Mean Rate	Malliaris Rate Reduction	Malliaris Error Rate
Fires	Cars	Yes	1.73	-6.61	0.90	1.73	5.3	1.5
Fires	Cars	No	1.91	-7.25	0.79	1.95	7.4	1.6
Fires	Trucks	Yes	1.83	-4.46	1.53			
Fires	Trucks	No	1.98	-5.77	1.58			
Leaks	Cars	Yes	5.52	-9.77	1.05	5.47	9.8	1.5
Leaks	Cars	No	6.19	-10.04	1.00	6.3	11.3	1.6
Leaks	Trucks	Yes	9.05	-15.37	1.43			
Leaks	Trucks	No	9.91	-13.31	1.36			

Table 3.2 expresses the percent change in fire and leak rates per model year in each group of fixed car age. The negative values imply a rate reduction and the variability is likely due to the many groups involved. The results obtained were similar Malliaris.

Table 3.2 Passenger Car Fire and Leak Rate Percentage Change Per Model Year (Michigan 1978-1984)

	Current Study		Malliaris	
	Percentage Change Per Model Year		Percentage Change Per Model Year	
Car Age	**Fire**	**Leak**	**Fire**	**Leak**
0	-9.8	-10.5	-10.7	-10.5
1	-3.2	-7.4	-3.1	-7.1
2	-0.5	-8.3	0.0	-8.7
3	-5.7	-11.8	-5.6	-11.4
4	-5.9	-10.6	-7.0	-12.1
5	-1.9	-11.5	-0.8	-13.1
6	-3.8	-12.8	-3.8	-13.8
7	-4.0	-12.9	-4.9	-12.8
8	2.7	-14.2	2.4	-14.5
9	-0.8	-11.3	0.4	-11.6
Weighted Mean	-3.4	-11.0	-3.6	-9.3
Standard Error	1.0	0.7	1.1	0.8

Table 3.3 represents Malliaris' approach to controlling for potential confounding effects associated with variations between model year and vehicle age related to the relative frequency of crash severity and impact mode. As Malliaris found, the rates within a model year group do not change much when they are controlled for crash severity and impact mode. Further, as shown in Table 3.3a our results generally agreed with Malliaris for the fire rates. The leak rates here appeared to be lower than Malliaris findings; one possible explanation is that our leak rates did not include the leaks that resulted in fires.

Table 3.3 Passenger Car Fire and Leak Rates by Model Year Group Controlled For Impact Mode And Crash Severity (Michigan 1978-1984)

Model Year group	Usual Fire Rate	Usual Leak Rate	Usual Fire Standard Error	Usual Fuel Standard Error	Controlled Weights: Fire Rate	Controlled Weights: Leak Rate	Controlled Weights: Fire Standard Error	Controlled Weights: Leak Standard Error
Pre-'76	2.33	8.79	0.35	0.71	2.29	8.88	0.35	0.73
'76-'78	1.62	5.88	0.13	0.27	1.61	5.85	0.13	0.28
'79-'81	1.54	4.76	0.14	0.27	1.55	4.73	0.14	0.26
'82-'84	1.28	3.47	0.21	0.38	1.35	3.66	0.22	0.40
All	1.61	5.43	0.03	0.06	1.62	5.44	0.17	0.33

Table 3.3a Passenger Car Fire and Leak Rates by Model Year Group Controlled for Impact Mode and Crash Severity Compared with Malliaris Results (Michigan 1978-1984)

	Car Fires per 1000 Impacts			
Model Year	Usual	Malliaris Usual	Controlled	Malliaris Controlled
Pre-1976	2.33	2.47	2.29	2.48
1976-1978	1.62	1.69	1.61	1.7
1979-1981	1.54	1.74	1.55	1.77
1982-1984	1.28	1.38	1.35	1.44
All	1.61	1.78	1.62	1.75
	Fuel Leaks per 1000 Impacts			
Pre-1976	8.79	11.5	8.88	11.7
1976-1978	5.88	7.7	5.85	7.7
1979-1981	4.76	6.7	4.73	6.8
1982-1984	3.47	5.1	3.66	5.3
All	5.43	7.4	5.44	7.4

Table 3.4 represents Malliaris' approach for evaluating variations in rate by model year controlled for vehicle age for particular impact conditions and excluding the "other non-collision and unknown accident type" cases. As might be expected the effect of excluding these cases compared to Malliaris' results was more pronounced for the fire rates than the leak rates. While the results generally agreed with Malliaris' results, the reduction percentage by model year in the "severe" impact category on a weighted basis was found to be near 0 and substantially different from Malliaris' results. Post-hoc investigation of this anomaly showed that the data for this category appeared as in Figure 3.11. Further investigation showed that the number of cases was concentrated more in the 1976-1981 model years, thus suggesting that the present results are consistent with the underlying data.

Table 3.4 Mean Rate and Rate Reduction Comparisons for Impact Fires and Leaks

Rate Type	Impact Category	Mean Rate per 1,000 impacts (Excluding other non-collision)	Rate Reduction Percentage, per MY, Weighted with original case count	Malliaris Rate per 1000 impacts	Malliaris Rate Reduction percentage, per MY
Fire	All	1.58	5.32	1.73	5.3
Fire	Hi Sever impact	5.81	-0.02	7.61	4.3
Fire	Rear imp & R/O	1.44	8.2	1.92	5.4
Leak	All	5.43	9.73	5.47	9.8
Leak	Hi Sever impact	28.03	8.91	32.04	10.9
Leak	Rear imp & R/O	9.34	12.14	9.35	12.3

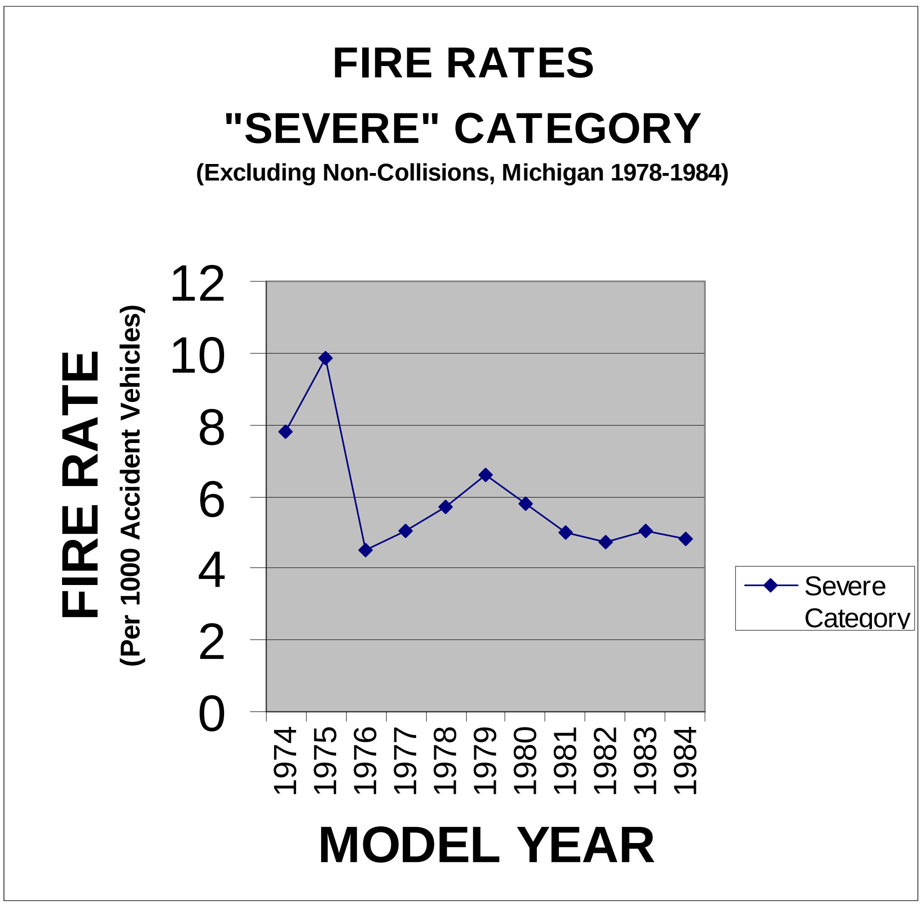


Figure 3.11 Fire Rates within the Severe Category by Model Year (Michigan 1978-1984)

Table 3.5 Mean Rate and Rate Reductions Comparisons by Vehicle Size for Fires and Leaks in Passenger Cars (Michigan 1978-1984)

Passenger Car Size	Fire Rate Per 1000 Accident Vehicles	Malliaris Fire Rate/1000	Mean Percent Reduction Compared to Previous Year Rate	Malliaris Percent Reduction	Malliaris Error Rate	Standard Error for Mean Percent Reduction
All	1.72	1.73	5.30	5.30	1.6	2.7
Small	1.56	1.50	5.16	8.30	2.7	8.6
Medium	1.70	1.73	3.89	4.90	1.9	3.4
Large	1.80	1.83	6.00	4.00	2.8	4.9
Passenger Car Size	Leak Rate Per 1000 Accident Vehicles	Malliaris Leak Rate/1000	Mean Percent Reduction Compared to Previous Year Rate	Malliaris Percent Reduction	Malliaris Error Rate	Standard Error for Mean Percent Reduction
All	5.48	5.47	9.26	9.80	1.6	2.6
Small	5.78	5.89	12.26	17.30	2.6	5.5
Medium	5.70	5.69	11.49	13.10	2.2	4.6
Large	5.16	5.11	7.43	6.90	1.8	2.7

Table 3.5 shows results similar to those found by Malliaris for the fire and leak rates by vehicle size and percent reduction by model year within these groups for vehicles 0-4 years old. These results do not exclude the “other non-collision” accident type cases.

Accident Type

Given the findings from the literature review (Section 1) and data sources (Section 2) on pre-collision fires, we examined the fire rates and frequencies associated with types of accidents. As indicated in Table 3.6, a significant number of cases in the file appear to be in the “other non-collision accident or unknown” category. The rate of fires in this category is about 15.43% and constitutes about 15.60% percent of the fire cases. The 15.43% fire rate is about 100 times larger than the typical fire rate; for example, the “collision with another motor vehicle” fire rate is about 0.15%. Because we have included these cases in the analyses so far, if it ultimately turns out that they actually are not collisions, then the fire rates we have observed can be expected to be reduced. We have also confirmed with Michigan that they put in records that do not involve an impact in the database. In the Michigan files, if a vehicle was going down the road, caught fire and pulled off to the side of the road and burned, it would be considered an accident for purposes of the accident database and would be included. If the vehicle had gone down the road, pulled over to the shoulder and parked and then there was a fire it would not be included in the database.

Initial analysis has shown that the accident types of "other non-collision or unknown", often involved an impact with another object of some sort (e.g. a ditch) and are primarily single vehicle cases.

Interestingly, within the analysis, the fire rates appeared to be dependent on impact type, with fixed objects and rollovers having the highest rates, vehicle to vehicle impacts the next highest, and impacts with bicyclists, pedestrians, and animals the lowest (see Figure 3.12). Except for rollovers the rates appeared to go with what one might expect to be the average crash severity for the groupings.

Table 3.6. Fire by Accident Type

Table of fire by accident type

fire(Car Fire) ACCIDENT TYPE)

fire(Car Fire)	Frequency / Percent / Row Pct / Col Pct	other non collision or unknown	roll	rail	parked motorveh	motor vehicle	pedestrn	fixed object	another object	animal	bicycle	Total
0	Frequency	5667	40687	1828	125471	2352001	24373	262443	4867	105611	22399	2945347
	Percent	0.19	1.38	0.06	4.25	79.68	0.83	8.89	0.16	3.58	0.76	99.78
	Row Pct	0.19	1.38	0.06	4.26	79.85	0.83	8.91	0.17	3.59	0.76	
	Col Pct	84.57	99.39	99.29	99.78	99.85	99.92	99.48	99.67	99.92	99.94	
1	Frequency	1034	249	13	276	3554	19	1368	16	85	14	6628
	Percent	0.04	0.01	0.00	0.01	0.12	0.00	0.05	0.00	0.00	0.00	0.22
	Row Pct	15.60	3.76	0.20	4.16	53.62	0.29	20.64	0.24	1.28	0.21	
	Col Pct	15.43	0.61	0.71	0.22	0.15	0.08	0.52	0.33	0.08	0.06	
Total	Frequency	6701	40936	1841	125747	2355555	24392	263811	4883	105696	22413	2951975
	Percent	0.23	1.39	0.06	4.26	79.80	0.83	8.94	0.17	3.58	0.76	100.00

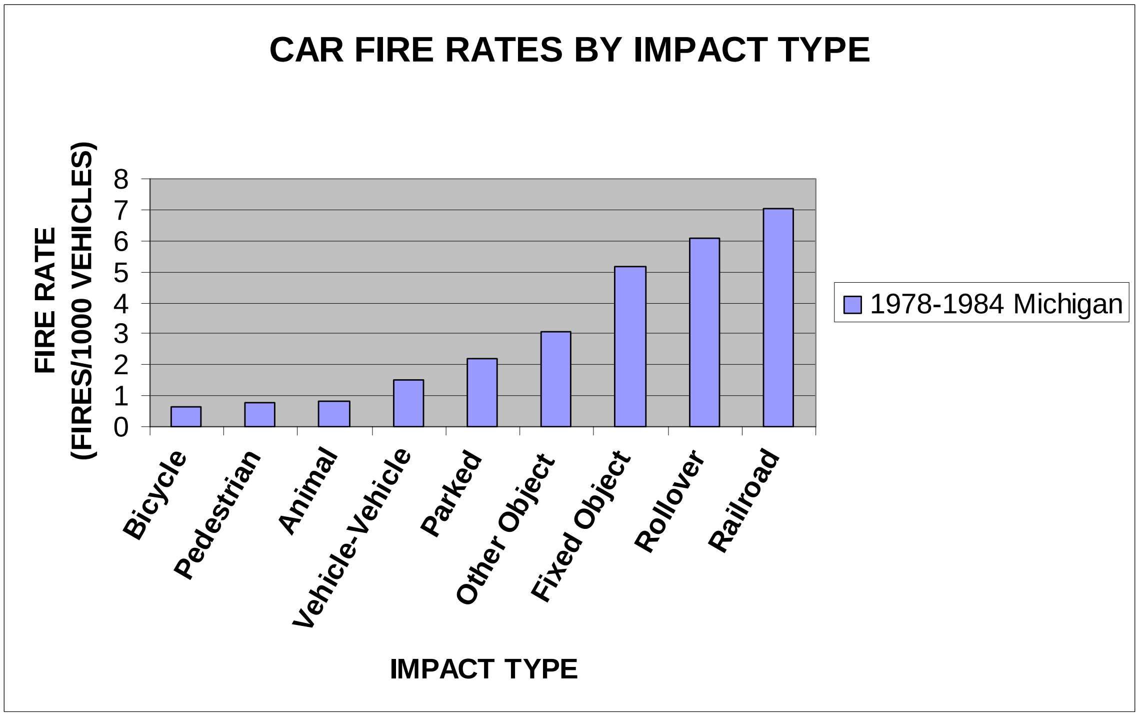


Figure 3.12 Fire Rates by Impact Type (Vehicle Age 0-4 Years)

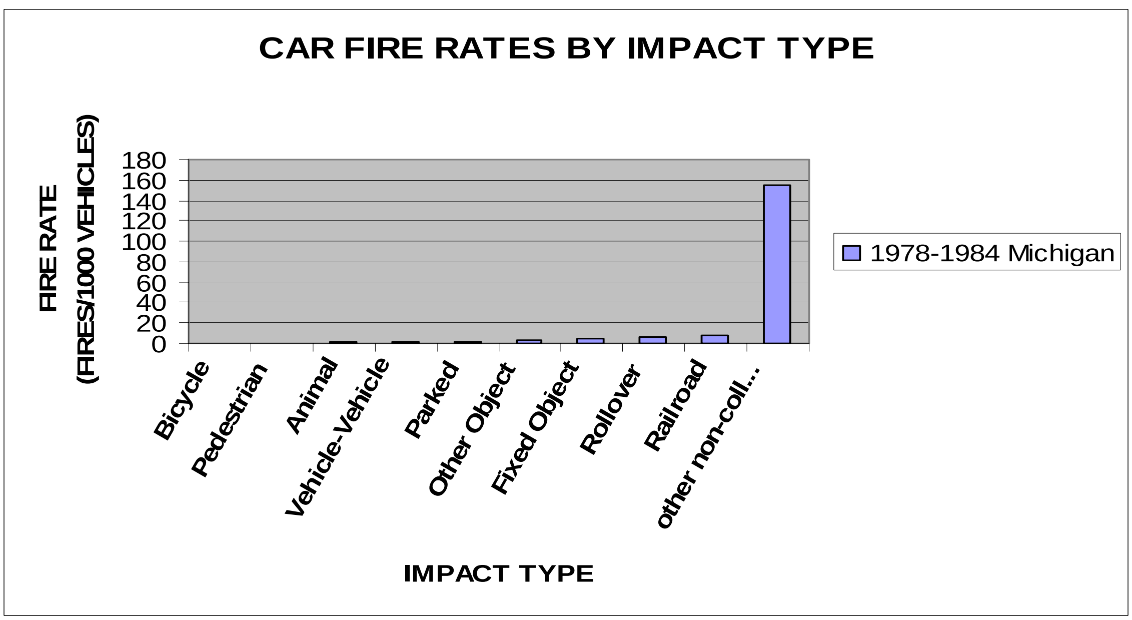


Figure 3.13 Car Fire Rates by Impact Type

While Figure 3.12 is shown without the other non-collision data, inclusion of the other non-collision cases Figure 3.13), dwarfs the fire rates of the other categories. A comparison of the results on fire rates by model year when including or excluding the "other non-collision accident or unknown accident type" is shown in Figure 3.14. As can be seen, the fire rates decline with the exclusion of the “other non-collision accident or unknown accident type”.

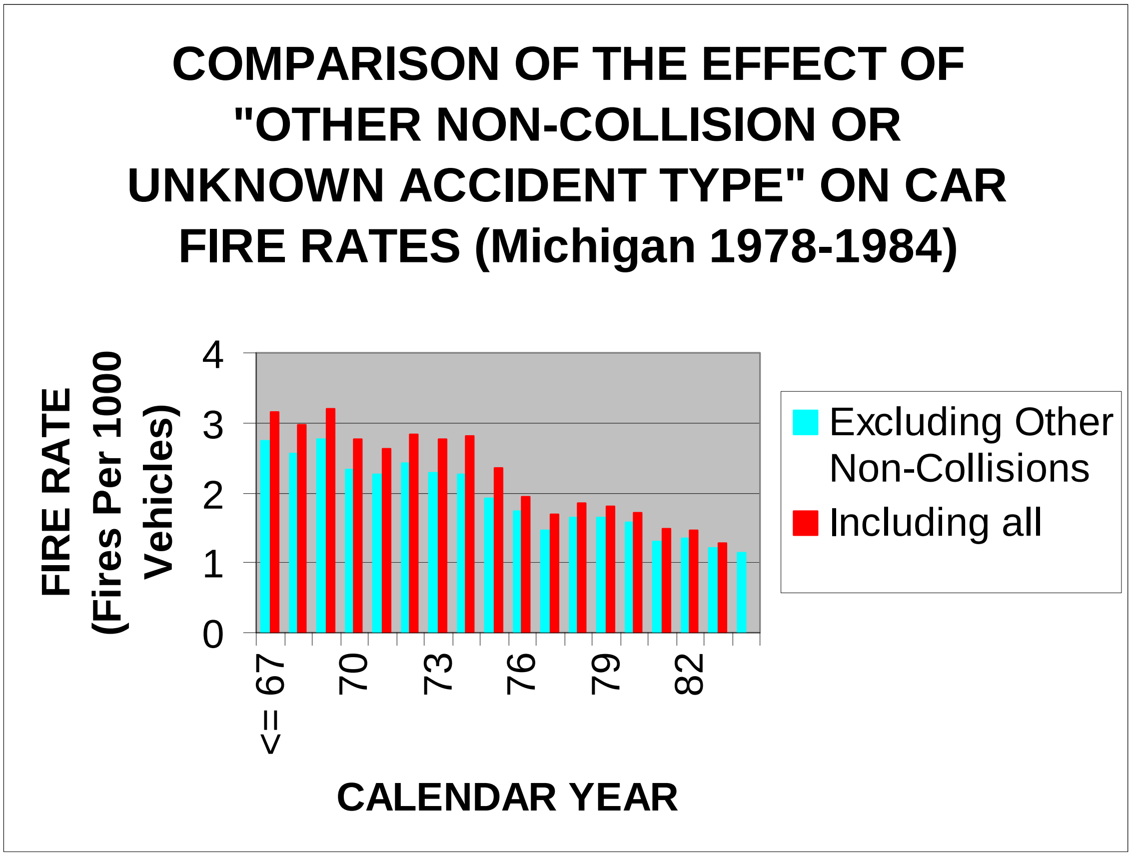


Figure 3.14 Comparison of the Effect of Other Non-collision or Unknown Accident Type on Car Fire Rates by Model Year (Michigan 1978-1984)

The fire and leak rates by passenger car size in the Michigan data are shown in Figures 3.15 and 3.16.

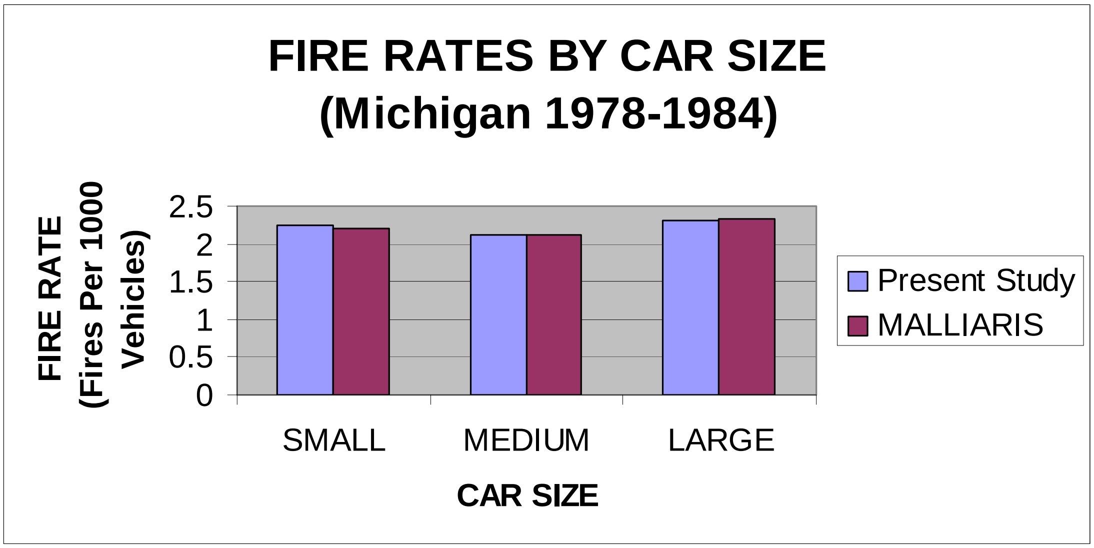


Figure 3.15 Fire Rates by Vehicle Size (Michigan 1978-1984)

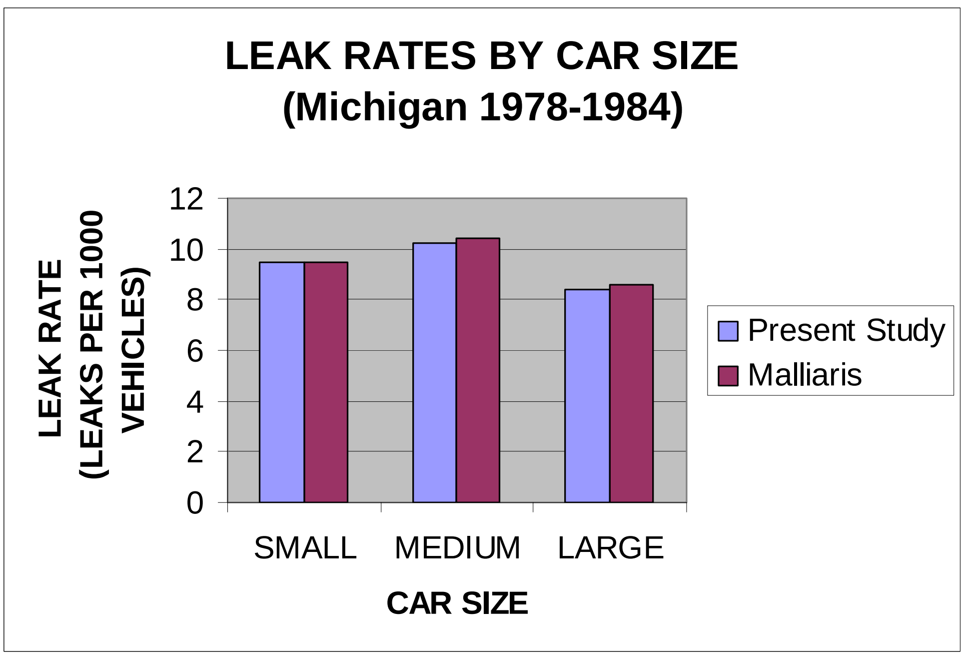


Figure 3.16 Leak Rates by Vehicle Size (Michigan 1978-1984)

By comparison, if the “other non-collision or unknown accident type” accident records are excluded, the results are as illustrated in Figure 3.17 and Figure 3.18 for fires and leaks, respectively.

