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Motor-Vehicle Collision-Fire Analysis Methods and Results

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1.0 Abstract

In 1967, Federal Motor Vehicle Safety Standard 30 1 was first issued. Its stated purpose was to "reduce deaths and injuries occurring from fires that result from fuel spillage during and after motor vehicle crashes [1]." Since that time, many studies have evaluated the effectiveness of this standard as well as fire safety in general. Most of the studies were analyses of motor vehicle crash databases providing little or no detailed information as to the actual fuels involved in ignition, ignition sources, propagation paths and times, and injury mechanisms.

This paper presents the methodologies used in and preliminary results of ongoing case studies of motor vehicle collisions involving fire. These case studies are conducted to provide sufficient detail of collision-fire incidents to further understanding of the cause(s) of fire, fire propagation rates and paths, and the mechanism and extent of resultant injuries. Methodologies described include detailed data collection forms and instructions, event selection criteria, the network of contacts established to provide timely notification of events, and systems necessary to protect privacy and comply with privacy regulations of participating agencies. Study of each selected event includes interviews, inspections of vehicles and crash sites, incident reconstruction, and analysis of injury mechanisms.

While fires resulting from collisions are rare and occur due to the confluence of improbable events, case studies show that fires can occur in a wide range of crash circumstances and severity. Data presented herein illustrate cases that include a wide variety of post-collision ignition times, fluid system breaches, ignition source availability, impact types and impact severity. Photographs, inspection results, witness statements and investigator experience are the bases for the data presented.

2.0 Introduction

Statistical studies of automotive collision-fires have been conducted for more than thirty years to examine trends of such events, the types of collisions, areas and types of vehicles involved, as well as the effectiveness of Federal Motor Vehicle Safety Standard 30 1 [2, 3, 4, 5]. Motor vehicle incident databases lack detail regarding fire events and often only provide affirmation of fire occurrence. Yet there have been very few publicly available studies that included vehicle field inspections such that conclusions could be drawn as to actual causation and propagation factors of the fires. The few available publications containing case studies of automobile collision-fires have not been extensive or have not included field investigation [6, 7, 8, 9]. While case studies in the field are labor intensive to perform, they are an independent source of specific information about collision-fires.

For fires to initiate, specific combinations of fuels, oxygen and ignition energy are required. Specific combinations of fuel and oxygen are again required to promote propagation, along with significant dependence on the location of the fire and the type and amount of combustible material in the area of ignition, adjacent surface properties for heat reflection, and local air flow and ambient weather conditions [10, 11, 12]. Numerous researchers have demonstrated the difficulty of reenacting realistic vehicle fire scenarios in the laboratory. Attempts to initiate non-collision vehicle fires with only the resources normally available in the vehicle have often failed either to initiate or propagate the fire. In addition to the numerous variables related to the fire, small differences in the crash configuration can make significant differences in the propensity to bum. The tremendous complexity of collision-fire events makes prediction of association between laboratory tests and field incidents even more difficult. Greater value can be gained from case studies by using them in conjunction with laboratory studies so that complementary data may be shared.

The field investigations described herein include information obtained through interviews of police and fire personnel and witnesses to estimate time from impact to fire initiation and propagation, and the location of initiation and path of propagation. Considering the stressful circumstances, all witness observations were used with caution. Witness time estimates in particular were not considered precise without corroborating information. Field inspections of vehicles were performed to independently evaluate initiation locations, fuel and ignition sources available, and propagation paths. Where applicable, incident reconstruction was conducted to provide an estimate of delta V[1] as an objective measure of collision severity. Before project completion, medical records will be reviewed to asses causes of injuries.

The goal of the project is to investigate 50 incidents though some will be limited in scope. At the time of writing, thirteen case studies have been largely completed. Given the nature of case studies, it should be understood that individual observations do not define trends in failure modes that are representative of specific vehicle makes and models. Also, inspectors were not authorized to disassemble vehicles during inspections, so observations were limited to exposed components. Independent laboratory tests or reenactments of incidents were not performed to confirm inspector assessments. Additionally, severe impact and fire damage often compromise evidence of fire causation Therefore, inspector evaluations of fuels, ignition sources and times should be considered the authors estimate of the most likely conditions involved. The authors do not expect their conclusions to be precise in all cases. Case studies do, however, demonstrate the range of possible factors related to collision-fires and resultant injuries associated with impact or fire. The authors expect that a range of factors presented in current results and the expected range in case studies to follow will be useful to designers, regulators, and investigators alike. The collision-fires studied included most-likely assessments indicating ignition of many automotive fluids by electrical sources, mechanical spark and autoignition, with large and small fires ensuing from coolant, engine oil and gasoline.

The study also included an evaluation of fire propagation paths. Windshields, dash panel openings, open doors and openings from deformed sheet metal were all found to contribute to propagation to the interior.