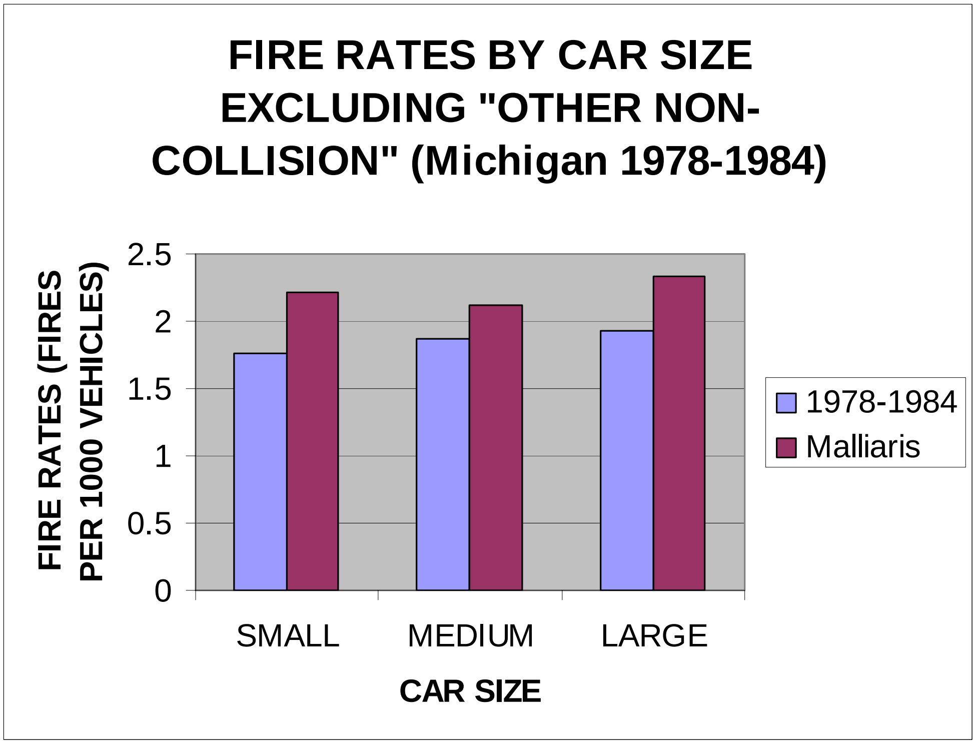


Figure 3.17 Fire Rates by Car Size excluding Other Non-Collision Michigan 1978-1984)

The reductions observed in the fire rates by the exclusion process did not show up when considering the leak rate data as can be seen in Figure 3.18. Thus the leak rates appeared to be unaffected by the exclusion of “other non-collision accident or unknown accident type” cases. This would be consistent with the premise that there are substantial numbers of non-impact fires contained within the Michigan data. These cases would be within the “other non-collision” accident type, because we would not expect many accident reports to be filed based on a vehicle stopping on the road due to a leak.

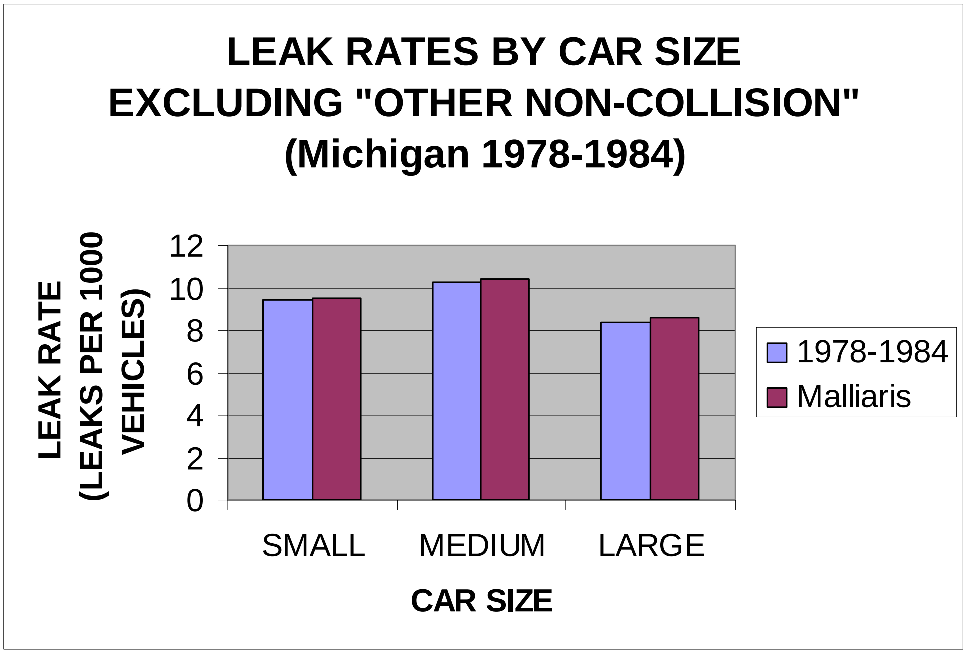


Figure 3.18. Leak Rates by Car Size Excluding Other Non-Collision (Michigan 1978-1984

Michigan Summary

The Michigan data was used to replicate the methods used by Malliaris and to a large degree this effort was successful. The most significant problem in reproducibility was deviation in the numbers of cases available for use between the present study (we had 29% more cases) and the Malliaris study. In addition, the observed fire rates for rollovers were found to be substantially reduced but still high. It was found that the Michigan data likely includes pre-impact fire cases in the accident data by virtue of the way the data was collected. Various methods were identified on how to infer the presence of such a case and effort was given to evaluating the effects of such methods. It is expected that the fire rates computed without the non-collision cases are better estimates of the impact fire rates, while leak rate calculations are not substantially affected.

Analysis of FARS Data

Fire Rates in Vehicles 0-4 Years Old Involved in Fatal Accidents

A determination of the fire rates for vehicles in fatal accidents based on fires that occurred and the number of registered vehicle years is shown is Figure 3.19. As can be seen, the fires rates in LTVs historically have been higher than passenger cars based on this exposure metric.

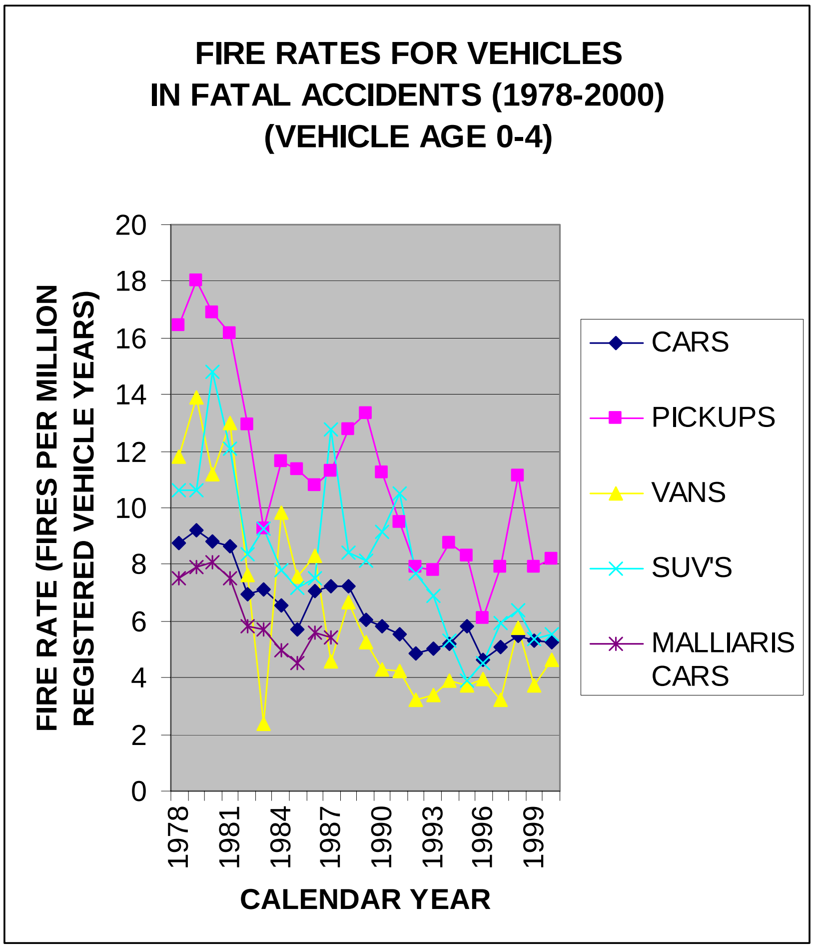


Figure 3.19 Fire rates for Vehicles in Fatal Accidents (1978-2000, Vehicles Age 0-4

Examination of the underlying components suggested that pickup truck fire rates have not improved as much as SUVs and Vans, as shown in Figure 3.19. However, due to the exposure measure used, care must be taken in the interpretation of the results because it is believed that a registration year based metric is not adequate. Also shown is a comparison of results with those of Malliaris which indicates that the current rates are higher than were obtained previously. Figure 3.20 shows the fire rates with the LTV vehicles consolidated into one group.

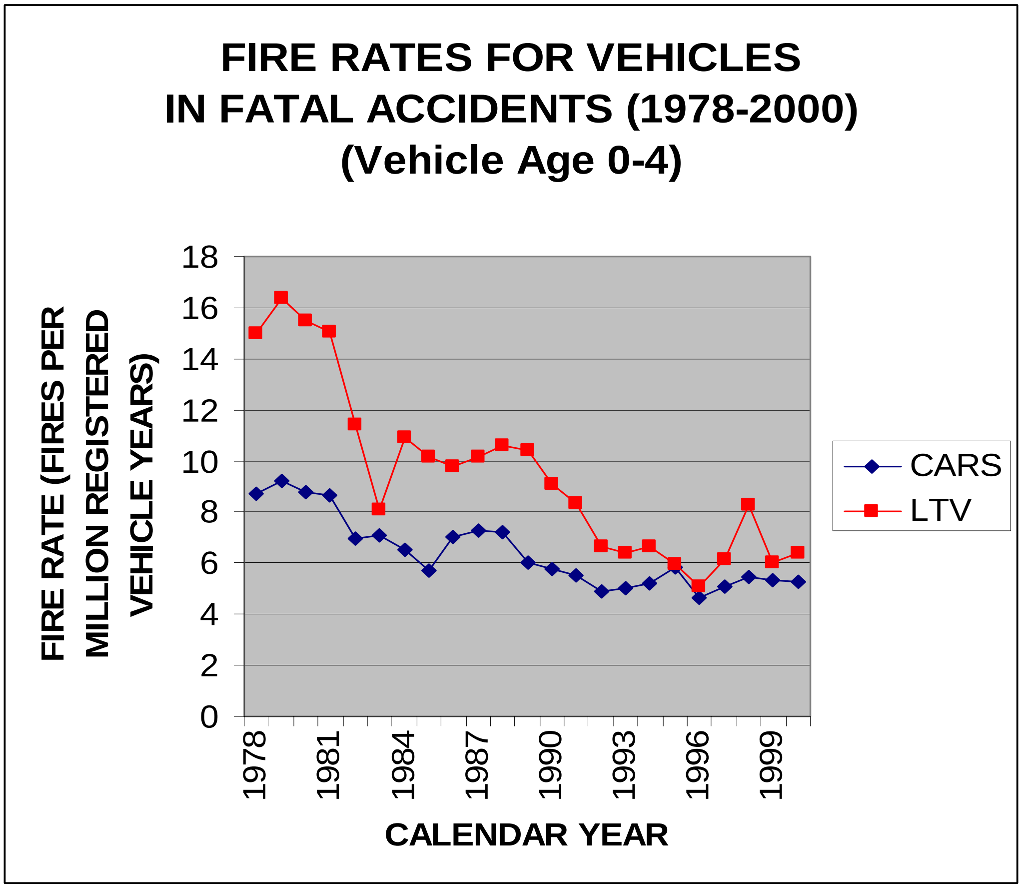


Figure 3.20 Fire Rates for Vehicles in Fatal Accidents (1978-2000 Vehicles 0-4 Years Old)

Fire Rates in Rear and Rollover Vehicles in Fatal Accidents

For vehicles 0-4 years old with rear or rollover involvement in fatal accidents the fire rates are shown in Figure 3.21. The LTV rates are higher than the computed passenger car rates. The passenger car rates are greater than the Malliaris rates again for this subset of the data.

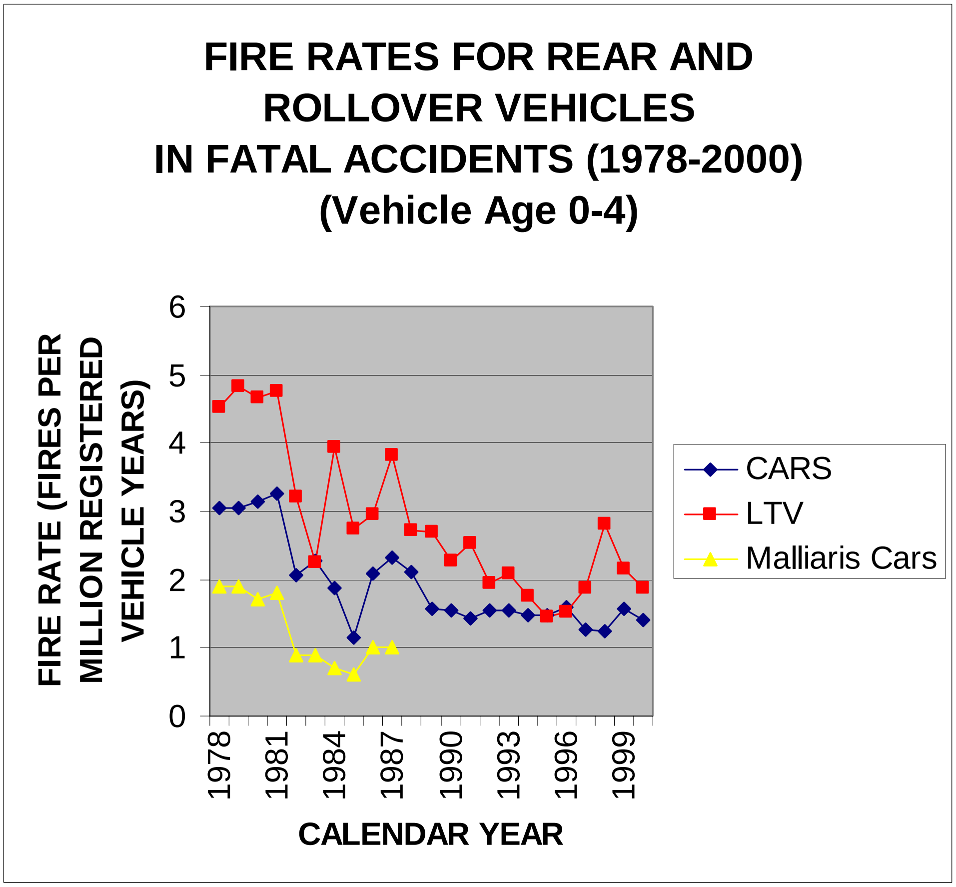


Figure 3.21 Fire Rates for Rear and Rollover Vehicles in Fatal Accidents (1978-2000; Vehicle Age 0-4)

Figure 3.22 shows the percentage increase in the fire rates computed here compared with the results from the Malliaris study. It is expected the variations in the values used for the denominator are likely the source of the variation, because the fatality numbers being for passenger cars and fires are well defined. The source of differences between Malliaris results and the present study were not identified definitively due to an absence of underlying quantitative values for comparison. However, the differences may be based on differences in definition of Polk registrations, an undefined normalizing factor that Malliaris may have used in conjunction with Polk, and the coding approach used to define what would be defined as a rollover.

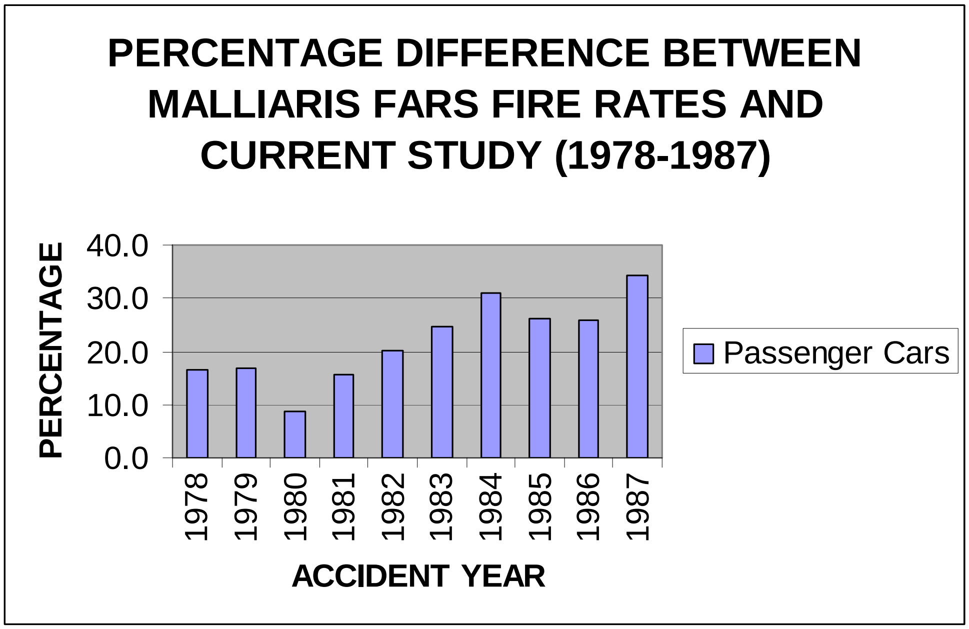


Figure 3.22 Percentage Difference in FARS Passenger Car Fire Rates in the Present Study and the Malliaris Study

Analysis of the FARS data shows declining fire rates by model years based on registered vehicle years as an exposure measure. We believe that a more appropriate exposure measure would at least take into account vehicle mileage. Based on the metric that was used it appears that the fire rates have leveled out in the FARS data. However, it must be noted that there may be significant underreporting of fires in FARS and the registered vehicle year metric is not the most appropriate for use as mentioned previously. While the Malliaris methodology characterized the metrics described above further analyses could be constructed utilizing the FARS data and alternative exposure measures. It is believed that the FARS data represents an opportunity to address the underreporting of fires through the utilization of additional data sources. As a result, it is expected that further work in this area would be fruitful.

SECTION 4: STATE OF MARYLAND ANALYSIS

In preparing to identify fire risk trends for a number of states and over a number of periods, we approached the problem by ensuring that the analysis methods used by earlier researchers were understood. The methodology described by Malliaris was defined in the contract as the methodology to be used. Our analyses began with the replication of Malliaris' (1991) study. In the Section 3, data from FARS and the State of Michigan were used to generate results for years 1978-1984. Analysis was performed to investigate the following areas of interest.

1. Impact fire rates vs. model year
2. Fuel leak hazard
3. Incidence of fire and leaks at high impact severity
4. Impact type
5. Vehicle type

In Section 4, we have used the State Accident file data from Maryland 1989 to 2000[1] to investigate these same variables with the exception of those related to fuel leaks. Maryland does not code for fuel leaks and therefore item #2 above was not analyzed. Item # 3 was revised to "Incidence of fire at high impact severity'.

Method

Maryland Accident Data

Maryland data from 1989-2000 was obtained from NHTSA based on authorization from the State of Maryland. NHTSA was reported to have more data than Maryland state files had available. The data represents accidents that involved towed vehicles or that had injuries or fatalities. There was a change in the data system after 1992 so the variables and coding change from 1992 to 1993[1].

[1] We have now located Maryland data from 1979 which would allow us to compare data to Michigan. However, due to the dramatic shift in the data rates across the 1992-1993 time frame, it is clear that there are some data collection system effects and therefore renders this information less useful.

Statistical Analysis

Distinction of pre and post impact fires was possible with Maryland's data file. Our intention had been to consider only post impact fires. Pre-impact fires were identified as though the primary or secondary cause of the accident was a fire or where the first accident event was a fire. Fires were identified for 1989-1992 as those vehicles with the vehicle damage variable (VEH_DAM) equal 13, and for 1993-2000 based on the fire variable having the value Y. For the time frame 1993-2000 those fire variable cases with a blank were considered to actually be an N. This later determination was made after extensive follow-up with the state and is related to the nature of their accident form as well as quality control issues during the data entry process. As a result of our inquiries they claim to be changing the instructions being given to the keypunching activities. Those cases with missing most harmful event or missing veh_dam1, veh_dam2, or veh_dam3 were eliminated from the analysis.

Classification of the vehicle types was done through a database variable called VEH_TYPE. When VEH_TYPE equals 2 or 3, then the vehicle is considered to be a passenger car. It was found that the vehicle type classifications provided by Maryland keypunchers have problems within the typical definition of LTVs. The resolution of these coding errors was outside the scope of the present effort (a more detailed discussion can be found in this report under Vehicle Type).

When VEH_TYPE equal 5 for 1989-1992 or 5,20,21 for 1993+, the vehicle was considered to be an Light Truck or Van (LTV).

Estimation of the change in fire rates as a function of model year was determined by taking the natural log of the fire rates, using linear regression to fit the estimated fire rates and determining the slope of the line that has been fit.

For fire rates by model year groups, vehicle ages 0-4 were selected and variations in crash severity and impact mode by calendar year were accounted for by separating the data into 8 cells: high and low crash severity groups and four impact modes (front, side, rear and rollover). We computed fire rates by model year groups (pre-91, 92-94, 95-97, 98-2000) within each cell and applied standardized frequencies of occurrence across the cells

Vehicle Type Considerations

The Maryland data did not include curb weight. The vindicator was used to obtain curb weights. However, the percentage of cases for which the VINs were decodable was less than fifty per cent. Due to the data entry issues previously identified in the Maryland file, extensive work would be required to determine whether the VINs that could be decoded would be reliable.

With the Michigan data we did an exploratory analysis of trucks and discovered that vehicles coded as trucks were primarily pickups, but other vehicles were included. The pickup fire rates had larger magnitudes by model years than are observed for the passenger cars.

An examination of the body type variable available in the Maryland data indicated that a change in 1993 added the categories of vans and pickups. However, the truck category still remained complicated by the inclusion of a wide variety of trucks .While a large portion of these included vans, pickups and LTVs it was also the case that it included larger trucks. Hence relying on the body types that included trucks would necessarily have trucks other than LTVs. Examination of the data in detail revealed that the quality control make, model name codes would require a significant effort to use make and model name variables. The use of vindicator was explored and a similar problem was found with the software because it did not provide an automated output that would easily distinguish LTVs from cars. While it did make this distinction when decoding a single vin it does not appear to do this for bulk processing based on the documentation that we have available. Hence, the LTV analysis conducted for Maryland necessarily had other vehicles that were not LTVs. Similarly, the passenger car category was likely to contain cases which might for example be LTVs. There are solutions to these problems, but they would require significant effort and cost. Even if implemented, there would still likely be quality control problems.