3.0 Research Participants

The prime contractor for Case Studies in Motor Vehicle Fires is the Washington State Transportation Center (TRAC) at the University of Washington. TRAC is a cooperative transportation research agency with members including the University of Washington, Washington State University, and the Washington State Department of Transportation. From its offices at the University of Washington in

[1] Delta V is the change of velocity of the vehicle that takes place during the collision event as a result of impact.

Seattle, TRAC coordinates research resources to address multidisciplinary applied research problems. This research was conducted with the expertise in vehicle systems and fire investigations provided by Leland E. Shields, Inc. in Seattle, Washington, Golder Associates Inc., in Redmond, Washington, and Design Research Engineering, L.L.C., in Novi, Michigan.

4.0 Selection of Collision-fire Incidents

Incident samples were selected to identify vehicle and collision factors in fire and injury causation. Cases were drawn from incidents involving 1990 model year design and newer passenger cars, pickup trucks, sport utility vehicles and vans, built by various manufacturers. Selection was also based on the extent of impact, fire damage and injury.

While it was understood that numerous vehicle, collision, and environmental factors are involved in the incidence of fire, it was also clear that it was not practical to control for all in the selection process for at least two reasons: 1) it is very difficult if not impossible to perform detailed investigations of enough observations to differentiate numerous variables, and 2) collision-fire events are rare and difficult to learn of in a timely manner for investigation. Therefore, samples are drawn from a limited pool of candidates.

The established selection criteria were intended to illustrate the range of factors involved in collision-fires and to raise questions for further study. As the project evolved, the criteria used for selection developed in two levels of priority as described below.

4.1 Primary Selection Criteria

Vehicle Age at Time of Collision-Fire Event:

Collision-fire vehicles selected were in production from 1990 model year or thereafter. By this criterion, a 1989 vehicle may be included if essentially the same design continued in production until at least 1990. The intent of this criterion is to investigate fire causation in vehicles of current or near-current vehicle models so that study results will be relevant to modem vehicle technology.

Extent of Vehicle Damage: It is difficult to determine specific fire causation and propagation factors in vehicles with extensive damage from both impact and fire. To maximize the information learned from each incident selected, samples were taken from three categories:

1) Vehicles with minor fire damage and any degree of impact damage.
2) Vehicles with minor collision damage and any degree of fire damage.
3) Incidents in which fatalities or burn injuries are involved with any degree of collision and fire damage.

For those incidents with either minor impact or fire damage, fire causation factors may be identified with a higher degree of confidence. For incidents with both extensive impact and fire damage, investigation still provided insight into causation of injuries, propagation times and entrapment issues.

Gasoline-powered vehicles only: In order to limit the scope of the already broad and complex problem, selection was restricted to gasoline-powered vehicles only.

All incidents for which notification was received were screened first to confirm that the vehicle age was within the specified range. Then information was gathered as necessary to determine the extent of collision and fire damage. If it was determined that valuable information could be gleaned from investigation, the incident was selected.

4.2 Secondary Selection Criteria

Before initiating research, TRAC identified four collision and vehicle factors for which it would be desirable to have some distribution within the sample: location of impact, vehicle type, size, and manufacturer. TRAC never intended to obtain a representative sample of any factors. Rather, the intention was to find examples of incidents over a broad range of field experience. For example, it would have been limiting if all incidents studied were frontal impacts. Through the random process of notification, the incidents referred to TRAC have naturally been distributed among the categories cited. While keeping these collision and vehicle factors as guidelines, TRAC has not found it necessary to use any of them for screening during selection. All selection has been determined from the primary factors alone. Details of the collision and vehicle factors are listed below for reference.

Location of Significant Impact to Vehicle:

Frontal impacts (clock points 11, 12, 1, no rollover)
Rear-end impacts (clock points 5, 6, 7, no rollover)
Side impacts (clock points 2, 3, 4, and 8, 9, 10, no rollover)
Rollover included (Other impact locations may also be involved)

Vehicle Size:

The sample includes light trucks (pickups, sport utility vehicles and vans), and various sizes of passenger cars.

Manufacturers:

The sample includes vehicles produced by a wide variety of manufacturers. No appropriate incident is excluded based on the manufacturer of the subject vehicle.

5.0 Notification of Events

An important component of the investigation was the establishment of a network of contacts at federal, state and municipal levels, in both public and private sectors, to alert the project team of collision-fire events. A considerable expenditure of project resources was and continues to be required to obtain sufficient numbers of events for investigation. The efforts required are fully described in Appendix A.

6.0 Data Collection

Nine forms were developed for collection of data related to each of the collision-fire incidents under investigation. The forms are filled out by investigating engineers and medical personnel familiar with their use. A number of the forms and procedures were based on the National Automotive Sampling System (NASS) developed by the National Highway Traffic Safety Administration (NHTSA). They' were kept as similar as possible for data fields that were comparable.

The forms were designed to be a general, comprehensive, standardized means for collecting data of interest for each incident investigated. Although the forms were developed to be self-explanatory and used only by a small number of trained individuals, supplemental instructions were written to assist in the consistency of form completion, especially for questions where there may be some ambiguity.

The nine forms developed for the research effort are listed below. A brief description of each form can be found in Appendix **B**.

Case Summary Worksheet
General Vehicle Form
Interview Form
Exterior Vehicle Form
Interior Vehicle Form
Field Fire Investigation Form
Incident Site Form
Incident Reconstruction Form
Occupant Injury Assessment Form (Engineers and Medical)

7.0 Data Availability

Upon completion of the project, data will be loaded into a database and made publicly available. **To** protect the privacy of subjects, the database does not include personal identifiers, vehicle identification numbers, or the state in which the incident occurred. The database will contain the significant technical information collected for each incident.

8.0 Preliminary Results

At the time of writing, thirteen cases were investigated in detail. While not all these investigations have been completed, the vehicle inspection portion was concluded for each incident. Table 1 summarizes the vehicles, collision types and evaluation of incident severity, initiating fuels, ignition sources and propagation times for all observations. Ranges of propagation times were reconstructed from witness observations, police and fire contact logs, and assessment of the narrative descriptions of the events and activities received from all sources. Reliance on participants' perception of the amount of time passing during the fire event was avoided whenever possible. Still, propagation times are estimated and should not be considered precise. Investigators subjectively estimated the time required for activities described by witnesses and, where possible, compared these estimates to emergency personnel logged times. Available data varied on a case-by-case basis.

Determinations of Delta V were intended to provide only an order of magnitude of crash severity. One or more of the most applicable incident reconstruction methodologies were used for each collision reconstruction. Precision varied depending on the crash configuration and data available. For example, in some cases only one of two vehicles was available for crush measurements, insufficient data were available for momentum calculations and/or crash configurations were significantly different from standard crash tests. In such cases, the Delta V calculated would be less precise than those cases with more data. Table 1 also contains a summary of reported occupant injury information from all the cases investigated at the time of writing.

Results in Table 1 are presented to demonstrate the type of information gathered in and derived from investigations in this ongoing study. The available evidence varied from incident to incident; investigators weighed the evidence and used their own experience to determine the highest probability fuels and ignition sources. Some of these events are described in greater detail in the discussion (Section 9). Within those descriptions, the reader will find examples of how investigators formulated the conclusions in Table 1. The final database will contain more detailed information about each of the incidents investigated.

9.0 Discussion

Even though the number of samples is relatively small, the selected cases illustrate some important factors regarding collision fires, the fuels and ignition sources involved, and the resulting propagation times.

1. A large variation in ignition and propagation times were evident.

   Evaluations included cases solely involving gasoline, engine oil and coolant as the most likely initiating fuels. For each initiating fuel, a wide variation in propagation time was evident from incident to incident. Propagation was quite slow for gasoline and engine oil in Samples 2 and 4 respectively. For sample 6, ignition of coolant did not occur until approximately 8-10 minutes after impact (with engine running). Numerous factors affect both ignition and propagation times, including availability of ignition sources, volume of fluids leaked, rate of leakage, form of leak (atomized spray, dripping, etc.), proximity and flammability of secondary fuels, thermal characteristics of adjacent materials, and environmental conditions.

   In Samples 1, 3 and 5, there were indications that fire reached the passenger compartment in less than eight minutes due to leaks of gasoline, engine oil, and coolant respectively. In the case of Sample 5, there was very little impact damage to the engine compartment and coolant was the only liquid fuel available in the region. Witnesses also reported that the fire erupted in the same area, further confuming the identification of coolant as the initial fuel for the fire. Based on witness statements and evaluation of described activities, the fire propagated to the passenger compartment in approximately 2-4 minutes. Propagation paths included openings in the dash panel for the HVAC system which were directly adjacent to the location of fire initiation. Based on the observed collision damage, the windshield was not likely to have been broken in the impact, but it ruptured due to fire and possibly allowed propagation into the passenger compartment as well. Given the example of propagation to the passenger compartment due to a fire initiating from coolant, it is reasonable to expect that fires initiating from other under-hood fluids could propagate as quickly under certain conditions. Underhood fluids with a potential for ignition include gasoline, engine oil, power steering, transmission, brake and windshield washer fluids.