The coding for the LTVs in Maryland utilized the following approach.
1989-1992 vehtype = 5
1993+ vehtype = 5, 20,21

Impact Mode Considerations

Due to the changes in the data system in 1993, two different coding schemes were utilized to determine impact modes. Prior to 1993 three damage areas were available for a given vehicle. For the pre 1993 data, the first damage area coded was utilized for the impact mode unless a code of 11 (rollover) was found in one of the other damage areas in which case the impact mode was considered to be rollover. For the 1993 and later data a variable was added to indicate the main impact and that coding was then utilized for the impact mode. Examination of this approach showed that for the post 1993 data that there can be rollovers coded (value=23) in the damage area coding, that are not shown in the main impact. Because someone with knowledge of the accident had determined the most significant impact event, it was decided to utilize this information. *However, it should be recognized with this method that the post 1993 results actually understate the occurrence of rollovers*

Rate Reduction

The method for each of the rate reduction tables is described in this section.

Table 4.1. Estimation of the percent change in fire rates controlled for vehicle model year was done by regressing the natural log of the fire rates by model year onto the model year. The resulting parameter estimate for the time component represents the percent change in rates across time. The standard error for this parameter estimate was reported as the standard error for the estimate of percent change in rates. Vehicles were limited to ages between 0 and 4 years.

Table 4.2 Estimation of the percent change in fire rates as a function of model year within a vehicle age group have been determined by taking the natural log of the fire rates, using linear regression to fit the estimated fire rates and determining the slope parameter that was fit, as with Table 4.1.[1]

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[1] This estimate for the slope parameter (beta) represents the percent change in rates over time. (Chatterjee & Price, 'Regression Analysis by Example', pages 32-34 shows an example based on decay rates of bacteria, which has a exponential non-linear relationship with time and an asymptotic limit, much like changes in fire rates over time).

Table 4.3. To control for crash severity and impact mode across model years the overall probabilities for falling into a given crash severity and impact mode cell were computed. The overall probabilities were applied to the model year groups of interest to compute a "controlled" rate (fire or leak as appropriate). While the appropriate method for calculating the standard error could be debated, in this case the standard errors associated with the respective cells were combined in accordance with their respective probabilities in an effort to characterize the standard error for the model year group. The ‘usual’ mean rates and standard error were calculated from the same groups, using the vehicle counts within cell as weights.

Table 4.4. Cars and LTVs with known damage area and severity were selected for vehicle ages 0-4. For each combination of vehicle type and the all, high severity and rear/rollover, and inverse groups, linear regression was done on the natural log of fire rates by model year to obtain the estimated percent reductions by model year and to determine the slope parameter that was fit, as in Table 4.1 above.[1] The inverse group consists of vehicles that have age 0 to 4 but with missing or invalid impact mode and or severity class as well as the vehicles that do not meet the vehicle age criteria. The “all” category includes all vehicles that have valid impact mode and crash severity information and meet the vehicle type requirements and are 0-4 years old.

Table 4.5. Vehicles were classified by vehicle size and type. Estimated percent reductions by model year were obtained by using linear regression on the natural log of the fire rates by model year for vehicles within the 0-4 year old group and to determine the slope parameter that was fit. The inverse group consists of vehicles that do not meet the vehicle age criteria or have missing vehicle size codes. The “all” category includes car and LTV vehicles with valid vehicle size coding including unknown (but not missing) and that are 0-4 years old.

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[1] *Ibid*

Findings

Impact Fire Rates vs. Model Year

From the Figures 4.1 and 4.2, it is clear that older model year vehicles have higher fire rates. On average the LTV fire rates were 11 percent greater than the passenger car fire rates for this range of vehicles.

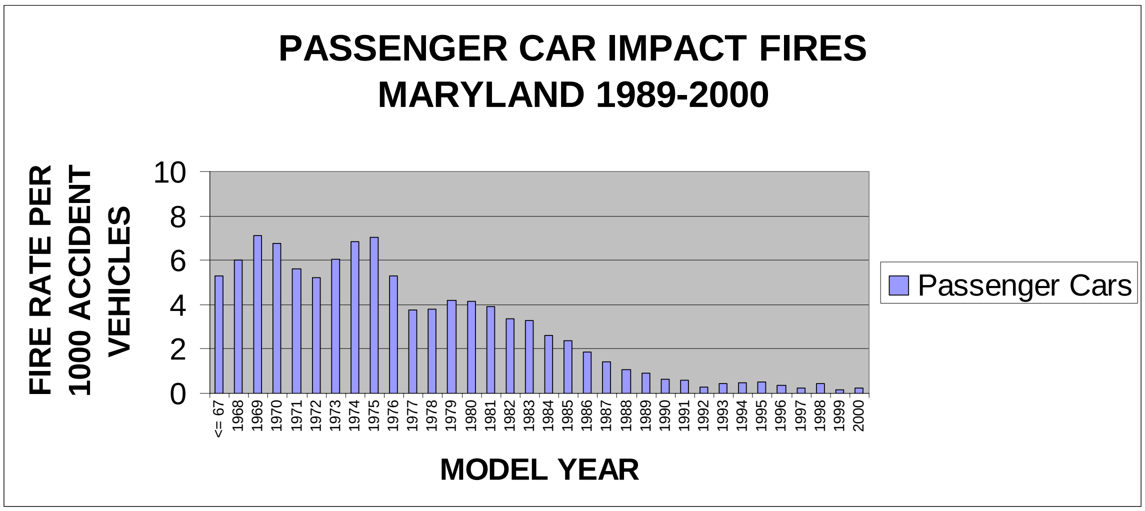

Figure 4.1. Passenger Car Impact Fires Maryland (1989-2000)

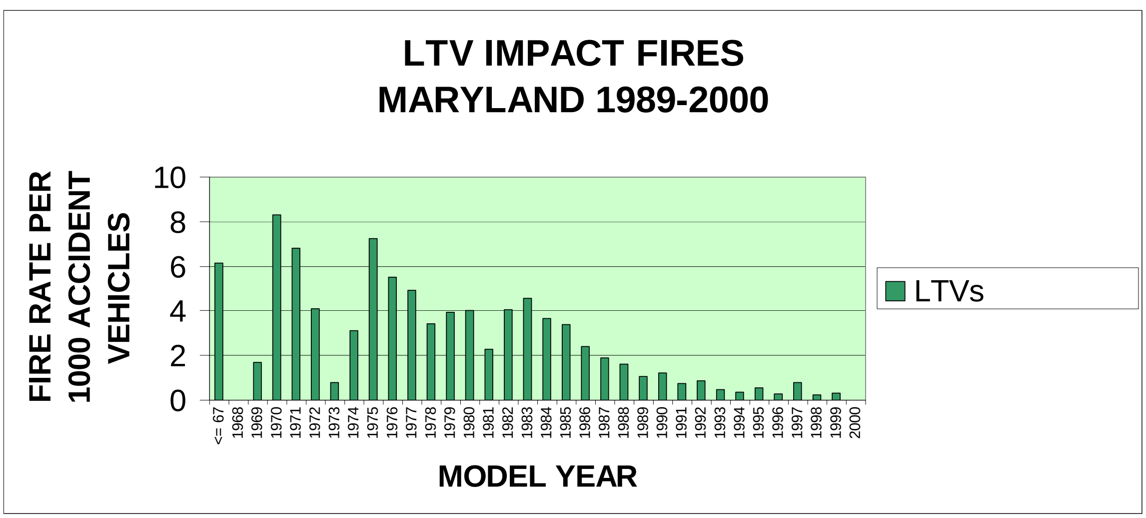

Figure 4.2. LTV Impact Fires Maryland (1989-2000)

As can be seen in Figure 4.3, the most consistent range for the large differences in fire rates between the LTVs and cars is between the 85-93 model year vehicles.

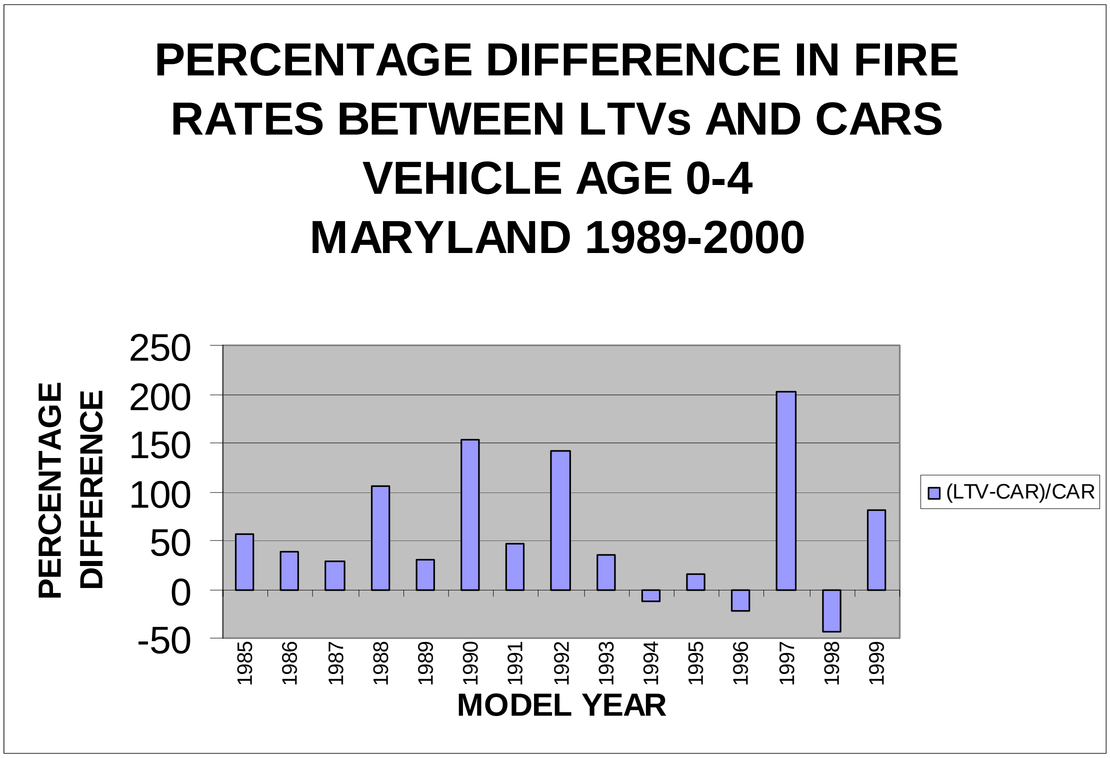

Figure 4.3. Percentage Differences in Fire Rates between LTVs and Cars Maryland (1989-2000)

Fire Rates by Accident Calendar Year

The overall trend of fire rates for 0 to 10 year old passenger cars by calendar year is in Figures 4.4. and 4.5. It can be seen in Figure 4.6 that the LTV fire rates are still higher than the passenger cars for this control on vehicle age.

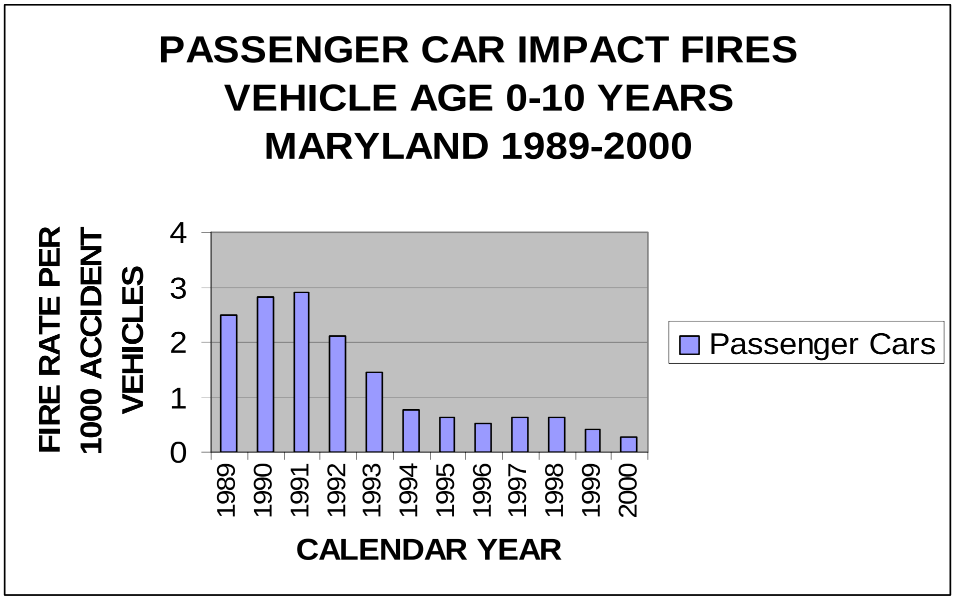

Figure 4.4. Passenger Car Impact Fires Vehicle Age 0-10 Years Maryland (1989-2000)

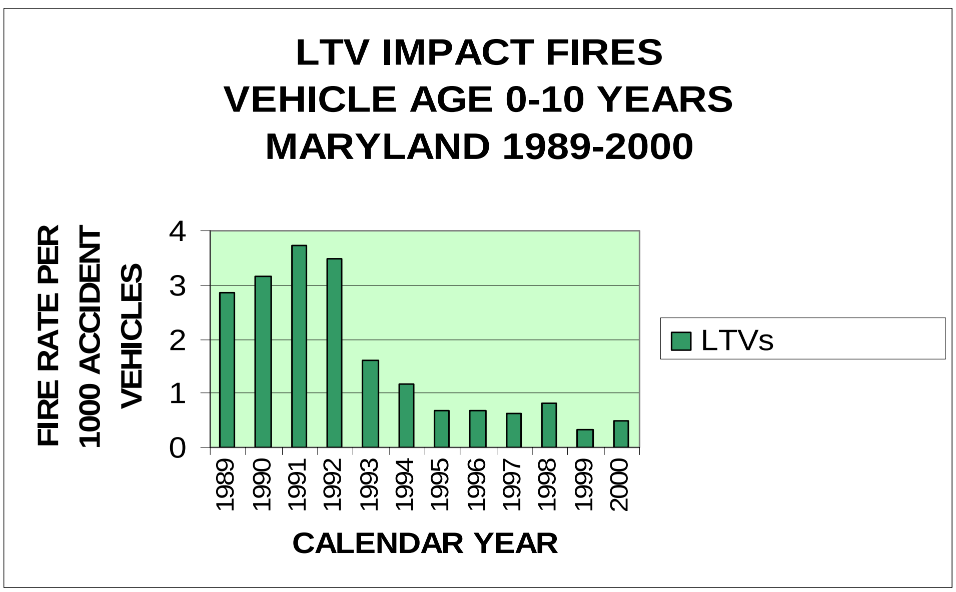

Figure 4.5. LTV Impact Fires Vehicle Age 0-10 Years Maryland (1989-2000)

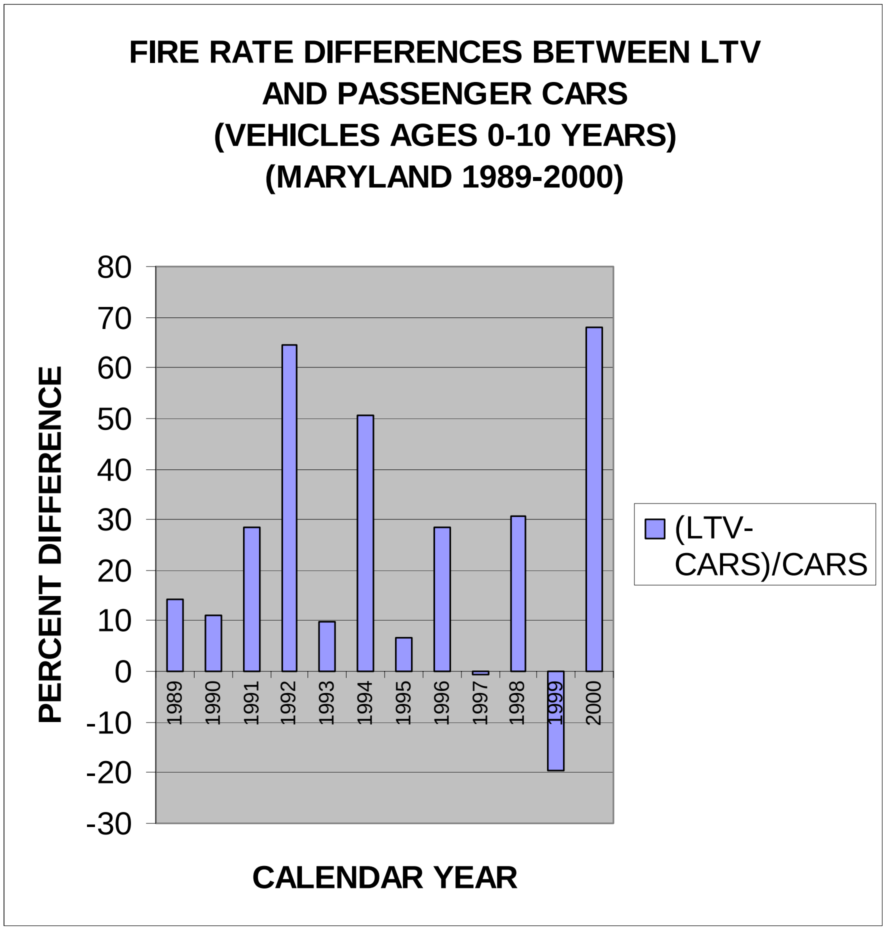

Figure 4.6. Fire Rate Differences Between LTV and Passenger Cars Vehicle Age 0-10 Maryland (1989-2000)

Fire Rates Controlling for Vehicle Age 0-4 Years Old

The examination of fire rates controlling for vehicle age 0-4 years old continued to show the LTV fire rates being larger than the passenger cars. For these conditions the average LTV fire rate was 44 percent higher than the passenger cars (see Figures 4.7 and 4.8).

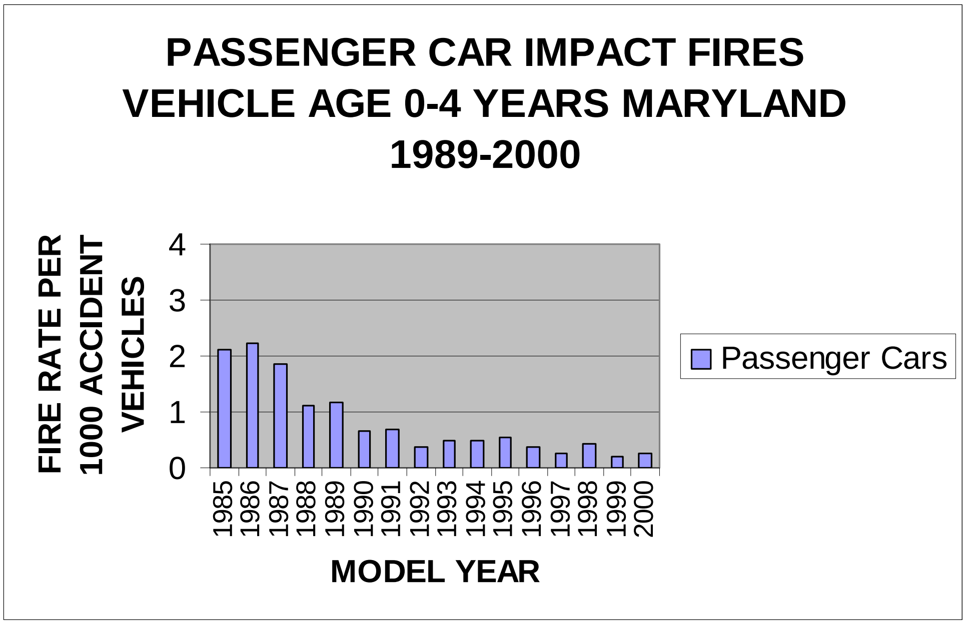

Figure 4.7. Passenger Car Impact Fires Vehicle Age 0-4 Maryland (1989-2000)

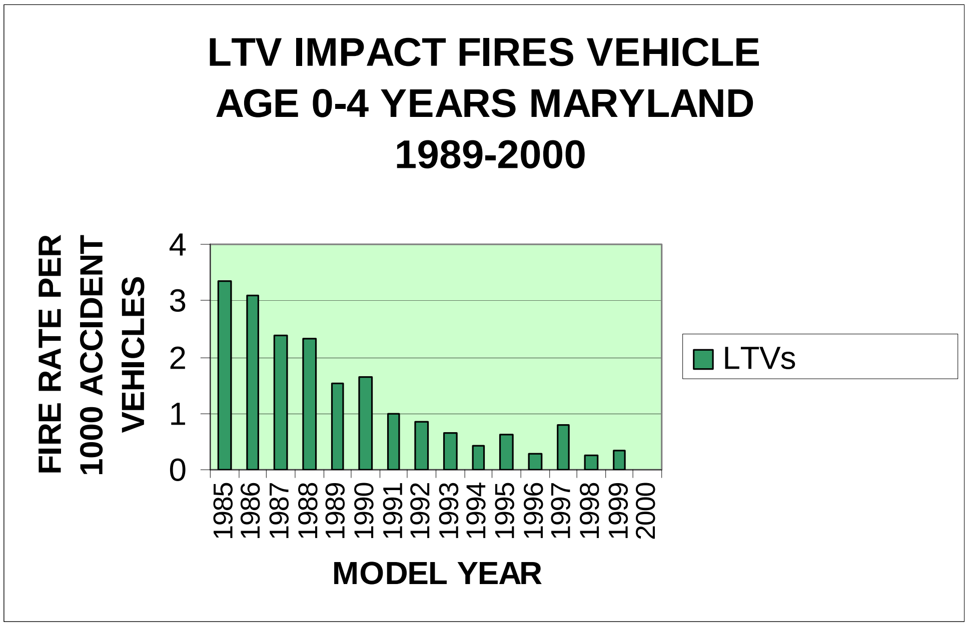

Figure 4.8. LTV Impact Fires Vehicle Age 0-4 Years Maryland (1989-2000)

Impact Mode and Severity

The examination of the relative frequency of occurrence of the coding for damage area and severity revealed the relative frequency in the respective collision groups as shown in Figures 4.9 and 4.10.