TABLE 1
SUMMARY OF INVESTIGATOR EVALUATIONS
DETAILED INVESTIGATIONS

Sample No.	Fire Vehicle	Impact Description	Estimated Delta V kph/ mph	Most Likely Fuel/Ignition Source(s)[2]	Estimated Time to Ignition/Time to Interior[3] (minutes)	Initial Location of Fire	Reported Injuries: Fire Vehicle (Other Vehicle)	Assistance in Egress (Fire Veh.)
1	1995 BMW 525i	Frontal with barrier, narrow	47-63/ 30-40	Gasoline*, coolant/ electrical spark, hot manifold surface	2-3/4-6	Engine compartment	Driver unconscious, passenger spinal injuries	Yes
2	1997 Plymouth Voyager	Frontal with side of van, underride	19-27/ 12-17	Gasoline*, other fluids/ electrical spark, hot exhaust manifold	Immediate/4-7	Engine compartment	Driver, broken hand (Driver, cut to head)	No
3	1992 Mitsubishi Eclipse	Frontal with front of pickup	47-53/ 29-33	Engine oil*, coolant/ hot exhaust manifold*, elec. spark	Immediate/ 5-8	Engine compartment	Minor (none)	Yes
4	1995 Ford Escort	Frontal with rear of pickup	9-15/ 6-10	Engine oil* and coolant/exhaust manifold* and electrical	<2/extinguished within 5 min. with no spread to interior	Engine compartment	None	No
5	1992 Ford Explorer	Right side with front of car	19-29/ 12-18	Coolant/electrical spark	Immediate/ 2-4	Engine compartment	Driver ejected, broken vertebra (Driver, cuts, broken knee, back pain)	Yes (for children)
6	1991 Plymouth Acclaim	Frontal with side of pickup	3-8/ 2-5	Coolant/ electric motor	8-10[4]/extinguished 9-11 with no spread to interior	Engine compartment	None	No
7	1988 Plymouth Sundance	Undercarriage impact and rollover	Minor	Unknown fluid(s)/ Unknown	<5[4]/ fully engulfed within 10	Between front wheels on inverted car	Driver, non-incapacitating	Yes
8	1990 Dodge Caravan	Frontal impact with tree	64-80/ 40-50	All fluids/ electrical, hot exhaust manifold	Immediate/5-10	Engine compartment	Driver, bums. Passengers: one fatal, two seriously injured, one with bums	Yes

[2] * Asterisk indicates one or more fuels or ignition sources are believed to be more likely than others present.

[3] Times estimated from witness descriptions of events and responder logs. High estimates of propagation time used. Times are with respect to rest after impact.

[4] Engine reported to be on after impact.

TABLE 1 (CONTINUED)
SUMMARY OF INVESTIGATOR EVALUATIONS
DETAILED INVESTIGATIONS

Sample No.	Fire Vehicle	Impact Description	Estimated Delta V kph/ mph	Most Likely Fuel/Ignition Source(s)[5]	Estimated Time to Ignition/Time to Interior[6] (minutes)	Location of Fire	Reported Injuries: Fire Vehicle (Other Vehicle)	Assistance in Egress
9	**1996** Chrysler **Sebring**	Side with side of tractor-trailer	**8-21/ 5-13**	Coolant, engine oil, power steering **&** transmission **fluids/** electrical, hot exhaust manifold	**3-5[4]/4-6**	Engine compartment	Driver, lacerations.	No
10	**1991** Mitsubishi Eclipse	Override of culvert, rollover	Minor	Engine oil/exhaust pipe*, mechanical spark	-Immediate/ extinguished without spread to interior	Exhaust system, car inverted.	Driver, concussion, back pain, bruises, scratches	No
11	**1994** Mazda **323**	Rear-end by front of passenger car	**66-69/ 41-43**	Gasoline from tank/ electrical or mechanical spark	**Immediate/<2**	Rear end and/or interior	Driver fatal, cause(s) unknown. (Minor injuries)	Driver remained in vehicle
12	**1990** Lincoln Town Car	Rear-end by front of **3/4** ton van	**73-88/ 50-60**	Gasoline from tank/ electrical or mechanical spark	Immediate/ fully engulfed within 9	Rear end and/or interior	Driver and passenger fatal, causes unknown. (Driver none, four passengers minor and major injuries)	Driver and passenger remained in vehicle
13	**1991** Toyota **Previa**	Override of tow dolly	Minor	Gasoline from tank/ mechanical spark	Immediate/immediate to exit paths	Pool fire under driver door	Driver and passenger bum injuries	No

[5] * Asterisk indicates one or more fuels or ignition sources are believed to be more likely than others present.

[6] Times estimated from witness descriptions of events and responder logs. High estimates of propagation time used. Times are with respect to rest after impact.

Through careful selection of cases included in this study, the samples chosen show the characteristics of fires initiated by individual liquid fuels. In many engine compartment impacts, there are multiple fluids released (Sample 8 and 9). In such cases it is not often possible or relevant to identify the specific fuel first ignited. What has been suggested in this research is that many of the fluids can be the initiating fuel for fires that propagate to the interior within minutes of impact; such propagation is dependent upon numerous factors, conditions, crash configurations and damage.

2. Ignition is possible from varied and sometimes subtle sources.

Fires ignited by a hot exhaust manifold, an exhaust pipe, sparks from mechanical abrasion of metal, and electric sparks have all been identified as possible ignition sources in this study

Hot surface ignition: In Sample 4, the valve cover was cracked by impact damage, releasing engine oil onto the exhaust manifold and under its heat shield. The manifold shield was blackened by combustion product and the extent of burning was limited to a classic 'V' pattern above the shield. Witnesses observed a small flame in the engine compartment in the area of the exhaust manifold and shield. Coolant was also available but was not as likely to have caused this fire for two reasons: 1) the location of the coolant leaks would not be consistent with the observed burn pattern and 2) a much higher (hence less likely) surface temperature would be necessary to ignite coolant.