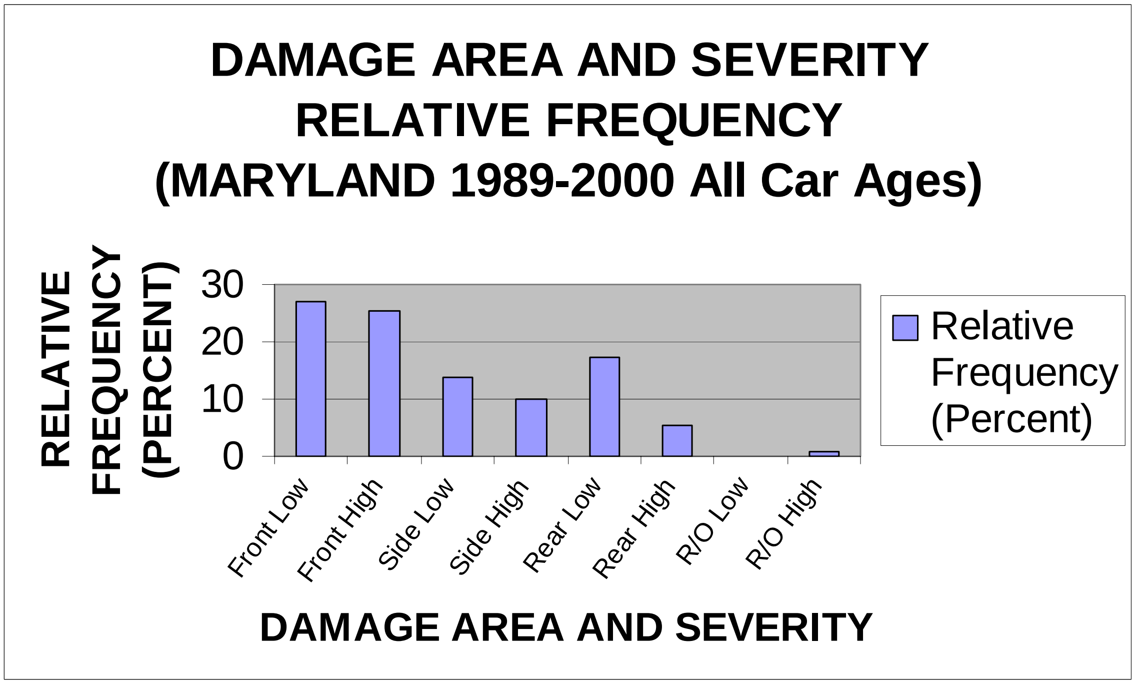

Figure 4.9. Damage Area and Severity Relative Frequency All Car Ages Maryland (1989-2000)

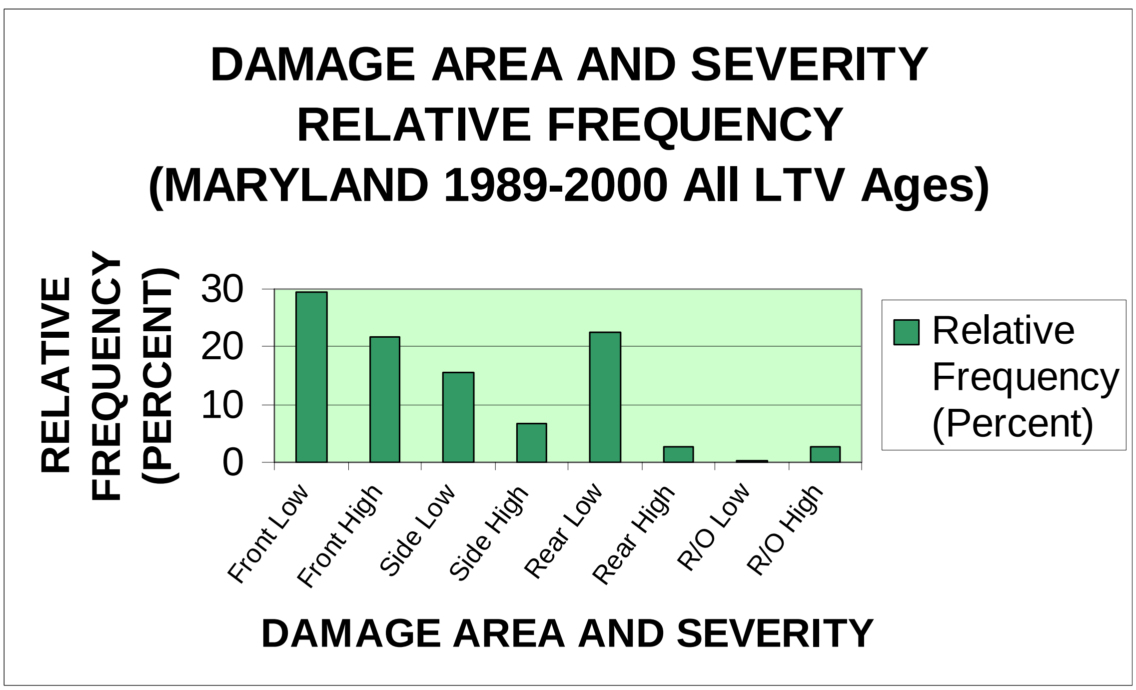

Figure 4.10. Damage Area and Severity Relative Frequency All LTV Ages Maryland (1989-2000)

Examination of the fire rates within these impact modes and severity classifications found the fire rates as shown in Figures 4.11 and 4.12. The data indicated generally higher fire rates in high severity impacts and rollovers. For the low severity rollover cell there were very few cases and the differences between LTVs reflects 0 fire cases for the cars and 1 fire case for the LTVs both with approximately the same number of total cases for these cells.

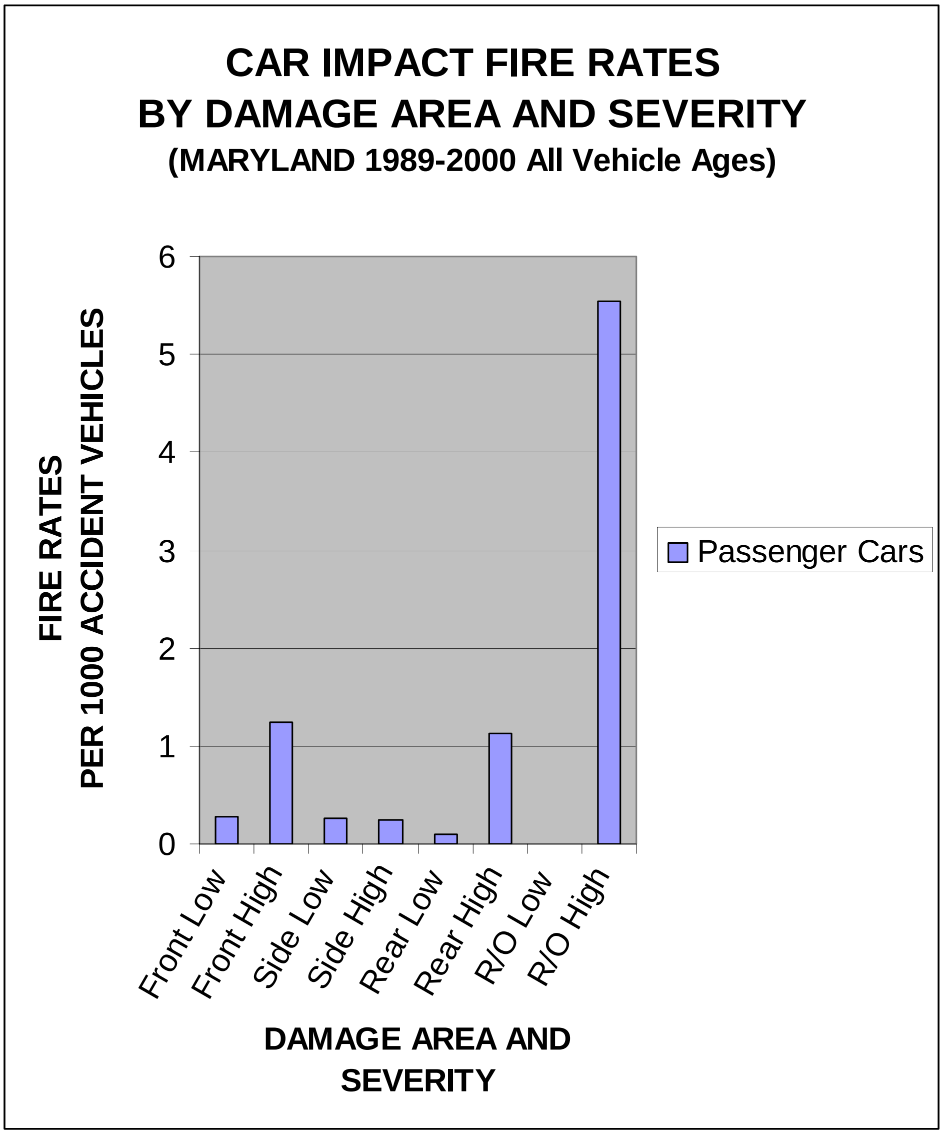

Figure 4.11 Car Impact Fire Rates by Damage Area and Severity All Vehicle Ages Maryland (1989-2000)

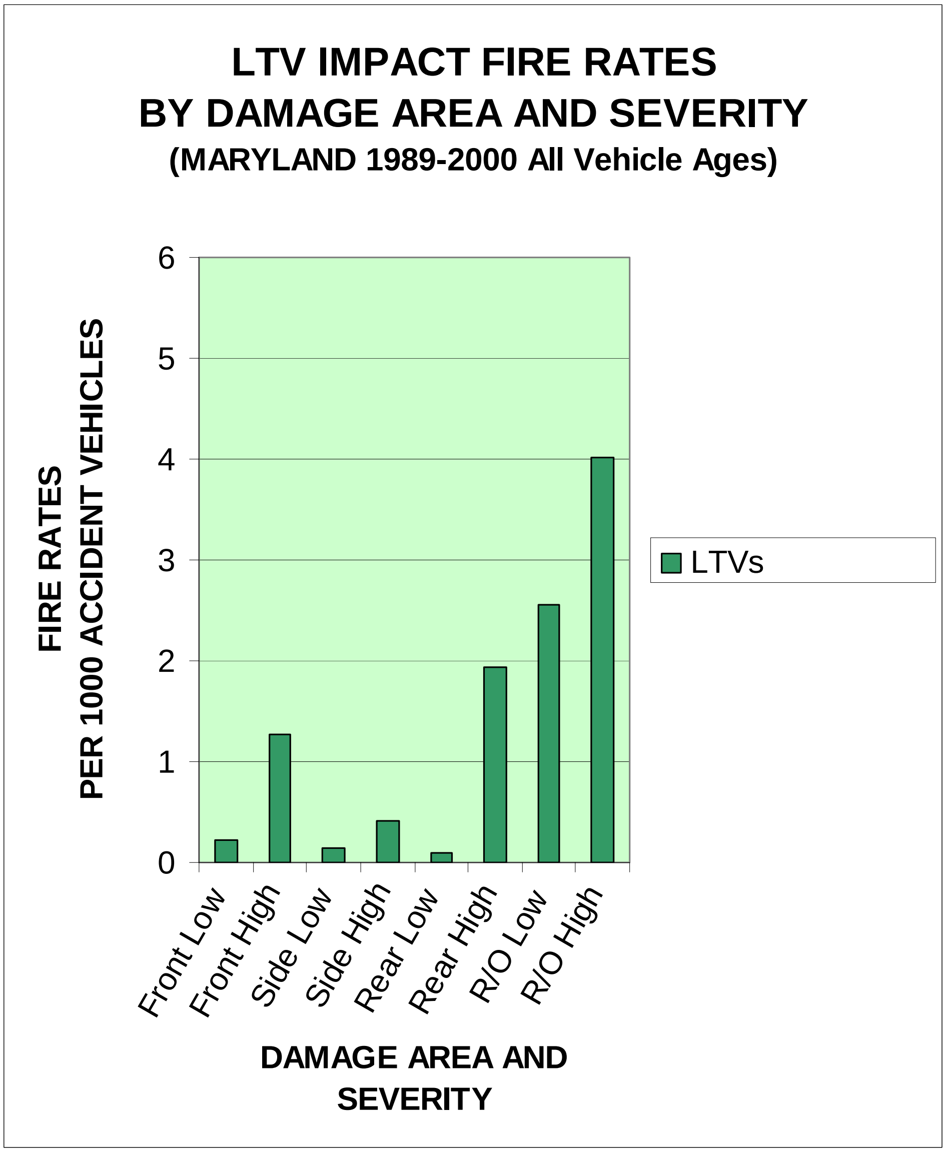

Figure 4.12 LTV Impact Fire Rates by Damage and Severity All Vehicle Ages Maryland (1989-2000)

The effect of vehicle size in the Maryland data is shown in Figurer 4.13.

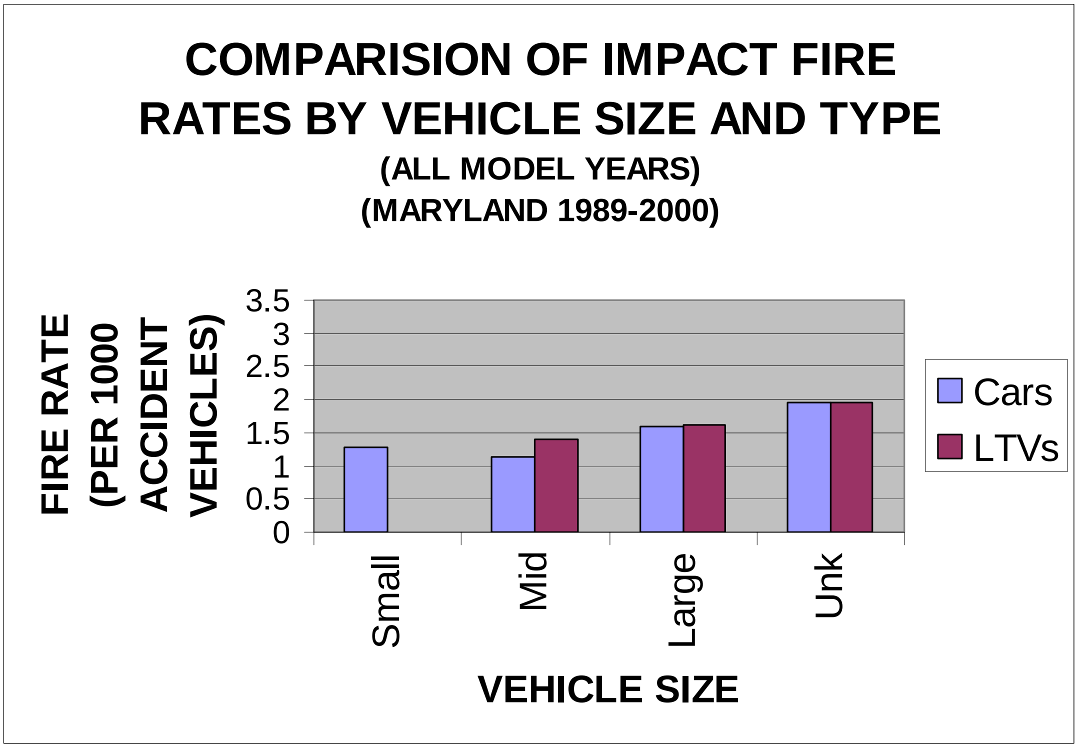

Figure 4.13 Fire Rates by Vehicle Size and Type Maryland 1989-2000

Average Changes in Fire Rates for Cars and LTVs by Model Year

These data considered only model year vehicles greater than 1986 whether the age control for 0-4 years was used or not. As can be seen in Tables 4.1 and 4.2 the LTV group mean fire rate was greater than the corresponding rate for the passenger car group for this same filtering (also see Figure 4.14).

Table 4.1 Cars and LTVs Maryland 1989-2000

Car Age Control	Mean Rate per 1,000 impacts	Rate reduction Percentage, per MY	Standard Error for reduction percentage
yes	0.78	-14.81	1.79
no	0.83	-13.59	1.79

LTV Age Control	Mean Rate per 1,000 impacts	Rate reduction Percentage, per MY	Standard Error for reduction percentage
Yes	1.13	-18.20	2.13
No	1.09	-15.72	2.23

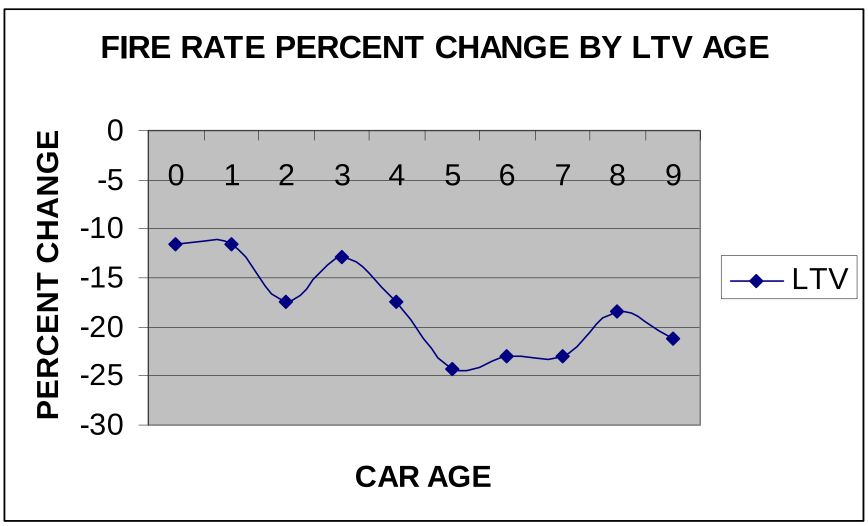

Figure 4.14 Percent Change Per Model Year As A Function Of Vehicle Age

Table 4.2 Maryland Percent Change per Mode

Car Age	Percent Change per model year, Fires
0	-10.10
1	-15.99
2	-12.68
3	-20.00
4	-20.37
5	-24.13
6	-25.05
7	-32.20
8	-23.97
9	-23.56
Weighted	-20.51
Std. err.	2.00

LTV Age	Percent Change per model year, Fires
0	-11.60
1	-11.58
2	-17.48
3	-12.82
4	-17.37
5	-24.24
6	-22.96
7	-23.03
8	-18.41
9	-21.27
Weighted mean	-17.41
Std. err.	1.55

In Table 4.3 the fire rates within model year groups for the passenger car and LTV groups were computed using the Malliaris methods for controlling for impact conditions.

Table 4.3-Cars & LTVs by Model Year Controlled for Impact Conditions Maryland 1989-2000

Vehicle Class	Model Year Group	Usual Fire Rate	Usual Fire Standard Error	Controlled Weights: Fire Rate	Controlled Weights: Fire Standard Error
Pcar	Pre-'91	0.56	0.14	0.52	0.13
Pcar	'92-'94	0.35	0.13	0.36	0.13
Pcar	'95-'97	0.43	0.14	0.44	0.15
Pcar	'98-2000	0.28	0.13	0.29	0.14
Pcar	All	0.43	0.03	0.43	0.14
LTVs	Pre-'91	0.91	0.33	0.84	0.31
LTVs	'92-'94	0.50	0.23	0.52	0.25
LTVs	'95-'97	0.44	0.22	0.47	0.24
LTVs	'98-2000	0.22	0.17	0.24	0.19
LTVs	All	0.58	0.07	0.58	0.26

Fire Rate Reductions Controlled For Impact Configuration

Fire rates controlled for high severity impacts and rear and rollover impacts are shown in Table 4.4.

Table 4.4 Cars & LTVs Impact Event Maryland

Passenger Car Event Class	Mean Fire Rate per 1,000 impacts	Rate Reduction Percentage, per MY	Mean Standard error of all MY
1: All	0.43	-8.99	3.96
2: Hi Sever impact	0.84	-7.92	3.83
3: Rear imp & R/O	0.40	-4.73	5.83
4: Inv of ALL	0.67	-5.57	4.40

LTV Event Class	Mean Fire Rate per 1,000 impacts	Rate Reduction Percentage, per MY	Mean Standard error of all MY
1: All	0.58	-14.76	3.52
2: Hi Sever impact	1.45	-14.07	5.07
3: Rear imp & R/O	0.49	-8.30	5.11
4: Inv of ALL	0.92	-1.68	6.53

Fire Rate Changes by Vehicle Size Controlled for Vehicle Age 0-4 years old

The fire rates for passenger cars and LTVs controlled by vehicle size are shown in Table 4.5. These results are for vehicles with ages 0-4 years old during the 1989-2000 accident years and likely include effects from the data collection system revision reported earlier.

Table 4.5 Fire Rates by Vehicle Size Maryland Vehicle Ages 0-4

	Fire Rate per 1000 Accident Vehicles	Percent change in Rate	Standard Error for percent change
All Cars	0.81	-15.10	1.58
Small Cars	0.91	-13.17	3.47
Mid Cars	0.74	-14.49	1.53
Large Cars	0.76	-7.79	4.42
Unk Cars	0.81	-16.26	3.15
All LTVs	1.17	-18.18	1.84
Small LTVs	3.37	16.63	14.41
Mid LTVs	1.04	-19.70	4.59
Large LTVs	1.12	-18.79	2.60
UNK LTVs	1.25	-14.51	3.28

Home Continent of Name Plate

Because of the problems with the manufacturer names and model names and the inability of VINDICATOR to output vehicle types, a selected set of manufacturer names were used to examine continental origin effects. Because of potential conflicts with interpretation of values put in during the data entry process, the distinction between Mercedes and Mercury could not be made confidently, so neither were included in the analysis.

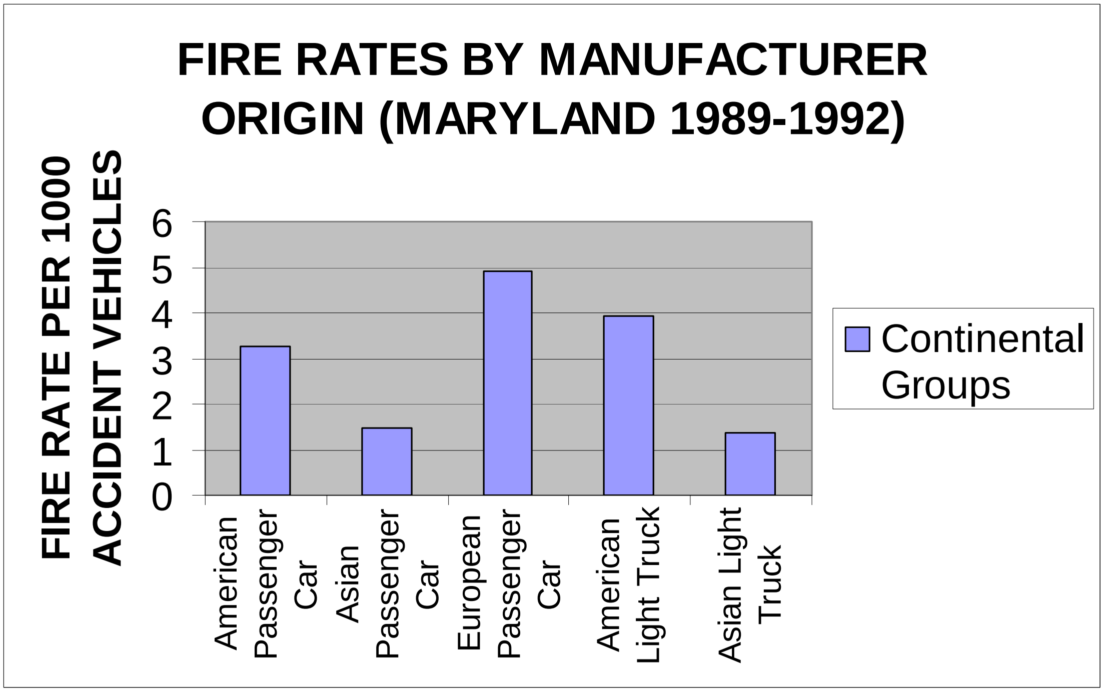

Figure 4.15. Fire Rates by Manufacturers Origin Maryland (1989-1992)

As is apparent in Figure 4.15 the Asian manufacturer vehicles had the lowest fire rates, while the remaining European manufacturer vehicle had the highest fire rates in the Maryland data.

Maryland Summary

The results of the Maryland analysis were affected by the change over in the data collection system around the 1993 time frame. The results indicated a higher fire rate in rollovers and the frontal high severity group. Fire rates for passenger cars and LTVs appeared to be fairly constant for model years after the data collection system change. Preliminary analysis indicated that the Asian origin manufacturer vehicles appeared to have lower fire rates than other manufacturer origin groups, while European passenger cars had the highest rates by this grouping method.

SECTION 5: STATE OF PENNSYLVANIA ANALYSES

In preparing to identify fire risk trends for a number of states and time periods, we approached the problem by ensuring that the analysis methods used by earlier researchers were understood. The methodology described by Malliaris was defined in the contract as the methodology to be used. Our analyses began with the replication of Malliaris' (1991) study. In Section 3 , data from FARS and the State of Michigan were used to generate the results for years 1978-1984. In Section 4 we used the State Accident file data from Maryland 1989 to 2000 to investigate these same variables with the exception of those related to fuel leaks. In Section 5 we added to our analyses the State of Pennsylvania. Analysis was performed to investigate the following areas of interest.

1. Impact fire rates vs. model year and accident year
2. Incidence of fire at high impact severity (high and low impact severity)
3. Impact mode (front, side, rear, rollover)
4. Vehicle type (passenger and LTV)
5. Vehicle size (small, medium, large curb weights)

The unique database characteristics of Pennsylvania necessarily influenced the time periods and variables that we were able to examine. We have described the specific methods used to optimize the utility of the Pennsylvania database and our subsequent findings.

Method

Pennsylvania Accident Data

The 1980-2000 accident year data was used for Pennsylvania. Pennsylvania was distinct in that it contains event sequence records at the accident level. There are 99 events at the accident event sequence level that identify the vehicle being referred to and the sequence number. State personnel report that the event sequence number is meaningful and refers to the order of events in the accident. Thus it enabled identifying pre-impact fires and post impact fires.

Statistical Analysis

To identify pre-impact fires, those vehicles with a first event that was a fire were identified; these were excluded from the analysis. Impact fire cases were identified as those vehicles that had a fire event that was not the first event for that vehicle.

HARM-EVENT in the Event record with a value of 2 was used to identify the occurrence of fire for a particular vehicle. If the first event for a vehicle was a fire, then it was considered to be a pre-impact fire. If a fire showed up in an event that was not the first event for the vehicle then the fire was considered to be an impact fire.

Impact mode was derived based on the variable "impact point" at the vehicle level and harmful event at the event level for the vehicle. The "harmful event" event level information when coded as a 2 was used to identify rollovers. Impact point codes of 1,11, and 12 were classified as front, 2,3,4,8,9,10 were classified as side, and 5,6, and 7 were rear. If there was a rollover coded, it superceded any damage area information classification in the formulation of impact mode.

To identify vehicle type the variable Vehicle Body Type was used. If the values were 1-9,13 or 67 it was classified as a passenger car, while if the value was 10-12,40,48,50,51,56-59,68 or 69, it was classified as an LTV.

Vehicle year was utilized as the basis for the model year of the vehicle. For vehicle age the accident year was subtracted from the model year. If the model year was less than zero, the vehicle age was considered to be zero.

Vehicle damage severity was classified using the Deformation variable. Values of 3 were classified into the High group, while values of 1 or 2 were classified into the Low group. It was found that in the accident files the Deformation variable was present but was coded with 9's for "unknown" for most of 1999 and 2000 accident years. As a result while the results associated with crash severity are for the full range of 1980-2000, it should be understood that the last two years are not actually being represented in the results involving vehicle deformation. Our investigation of this anomaly came up with a rather unique explanation: there were state budget cuts and coders were laid off and certain variables for data entry were eliminated!

Rate Reductions

A series of tables were developed to describe rate changes of fires under different variable conditions. The methodological approach for each of these tables is described herein.

Table 5.1. Estimation of the percent change in fire rates controlled for vehicle model year was done by regression of the natural log of the fire rates by model year onto the model year. The resulting parameter estimate for the time component represents the percent change in rates across time. The standard error for this parameter estimate was reported as the standard error for the estimate of percent change in rates. Vehicles were limited to ages between 0 and 4 years.

Table 5.2. Estimation of the percent change in fire rates as a function of model year within a vehicle age group have been determined by taking the natural log of the fire rates, using linear regression to fit the estimated fire rates and determining the slope parameter that was fit, as with Table 4.1.[1]

Table 5.3. To control for crash severity and impact mode across model years the overall probabilities for falling into a given crash severity and impact mode cell were computed. The overall probabilities were applied to the model year groups of interest to compute a "controlled" rate (fire or leak as appropriate). While there is discussion with regard to the appropriate method for calculating the standard error, in this case the standard errors associated with the respective cells were combined in accordance with their respective probabilities to characterize the standard error for the model year group. The ‘usual’ mean rates and standard error were calculated from the same groups, using the vehicle counts within cell as weights.

Table 5.4. Cars and LTVs with known damage area and severity were selected for vehicle ages 0-4. For each combination of vehicle type and the all, high severity and rear/rollover, and inverse groups, linear regression was done on the natural log of fire rates by model year to obtain the estimated percent reductions by model year and determining the slope parameter that

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[1] This estimate for the slope parameter (beta) represents the percent change in rates over time. (Chatterjee & Price, 'Regression Analysis by Example', pages 32-34 shows an example based on decay rates of bacteria, which has a exponential non-linear relationship with time and an asymptotic limit, much like changes in fire rates over time).

was fit, as in Table 5.1.[1] The inverse group consists of vehicles that have age 0 to 4 but with missing or invalid impact mode and/or severity class and the vehicles that do not meet the vehicle age criteria. The "all" category included all vehicles with valid impact mode and crash severity information and met the vehicle type requirements and are 0-4 years old.

Table 5.5. Vehicles were classified by vehicle size and type. Estimated percent reductions by model year were obtained by using linear regression on the natural log of the fire rates by model year for vehicles within the 0-4 year old group and determining the slope parameter that was fit. The inverse group consists of vehicles that do not meet the vehicle age criteria or having missing vehicle size codes. The "all" category includes car and LTV vehicles with valid vehicle size coding including unknown (but not missing) and are 0-4 years old.

[1] *Ibid*

Results

Fire rates by model years are shown in Figure 5.1 for all model years and vehicle ages. From Figure 5.1 and 5.2 it is clear that older model year vehicles have higher fire rates than newer model years that necessarily are not as old.

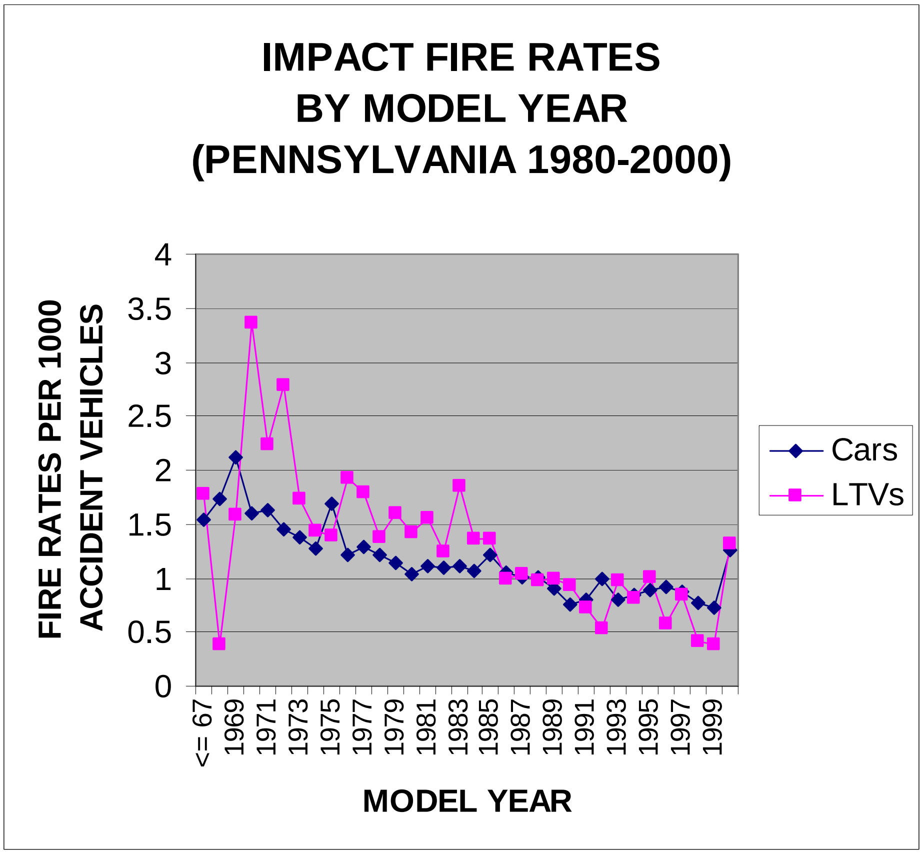

Figure 5.1 Impact Fire Rates by Model Year (PA 1980-2000)

The overall trend of fire rates for 0 to 10 year old passenger cars and LTVs by calendar year is in Figure 5.2. The overall trend of fire rates for 0 to 4 passenger cars and LTVs by model year is shown in Figure 5.3. Figure 5.3 indicates that the earlier model year LTVs had higher fire rates than passenger cars, but for more recent model years they are approximating the passenger car fire rates. The figures also indicate that the fire rates for passenger cars 0-4 years old have not come down substantially over time and model years.

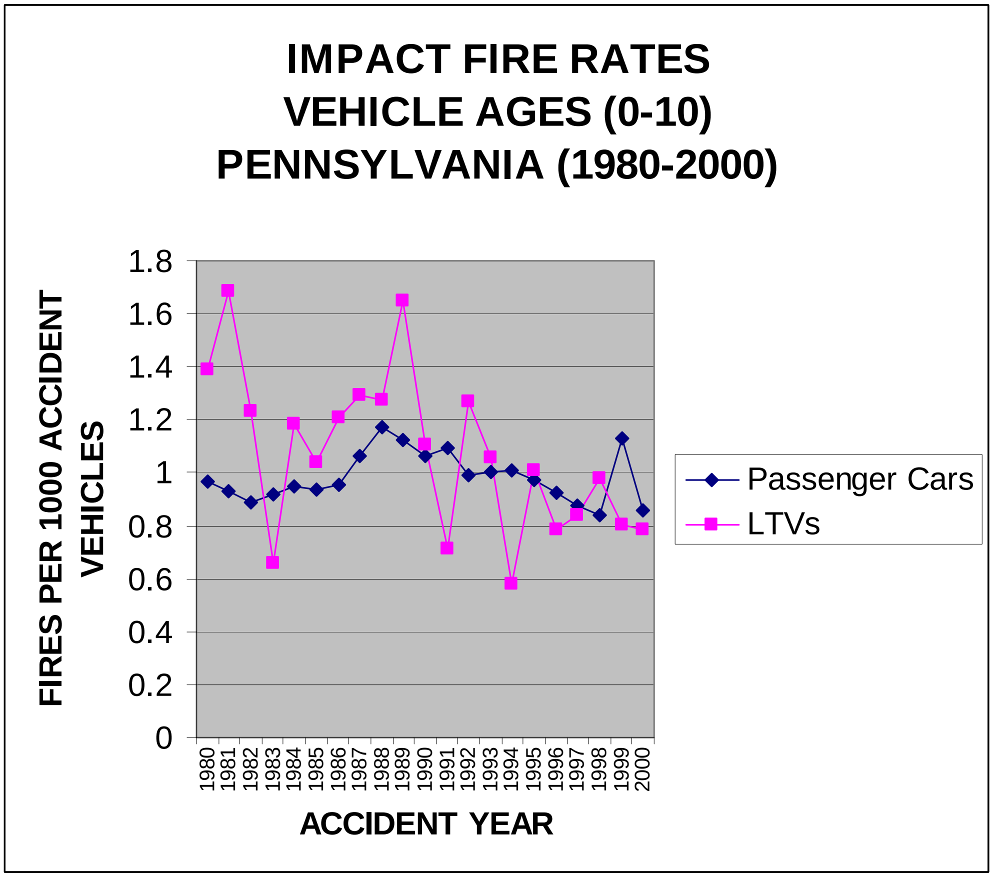

Figure 5.2. Impact Fire Rates Vehicle Age 0-10 Pennsylvania (1980-2000)

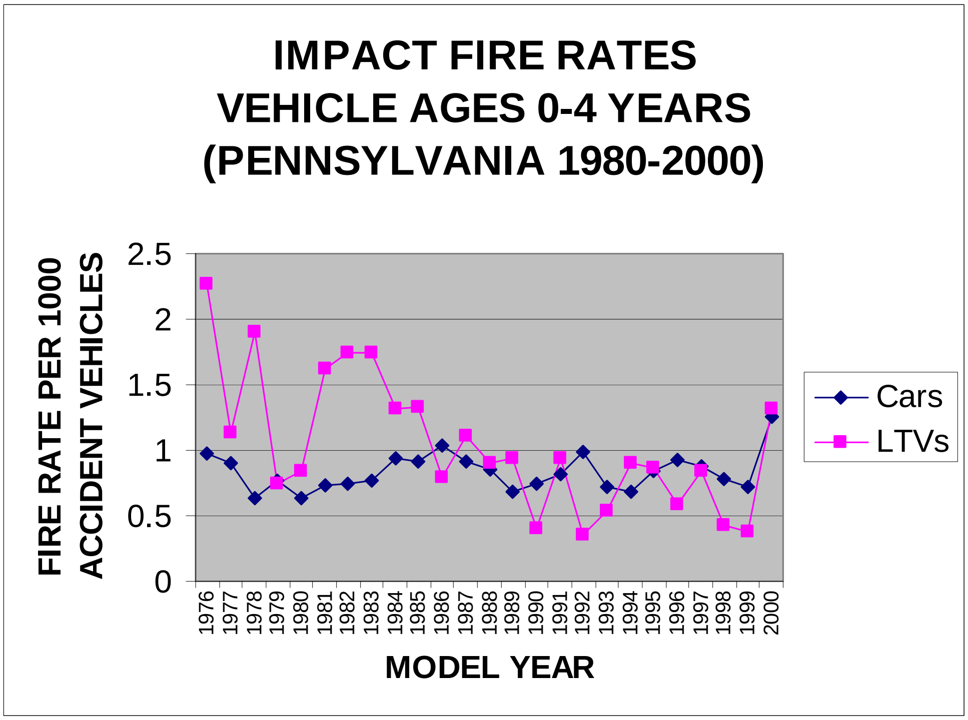

Figure 5.3 Impact Fire Rates Vehicle Age 0-4 Pennsylvania (1980-2000)

Figure 5.4 suggests that the effect of vehicle size within passenger cars or LTV groups was not large based on this data.   This lack of effect was consistent with Malliaris' findings. The fire rates observed were lower than those reported in the Malliaris study.

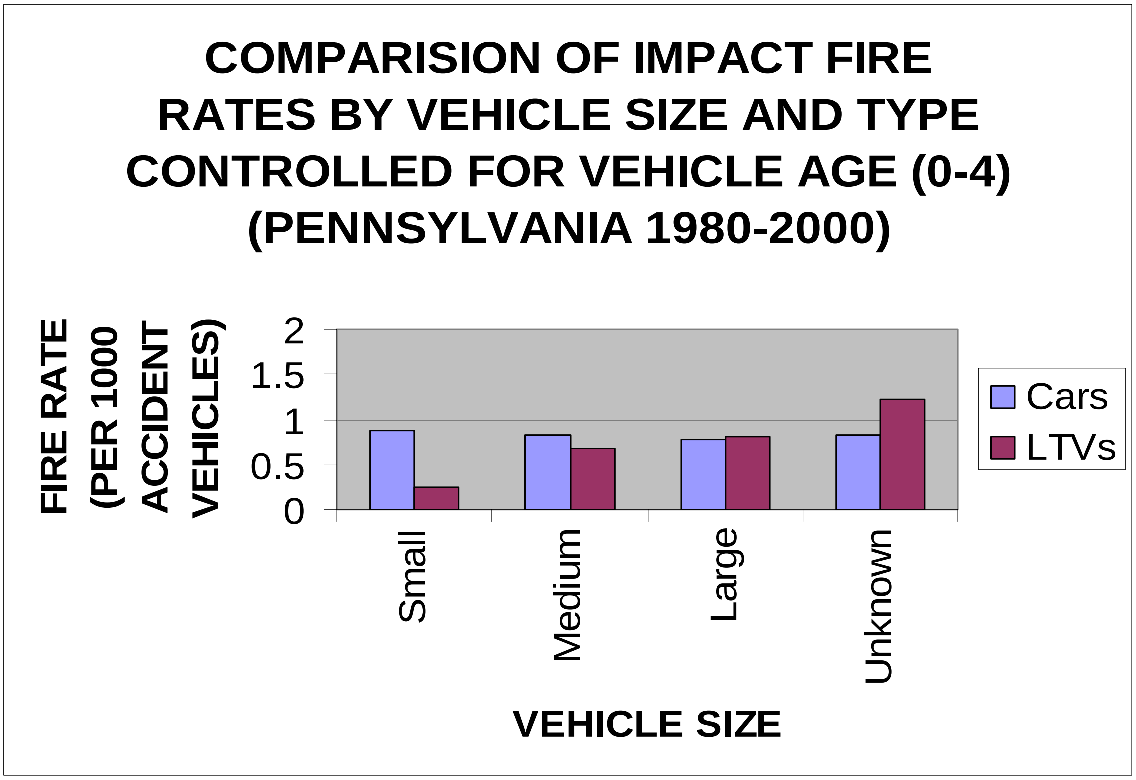

Figure 5.4 Vehicle Fire and Severity Relative Frequency Pennsylvania (1980-2000)

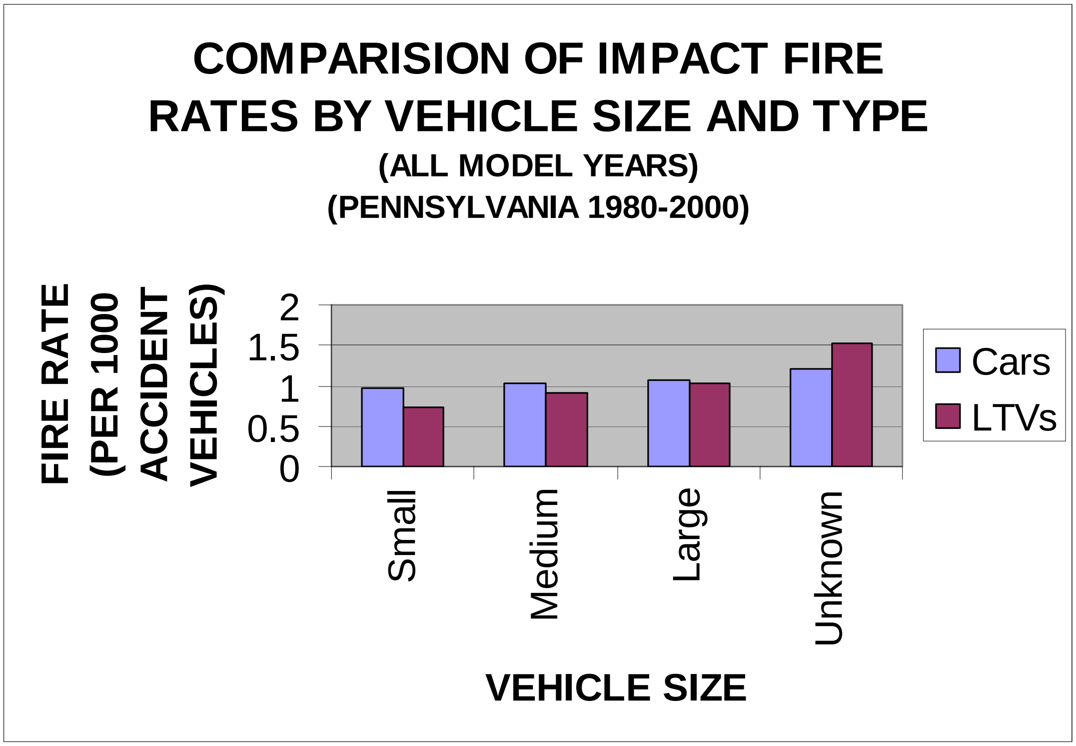

Figure 5.5 Comparison of Impact Fire Rates by Vehicle Size and Type Pennsylvania (1980-2000)

Figure 5.5 shows the fire rates in Pennsylvania by vehicle size and type controlled for vehicle ages 0-4. The low Small LTV rate simply reflects few vehicles in this group.

Examination of the relative frequency of occurrence of the coding for damage area and severity showed the relative frequency by the respective groups as illustrated in Figure 5.6.

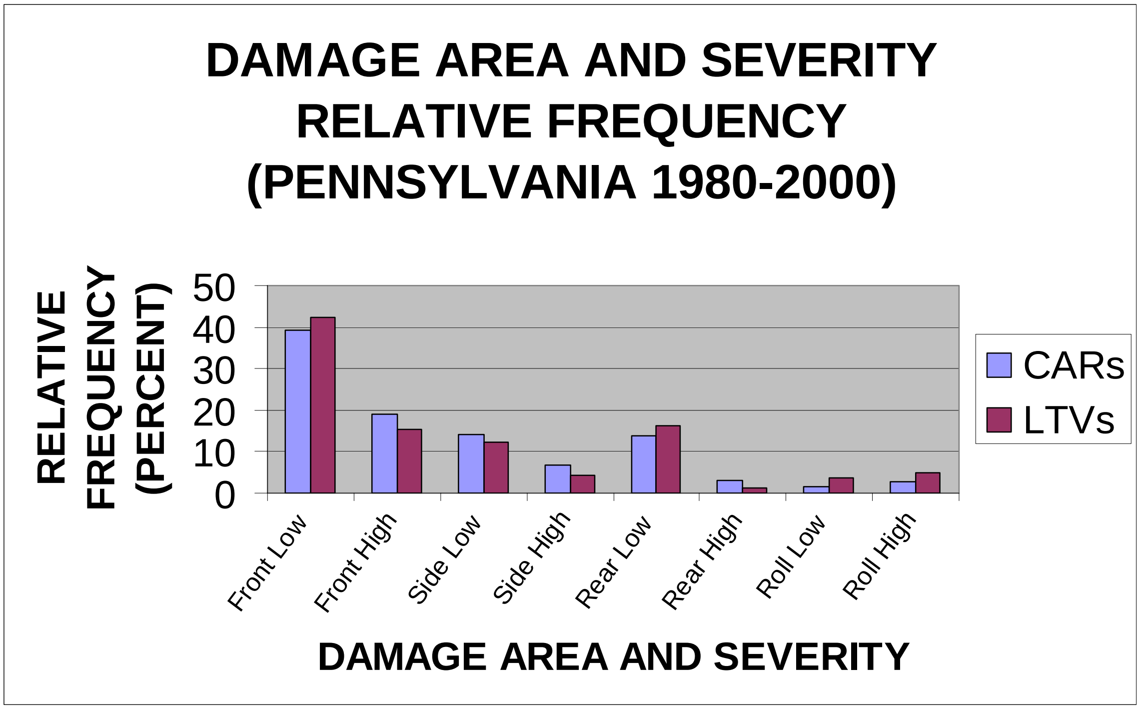

Figure 5.6 Damage Area and Severity Relative Frequency Pennsylvania (1980-2000)

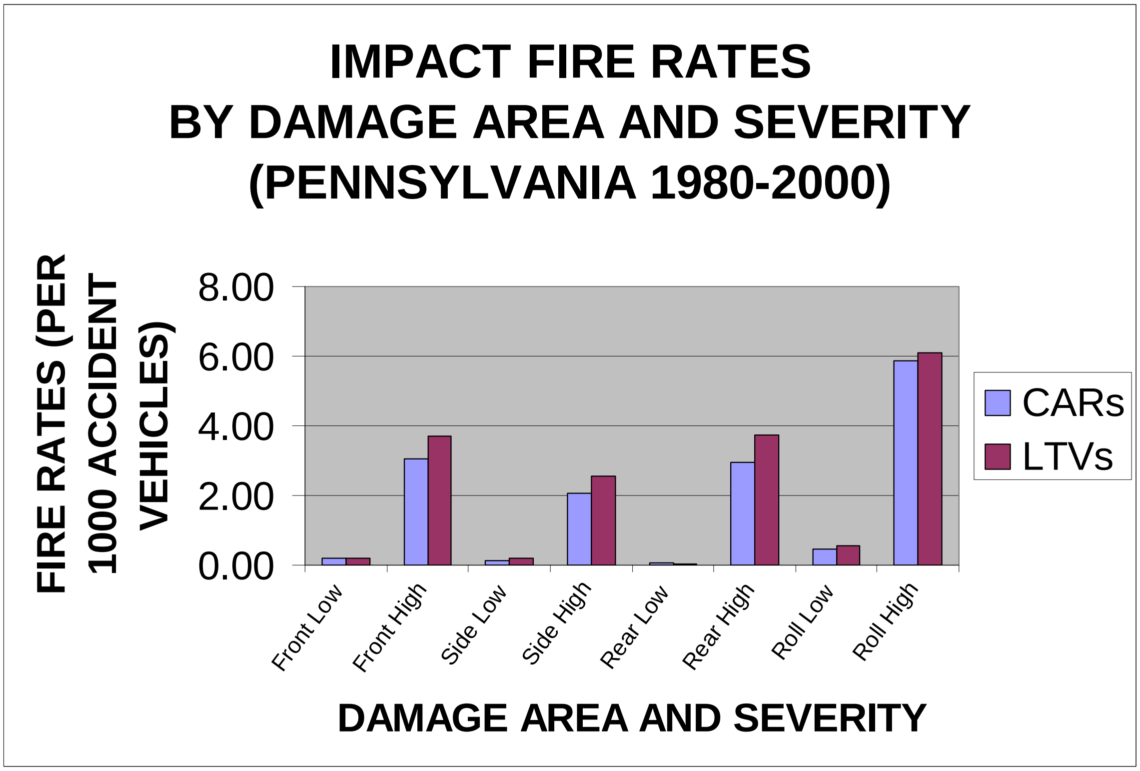

Figure 5.7 Impact Fire Rates Controlling for Damage Area and Crash Severity Pennsylvania (1980-2000)

Figure 5.7 shows the fire rates by damage area and crash severity for all model years in the 1980-2000 Pennsylvania data by vehicle type.