It should be noted that the generator mounting brackets were broken in the impact and thus the likelihood of ignition from electrical spark was also evaluated. Again, the burn pattern was more consistent with fire origination under the shield. This did not categorically rule out remote ignition that immediately flashed to the greatest source of engine oil vapors. Sparks tend to occur as one or more events of short duration; to cause ignition, a spark must 1) be of sufficient energy, 2) occur in the same location as a combustible mixture and 3) occur during the time when the mixture is combustible. The hot surface would have been a more prolonged source, available to provide ignition energy until the appropriate mixture developed.

Sample 10 provides another example of hot surface ignition. In this case, the vehicle drove over a culvert, tearing the oil pan and braided steel covering of the exhaust pipe, coming to rest on its roof The fire was extinguished immediately, leaving blackened combustion product only in the regions of the exhaust pipe adjacent to the oil pan. The exhaust pipe in this area was partially enclosed by a metal shield and a braided covering. No electrical spark sources were available. Mechanical spark could not be eliminated as an ignition source because witness statements could not adequately indicate time of fire ignition. Still, the locations of the combustion products were quite specific to the enclosed areas of the pipe. In both Samples 4 and 10 it is believed that the presence of exhaust systemshielding contributed to circumstances conducive to ignition.

Mechanical Sparks: In the case of Sample 13, the vehicle was driven over a tow dolly left on the highway. A cylindrical rod on the dolly punctured the gasoline tank below the driver's door. Scratches on the dolly showed that it had been dragged against the pavement while lodged under the van until rest. No other fuel or ignition sources were available.

Electrical Sparks: Sample 6 involved a minor impact with disruption of the cooling system alone. The fire, which began approximately 8-10 minutes after impact, was extinguished immediately. The investigating officer reported turning the engine off after he extinguished the fire. The only burn damage present was to the radiator fan shroud and cooling fan blade above the motor. The cooling fan motor itself was not burned, nor was the external motor wiring. There was no damage to the electrical system and the exhaust manifold was on the rear of the transverse engine. The only fluid released was coolant and the only ignition source identified was an electrical spark from the fan motor. This observation was not considered definitive; further discussion of the possibility of coolant ignition by sparks will be presented in a future publication.

The examples cited demonstrate the difficulty in identifying ignition sources in high energy impacts, where numerous electrical sources, hot surfaces, and (if the fire is immediate) mechanical sparks are available in areas of fluid release. But ignition is clearly possible from all these sources under specific conditions.

3. Upper-engine impact (underride) may increase intrusion damage to the engine compartment with subsequent fluid release.

   Samples 2, 3, 4, and 6 all involved some degree of underride of engine compartments to subject vehicles. In each case, fluid containment was disturbed further inboard than would have been probable with the same collision energy and lower structure engagement. In Samples 1 and 5, stiffer lower structures were engaged but fluid systems were compromised in the softer upper engine compartment due to dynamic motion of the vehicles during impact.

4. Most of the cases investigated did not involve burn injures, though occupants received assistance in egress in some incidents due to the presence and commitment of passing motorists or non-incapacitated occupants.

   In five of thirteen incidents investigated, fire-involved vehicle occupants were assisted in egress by occupants or other motorists (Samples 1, 3, 5, 7, and 8). In Sample 1, a motorist approached the car and offered assistance. After speaking with the occupants, fire initiated. The motorist assisted the unconscious driver and told the conscious passenger to exit the vehicle. The passenger, having suffered a spinal injury in the impact, rolled out the driver's door without the use of his legs. It was reported that fire propagated to the passenger compartment after his exit. The driver of Sample 5 was reportedly ejected and also had spinal injuries. The driver reported that she looked up from the street and saw her vehicle on fire, she stood, ran to the vehicle, extracted two children, then collapsed. Fire (as described above) was reported to have entered the passenger compartment within minutes.

   In three incidents, occupants were unable to exit the vehicle before fire engulfed the passenger compartment. Two of these incidents were high energy rear-end impacts (Samples 11 and 12). Sample 8 was a high-energy frontal impact. Medical reviews have not been completed to determine whether death was caused by impact or fire for occupants of these incidents.

   In Sample 13, puncture of the gasoline tank caused a pool fire by the exit paths of the vehicle. While propagation to the passenger compartment was not immediate, both received burn injuries while exiting.

10. Summary

Methods and procedures used in an ongoing case study of motor vehicle fires were described. Preliminary results demonstrated the complexity of vehicle collision fires, and the array of factors upon which they are dependent. Investigator evaluations included examples with gasoline, engine oil, and coolant as the most likely initiating fuels in engine compartment impacts. Examples of each of these fuels were reported to have varying ignition and propagation times. Other characteristics and impact configurations were also described.