Table 5.1 provides results using Malliaris' approach for showing the effect of vehicle age on mean rates or percentage rate reductions per model year. For vehicle age control "yes" indicates the analysis was for vehicles 0-4 years old, while "no" indicates the analysis was for all model year vehicles. These reductions were relatively small and inconsistent for passenger cars, while for LTVs the reductions had a more consistent downward trend across model years.

Table 5.1 Impact Fire Rates Pennsylvania (1980-2000)
Note: Comparing rates with and without 0-4 year age control and between Cars versus LTVs

Vehicle	Vehicle Age Control	Mean Rate per 1,000 Vehicle impacts	Rate Reduction Percentage, per MY	Standard Error for reduction percentage
Car	Yes	0.82	0.45	0.46
Car	No	1.04	-1.59	0.35
LTVs	Yes	0.89	-4.42	1.16
LTVs	No	1.11	-4.68	0.77

Table 5.2 provides additional results using Malliaris' approach for showing the effect of vehicle age on mean rates or rate changes per model year controlling for car ages for 0 to 9 years old. These changes were relatively small and inconsistent for passenger cars while for LTVs the reductions had a more consistent downward trend across the age groups.

Table 5.2 Comparison of Car and LTV Fire Rate reductions by Vehicle age Pennsylvania (1980-2000)

Vehicle type	Car Age	Percent Change per model year, Fires		Vehicle type	Car Age	Percent Change per model year, Fires
Pcar	0	1.09		LTVs	0	-3.58
Pcar	1	0.24		LTVs	1	-4.79
Pcar	2	-0.19		LTVs	2	-4.02
Pcar	3	0.59		LTVs	3	-5.57
Pcar	4	-2.30		LTVs	4	-13.06
Pcar	5	1.11		LTVs	5	2.63
Pcar	6	1.28		LTVs	6	-3.02
Pcar	7	-3.65		LTVs	7	-4.12
Pcar	8	-2.39		LTVs	8	-2.73
Pcar	9	-2.28		LTVs	9	-5.64
Vehicle Class	Pcar			Vehicle Class	LTVs	
Weighted mean	-0.61			Weighted mean	-4.50	
Std. err.	0.57			Std. err.	1.24	

Table 5.3 shows the fire rates for passenger cars and LTVs after controlling for damage area and crash severity for vehicles 0-4 years old. As can be seen there was little effect showing up that can be related to variations in damage areas and severity variations between model year groups.

Table 5.3 Comparison of Car and LTV Fire Rates Using Malliaris Control Method for Pennsylvania 1980-2000 (Vehicle Age 0-4)

Vehicle Class	Model Year Group	Usual Fire Rate	Usual Fire Standard Error	Controlled Weights: Fire Rate	Controlled Weights: Fire Standard Error
Pcar	Pre-'85	0.80	0.10	0.75	0.10
Pcar	'86-'90	0.87	0.11	0.89	0.12
Pcar	'91-'95	0.83	0.13	0.88	0.14
Pcar	'96-2000	0.90	0.35	0.97	0.38
Pcar	All	0.83	0.03	0.84	0.12
LTVs	Pre-'85	1.39	0.34	1.22	0.31
LTVs	'86-'90	0.85	0.22	0.84	0.22
LTVs	'91-'95	0.78	0.22	0.84	0.24
LTVs	'96-2000	1.03	0.53	1.16	0.59
LTVs	All	0.95	0.06	0.94	0.26

Table 5.4 shows the fire rates and changes by model year controlling for passenger cars and LTVs that were 0-4 years old using the Pennsylvania data from 1980-2000. These metrics were computed for impacts characterized as all, high severity, rear and rollover, and the inverse of these impact types. The passenger car results indicated no consistent effect by model year, while there was a consistent downward trend observed over this period for the LTVs.

Table 5.4 Fire Rates Controlled For All, Severe, Rear And Rollover Impacts

Vehicle class	Event Class	Mean Rate per 1,000 impacts	Rate Reduction Percentage, per MY	Mean Standard error of all MY
Pcar	1: All	0.83	0.26	0.51
Pcar	2: Hi Sever impact	2.34	1.40	0.57
Pcar	3: Rear imp & R/O	0.77	-1.64	1.28
Pcar	4: Inv of ALL	1.24	-2.27	0.24
LTVs	1: All	0.99	-3.54	1.50
LTVs	2: Hi Sever impact	3.40	-1.60	1.57
LTVs	3: Rear imp & R/O	1.10	-5.17	1.73
LTVs	4: Inv of ALL	1.27	-3.42	0.81

Note: 1999-2000 excluded due to data unknowns

Using the Pennsylvania data from 1980-2000,Table 5.5 shows fire rates and changes by model year controlling for passenger cars and LTVs that were 0-4 years old. These metrics were computed for small, medium, and large vehicles separately within the vehicle types. The passenger car results indicated no consistent effect by model year, while there was a consistent downward trend observed over this period for the LTVs.

Table 5.5 Fire Rates Vehicle Size by Vehicle Age 0-4 Years

Vehicle type	Vehicle Size	Rate	Percent change in Rate	Standard Error for percent change
Car	All	0.82	0.45	0.46
Car	Small	0.87	-1.44	1.77
Car	Medium	0.82	-0.95	1.41
Car	Large	0.78	-1.33	2.88
Car	Unknown	0.82	0.75	1.29
LTV	All	0.89	-4.42	1.16
LTV	Small	0.24	0.00	.
LTv	Medium	0.67	-4.72	2.92
LTV	Large	0.81	-5.06	2.53
LTV	Unknown	1.23	-1.07	1.69

Figure 5.8 shows the results of looking at fire rates by continent of manufacturer origin. Again (as with the Maryland data) the vehicles put into

the Asian category had lowest fire rates, while the vehicles in the European category had the highest fire rates.

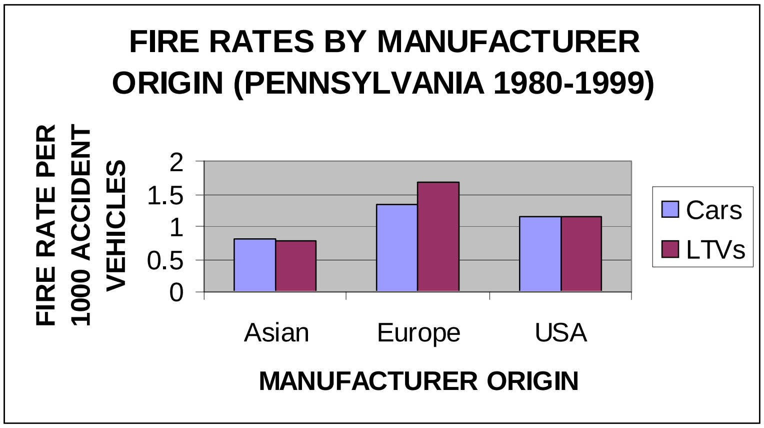

Figure 5.8 Fire Rates by Manufacturer Origin Pennsylvania (1980-1999)

Pennsylvania Summary

The Pennsylvania data revealed that there have been substantial declines in the LTV fire rates over the time covered, but that these are not seen in the passenger car rates. Fire rates in Pennsylvania were substantially lower than those rates reported by Malliaris for Michigan. The number of non-collision fires in Pennsylvania was substantially higher than could be identified in other states files. A sampling of accident cases would be useful to confirm this observation. Consistent with previous observations the vehicles in the Asian origin category had the lowest fire rates while the European origin category had the highest rates.

SECTION 6: STATE OF ILLINOIS ANALYSIS

In preparing to identify fire risk trends for a number of states and time periods, we approached the problem by ensuring that the analysis methods used by earlier researchers were understood. The methodology described by Malliaris was defined in the contract as the methodology to be used. Our analyses began with the replication of Malliaris' (1991) study. In Section 3 , data from FARS and the State of Michigan were used to generate the results for years 1978-1984. In Section 4 we used the State Accident file data from Maryland 1989 to 2000 to investigate these same variables with the exception of those related to fuel leaks. In Section 5 we added to our analyses the State of Pennsylvania. In Section 6 we have analyzed the accident data files from Illinois. We investigated the following areas of interest.

1. Impact fire rates vs. model year and accident year
2. Incidence of fire at high impact severity (high and low impact severity)
3. Impact mode (front, side, rear, rollover)
4. Vehicle type (passenger and LTV)
5. Vehicle size (small, medium, large curb weights)

The unique database characteristics of Illinois necessarily influenced the time periods and variables that we were able to examine. Illinois data was used in the analyses due to the large expense associated with acquiring the Minnesota data containing VIN information.

Method

Illinois Accident Data

The 1996-2001 Illinois accident data was used for the analysis due to the consistency of coding for these years.

Statistical Analysis

To define impact mode, the variables, FRST_CNT (first contact area), F_EVENT (first event at the vehicle level), S_EVENT (second event at the vehicle level), T_EVENT (third event at the vehicle level) and COL_TYPE (collision type) at the Vehicle Level were utilized. The “Front” impact mode was defined as those cases with FRST_CNT equal to 1, 2 or 8 or COL_TYPE had a value of 13. A “side” impact mode was considered to be those with FRST_CNT equaling 3 or 7. The “rear” impact mode was those cases with FRST_CNT equal to 4, 5, or 6. “Rollovers” were defined as those cases with COL_TYPE having a value of 2, or when F_EVENT, S_EVENT, or T_EVENT had the value 2. One last category considered as a rollover were those cases with FRST_CNT having a value of 9 corresponding to top damage. The “inverse” category was defined as everything else.

Fires were determined as those cases were the variable FIRE had a value of 1. If the variable F_EVENT had the value of 3, then the fire was considered to be a pre-impact fire for that vehicle. The value of 3 in F_EVENT, S_EVENT, or T_EVENT indicated a fire. This information was used as a quality control check, to ensure we didn’t have a situation where these variables indicated a fire, but the FIRE variable was not 1. All cases found having an event of fire also had FIRE equal to 1, thus confirming data integrity at this level. The FIRE variable also has values of 0 for not stated, 2 for no, and 9 for unknown.

The variable VEHTYP was used to establish the vehicle type. Passenger cars were defined as those vehicles with VEHTYP equal to 1. LTVs were defined as those vehicles with VEHTYP equal 2 or 3 and from accident year 1995 on, values of 15 as well.

Vehicle model year was determined using VEHYR (vehicle year) which contained four digits or VEHYR2 which contained 2 digits.

Because the vehicle damage was not coded explicitly, the crash severity was defined utilizing the variable TOW (towaway) and ACC_SEV (accident severity). The “High’ group was defined as those with TOW equal to 1, and ACC_SEV equal to 1 or 2, corresponding to towaway accidents with a fatality or injury respectively. The “Low” group was defined as a vehicle with TOW equal to 2 (not towed) and ACC_SEV equal to 1,2, or 3, or a towed vehicle (TOW equal 1) with property damage only (ACC_SEV equal 3).

Estimation of the change in fire rates as a function of model year were determined by taking the natural log of the fire rates, using linear regression to fit the estimated fire rates and determining the slope of the line that has been fit.

Vehicle year was utilized as the basis for the model year of the vehicle. For vehicle age the accident year was subtracted from the model year. If the model year was less than zero, the vehicle age was considered to be zero.

Rate Reductions

Table 6.1. Estimation of the percent change in fire rates controlled for vehicle model year was done by regression of the natural log of the fire rates by model year onto the model year. The resulting parameter estimate for the time component represents the percent change in rates across time. The standard error for this parameter estimate was reported as the standard error for the estimate of percent change in rates. Vehicles were limited to ages between 0 and 4 years.

Table 6.2. Estimation of the percent change in fire rates as a function of model year within a vehicle age group have been determined by taking the natural log of the fire rates, using linear regression to fit the estimated fire rates and determining the slope parameter that was fit, as with table 4.1.[1]

Table 6.3. To control for crash severity and impact mode across model years the overall probabilities for falling into a given crash severity and impact mode cell were computed. The overall probabilities were applied to the model year groups of interest to compute a "controlled" rate (fire or leak as appropriate). While there is discussion with regard to the appropriate method for calculating the standard error, in this case the standard errors associated with the respective cells were combined in accordance with their respective probabilities to characterize the standard error for the model year group. The ‘usual’ mean rates and standard error were calculated from the same groups, using the vehicle counts within cell as weights.

Table 6.4. Cars and LTVs with known damage area and severity were selected for vehicle ages 0-4. For each combination of vehicle type and the

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[1] This estimate for the slope parameter (beta) represents the percent change in rates over time. (Chatterjee & Price, 'Regression Analysis by Example', pages 32-34 shows an example based on decay rates of bacteria, which has a exponential non-linear relationship with time and an asymptotic limit, much like changes in fire rates over time).

all, high severity and rear/rollover, and inverse groups, linear regression was done on the natural log of fire rates by model year to obtain the estimated percent reductions by model year. The slope parameter was determined as in Table 6.1.[1] The inverse group consists of vehicles that have age 0 to 4 but with missing or invalid impact mode and or severity class and the vehicles that do not meet the vehicle age criteria. The “all” category includes all vehicles with valid impact mode and crash severity information and that meet the vehicle type requirements and are 0-4 years old.

Table 6.5. Vehicles were classified by vehicle size and type. Estimated percent reductions by model year were obtained by using linear regression on the natural log of the fire rates by model year for vehicles within the 0-4 year old group and determining the slope parameter that was fit. The inverse group consists of vehicles that do not meet the vehicle age criteria or have missing vehicle size codes. The “all” category includes car and LTV vehicles with valid vehicle size coding including unknown (but not missing) and that are 0-4 years old.

Findings

Fire rates by model years are shown in Figure 6.1 for all model years and vehicle ages. From Figure 6.1 it is clear that older model year vehicles have higher fire rates from newer model years that are necessarily less old.

[1] *Ibid*

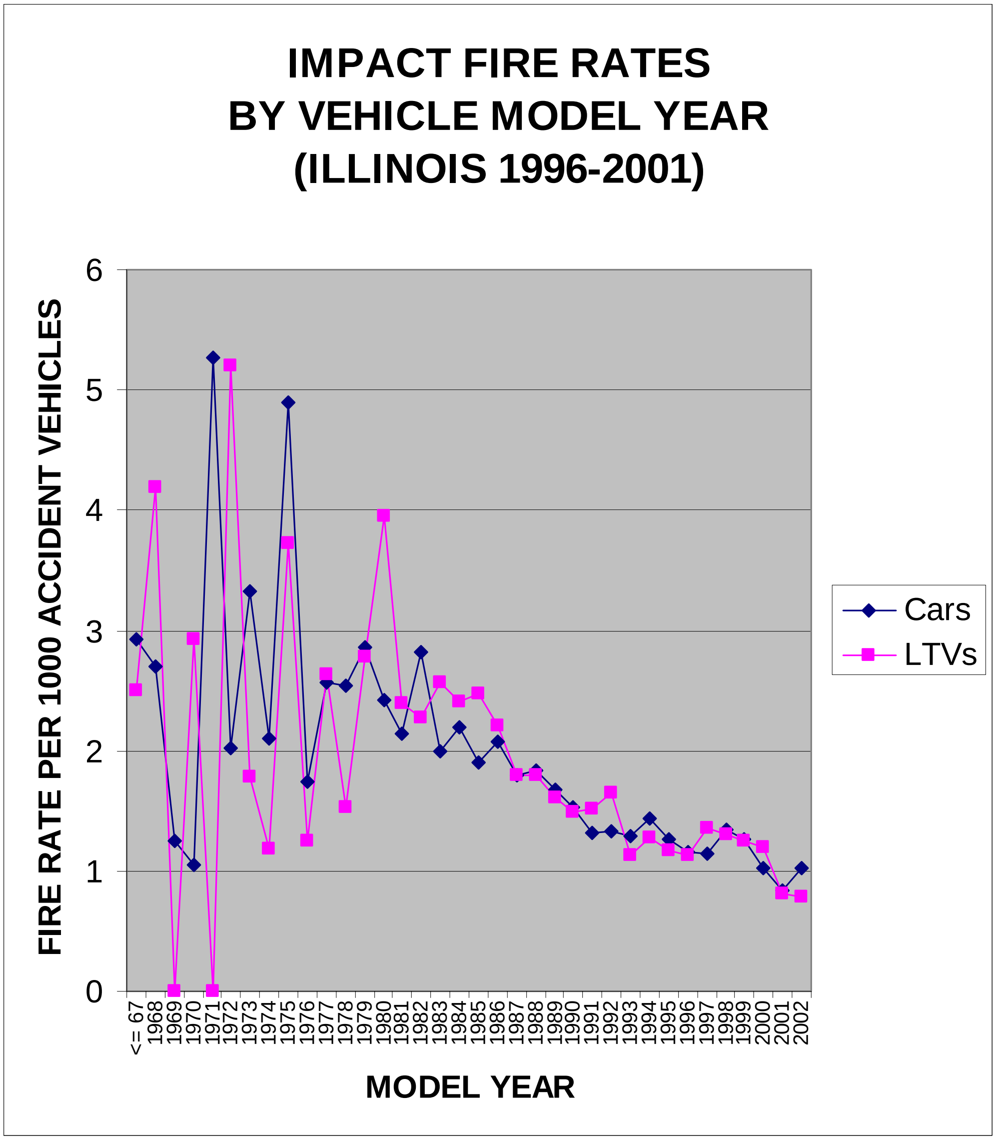

Figure 6.1 Impact Fire Rates by Vehicle Model Year Illinois (1996-2001)

The Illinois fire rates for 0 to 10 year old passenger cars and LTVs by calendar year is shown in Figure 6.2. There does not appear to be much of a trend over this period for these groups

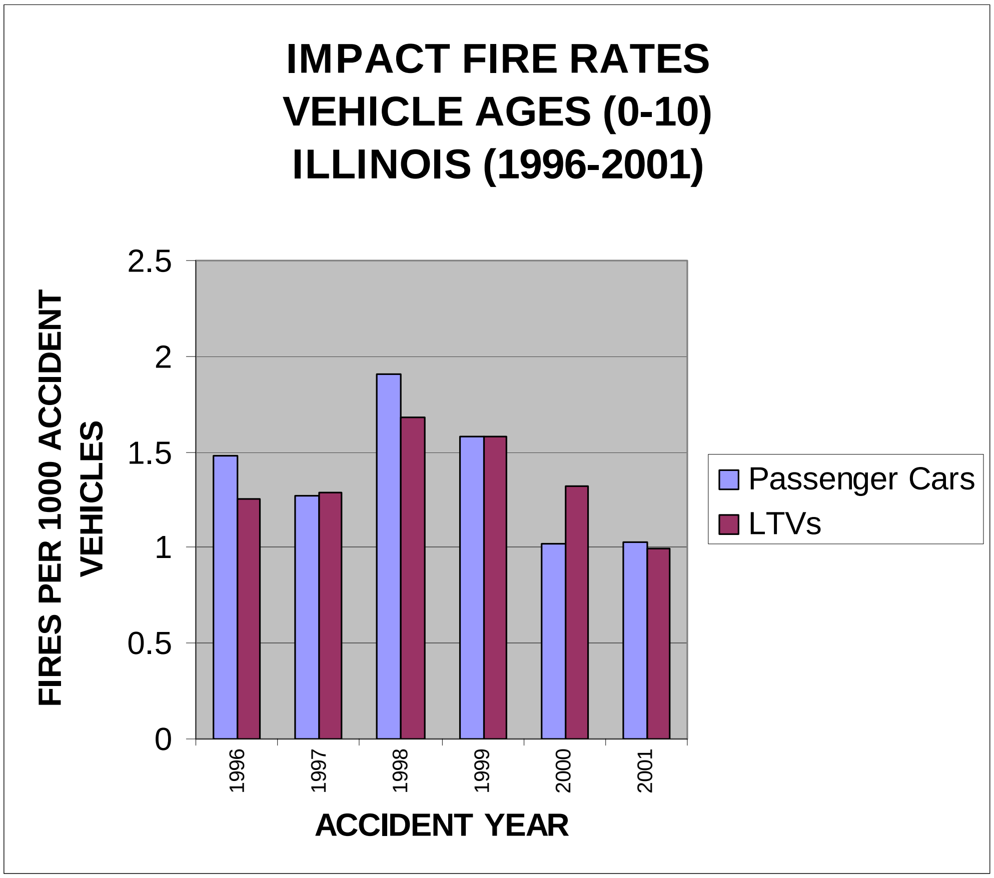

Figure 6.2 Impact Fire Rates Vehicle Age 0-10 Illinois (1996-2001)

The overall trend of fire rates for 0 to 4 passenger cars and LTVs by model year is shown in Figure 6.3. Figure 6.3 indicates that over the past decade of model years the fire rates for both the passenger cars and LTVs have been fairly constant.

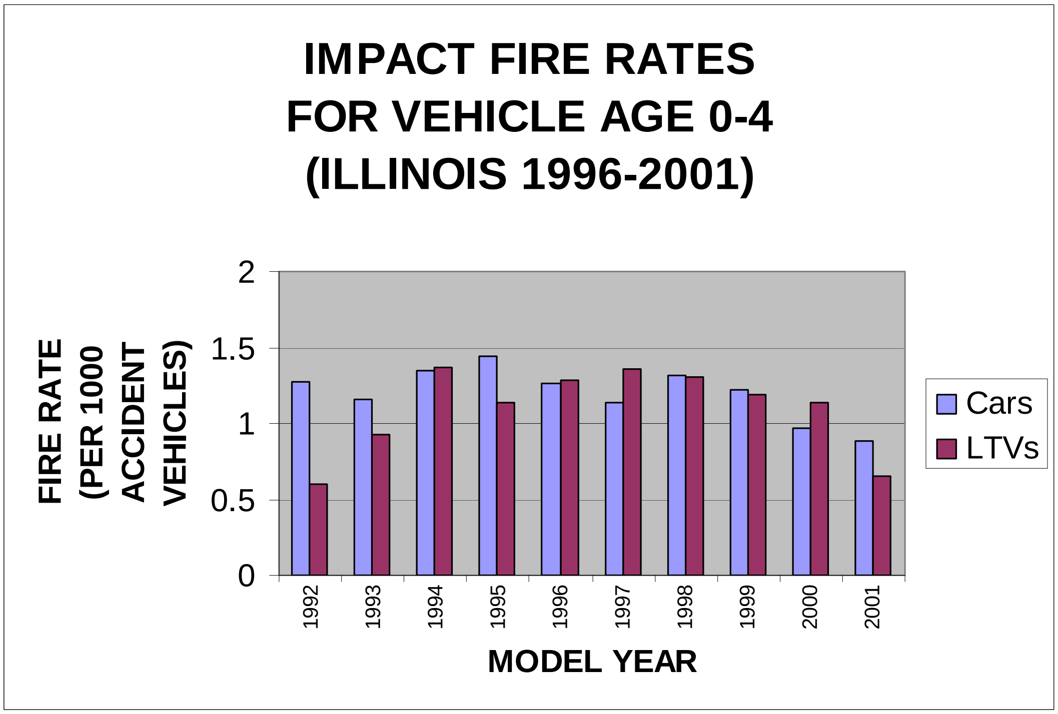

Figure 6.3 Impact Fire Rates for Vehicle Age 0-4 Illinois

Figure 6.4 suggests that the effect of vehicle size within passenger cars or LTV groups is not large based on this data. The Small LTV group had a few cases accounting for the apparent deviation. The lack of vehicle size effect was consistent with Malliaris' findings. The fire rates observed are lower than those reported in the Malliaris study.

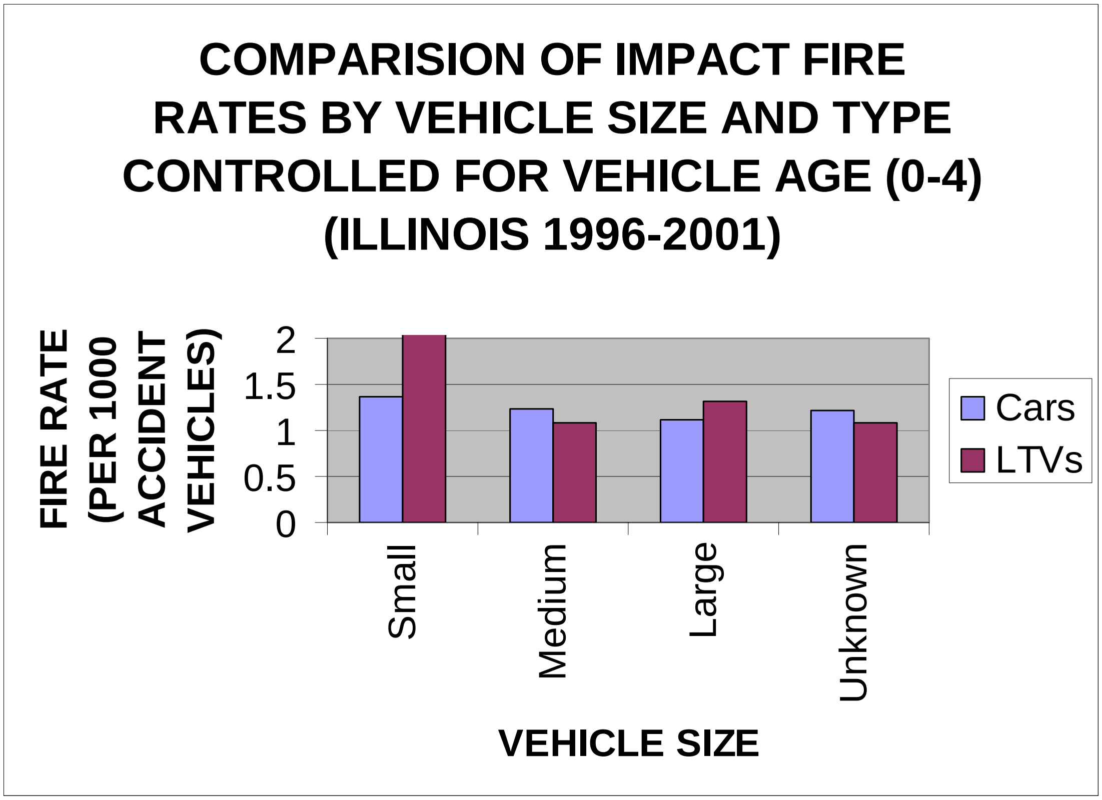

Figure 6.4 Comparison of Impact Fire Rates by Vehicle Size and Type Illinois (1996-2001)

Figure 6.5 shows the relative frequency of occurrence by impact area and derived severity for the passenger cars and LTVs in Illinois for the 1996-2001 data.

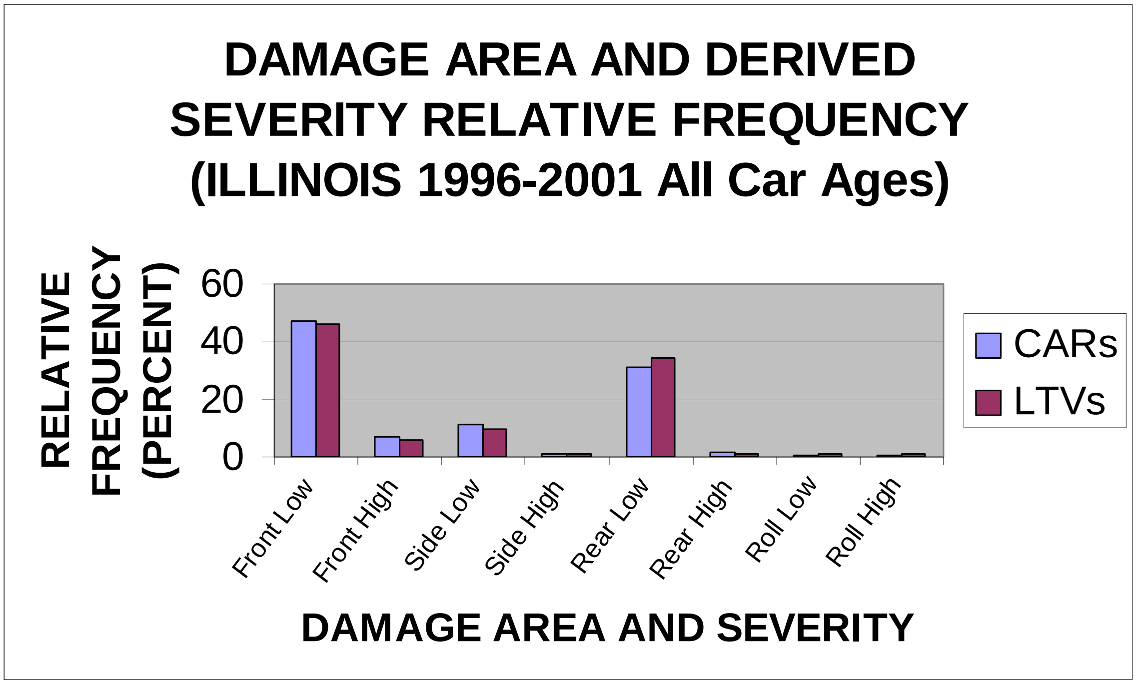

Figure 6.5 Damage Area and Derived Severity Relative Frequency All Car Ages Illinois (1996-2001)

Examination of the fire rates within these impact modes and severity classifications found the fire rates Figures 6.6. The data indicated generally higher fire rates in high severity impacts and rollovers.

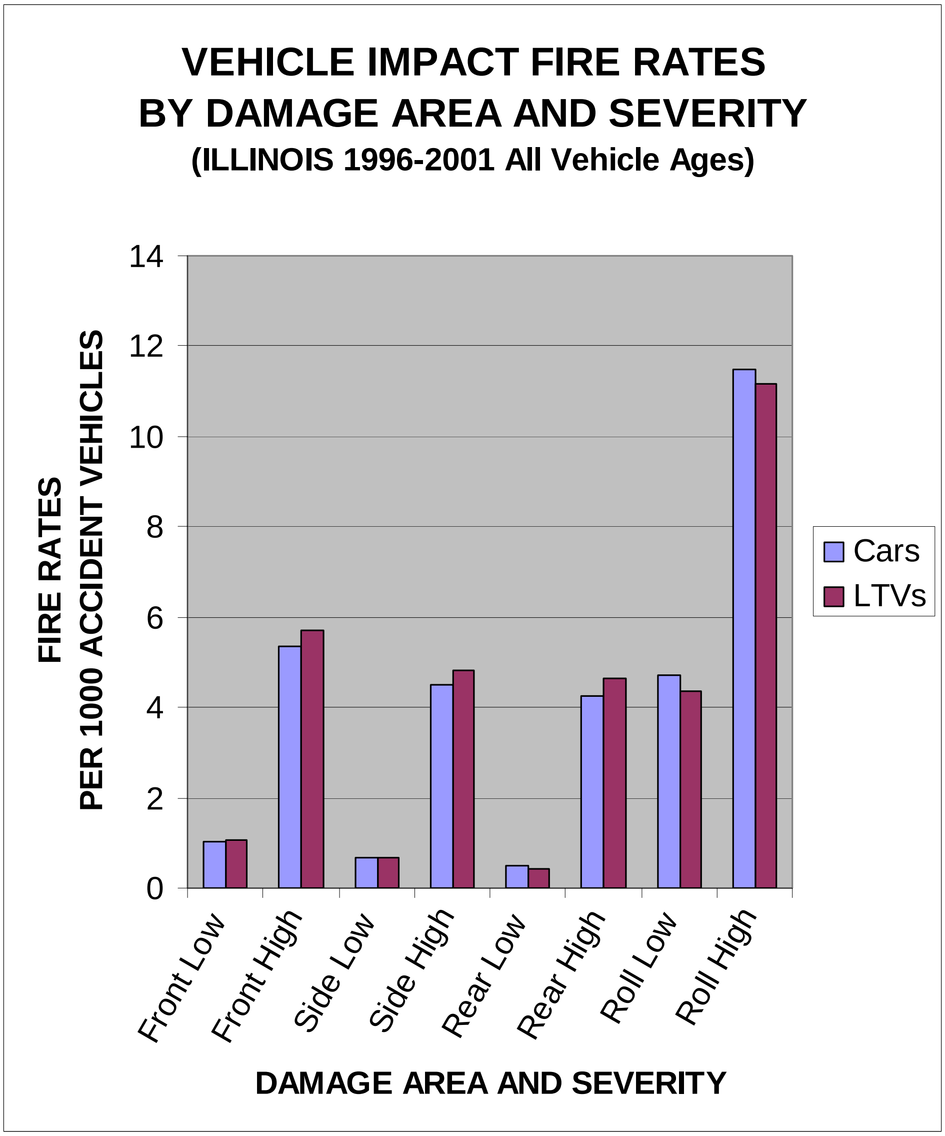

Figure 6.6 Vehicle Impact Fire Rates by Damage Area and Severity Illinois All Vehicle Types (1996-2001)

Table 6.1 provides results using Malliaris' approach for showing the effect of vehicle age on mean rates or percentage rate reductions per model year. For vehicle age control "yes" indicates the analysis is for vehicles 0-4 years old, while "no" indicates the analysis is for all model year vehicles.

Application of the Malliaris approach for the estimation of percent change in fire rates across accident years (controlling for model year) to later years does not result in a goodness of fit, that contributes to a logical explanation of the variations in fire rates for those years. Other approaches, such as a simple examination of the linear rate of change in fire rates seemed to offer greater explanatory value, however, the trends tend to be masked by variation in the rates. This led us to conclude that the distribution of fire rates in later years of data is uniform, or near uniform, and not following the exponential decay like distribution displayed in the Michigan 1978-1984 data.

Because the number of years is small and the fire rates are fairly constant between model years, the model selected for use, does not fit the data well. A simple linear model would have fit the data better and would have shown little if any trend. We have included the results here for completeness.

Table 6.1 Vehicle Impact Fire Rates and Model Year (Age 0-4 Illinois 1996-2001)

Vehicle	Vehicle Age Control	Mean Rate per 1,000 impacts	Rate reduction Percentage, per MY	Standard Error for reduction percentage
Car	Yes	1.23	-3.28	1.34
Car	No	1.25	-3.58	1.02
LTVs	Yes	1.21	1.26	3.50
LTVs	No	1.26	-4.53	1.55

Table 6.2 provides additional results for Illinois using Malliaris' approach for showing the effect of vehicle age on percent rate change per model year controlling for car ages for 0 to 9 years old.

Table 6.2 Vehicle Class and Vehicle Age (Illinois 1996-2001)

Vehicle Class	Car Age	Percent Change Per Model Year, Fires		Vehicle Class	Car Age	Percent Change Per Model Year, Fires
Pcar	0	-16.00		LTVs	0	-22.71
Pcar	1	-16.61		LTVs	1	5.62
Pcar	2	-13.21		LTVs	2	2.24
Pcar	3	-13.11		LTVs	3	-8.57
Pcar	4	-9.27		LTVs	4	-3.41
Pcar	5	-13.62		LTVs	5	-26.44
Pcar	6	-9.54		LTVs	6	-14.96
Pcar	7	-7.53		LTVs	7	-11.75
Pcar	8	-7.09		LTVs	8	-8.81
Pcar	9	-9.93		LTVs	9	-28.19
Vehicle Class	Pcar			Vehicle Class	LTVs	
Weighted mean	-11.72			Weighted mean	-9.99	
Standard Error	1.06			Standard Error	3.70	

Table 6.3 shows the fire rates for passenger cars and LTVs after controlling for damage area and crash severity for vehicles 0-4 years old. As can be seen there is little effect showing up that can be related to variations in damage areas and severity variations between model year groups.

Table 6.3 Illinois Impact Fire Rates By Model Year Grouping For Passenger Cars And LTVs

Vehicle class	Model Year group	Usual Fire Rate	Usual Fire Standard Error	Controlled Weights: Fire Rate	Controlled Weights: Fire Standard Error
Pcar	96-97	1.14	0.15	1.11	0.14
Pcar	98-99	1.20	0.18	1.23	0.19
Pcar	2000	0.86	0.26	0.92	0.29
Pcar	2001	0.79	0.37	0.87	0.42
Pcar	All	1.11	0.04	1.12	0.19
LTVs	96-97	1.27	0.26	1.24	0.25
LTVs	98-99	1.20	0.28	1.20	0.28
LTVs	2000	0.87	0.41	0.93	0.44
LTVs	2001	0.51	0.41	0.54	0.43
LTVs	All	1.16	0.07	1.16	0.29

Tables 6.4 and 6.5 shows fire rates and changes by model year controlling for passenger cars and LTVs with vehicles that were 0-4 years old (Illinois data from 1996-2001). These metrics were computed particular impact conditions and for small, medium, and large vehicles separately within the vehicle types respectively. Because the number of years is small and the fire rates are fairly constant between model years, the model selected for use, did not fit the data well. A simple linear model would have fit the data better and would likely have shown little if any trend. We have included the results here for completeness.

Table 6.4 Illinois 1996-2001 Controlled for Vehicle Age

Vehicle class	Event Class	Mean Rate per 1,000 impacts	Rate Reduction Percentage, per MY	Mean Standard error of all MY
Pcar	1: All	1.16	-4.01	1.47
Pcar	2: Hi Sever impact	4.61	1.16	2.58
Pcar	3: Rear imp & R/O	0.91	-5.29	2.84
Pcar	4: Inv of ALL	1.66	-1.43	0.63
LTVs	1: All	1.15	-1.14	3.91
LTVs	2: Hi Sever impact	5.48	0.94	3.28
LTVs	3: Rear imp & R/O	0.90	-3.86	5.24
LTVs	4: Inv of ALL	1.71	-1.44	0.80

Table 6.5 Illinois Impact Fires Rates by Vehicle Size for Passenger Cars and LTVs

Vehicle type	Size	Rate	Percent change in Rate	Standard Error for percent change
Car	All	1.23	-3.28	1.34
Car	Small	1.36	-2.69	3.72
Car	Medium	1.24	0.09	1.19
Car	Large	1.11	0.56	2.91
Car	Unknown	1.22	-6.70	2.31
LTVs	All	1.21	1.26	3.50
LTVs	Small	2.46	5.80	12.19
LTVs	Medium	1.09	-1.91	4.64
LTVs	Large	1.31	0.69	2.91
LTVs	Unknown	1.09	-2.12	4.90

A preliminary comparison of the fire rates by manufacturer country of origin is shown in Figure 6.7 for the Illinois data. Consistent with the previous analyses in Maryland and Pennsylvania, the Asian origin manufacturers had the lowest fire rates, while the European passenger cars had the highest fire rates.

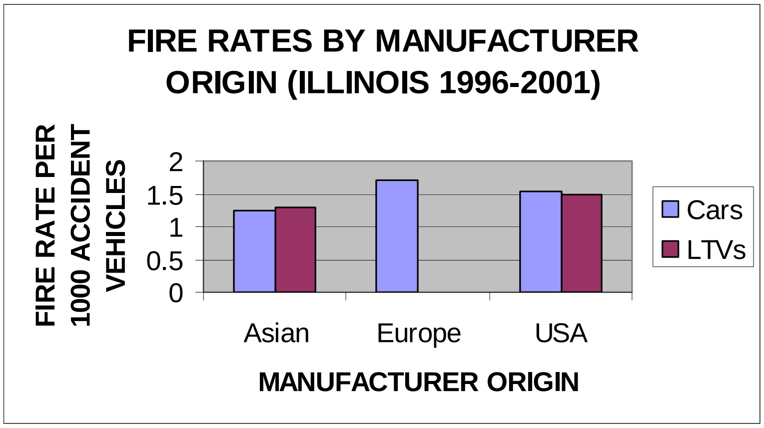

Figure 6.7 Fire Rates by Manufacturer Origin Illinois 1996-2001

Illinois and Pennsylvania Summary

The results show relatively consistent results for Pennsylvania and Illinois. The impact fire rates are slightly higher for the Illinois data compared with the Pennsylvania data. For example, typical rates of 0.8 to 1 per 1000 accident vehicles were found in Pennsylvania for recent vehicle years during the 1996-2000 time period, while Illinois showed rates of about 1 to 1.5 per 1000 accident vehicles. Both states show fire rates dramatically rising when considering the higher crash severity categories; typically the rates were observed in the 4-12 per 1000 accident vehicle range for the high crash severity regime. Frontal damage areas predominate in frequency of occurrence although rollover impacts tend to have the highest fire rates.

Pennsylvania does not show any dramatic change in fire rates across model years or accident years for passenger cars. LTV fire rates declined to be become more in line with passenger cars in Pennsylvania. Neither state shows much effect with regard to vehicle size.

SECTION 7: IDENTIFICATION OF DATA REQUIREMENTS FOR IMPROVED ACCURACY

Throughout this project we have had an opportunity to identify significant issues concerning data accuracy, quality, availability and accessibility. It is our intention to describe specific characteristics in the databases that are serious impediments to data analysis and those data characteristics that are excellent examples of accuracy, consistency, documentation, and utility for data analysis. We believe that while it is important to identify any negative characteristics, it is equally important to identify those characteristics that should be emulated by others.

In this report we have included specific methods for developing modifications that would improve the data resources, including formal processes that would be necessary to accomplish these changes. We have organized our findings around each of the databases that we have worked with throughout the project. Our recommendations for data improvement and consistency are listed point-by-point in the Conclusions and Overall Recommendations.

State Databases

In general, we found vast inconsistencies with regard to the data collected at the state level. These inconsistencies occurred in great frequency in the coding of vehicle damage area, damage severity, and fire-related codes. It appeared that information on fuel leaks is being collected for commercial vehicles as a part of hazardous materials spills, but leak information is not being computerized for passenger vehicles (with the exception of Michigan that collected leak information until 1991 and Washington that collected leak information until 1996. However, Washington’s accident data has not been computerized since the state converted to a new database system in 1996).

Unfortunately, many states are not uniformly collecting information on fires; however, it appeared that one of the best ways to ensure fire coding was to incorporate at least two event sequences at the vehicle level and a fire yes/no variable. Such coding enables the distinction to be made between pre-impact fires (fires started before there was an impact or where there was no subsequent impact) and impact related fires. Alternatively, separate event sequence records at the accident level that identifies event type and vehicle number among other variables can be used effectively. Specific examples will be given to highlight existing data quality issues.

National Databases

FARS:

Although Information on vehicle fires is collected, it is dependent on state sources of information. The states necessarily depend on police reports to provide the accident information. When a specific variable is not available on the police report, then FARS must rely on information from the narrative. Even follow up information (i.e. deaths within 30 days) regarding fatal accidents are not consistent across states (subsequent death not necessarily required to be reported to police) and therefore likely to be underreported. In this case underestimates could be characterized with detailed study by state against medical death records and NFIRS files

NASS

The NASS database has good quality information, but the size of the sample needs to be expanded through addition of more investigation teams. In the original design of the NASS program there was significantly more teams recommended then are currently being utilized.

HSIS;

The HSIS files only have state information and are not augmented with information useful for the understanding of fire-related events.

NASS-GES

GES files only have state information that is not detailed in relation to fires and still relies on police reports.

NFIRS

The NFIRS program for data collection should be augmented with fire and vehicle damage details for state accident files. NFIRS could pay states to expand the vehicle fire section.

STATE FIRS

Some states are utilizing the NFIRS system but are not submitting the information to the state or national organization. These locations should be encouraged to become a part of the larger system to ensure maximum coverage from the data.

CODES

The state accident files are augmented with more detailed injury information and could be improved by the inclusion of fire information from NFIRS. See Appendix for a more detailed description of CODES.

CCIS

The CCIS European accident data has good information and should be studied for comparison of practices.

STAIRS

The STAIRS project has been initiated to define the fundamental requirements for a Pan-European, in-depth accident and injury database. Although a promising project, the data collection effort has just recently begun. (Personal communication, TNO, Delft Netherlands, September 23, 2003)

Specific Coding Issues and Suggested Remedies

We worked intensively with the State data files of Michigan, Maryland, Pennsylvania, Illinois and Minnesota. To accomplish a valid and reliable analysis of the data around the questions of fire and fuel leaks involved in non-impact and post-collision fires with passenger vehicles, we attempted to understand the minutest details of coding protocols and data reliability. We have identified deficits of data quality and exemplar practices. Our experience has also given us insight into potential remedies for these thorny and unfortunately, longstanding problems with data quality.

Fire Code Quality Issue

Overall data quality problems are associated with changes in data collection techniques or instructions. For example, in Maryland post 1993 data police forms have a box to check when there is a fire. If there is no fire, there is no corresponding NO box. A significant problem arises when the database documentation says that the valid codes in the file are 1 – YES, 2 – NO. There is no provision for a blank or any other valid result in the file. Yet examination of the file showed a large percentage of cases were blank, without a 1 or a 2. Normal procedure would assume that without a valid code the data was missing and should be excluded. Further investigation showed that there were no quality control procedures to protect against this kind of result in the Maryland file. It was reported that keypunchers would just not enter anything or sometimes they would enter the code for NO if the FIRE box was not checked. In this situation there is no way to determine if the keypuncher overlooked entering the information or if there was actually nothing there. Checks can be built into the system so that they can be caught at the time of data entry.

Recommendations. First, quality control checking for valid codes in the creation of the database is essential. Second, confirming that the police officer actually addressed the item of interest is necessary as well. The latter leads to the idea of an explicit box for fires with a YES/NO answer. This coupled with the provision for at least 2 event sequence codes at the vehicle level provided for the best detailed analysis. Additionally, coding the sequence of events for each vehicle with event coding including fire gives the police officer a convenient template to use. An explicit fire box with yes and no boxes, in an prominent location (i.e. near the events) are a way to check for consistency with the event sequence coding. Pre-impact versus impact-related fire distinctions would be helpful, but with event sequence coding, it is thought that this should solve that issue. States should avoid coding the fire in the damage box, as it will overwrite the ability to code the damage area.

Fire Related Variables

The ability to identify the location of fires (front, side, rear), engine fire, dash fire (electrical), and sources of ignition is significant. It should be noted that impact fires are not the only fires that are reported in the accident data files, but many states are without ability to distinguish pre and post impact fires. The Michigan investigation shows that if a vehicle was driving down the road and caught fire and pulled over, it could be coded as an accident. Also if the vehicle was driving down the road, pulled over and then caught fire, it should not be included as an accident.

Recommendations. Fire location and origination should be a variable that is added (compartment, engine compartment, rear of vehicle, whole vehicle, fuel tank, filler neck); fuel source (e.g. fuel identification) should be provided. *:* Event sequence coding appears to be very useful in terms of distinguishing pre-impact from post-impact fires. Use of other “event” information to distinguish these non-impact events in Michigan was explored. It was found that a combination of variables might be utilized to suggest a non-impact event, but the coding did not prevent the potential for misinterpretation.

Vehicle Type and Vindicator Codes

- The use of Vindicator is limited in that the coding of vehtype is not available in the aggregate data output format. Hence while vehicle weights are available, the vehtype would be helpful.
- Vehicle type was not found to be coded correctly in some state files (e.g. Maryland) in some cases. Reliance on the keypunchers to decide between vehicle types probably relies too much on their personal knowledge of vehicles. Further, the lack of SUV, pickup, van distinctions from straight trucks and other heavier vehicles or rules on how to code a FORD E350, or F350 present challenges that should be addressed.
- Vehicle type distinctions are not as refined as desirable in terms of being able to distinguish large trucks from LTVs.
- Maryland VIN decodes are available for about 50% of the vehicles. (VIN decoding is only possible on passenger cars and LTVs)
- Minnesota, while claiming to include the VIN information in their accident database, did not disseminate the file with the VIN information included to HSIS and hence limits its utility.

<u>Recommendations:</u> Computerized quality control checking should be implemented at the state levels to input VIN's automatically. A national VIN and license plate registration database would facilitate this system and reduce data collection costs. VIN coding should be integrated in an automated way since the license plates are available and the corresponding VIN's should be located in the computer file.