11. Acknowledgments

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13. Appendices

Appendix A: Notification of Events

The establishment of a broad network of contacts to alert the project team of collision-fire events was critical to the investigation. The effort to create the network at federal, state and municipal levels targeted states in proximity to the team centers in Seattle, Detroit, and Buffalo. Some additional states were included due to their own enthusiasm for participation. States that agreed to cooperate were Washington, Oregon, California, Idaho, Illinois, Indiana, Ohio, Minnesota, New York, Connecticut, New Jersey, Texas, Colorado and Missouri. Of these, a smaller number of states have been able to maintain field awareness of our project and regularly provide notification of events. Due to minimal participation of agencies on the East Coast, the Buffalo team center was not employed.

The notification system was designed to require a minimum of effort on the part of all participating agencies. A toll-free phone call, fax, or e-mail note to project team headquarters at TRAC in Seattle was sufficient to begin investigation of an event. A one-page flyer with a description of the type of incidents and information being sought was distributed in both hard copy and electronic format to a wide variety of sources around the country. Assistance on a national basis was solicited from:

- NHTSA regional offices
- National Automotive Sampling System (NASS), operated through the NHTSA
- International Association of Chiefs of Police
- National insurance companies
- Electronic media and literature search services

State assistance was sought through:

- State highway police or patrol organizations
- State fire marshals' offices
- State traffic safety agencies
- State DOT incident management offices
- State motor vehicle incident records agencies
- State major crash investigation units

Local assistance was requested through

- City and county police and fire districts
- County fire marshals' offices

Effort was directed toward reaching organizations with access to the most centralized vehicle data, in order to minimize the number of contacts necessary. Several issues were encountered in this process. First, organizations that become central repositories for such information typically do not have the data centralized for many months or even years. Such notice of a fire event would not be received until long after most subject vehicles were destroyed. Hence, it became necessary to solicit notification assistance on a less centralized basis, adding exponentially to the process of establishing a network. Second, organizations with access to records such as these are typically governmental; as such, they are busy and often not staffed adequately to devote much time to sifting through incident records for collision-fire events. Further, some records-keeping agencies do not code fires, or perhaps do not distinguish in their coding between collision and non-collision fires, rendering computerized searches less expedient. Finally, collision-fire events are infrequent, and as such, the staff involved may encounter them so rarely that they forget to contact the team when such an event occurs.

It was found that the most successful approach to establishing a network was to start with contacts at the national level (NHTSA, NASS, IACP, etc.) and 1) have notification flyers sent out in a broad manner to blanket the regions of interest, and 2) obtain personal contacts in these regions of interest and make individual phone calls followed by a letter. Simultaneously, state agencies, especially law enforcement and fire officials were approached by phone and letter, and similarly, police and fire agencies from the most populous cities in each state were contacted.

Assistance was also sought from the private sector in developing the notification network. Researchers at one major national insurance company have stepped forward recently to offer notification of collision-fire events from their national database, and the research team is optimistic that this will improve the notification network considerably.

Privacy issues also constrained the process at all levels. In many states, police accident reports (PARs) contain information that is considered confidential. In Washington for instance, there is a statute that forbids state and local law enforcement agencies from sharing PARs with anyone not directly associated with the incident. Even if there was no specific statute, some agencies were hesitant to share the names of victims and witnesses, fearing that a release of such information would put them at risk.

To address privacy concerns, several steps were taken. First, for the issue of state regulations forbidding release of data, several states from the initial target list were chosen for concentration because access to police reports was less restrictive. Second, it was found that for some states with restrictions on PARs, there were no such restrictions on fire incident reports. Hence, police agencies who were willing to notify of collision-fire incidents needed only to alert the research team to the incident date, location, and the responding fire department. The team was then able to legally receive contact information for the incident victims and witnesses from fire agencies. Third, team members worked with police and fire agencies in each state to resolve their questions about privacy protections incorporated within the study. Many reviewed and discussed our written procedures and contact scripts to confirm that participation was voluntary.

For the broader concern of control of confidential information, a Certificate of Confidentiality (COC) was obtained from the National Institutes of Health. This certificate helps protect the research team from involuntary disclosure of personally identifying information, such as pursuant to a subpoena in litigation involving the incidents. The receipt of the COC was also useful in convincing state agencies that were hesitant to participate that the research team had taken significant steps to protect sensitive data.

Appendix B Data Collection Forms

Case Summary Worksheet

The Case Summary Worksheet is used for the convenience of the investigators to reduce data from other forms and sources to a manageable summary that will be useful for quick reference. It includes a narrative summary of the incident sequence, with general information about the impact dynamics, fire, and injuries. Brief profiles are developed for each impact, vehicle, and occupant, and an incident scene sketch is provided for visual clarity.