Damage Severity

Damage severity coding is not standardized across states. For example, Illinois had to be constructed from tow-away (yes/no) and accident severity (fatal accident, injury accident or property damage). In Pennsylvania, deformation was none, light, moderate, severe. In Maryland, the coding changed in 89-92. It was disabling damage, functional damage, other vehicle damage and no damage. From 93 on, it was no damage, superficial or minor damage, functional damage, disabling damage and destroying damage.

- While not explicitly confirmed, confounding of the damage area and damage severity from the fire and the damage area and severity from actual impacts is likely to be present. Thus, if a fire was large, is the damage severity being coded as severe because of the fire or because of the impact? Likewise, if the fire is in the engine compartment in a side impact, is the damage area being coded as the side or the front? For example, in Texas, if a fire occurred it is entered in the damage area field. Thus if we know there is a fire, we do not know the damage area of the impact. In Alabama and Florida we know if a fire occurred in the accident, but not which vehicle it occurred in.
- Illinois data while having a damage variable of sorts, does not utilize a standardized damage variable such as TAD or CDC.

<u>*Recommendation.*</u> Damage areas should be identified as “impact damage areas” to avoid confounding the damage from the fire. Damage coding on a nationally consistent basis with training guidelines is needed.

Make Model Coding

- Maryland make, model coding is apparently a free field for the keypuncher to type in names. Variations for make and model name were as wide ranging as all possible spellings. Apparently there is no quality control on the typing, thus Chevrolet could be Che, Chev, Cheb, Chevr, etc. The problem becomes more acute with model names where virtually any spelling would be possible. There are clear clusters of spellings that allow analysis, but the use of the dominant spelling is likely to omit vehicles that should be included.

Recommendation. Given the typing problems, it is not clear that the VIN information would end up being particularly reliable. However, a sample of hardcopy cases for comparison would resolve the reliability of the VIN coding at least insofar as the transcription from the police report to the file. It is clear that automated techniques should be used during the data entry process to ensure greater reliability and accuracy (for example checking that the VIN entered is valid).

Inconsistency of Coding Protocols across Years

- The change in the Maryland data collection system occurring in the 1993-1994 time frame appears to have dramatically changed the fire rates.
- The Illinois data was found to omit some information associated with Chicago for some years apparently due to fiscal constraints.
- The change in the Washington data collection system apparently led to a complete collapse of the state's accident data system and the data has not been entered since its conversion in 1997
- The change in the Michigan data system omitting fire all together eliminated its utility. Further, Michigan eliminated the VIN and make-model and model year coding which further obstructs any utility from this database.
- Minnesota changed its data collection system in 1992.

Recommendations for National and State Accident Files

- Damage area and rollover distinctions should be standardized across the state data collection systems.
- Collision type should be standardized.
- Fire coding should be standardized.
- Police reports should be standardized; there are 50 different forms for accident reports.
- A linkage system between the death collection system and FARS should be implemented to avoid the undercounting of fatal accidents. There are states where there is no requirement to report the subsequent death of a vehicle occupant to the police. Hence the state accident information doesn't acknowledge fatalities that are occurring immediately after

the time of the accident. Given the 30-day time frame for FARS, an analysis should be done to assess the magnitude of underreporting on a state by state basis. This would allow correction estimates to be applied to data reported in FARS.

- Many state systems do not report even rudimentary information needed for useful analyses. For example, damage areas, damage severity, incidence of fire at the vehicle level (as compared to the accident level),and data to identify the vehicles involved (VIN, license plate, make, model, model year information, vehtype). No states currently report fuel leakage as a variable.
- With the likely introduction of alternative fuel systems, information on these new types of systems under crash conditions will become increasingly important. Preparation for the systematic collection of this information should be done now in preparation for analyzing effects as they occur and to enable early identification of problems. Databases should accommodate fuel type variables, for example, gasoline, diesel, CN6, H2, methanol, etc
- The NASS system should be vastly expanded to facilitate the collection of information it has already identified.
- Archiving of the historical data should be done at the state level. Throwing away the data after 10 years loses a vast investment that limits the ability to do historical analyses. The cost for storage would appear to be minimal given current technology and given the expenditures already made to collect the data.

Recommendations for Non-NHTSA Accident Files

- NFIRS data collection fields should be expanded with regard to vehicle identification and fire damage information.
- Event sequence coding should be implemented nationally; alternatively, explicit pre impact fire and impact fire coding should be implemented.
- A system like CODES applied to the fire information, NFIRS, or state versions would augment the state accident information for fires.

SECTION 8: CONCLUSIONS

During the execution of this large database study of state accident files we have identified critical issues in the areas of accident data collection methods, database maintenance and accuracy, and vehicle fire incidence. Throughout this report we have provided a critical analysis of these issues as they relate to the extant literature and the state databases under discussion. In these concluding remarks we have made overall comparisons of significant findings with the Michigan, Maryland, Pennsylvania, Illinois, and FARS accident files. Further we have identified the implications of these findings for future research.

Pre-Impact and Impact Fire Rates

The impact fire rates reported in Michigan (without control for pre-impact fires for passenger cars 0-4 years old for model years in the late 1970's to early 1980's) presented similar fire rates as found in Illinois for vehicles 0-4 years old. The average in the 1978-1984 accident years for 0-4 year old cars in Michigan was about 1.5 (per 1000 accident vehicles), while the average for the 0-4 year old vehicles in the 1996-2001 accident years in Illinois was 1.2.

Pennsylvania showed a lower reported impact fire rate than Michigan and Illinois over the same reporting periods. However, Pennsylvania data showed basically a constant ***impact*** fire rate across time. Perhaps even more importantly, Pennsylvania showed a dramatic increase in what we assessed as pre-impact fires during the study period (1980-2000).

The Maryland analysis suggested a rapid decline in fire rates, but there was a change in the data collection system just at the time rapid changes in fire rates are occurring. We have learned in our investigation that any shift in the data collection system demands a cautious interpretation of findings. However, it is clear that fire rates are consistently higher for the LTV category as compared to the passenger car. Again in Maryland there were concerns with regard to the vehicle type coding that could be a contributing effect.

The Pennsylvania data indicated a fairly constant fire rate independent of model year since 1980-2000 for passenger cars. LTV's showed some decline over the model years. Pennsylvania showed a large portion of pre-impact fires (about 15000 pre-impact fires, compared with about 5000 impact fires) compared to the other states (the opposite ratios). Thus changes in the cases categorized as pre-impact fires have the ability to dramatically affect the observed impact fire rates.

Illinois indicated an impact fire rate of about 1-1.5 per 1000 accident vehicles consistent with Pennsylvania (0.8-1.0) for the corresponding periods (1996-2000) for both passenger cars and LTVs. Maryland (which includes tow-away, injury and fatality accidents) has lower fire rates of 0.3 to 0.6 per 1000.

All the states indicated similar impact fire rate ratio between LTVs and passenger cars during recent accident years and they also demonstrated declines in past model year LTV fire rates over time gradually coming down to the impact fire rates observed in passenger cars (see Figure 8.1).

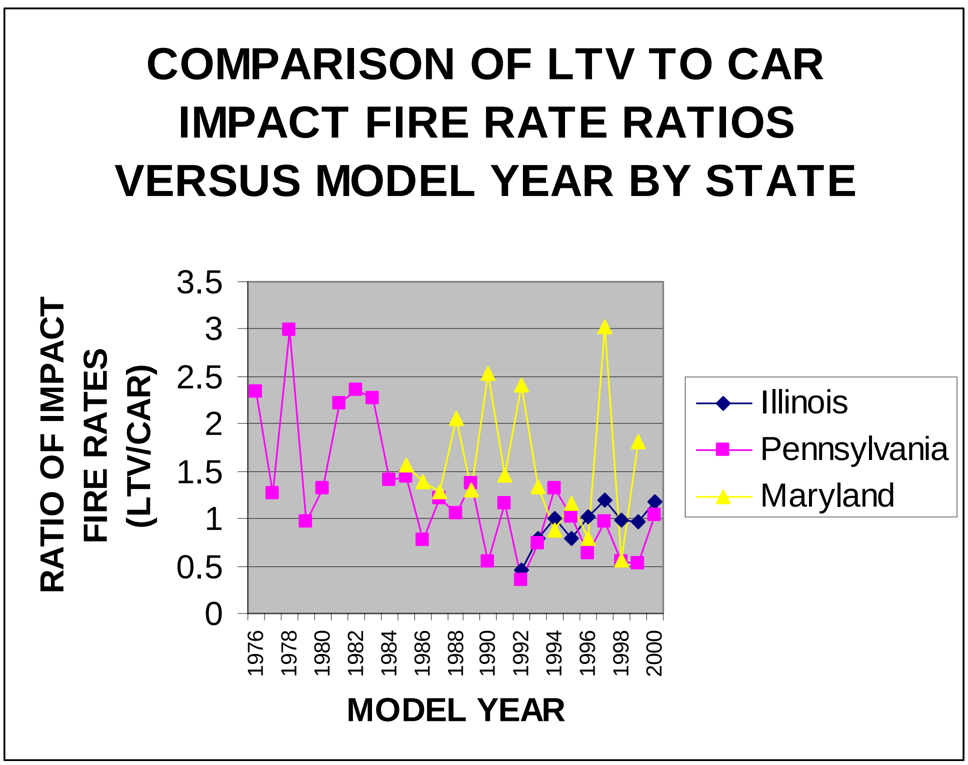

Figure 8.1 LTV to Car Impact Fire Rate Ratios

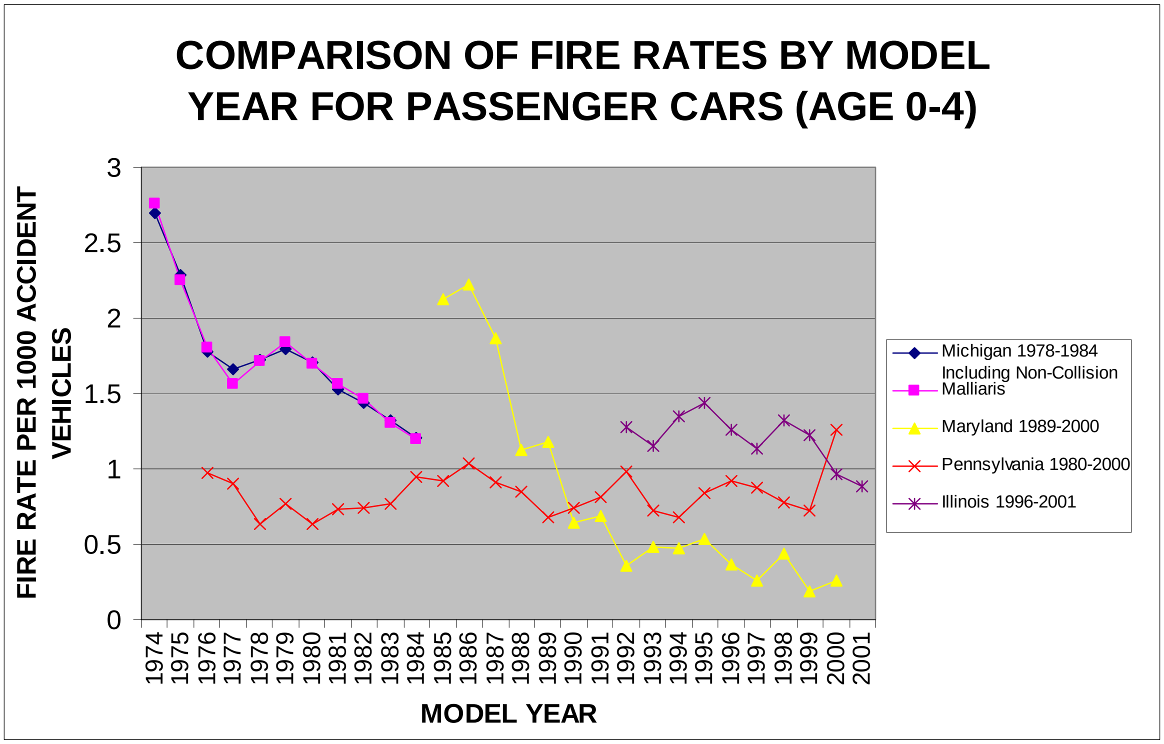

Figure 8.2 Comparison of Passenger Car Impact Fire Rates by States and Model Year

Figure 8.2 shows the results for the fire rates by model year controlled for vehicle age from the various states examined. The results suggest that passenger car fire rates have not changed much over the past 20 years. This is particularly evident given potential effects of the data collection system change in Maryland and the Malliaris results which likely incorporate the effects of non-collision fires.

By contrast it is apparent in Figure 8.3 that LTV impact fire rates have declined, based on the Pennsylvania data, across model years during the past 20 years with a leveling off during the past 10 years.

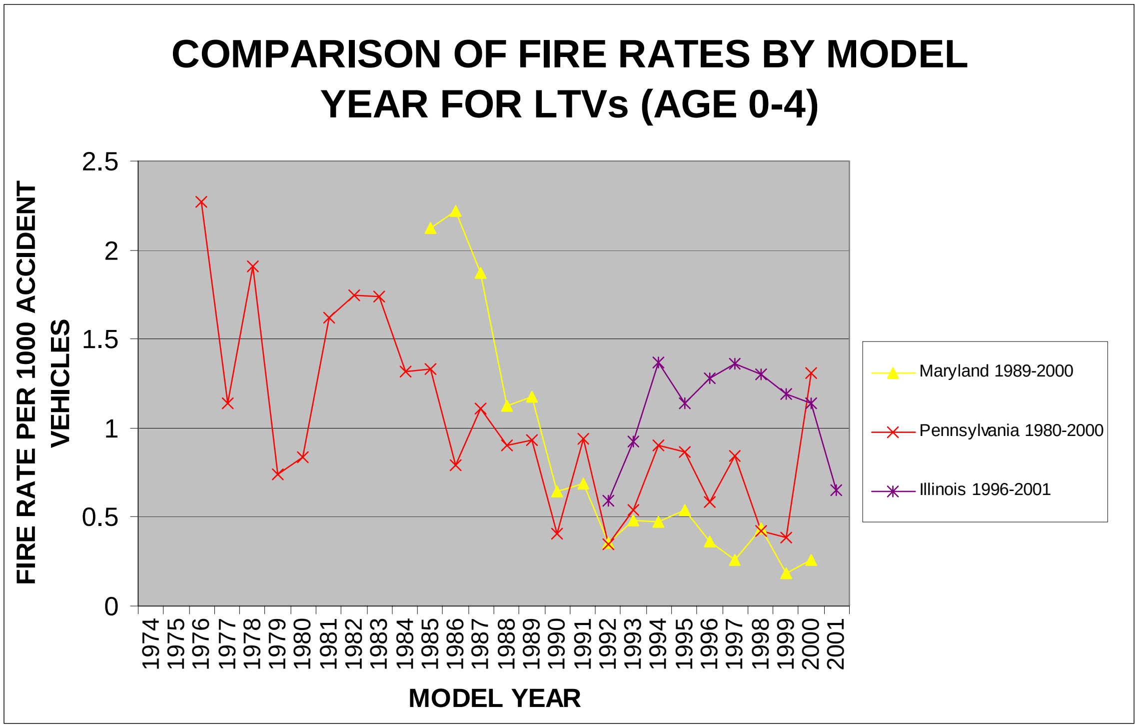

Figure 8.3 Comparison of LTV Impact Fire Rates by State and Model Year

The ratios of non-impact fires to impact fires are similar in Illinois and Maryland, but dramatically different in Pennsylvania (see Table 8.1). In Pennsylvania, there were about three times as many non-impact fires as impact fires (based on the coding), while in Illinois and Maryland there were respectively 10 and 2.5 times as many impact fires as non-impact fires reported. Further examination of this phenomena for Pennsylvania showed that about 99% of pre-collision fire cases had only one event after about 1988 (from 1980-1987 the percentage increased from 82% to 91%), thus at least confirming the expectation that most reported pre-impact fires did not have a subsequent impact event. Thus we have not found any reason to discount the Pennsylvania pre-impact to post-impact fire ratio results.

Table 8.1 Ratio of Pre-impact Fires to Impact Fires by State

	Cars	LTVs
Illinois	0.08	0.09
Pennsylvania	2.73	3.74
Maryland	0.40	0.52

Fire rates in Asian manufacturer's vehicles were found to be lower than American vehicles across each state examined (Maryland, Pennsylvania, and Illinois (see Figures 4.15, 5.8, and 6.7, respectively). Similarly European values were higher in each of these states. The reasons for these observations should be explored. For example, data from Minnesota and other states could be used to explore this preliminary observation further.

Given the results of controlling for vehicle size within vehicle type, crash severity and impact mode on the overall fire rates, it appears that opportunities exist for including additional states that may not have one or both of these variables, for the purpose of examining overall impact fire rates. Further, if the cost barrier to the Minnesota data was overcome that data may yield additional insights.

Analysis of the FARS data shows declining fire rates by model years based on registered vehicle years as an exposure measure. We believe that a more appropriate exposure measure would at least take into account vehicle mileage. Nevertheless, pickups exhibited higher fire rates generally than other vehicle types on an overall basis. As we have seen in the state data files, the fire rates for LTVs are generally seen to be above passenger cars in the past and have been approaching the passenger car levels more recently.

Impact Modes and Fire Rates

All the states analyzed for impact fires as a function of vehicle weight showed little effect associated with this factor consistent with Malliaris' findings. All states presented dramatic increases in fire rates for rollover impacts compared to the norm. Rates between 5 and 12 per 1000 accident vehicles were observed in the high severity rollover category. The effect appeared independent of passenger car and LTV distinctions.

Impacts classified as having high severity in the front, rear, and side (with the exception of Maryland) impacts resulted in increased fire rates. The increase was in the range of 4-10 times the average in Illinois, 3-6 times the average in Pennsylvania and 2-10 times the average in Maryland. Typically the high side of these ranges belonged to the rollover classified modes while the lower sides were associated with the front, rear and side impact modes. The frequency of fires was found to be greatest in frontal impacts uniformly across the states.

It appeared that the overall incidence of fires in rear impacts was substantially reduced compared with the Malliaris results. The implications appear to be that fire rates in rear impacts have declined since that time. On the other hand, the frontal impact categories had less substantial reductions while the rollover category remained high or higher than it was on an overall basis. About a third of the fire rates in FARS could be attributed to rear and rollover impacts.

Leak Rates

Leak rates were shown by Malliaris to have a substantially higher rate than fires. Information available in Europe suggested that this is still the case. European data from CCIS suggested a 1% fire rate, 5% leak rate, and 10% fuel system damage rate. Corroboration of these findings in the vehicle fleet in the United States should be accomplished using the NASS data or augmented state files (with regard to leak rates).

Impact Type

It was found that dramatic differences were observed when fire rates were examined by impact type. For example, fixed object impacts exhibited fire rates about 4 times greater than vehicle-to-vehicle impacts. This effect was only examined using the Michigan data, as it was not part of the Malliaris protocol.

Fuel System Design

Effects of specific vehicle fuel system design approaches on the incidence of collision related fires have not been analyzed utilizing large scale databases in the past 30 years. For example, identification of those vehicles with and without inertia activated cutoff switches for (with manual reset buttons) electric fuel pumps, the presence of plastic versus metal fuel tank systems, fuel tank position, and fuel injection versus carburetor based engines. These design features, among many others would allow analysis of whether the effects of such design differences can be observed in the accident data. The accident files that we examined would support the identification of fuel system design approaches such as flammable fluid locations, and ignition source protection systems. To analyze effectively design change effects on fire incidence, it is clear that linking a variety of data together (such as combining engineering analysis information on the design approaches and related observed fire incidence information for these engineering design approaches) to enhance the quality of the information available for analysis would be highly desirable. A concerted effort to accomplish these goals can be expected to produce significant enhancements in determining the effects of vehicle design factors on the incidence of fires in collisions.

Data Quality

Data quality issues in accident data files have been reviewed and recommendations have been made for numerous years. Our three most significant observations in the state data files were: a) the need for standardization in reporting across states, b) the need for quality control within the states at data collection, data entry, and system maintenance levels and c) the need to augment the state data with fire data by expanding NFIRS and integrating it with the state information much in the way CODES (see Volume II: Appendix E) is being done currently. On a real-time basis tying NFIRS data collection systems into a national or state based system integrated with the state accident data systems would expand the opportunities for the FARS state analysts to identify the presence of fires in any given accident. The integration would be enabled through the correlation of date, time and location of accidents.

The two most significant issues with regard to FARS data are a) the need to make available to the FARS analyst standardized fire information for the correct coding of the fire incidents (this would be accomplished through the use of standardized state data collection), and b) analysis of the FARS data to calibrate the underreporting of fatalities and fire cases due to the inadequacies of the state data collection system. This occurs because FARS analysts do not utilize death registries and NFIRS to supplement the accident file information. For analysis purposes and estimation of underreporting of fires in various files, correlation of NFIRS information with state accident files and FARS represents an opportunity that should be implemented.

The state accident information received by FARS analysts is incomplete due to a lack of requirements in all states to report to the police department deaths that occur to traffic victims days after the accident has occurred. While FARS has a 30-day time window, it is clear that many states are not able to ensure that the police will know of a fatality that occurs to occupants subsequent to the immediate time frame of the accident. A number of ways have been suggested to address this problem. An immediate need exists to assess the magnitude of the problem by states utilizing the available death registry information to at least calibrate the inaccuracies present. An irrefutable instance of this problem was revealed when the Center for Auto Safety submitted four fatal fire cases to NHTSA that should have been included in the FARS data but were not.

NFIRS would profit by expanding the data variables collected. In the meantime NFIRS could be utilized to augment the available fire information. For example, NFIRS could be cross-referenced to establish the extent to which the fires are being underreported in FARS due to the inadequacy of the fire and death information in the police reports. Finally, NFIRs could be coupled with state files to augment the available fire notification and response time information. This information coupled with the CODES system would enable detailed analyses of occupant injuries as well.

In addition to NFIRS and FARS, the NASS dataset could make important contributions if the full set of teams originally designed in the project were implemented. Sufficiently trained data collectors would facilitate a more comprehensive and detailed database that would allow sophisticated and necessary understanding of vehicle fires. Other data sets from international sources, such as CCIS and STAIRS (when available), should be obtained and explored to identify the insights available from European vehicle accidents.

Closing Remarks

This project has uncovered both the importance of detailed and accurate analyses of fire rates and the critical need for further research that expands our understanding of the detailed interplay among vehicle design, accident sequelae, and occupant injury in motor vehicle fires. Throughout this report we have offered our perspective on the strengths and deficits of the primary data collection systems that support the investigation of vehicle fires A concerted effort to gain the resources that will allow significant cooperation among those agencies that are collecting accident and fire information would provide a strong foundation for complex analyses in future.

Data collection improvements are not anticipated as short-term projects- nonetheless the cross-validation of existing database information will allow a significant opportunity for important and immediately relevant research. Our investigation has uncovered the opportunity to investigate alternative engineering system design approaches on the incidence of impact and pre-impact fires. It is our strong recommendation, given the increasingly important role of alternative fuel systems in our modern fleet, that the existing national and international databases be employed to respond to this and other immediately relevant fuel system design questions. As a result, NHTSA should work with the states to accomplish the recommendations that have been identified herein.

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GLOSSARY OF TERMS

AMA	American Medical Association
ACIR	Automotive Crash Injury Research
CODES	Crash Outcome Data Evaluation System
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
HLDI	Highway Loss Data Institute
HSMVD	Highway Safety & Motor Vehicle Data
HSIS	Highway Safety Information System
LTV	Light Trucks and Vans
MHE	Most Harmful Event
MCOD	Multiple Cause of Death
NASS	National Accident Sampling System
NASS-CDS	NASS-Crashworthy Data system
NASS-GES	NASS-General Estimate System
NCSS	National Crash Severity Study
NCDS	National Crashworthiness Data System

NFIRS National Fire Incident Reporting System

NGES National General Estimates System

NFPA National Fire Protection Association Survey Data

PAR Police Accident Report

STAIRS Standardization of Accident and Injury Registration System

TAD Texas Accident Deformation Scale

SUV Sports Utility Vehicle