General Vehicle Form

The General Vehicle Form is designed to be a repository for vehicle data that is collected prior to field inspections. It does not rely upon field-collected data. The first page is required for each vehicle involved; the remaining pages are required for each impact of the fire vehicle (Vehicle No. 1). The form captures basic information about the incident date, vehicle identity, and the findings of the police accident report form, including the reported travel speed for each vehicle and any reported factors that may have contributed to the incident. For the fire-involved vehicle, data are also collected for roadway and environmental data, including details of the roadway type, surface, and grade, the lighting and atmospheric conditions at the time of impact, and whether there were functioning traffic control devices. Reported precrash driver-related data are also collected, including details of possible driver distraction or inattention, the type of maneuver the driver was undertaking when the collision occurred, and any avoidance actions taken by the driver.

Interview Form

Interviews are conducted with incident witnesses and victims, and occasionally with others who may have knowledge relevant to the investigation. A form was developed that provides a framework for collecting data of interest to the investigators. The basic structure of the interview form is as follows.

- General Information
  - Description of Events
  - Description of Incident Site
- Crash Information
  - Description of Crash Event
  - Description Rollover Event
  - Description Fire Event
  - Vehicle Information (including service history)
- Occupant Information
  - General
  - Restraint Use
  - Ejection, Entrapment, Mobility Information
  - Child Safety Seat Presence and Use
- Occupant Injury Information
  - Description of Injury
  - Injury Sketches
  - Burn Chart

The interview form is a comprehensive list of topics of greatest concern, but large portions of it may not apply, depending upon a host of factors. Initially, the interviewer introduces him/herself to the interviewee and reads from a carefully worded script that discloses the end use of the data and describes privacy protections. Once the interviewee has accepted the terms of participation in the program, the interview commences.

The interview begins with a narrative description of the incident, recorded on paper in the words used by the interviewee. Details of the incident site, including the roadway type and direction, the lighting and environmental conditions, driver actions, travel speed, and avoidance actions are discussed. If the vehicle rolled over, data about the rollover are gathered. The interviewee is then asked in detail about the fire, including observations about how and where it began, when it initiated and how quickly it spread, and any other information that may be useful for establishing and understanding the fire cause and propagation path and rate. The interviewee is questioned about their recollection of the vehicle damage, including a description of the impact damage, whether doors and/or windows were open before or after impact (for an understanding of fire propagation paths), and a list of any vehicle modifications that may have had an effect on the fire or injuries, such as presence of a running boards, cooling or fuel (gasoline) system modifications, or installation of electrical devices. The vehicle service history is ascertained, including information about any problems (such as fluid leaks or overheating) that may be factors in the collision-fire event. The interviewee is asked about occupant restraints, whether they were present, if (and how) they were used, and if they operated correctly. Finally, data are charted for occupant injuries, including impact trauma and burns.

If appropriate, the interviewee is asked if they would sign a written consent form which releases medical information to the research team. Consent forms are usually sent out in a packet with introductory materials including a letter of introduction from the NHTSA.

Exterior Vehicle Form

The Exterior Vehicle Form is designed to be a comprehensive field data collection tool for documenting vehicle damage profiles and associated relevant measurements. Vehicle damage data are collected according to standard Society of Automotive Engineers (SAE) Collision Damage Classification (CDC) guidelines [13].

Interior Vehicle Form

The Interior Vehicle Form is intended for field data collection during an inspection of the incident vehicle(s), though some information may be considered from other sources. One form is used for each vehicle involved in the incident. Data are collected primarily to document occupant compartment intrusion and integrity, for purposes of understanding both the nature and extent of injuries due to impact, and the use (and functionality) of passenger restraints.

Field Fire Investigation Form

The Field Fire Investigation Form is a comprehensive field data collection tool for the documentation of fire and heat damage to the vehicle and the type, presence and conditions of various vehicle systems and components. It is used to gather consistent data that provide insight into the cause, origin and propagation of the fire in the context of the use, maintenance and design state of the vehicle. The form can be used to record impact damage, heat damage and components that have both heat and impact damage.

The fire form is divided into the following sections:

- General Exterior
- Engine Compartment
- Interior Fire Examination
- Undercarriage Fire Examination
- Fire Inspection Summary

In addition to the coded fields, eight narrative summaries placed throughout the fire investigation form are used to capture all information of significance to the fire event. These contain conclusions regarding the fire investigation based on all documented sources of information. Sources include evidence observed from the vehicle inspection as well as information from police documentation, driver or witness interviews, and vehicle service manuals. The narrative sections allow the investigator to document significant observations and conclusions regarding the available fuels and combustibles, ignition sources, propagation paths and estimated propagation times.

General Exterior

The general exterior section of the form provides a format suitable for database coding to document the extent and location of fire damage on the exterior of the vehicle. Although photo-documentation of the vehicle is performed during each investigation, the form provides a written record of each major body panel that may be heat and/or impact damaged. The form also records other exterior details regarding fuel (gasoline) filler locations and equipment not made by original equipment manufacturers (OEM). The location of heat damage body panels provides a "zone" of heat intensity that may give insight into the fire origin location and propagation.

Engine Compartment

The engine compartment section of the form allows for detailed documentation of the components and systems found damaged or burned in the engine compartment. Impact and heat damage to the engine cooling subsystem, fuel (gasoline) delivery subsystem, engine electrical subsystem, power steering subsystem, brake subsystem, air intake subsystem, and other miscellaneous engine compartment components are documented. Most engine compartments manufactured today include eight necessary and combustible fluids:

Gasoline
Engine Oil
Engine Coolant
Brake Fluid
Power Steering Fluid
Transmission Fluid
Windshield Washer Solvent
NC Compressor Oil

A summary of the evidence collected as to the condition and potential release of engine compartment fluids of each of the major vehicle subsystem are entered on the form. The engine compartment also contains numerous combustible polymeric components. The Field Fire Investigation Form includes coding for many such components specifically and in general in order to illustrate the fuels available and the path and severity of the fire.

Interior Fire Examination

The extent of heat damage to the vehicle interior and cargo area is documented to identify interior components consumed and to develop a thermal damage mapping of the interior. Flammable cargo and other non-OEM consumable products are identified to help determine any role that they may have had in the fire or propagation. Other documented interior components include fixed and non-fixed glass damage (condition and pre-fire positions) and electrical control positions (fuel (gasoline) tank selectors, heater, fan, headlamps, wiper, etc.). The investigator, when possible, will identify the most likely path by which fire entered the occupant compartment as a result of collision damage and/or exterior fire propagation.

Undercarriage Fire Examination

Undercarriage heat damage is documented to assess the distribution of involvement of the undercarriage components. Undercarriage subsystems, including fuel (gasoline), exhaust, transmission (transaxle) and brake systems are documented. Fuel (gasoline) system integrity is assessed for heat and/or impact damage to the fuel tank(s), sending unit, fuel lines (including connections), fuel tank shields, filler caps, filler necks and filler hoses. Exhaust system damage or degradation from corrosion is examined to establish its potential involvement in damage to adjacent components or as a source for ignition. Fluid release from other potential undercarriage systems, such as brake and transmission line damage is also documented.

Fire Inspection Summary

The investigator provides a narrative summary of fuel sources, ignition sources, propagation paths and times that is intended to distill and explain all findings of the inspection.

Incident Site and Incident Reconstruction Forms

Full potential of this research can be facilitated by obtaining a measure of impact severity in a collision-fire event and to relate it to the propensity for vehicle fires and injuries. Impact severity, measured through "delta V," is determined from calculations based on physical (crush) damage to the vehicles. An incident site inspection is performed when it is necessary to develop geometrical information and to support the reconstruction analysis.

The Incident Site Form provides the means to document roadway dimensions, characteristics, traffic controls, landmarks, skidmarks, burn patterns, roadway debris, roadway grade, surface type, condition and coefficient of friction. This information, in addition to the documentation of the vehicle crush damage (see Exterior Vehicle Form), provides a basis for standard reconstruction techniques involving energy and momentum. Additional information for these calculations such as vehicle stiffness coefficients are researched and acquired. The Incident Reconstruction Form documents the results, techniques and data sources for the reconstruction calculations.

Occupant Injury Assessment Form – Engineers

The Occupant Injury Assessment Form is divided into two major sections, one to be completed by the investigating engineers, and the other to be completed by the medical team. For the engineering portion of the form, required information is gathered from a variety of sources, including vehicle inspection, interviews, and the police accident report. In many cases, information to be coded on the Occupant Injury Assessment will have been collected in worksheet format on other forms. The form addresses the following occupant-related information:

Occupant's Characteristics: Information is documented regarding the occupant's age, gender, height, weight and role (driver, passenger, etc.) in the incident.

Occupant's Seating: Ejection paths and portals, entrapment and mobility following the incident are documented for each occupant by seating position.

Belt System Function and Usage: Detail is documented regarding the manual (active) and automatic (passive) belt systems including restraint type, anchorage adjustment positions, functionality, failure modes, and occupant use of the restraint system and the use of child restraint systems.

Air Bag Performance: The availability and deployment of the occupant's position air bag are documented.

Child Safety Seat: Child safety seat identification, orientation, and child seat features are coded for installed and occupied child seats.

Police Reported Injury Coding: The engineer's assessment of the occupant's injury severity, treatment and hospitalization information is documented based on police-reported data, and occupant and witness interviews.

Occupant Injury Assessment Form – Medical

After the engineering investigation is completed, TRAC medical analysts review vehicle, incident, and medical documents. Injury data for each occupant are coded, and AIS values are assigned. The cause(s) of death are coded and narrative conclusions drawn and entered on the data collection form. Instances of fatality due to bum injury are distinguished from fatalities due to other trauma when possible.